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(54) Title: PREAMBLE STRUCTURE FOR TIME-FREQUENCY ACQUISITION IN OFDM SYSTEMS WITH MULTIPLE STRONG NARROWBAND INTERFERENCE

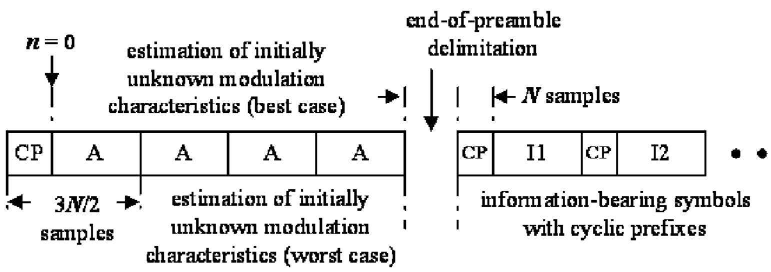

Fig. 2

(57) Abstract: A method for time-frequency acquisition in orthogonal frequency-division multiplexing (OFDM) systems without knowledge of channel characteristics and in presence of multiple strong narrowband interference is provided. Preamble structure and associated time-frequency acquisition method are disclosed. The preamble structure comprises a cyclic prefix of a baseband symbol A and a concatenated repetitions of the baseband symbol. The acquisition method employs frequency-domain correlation techniques, which are robust to narrowband interference, in order to estimate time offset and frequency offset in an efficient manner.

WO 2011/117673 A1

Description

PREAMBLE STRUCTURE FOR TIME-FREQUENCY ACQUISITION IN OFDM SYSTEMS WITH MULTIPLE STRONG NARROWBAND INTERFERENCE

Technical Field

[01] The present invention relates generally to wireless communication systems employing orthogonal frequency-division multiplexing (OFDM) or similar multi-carrier techniques, more particularly, to systems and methods for receiving modulated symbols over a transmission channel with initially unknown modulation characteristics and in presence of narrowband interference.

Background Art

[02] Some wideband communication systems are supposed to use OFDM and to work in presence of multiple strong narrowband interference. They are supposed to be part of a spectrum-sharing scheme, where many different wireless communication systems are co-located and dynamically using same range of radio spectrum, in order to utilize seemingly scarce radio spectrum in a more economical way.

[03] Despite such narrowband interference a receiving device must be able to detect a signal and determine its content. In wideband OFDM systems a receiving device must be able to estimate the initially unknown modulation characteristics, which are time offset and frequency offset between transmitting and receiving devices, and channel state information, at sufficient accuracy before content of the signal can be reliably detected. To facilitate estimation of the initially unknown modulation characteristics at a receiving device, the signal transmitted by a transmitting device contains a preamble as a sequence of pilot symbols before information-bearing symbols.

[04] Preamble structures designed for today practical systems and associated time-frequency acquisition methods fail in the presence of strong narrowband interference, since they are derived assuming absence of narrowband interference. The purpose of the present invention is to provide system and method, which are aware of strong narrowband interference and able to tolerate it via frequency-domain correlation processing, enabling a receiving device to estimate the initially unknown modulation characteristics in an efficient manner.

Brief Descriptions of the Drawings

[05] **Fig. 1** shows a preamble structure, forming the main scope of the invention.

[06] **Fig. 2** shows an exemplary embodiment of preamble according to the invention.

[07] **Fig. 3** shows an exemplary embodiment of preamble according to the invention.

[08] **Fig. 4** shows an exemplary embodiment of preamble according to the invention.

Disclosure of the Invention

Definitions:

[09] 1. **Cyclic prefix**: Cyclic prefix of an OFDM symbol is a repeat of the end of the symbol at the beginning.

[10] 2. **Information-bearing symbol and notation of *N***: An information-bearing symbol is an OFDM symbol excluding cyclic prefix that carries a piece of payload data. Hence, the length of an information-bearing symbol equals $1/\Delta f$ seconds, where Δf is the OFDM subcarrier spacing in Hz. This length will be denoted in discrete-time domain as N samples, meaning that the sampling rate is $N\Delta f$ samples/second.

[11] 3. **Prototype of a symbol**: An OFDM symbol X is said to be the prototype of an OFDM symbol Y, if symbol Y is derived from symbol X either as identical copy of symbol X or by some modification methods introduced to help manage interference. A receiving device according to the present invention is expected to receive a preamble generated from an OFDM symbol that has been advantageously modified from a prototype, the modification method is not known generally but the prototype is known to the receiver.

[12] 4. **Differential-phased signal**: Signal $X(n)$ of length N samples is said to be the differential-phased signal of $Y(n)$ of length N samples also, if $X(n)=Y(\mathrm{mod}(n+1,N))Y^*(n)$, where Y^* is the complex conjugate of Y and $\mathrm{mod}(k,N)$ is the remainder of division of k by N.

[13] 5. **Cyclic correlation**: The cyclic correlation value between signals $X(n)$ and $Y(n)$ of length N samples for a discrete shift m is computed as $\sum_{n=0}^{N-1} X(\mathrm{mod}(n+m,N))Y^*(n)$.

Preamble structure:

[14] Preamble structure to be described just below seems to be too unsophisticated to facilitate efficient time-frequency acquisition (estimation of both time offset and frequency offset), as it has not been proposed for such use in prior art. However, the present invention incorporates it, as the inventor envisions that it has an important desirable property about mitigating interference and it can be associated with an efficient time-frequency acquisition method.

[15] The present invention employs a preamble structure, comprising a sequence of pilot

symbols generated from a baseband symbol A of length *N* samples by concatenating a cyclic prefix (CP) of the symbol A and a plurality of identical copies of the symbol A, as illustrated in **Fig. 1**. Also shown in **Fig. 1** is that the whole preamble is expected to contain additional parts for other necessary purposes, comprising signal detection, automatic gain control and end-of-preamble delimitation (in certain embodiments) which depart from the scope of the present invention. The reason to why an end-of-preamble delimitation is necessary for certain embodiments will be apparent after a time-frequency acquisition method is described in this document. It is obvious that time-frequency acquisition could be started, only after signal detection has declared presence of a preamble and automatic gain control has been settled.

[16] Assuming signal detection with automatic gain control requires a part of preamble to be processed (before time-frequency acquisition could be started) by a number of samples between $N/2$ (in the best case) and $3N/2$ (in the worst case), a preamble employing the said structure is shown in **Fig. 2** as an exemplary embodiment. In this embodiment, signal detection with automatic gain control also employs pilot symbols generated from the symbol A and end-of-preamble delimitation simply employs a null symbol. According to time-frequency acquisition method of the present invention, this embodiment meets a desirable requirement that computation of N-point DFT (discrete Fourier transform) is required about only once every *N* samples.

[17] According to the present invention, the symbol A is derived from a prototype in order to gain desirable effects about interference management. The following two methods of derivation are obvious from prior art. In one embodiment, the symbol A is derived from a prototype by subcarrier nulling (zeroing some subcarriers of the prototype) in order to reduce interference to other co-locating systems as well as to reduce waste of energy. In addition to subcarrier nulling, another embodiment may also derive the symbol A from a prototype by replacing some subcarriers with interference cancellation tones according to US 7573960 B2 in order to further reduce interference to other co-locating systems.

[18] However, regarding the use of interference cancellation tones and according to time-frequency acquisition method of the present invention, it is desirable that a receiving device de-emphasizes signals in the frequency domain which are interference or interference cancellation tones. For this purpose, it is assumed that a receiving device determines existence of interference in the radio spectrum from a spectrum sensing device or method. It is then suggested that a transmitting device generates artificial narrowband interference on the frequency of each interference cancellation tone for some intervals, in order to stimulate the receiving device to treat interference cancellation tones as interference.

[19] According to the present invention, a time-frequency acquisition method to be described just below mitigates interference effect by using a frequency-windowing function as a mean to selectively emphasize desirable signals as well as to selectively de-emphasize undesirable signals in the frequency domain. It is desirable that the frequency spacing between samples of the frequency-windowing function equals the OFDM subcarrier spacing, in order to obtain an optimal resolution of selectivity in the frequency domain. Therefore, length of the frequency-windowing function equals N samples, and frequency spacing between samples equals the OFDM subcarrier spacing. The preamble structure of the present invention is designed to have rich frequency components, optimally compatible to the said frequency-windowing function.

Time-frequency acquisition method:

[20] Time-frequency acquisition method of the present invention employs a frequency-windowing function of length N samples, wherein frequency spacing between samples equals the OFDM subcarrier spacing. The function will be performed on received frequency-domain signals, in order to selectively emphasize desirable signals as well as to selectively de-emphasize undesirable signals in the frequency domain. In one embodiment, the frequency-windowing function equals one for samples corresponding to frequency with insignificant interference as determined by an assumed spectrum sensing device or method, and it equals zero otherwise.

[21] With a description of a time-frequency acquisition method for the embodiment shown in **Fig. 2**, it should be obvious for a person having ordinary skill in the art to derive a time-frequency acquisition method of the present invention in general. The acquisition method for the embodiment shown in **Fig. 2** processes the received preamble in baseband according to the following sequence. First FFO (fractional part of frequency offset normalized to OFDM subcarrier spacing) is estimated, and then IFO (integral part of frequency offset normalized to OFDM subcarrier spacing) and time offset are estimated. It is then desirable to first describe a method of estimating FFO and a method of estimating IFO and time offset, before the complete acquisition method is described.

[22] Estimation of FFO employs a variant of method in Paul H. Moose, “A technique for orthogonal frequency division multiplexing frequency offset correction,” IEEE Transactions on Communications, vol. 42, No. 10, pp. 2908-2914. The estimation of FFO takes two symbol samples of length N samples, each symbol sample is obtained by performing a rectangular windowing function of length N samples on the received preamble, and the windowing time of the first symbol sample is N-sample earlier than that of the second symbol sample. The two symbol samples are required to obtain a correlation value that contains information of the FFO, by a

method comprising steps of:

obtaining N-point DFT of the first symbol sample;

obtaining N-point DFT of the second symbol sample;

multiplying the frequency-windowing function (mentioned above) with the DFT of the second symbol sample to obtain a first signal;

multiplying the first signal with complex conjugate of the DFT of the first symbol sample to obtain a second signal; and

summing all the values of the second signal to obtain the correlation value.

After the correlation value is obtained, the FFO is then estimated by FFO = $\theta / 2\pi$ where θ is the angle $\left(-\pi < \theta \leq \pi\right)$ of the correlation value.

[23] Estimation of IFO and time offset employs a variant of method in Jae Yeon Won, Hyun Gu Kang, Yun Hee Kim, Iickho Song, and Myung Sun Song, "Fractional bandwidth mode detection and synchronization for OFDM-based cognitive radio systems," 2008 IEEE 67th Vehicular Technology Conference (VTC2008-Spring), pp. 1599-1603. The estimation takes one symbol sample of length N samples (denoted as symbol sample X) from the received preamble and processes it by a method comprising steps of:

obtaining an FFO-compensated symbol sample from the symbol sample X and an estimated FFO;

performing N-point DFT on the FFO-compensated symbol sample to obtain a third signal;

multiplying the frequency-windowing function (mentioned above) with the third signal to obtain a fourth signal;

obtaining a fifth signal as differential-phased signal of the fourth signal;

computing the cyclic correlation value between the fifth signal and (pre-computed) differential-phased signal of N-point DFT of the prototype of symbol A, for every discrete shift being an element of the set $\{m \mid m \text{ is a possible value of IFO}\}$;

determining, out of all the relevant values in previous step, best discrete shift which corresponds to largest cyclic correlation value;

determining an estimated IFO as the integer identical to the best discrete shift; and

estimating the time offset (defined by $n_{\mathrm{A}} - n_{\mathrm{X}}$, where n_{A} is the beginning time of a symbol A in the received preamble and n_{X} is the beginning time of symbol sample X) from the angle of the largest cyclic correlation value by $n_{\mathrm{A}} - n_{\mathrm{X}} = \mathrm{round}\left(-\phi N / 2\pi - K\right)$ samples, wherein the angle is denoted as ϕ with $-2\pi < \phi \leq 0$, K is a constant that compensates an effect of channel time dispersion, and $\mathrm{round}(\cdot)$ denotes rounding to the nearest integer.

It may be noted also that the fourth signal and the estimated IFO can be used to estimate channel state information (for some useful subcarriers) by a method in prior art.

[24] According to the embodiment shown in **Fig. 2**, there is uncertainty about time to start time-frequency acquisition. This is due to the assumed uncertainty about signal detection and automatic gain control. Specifically, referring to the beginning time of first symbol A in the preamble as $n=0$ (see **Fig. 2**), and denoting the time to start the said acquisition as $n=n_0$, the uncertainty means that $0 \le n_0 \le N-1$. Based on the methods of estimating FFO, IFO and time offset described above, the complete time-frequency acquisition method comprises steps of:

performing a rectangular windowing function of length N samples on the received preamble, the windowing time is from n_0 to n_0+N-1, to obtain a first symbol sample;

performing a rectangular windowing function of length N samples on the received preamble, the windowing time is from n_0+N to n_0+2N-1, to obtain a second symbol sample;

estimating FFO from the first symbol sample and the second symbol sample;

performing a rectangular windowing function of length N samples on the received preamble, the windowing time is from n_0+2N to n_0+3N-1, to obtain a symbol sample X; and

estimating IFO and time offset from the symbol sample X.

[25] However, just after the time and frequency offsets have been estimated, a receiving device does not gain enough information yet to locate the first information-bearing symbol and so on. This is due to the mentioned uncertainty of n_0, and is the reason to why this embodiment requires end-of-preamble delimitation. To locate the first information-bearing symbol, the receiving device may employ a method comprising steps of:

initializing $M \leftarrow \Delta n$ where Δn is the estimated time offset; and

repeating the following steps until the symbol sample obtained therein is unlikely to be the symbol A, but more likely to be essentially end-of-preamble delimitation: (1) performing a rectangular windowing function of length N samples on the received preamble, the windowing time is from n_0+M+3N to $n_0+M+4N-1$, to obtain a symbol sample; and (2) setting $M \leftarrow M+N$.

While the above steps require a method about to efficiently discern between the symbol A and end-of-preamble delimitation, it may be derived easily from prior art, and it departs from the scope of the present invention.

Advantageous effects of invention:

[26] Key setting of the present invention is to perform all the estimation from frequency-domain signals while using a frequency-windowing function to selectively emphasize desirable signals as well as to selectively de-emphasize undesirable signals in the frequency domain. While it does not require any computationally intensive band-stop filters as in prior art, this setting is in principle making the estimation performance insensitive to the power of narrowband interference. This advantageous effect has not been achieved in prior art.

Variations of embodiment:

[27] In certain embodiments, it is not necessary to have end-of-preamble delimitation. If signal detection with automatic gain control requires a part of preamble to be processed by a number of samples between N (in the best case) and $3N/2$ (in the worst case), an exemplary embodiment of complete preamble may be shown in **Fig. 3**. In this case, because the uncertainty of n_0 is $N/2 \leq n_0 \leq N-1$, a receiving device gains enough information to locate the first information-bearing symbol after performing the above time-frequency acquisition method. End-of-preamble delimitation is then not necessary.

[28] According to the embodiments shown in **Fig. 2** and **Fig. 3**, it may be noted that the associated time-frequency acquisition methods take only $3N$ samples from the received preamble for the estimation. However, the part of preamble for time-frequency acquisition must have length of $3N$ samples plus a margin of length depending on uncertainty about signal detection and automatic gain control.

[29] The embodiment shown in **Fig. 2** can be considered as an exemplary embodiment, wherein the part of preamble for time-frequency acquisition has length of $3N$ samples plus a margin of not more than N samples. The embodiment shown in **Fig. 3** can be considered as an exemplary embodiment, wherein the part of preamble for time-frequency acquisition has length of $3N$ samples plus a margin of not more than $N/2$ samples. Depending on computational intensity supported by a receiving device, the preamble may be further shorten. According to the present invention, the part of preamble for time-frequency acquisition has minimum length of $2N$ samples.

[30] **Fig. 4** shows an exemplary embodiment, wherein the part of preamble for time-frequency acquisition has length of $2N$ samples plus a margin of not more than $N/2$ samples. This embodiment assumes uncertainty of n_0 to be the same as that of the embodiment shown in **Fig. 3**. Referring to the time-frequency acquisition method described above, an acquisition method for the

embodiment of **Fig. 4** can be obtained from the referred method by: omitting the step that obtains the symbol sample X; and replacing the symbol sample X with the second symbol sample.

[31] Better accuracy of time-frequency acquisition can be obtained by using a longer preamble in certain embodiment. By a longer preamble, a receiving device can take more than a single pair of symbol samples in the estimation of FFO. In addition, it can take more than a single symbol sample in the estimation of IFO and time offset. In an embodiment of longer preamble, it is essential to modify the relevant methods of estimation described above to take more data for the estimation. Although such modification should be already obvious to a person having ordinary skill in the art, outline of the modification is given below:

[32] Referring to the method of estimating FFO described above, the FFO is estimated from a correlation value obtained from a pair of symbol samples. In order to modify the method to take more pairs of symbol samples, each different pair of symbol samples is processed to obtain an individual correlation value, and then all the individual correlation values are summed to obtain the correlation value for estimating the FFO.

[33] Referring to the method of estimating IFO and time offset described above, the IFO and time offset are estimated, based on a differential-phased signal (denoted as the fifth signal) obtained from a symbol sample. In order to modify the method to take more symbol samples, each different symbol sample is processed to obtain an individual differential-phased signal, and then all the individual differential-phased signals are summed to obtain the differential-phased signal on which estimation of IFO and time offset is to be based.

[34] While the present invention has been described with respect to certain embodiments, it will be obvious to a person having ordinary skill in the art that various changes and modifications may be made without departing from the scope of the invention as defined in the appended claims.

Claims

1. A method, comprising:

receiving an OFDM preamble comprising a sequence of pilot symbols generated from a baseband symbol A of the same length as of an information-bearing symbol by concatenating a cyclic prefix of the symbol A and a plurality of identical copies of the symbol A; and

utilizing the said part of preamble received consisting of a sequence of pilot symbols generated from the symbol A to estimate initially unknown modulation characteristics comprising time offset and frequency offset between a transmitting device and a receiving device.

2. A method of claim 1, wherein the said part of preamble has length of $3N$ plus a margin of not more than N, where N is the length of the symbol A.

3. A method of claim 1, wherein the said part of preamble has length of $3N$ plus a margin of not more than $N/2$, where N is the length of the symbol A.

4. A method of claim 1, wherein the said part of preamble has length of $2N$ plus a margin of not more than $N/2$, where N is the length of the symbol A.

5. A device designed to carry out the method of claim 1.

6. A device designed to carry out the method of claim 2.

7. A device designed to carry out the method of claim 3.

8. A device designed to carry out the method of claim 4.

9. An OFDM system, comprising a transmitting device and a receiving device, the transmitting device being designed to transmit a preamble generated as stated in the method of claim 1 in order to facilitate estimation of initially unknown modulation characteristics comprising time offset and frequency offset between the transmitting device and the receiving device.

10. An OFDM system, comprising a transmitting device and a receiving device, the transmitting device being designed to transmit a preamble generated as stated in the method of claim 2 in order to facilitate estimation of initially unknown modulation characteristics comprising time offset and frequency offset between the transmitting device and the receiving device.

11. An OFDM system, comprising a transmitting device and a receiving device, the transmitting device being designed to transmit a preamble generated as stated in the method of claim 3 in order to facilitate estimation of initially unknown modulation characteristics comprising time offset and frequency offset between the transmitting device and the receiving device.

12. An OFDM system, comprising a transmitting device and a receiving device, the transmitting device being designed to transmit a preamble generated as stated in the method of claim 4 in order to facilitate estimation of initially unknown modulation characteristics comprising time offset and frequency offset between the transmitting device and the receiving device.

AMENDED SHEET
[Received by the International Bureau on 24 February 2011 (24.02.11)]

1. A method of operating a receiving device of an OFDM system in an environment where narrowband interference exists due to sharing of radio spectrum between the OFDM system and other wireless communication systems which occupy relatively narrow spectrum, comprising:
   receiving an OFDM preamble comprising a sequence of pilot symbols generated from a baseband symbol A of the same length as of an information-bearing symbol by concatenating a cyclic prefix of the symbol A and a plurality of identical copies of the symbol A; and
   estimating initially unknown modulation characteristics comprising time offset and frequency offset between a transmitting device and the receiving device by an estimation method that utilizes said sequence of pilot symbols received.

2-12. The claims are canceled.

13. The method of claim 1, wherein said estimation method comprises utilizing a result determined by spectrum sensing in mitigating an undesirable interference effect.

14. The method of claim 13, wherein said utilizing a result determined by spectrum sensing comprises:
   deriving a frequency-windowing function from said result;
   obtaining a frequency-domain signal from said sequence of pilot symbols received; and
   performing said frequency-windowing function on said frequency-domain signal to obtain another frequency-domain signal that is less plagued by interference.

15. A method of operating a transmitting device of an OFDM system for providing a receiving device with information for estimation of initially unknown modulation characteristics comprising time offset and frequency offset between the transmitting device and the receiving device in an environment where narrowband interference exists due to sharing of radio spectrum between the OFDM system and other wireless communication systems which occupy relatively narrow spectrum, comprising:
   generating an OFDM preamble comprising a sequence of pilot symbols generated from a baseband symbol A of the same length as of an information-bearing symbol by concatenating a cyclic prefix of the symbol A and a plurality of identical copies of the symbol A; and
   transmitting said OFDM preamble.

16. The method of claim 15, wherein said symbol A is obtained from a prototype by a modification method for a purpose comprising reducing emission of interference to other co-locating systems, the modification method is not known generally but the prototype is known to the receiving device.

17. The method of claim 16, wherein said modification method comprises zeroing some subcarriers of said prototype.

18. The method of claim 17, wherein said modification method further comprises replacing some subcarriers of said prototype with interference cancellation tones in order to further reduce emission of interference to other co-locating systems.

19. The method of claim 18, wherein the method further comprises transmitting dummy subcarriers on frequencies of said interference cancellation tones during an interval before transmission of said sequence of pilot symbols for stimulating the receiving device to treat said interference cancellation tones as interference.

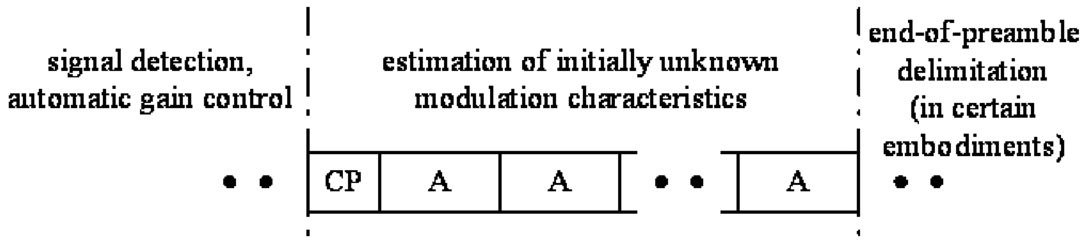
signal detection,
automatic gain control
estimation of initially unknown
modulation characteristics
end-of-preamble
delimitation
(in certain
embodiments)
CP
A
A
A

Fig. 1

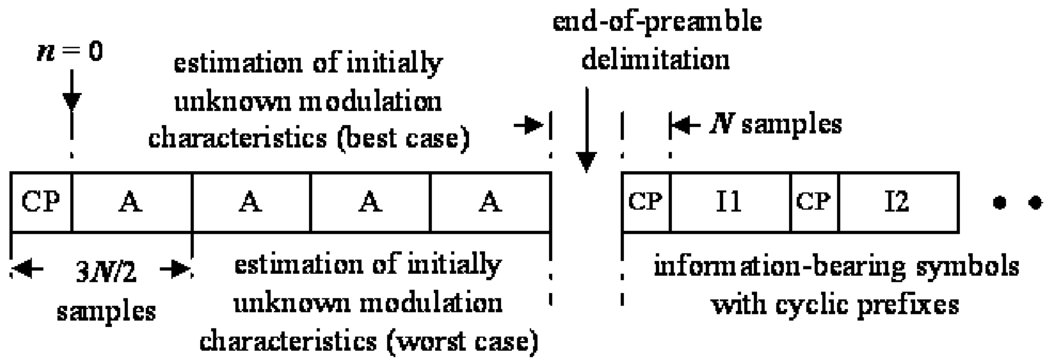
n = 0
estimation of initially
unknown modulation
characteristics (best case)
end-of-preamble
delimitation
N samples
CP
A
A
A
A
CP
I1
CP
I2
3N/2
samples
estimation of initially
unknown modulation
characteristics (worst case)
information-bearing symbols
with cyclic prefixes

Fig. 2

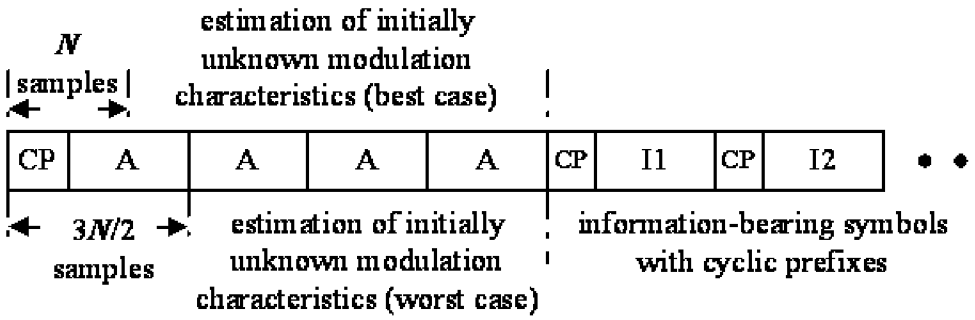
N
samples
estimation of initially
unknown modulation
characteristics (best case)
CP
A
A
A
A
CP
I1
CP
I2
3N/2
samples
estimation of initially
unknown modulation
characteristics (worst case)
information-bearing symbols
with cyclic prefixes

Fig. 3

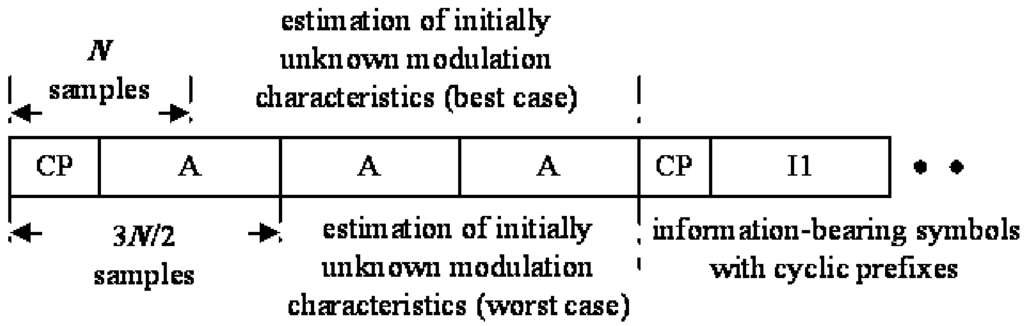
N
samples
estimation of initially
unknown modulation
characteristics (best case)
CP
A
A
A
CP
I1
3N/2
samples
estimation of initially
unknown modulation
characteristics (worst case)
information-bearing symbols
with cyclic prefixes

Fig. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2010/051239

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04L27/26
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2008/019350 A1 (ONGGOSANUSI EKO N [US] ET AL) 24 January 2008 (2008-01-24) figures 3A,3B,7 paragraphs [0052], [0053], [0055]	1-12
X	US 2004/004934 A1 (ZHU JUNJIE [SG] ET AL) 8 January 2004 (2004-01-08) figure 2(b)	1-12

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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Date of the actual completion of the international search	Date of mailing of the international search report
14 December 2010	21/12/2010

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2010/051239

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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