The present invention relates to a transmitter wherein channel estimation errors observed in unequal amplitude constellations in the additive noise and frequency equalization process in OFDM (Orthogonal frequency-division multiplexing) based multi-carrier systems are reduced by means of the channel and/or source coding performed by a generated dictionary, and a receiver which detects according to the said code dictionaries. A coding system is selected such that requirements on apriori probabilities for each constellation point are met by this code.
The present invention relates to a transmitter wherein channel estimation errors observed in unequal amplitude constellations in the additive noise and frequency equalization process in OFDM (Orthogonal frequency-division multiplexing) based multi-carrier systems are reduced, and a receiver operating in accordance with the said transmitter.

Prior Art

Performance degradation due to channel estimation error in OFDM based multi-carrier systems is a known problem in the art. The severity of the performance degradation depends on the method used during channel estimation and the physical channels used during data transmission. One method used in multi-carrier communication systems is "channel coding" and another is "source coding".

Each channel through which communication is realized, distorts the transmitted data in a way differing according to the characteristics of the channel. As this distortion can be random addition of noise to the message, it can also be changes in the essence of the message.

The accuracy of the information transmitted through the channel is generally inversely proportional to the noise rate in the channel and directly proportional to the power that can be transmitted from the transmitter to the receiver. For example, in a noisy room, while people are talking, two people can understand each other more easily the closer they are located to each other. While it may not
be possible to talk to a person standing nearby in a completely full stadium, after
the stadium is totally vacated, it may be possible that a person at one end hears the
person at the other end.

If the receiver detects that a data is being sent, but cannot receive the sent data, it
will reprompt for it. However, it may also be the case that the receiver
misunderstands the incoming data and does not reprompt for it. This has required
the first channel coding method which is the repetition codes. When the same
message is repeated three times; if the receiver detects the message correctly twice
and wrongly once, it will opt for the majority whereby detecting the message
correctly.

In addition to the repetition codes, coding also have types which provide security
by adding extra but known information into the sent information. However, since
more information than the sent information is transferred to the channel regardless
of the type of coding, an extra source use occurs in the channel.

Purpose of channel coding is to ensure that the information is transmitted in the
channel in an optimal way. This method frequently comprises conversion of
analog signals such as audio or a light intensity in a picture into digital signals
(binary representation) and thus transmission thereof via a modem. Channel
coding is also applied in algorithms that are used in data compression in addition
to the standard processes such as quantization and A/D (analog to digital)
conversion of bit or symbol contents. Standard image compression algorithms are
MPEG and JPEG formats. MPEG is used for compression of motion images like
films, while JPEG is used for compression of still images like pictures.

While the channel coding performed converts different information into digital
form, the way the conversion will be performed varies depending on the main
purpose. For example, if protection of some information is more important than
others, channel coding can be performed such that it enhances security of this
information. For example, this information can be coded using more bits. Another example is coding information, which is sent very frequently, with less bits.

The symbols sent by the transmitter which are defined in the receiver are named as "pilot symbols". These pilot symbols are coded according to the code set to be used and sent to the receiver.

In OFDM based systems, the entire frequency band (B Hz) is divided into N sub-channels.

In the transmitter, the incoming serial data sequence \( (X_n) \) is first error correction coded in the source and/or channel encoder (103) and then converted into a parallel structure at the serial to parallel converter (104). Subsequently, pilot tone(s) is/are added to the signal based on the used communication standard. Then an N point IFFT (Inverse Fast Fourier Transform) block (105) converts the signal into time domain. After the signal is passed through the parallel to serial converter (106), a prefix and/or suffix is added to the signal by the cyclic prefix/suffix adder (107) in order to protect the data against channel dispersion. Finally, the signal is converted into analog form by passing it through a digital to analog converter (D/A converter) (108) (Figure 1).

Each subcarrier has a bandwidth of \( B/N \) Hz. Each subcarrier can be modulated by a digital modulation technique such as binary shift keying, M-ary phase shift keying (MPSK) or M-ary quadrature amplitude modulation (M-QAM).

On the receiver side, the received signal is first passed through an analog to digital (A/D) converter. Then the cyclic prefix and/or suffix are removed from the signal to get rid of the dispersion that might be added by the channel.

Equalization in OFDM systems can simply be performed on each subcarrier by using a single tap frequency domain equalizer (single tap FDE). Frequency
domain equalizers are frequently used in OFDM based systems since they are simple to implement. Channel taps are estimated based on transmission of a known data sequence. This process is called data aided or pilot based channel estimation.

The baseband model of transmitted OFDM symbol can be denoted as:

\[ A_n = \frac{1}{\sqrt{N}} \sum_{\tau=0}^{N-1} j_{\tau,n} e^{j2\pi \frac{n}{N} \tau}, \quad k = 0, 1, \ldots, N - 1 \quad (1) \]

where, \( N \) represents the FFT size, \( n \) indicates frequency domain index, \( k \) indicates time domain index and \( (A_n) \) indicates the transmitted symbol/bit sequence.

The received OFDM symbol at the output of the FFT block can be denoted as:

\[ R_n = \frac{1}{\sqrt{N}} \sum_{\tau=0}^{N-1} r_{\tau} e^{-j2\pi \frac{n}{N} \tau}, \quad r_{\tau} = 0, 1, \ldots, N - 1 \quad (2) \]

\( r_{\tau} \) in Equation 2 is the received symbol sample.

The received OFDM symbol at the output of the FFT block can also be expressed as:

\[ R_n = H_n X_n + J_n + W_n \quad (3) \]

In equation 3, \( H_n \) represents \( n \)th channel tap, \( J_n \) represents interchannel interference on the \( n \)th channel, and \( W_n \) represents additive white Gaussian noise (AWGN) component.

Channel estimation is performed by using the known pilot symbols. The channel estimation can basically be obtained by the following equation

\[ B_{n,e} = \frac{r_{n,e}}{r_i} \quad (4) \]

In equation 4, \( P_1 \) denotes the \( i \)th pilot symbol.
Where the number of pilot symbols used in the system is $L$, the channel taps used in FDE can be obtained by averaging the per symbol channel estimates (5) as follows:

$$\tilde{H}_n = \frac{1}{L} \sum_{l=1}^{L} \tilde{H}_{n,l}$$

(5)

The received samples at the output of FDE are

$$Z_n = \frac{\tilde{R}_n}{\tilde{R}_n} = \frac{H_n}{R_n} X_n + \frac{j}{R_n} Y_n + \frac{W_n}{R_n}$$

(6)

As can be seen from the above given explanations, the estimation error associated with the channel tap estimate, $\tilde{H}_n$, causes performance degradation in OFDM systems.

As a result of the experimental and analytical studies conducted, it is observed in the state of the art applications that in the OFDM based communication methods, the noise added to the transmitted data and the interchannel interference (ICI) occur more in constellation points with high amplitudes than the points that are close to the origin where the real (inphase) and virtual (quadrature) amplitudes are zero (Figure 3 and 4).

$$H_n = \tilde{H}_n + \Delta H_n$$

(7)

In equation 7, $\Delta H_n$ represents the channel estimation error. Then the received symbol can be expressed as

$$Z_n = X_n - \frac{\tilde{R}_n}{\tilde{R}_n} X_n + \frac{j}{\tilde{R}_n} Y_n + \frac{W_n}{\tilde{R}_n}$$

(8)

In equation 8, there is a noise term scaled by the constellation amplitude of the transmitted symbol. In order to demonstrate this effect, a 64-QAM constellation is used.
A regular 64-QAM constellation is shown in Figure 3. The average symbol energy in the constellation is normalized to 1. Received samples of this constellation through ideal channels with 3 pilot symbols are shown in Figure 4. As can be observed from this figure, constellation points with higher amplitude values are subject to more noise during channel estimation.

The solution methods provided in the state of the art for the problem of improving accuracy of channel estimation are generally based on transmission of a known data sequence named as pilot symbols.

One of the applications in the state of the art is disclosed in United States patent document US6327314. The said document relates to improving the channel estimation process for a more precise channel frequency response.

Another application in the state of the art is disclosed in United States patent document US2004240376. In the said document, a virtual training symbol is created and processed for correcting the channel estimation error.

Summary of the Invention

The objective of the present invention is to realize an OFDM based transmitter wherein performance degradation resulting due to channel estimation error is reduced and a receiver operating in accordance with the said transmitter.

Another objective of the invention is to realize a transmitter which takes measures against performance loss originating from channel estimation errors, by using source coding and/or channel coding methods.

A further objective of the invention is to minimize the number of constellation elements getting more affected from the channel estimation error in the codes.
revealed during channel or source coding, and thereby to decrease the performance loss originating from channel estimation error.

**Detailed Description of the Invention**

The transmitter realized to fulfill the objective of the present invention and the receiver operating in accordance with the said transmitter are illustrated in the accompanying figures wherein,

- Figure 1 shows the block diagram of a transmitter of the state of the art.
- Figure 2 shows the schematic block diagram of the inventive transmitter and receiver.
- Figure 3 is the graphic showing the line up of the points of a regular 64-QAM constellation in the state of the art.
- Figure 4 is the graphic showing the line up of the points of a regular 64-QAM constellation of the state of the art when noise is added thereto.
- Figure 5 is the flowchart of the method used in the transmitter.
- Figure 6 is the flowchart for generation of the dictionary used by the transmitter in the method described in Figure 5.

The parts in the figures are each given a reference numeral where the numerals refer to the following:

1. Receiver
2. Analog to digital converter
3. Cyclic prefix/suffix remover
4. Serial to parallel converter
5. N-FFT block
6. Channel estimator
7. FEQ- Frequency Domain Equalizer
8. Demodulator
9. Parallel to serial converter
10. Decoder
11. Transmitter
12. Memory
103. Encoder
104. Serial to parallel converter
105. N-IFFT block
106. Parallel to serial converter
107. Prefix/suffix adder
108. Digital to analog converter

The transmitter (11) comprises a memory (12), a source and/or channel encoder (103), a serial to parallel converter (104), an N-IFFT block (105), a parallel to serial converter (106), a prefix/suffix adder (107) and a digital to analog converter (108).

The symbols encoded and sent by the inventive transmitter (11) are detected by the receiver (1). The receiver (1) operating in accordance with the transmitter (11) comprises an analog to digital converter (2), a cyclic prefix/suffix remover (3), a serial to parallel converter (4), an N-FFT block (5), a channel estimator (6), a frequency domain equalizer (7), a demodulator (8), a parallel to serial converter (9) and a source and/or channel decoder (10).

Some symbols are subject to a higher noise level depending on the channel estimation error. In the present invention, in order to increase the performance, symbols with higher noise level are intended to be used less, while the symbols with lower noise level are intended to be used more. Amount of these symbols to be used is calculated according to the noise distribution, and thus the desired apriori probability values of symbols are determined.

The transmitter (11) operates according to the following method:
- Generates pilot symbols (201),
- Measures the noise ratio at the channel through which transmission will be realized (202),
- Generates a dictionary wherein the desired apriori probabilities of different symbols are determined according to the noise ratio in the channel (203),
- Saves the generated dictionary into the memory (12) (204),
- Changes the code set to be used according to the generated dictionary (205),
- Receives the uncoded data and performs channel coding according to the changed channel and/or source code set (206),
- Transmits the coded data to the source and/or channel decoder (10) in the receiver (1) (207).

The uncoded data are the data received from sources such as audio and/or video recording devices, data banks, internet sites.

The dictionary generated in the transmitter (11) is defined in the source and/or channel decoder (10). The source and/or channel decoder (10) decodes the signals that it detects by converting them into the closest dictionary term.

The dictionary is generated in the transmitter (11) with the following method:

- Channel estimation error of each point in the constellation is calculated according to the noise ratio in the channel (301),
- The desired apriori probabilities are calculated so as to minimize the total error probability according to the error rates of the constellation points (302),
- The coding dictionary to be used is generated according to the probabilities (303).
In one embodiment of the invention, the source code set is changed in the
transmitter (11) according to the dictionary generated and thus source coding is
carried out. In this embodiment, a source encoder (103) is used as an encoder
(103).

In another embodiment of the invention, the channel code set is changed in the
transmitter (11) according to the dictionary generated and thus channel coding is
carried out. In this embodiment, a channel encoder (103) is used as an encoder
(103).

In the invention, it is assumed that there are M points in the constellation and the
expected channel estimation error of each of the M points is calculated. As a result of these channel estimation calculations, error probability of each point
changes. The desired apriori probability values of symbols are calculated such that
the total error probability is minimized. The dictionary to be used in the channel
and/or source coding is generated using these probabilities.

In the art, when symbols with high amplitudes are generated, the channel
estimation error increases. Therefore, it is ensured that presence of symbols with
high amplitudes is decreased in certain ratios by changing channel and/or source
coding in the transmitter (11). The noise amount in the channel is measured and
the said ratio is decided on according to the measurement results. Since channel
estimation error will increase as the noise level increases, the transmitter (11) uses
the symbols close to the center in the constellation more frequently.

By means of the channel and/or source coding dictionary generated according to
the measured noise amount, symbols with high amplitudes occupy less space in
the coding dictionary of the information. Through this dictionary, which is also
defined on the receiver's (1) side, a transmission more robust against channel
estimation errors is provided.
It is possible to develop a wide variety of embodiments of the inventive
transmitter (11) and the receiver (1) operating in accordance with the said
transmitter. The invention cannot be limited to the examples described herein and
it is essentially according to the claims.
CLAIMS

1. A transmitter (11) used in OFDM communication, comprising a memory (12), a source and/or channel encoder (103), a serial to parallel converter (104), an N-IFFT block (105), a parallel to serial converter (106), a prefix/suffix adder (107) and a digital to analog converter (108); and characterized in that it
   - generates pilot symbols (201),
   - measures the noise ratio at the channel through which transmission will be realized (202),
   - generates a dictionary wherein the desired apriori probabilities of different symbols are determined according to the noise ratio in the channel (203),
   - saves the generated dictionary into the memory (12) (204),
   - changes the code set to be used according to the generated dictionary (205),
   - receives the uncoded data and performs channel coding according to the changed code set (206), and
   - transmits the coded data to the source and/or channel decoder (10) in the receiver (1) (207).

2. A transmitter (11) according to Claim 1, which
   - calculates the channel estimation error of each point in the constellation according to the noise ratio in the channel (301),
   - calculates the desired apriori probabilities so as to minimize the total error probability according to the error rates of the constellation points (302), and
   - generates the coding dictionary to be used according to the probabilities (303).
3. A transmitter (1) according to Claim 2, using the source code set as the code set.

4. A transmitter (1) according to any of the preceding claims, using the channel code set as the code set.

5. A receiver (1) operating in accordance with the transmitter (1) according to any of the claims 2-4; which receiver comprises an analog to digital converter (2), a cyclic prefix/suffix remover (3), a serial to parallel converter (4), an N-FFT block (5), a channel estimator (6), a frequency domain equalizer (7), a demodulator (8), a parallel to serial converter (9) and a source and/or channel decoder (10); and is characterized in that it comprises a source and/or channel decoder (10) in which the generated dictionary is defined and which decodes the signals that it detects by converting them into the closest dictionary term.
Figure 5

201
Generating pilot symbols

202
Measuring the noise ratio at the channel through which transmission will be realized

203
Generating a dictionary wherein the desired a priori probabilities of different symbols are determined according to the noise ratio in the channel

204
Saving the generated dictionary into the memory (12)

205
Changing the code set to be used according to the generated dictionary

206
Receiving the uncoded data and performing channel coding according to the changed channel and/or source code set

207
Transmitting the coded data to the source and/or channel decoder (10) in the receiver (1)
Figure 6

- Calculating the channel estimation error for Constellation Point 1
- Calculating the channel estimation error for Constellation Point 2
- Calculating the channel estimation error for Constellation Point M

1. Channel noise ratio

2. Calculating the desired a priori probabilities so as to minimize the total error probability according to error rates of the constellation points

3. Generating the coding dictionary to be used according to the probabilities
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04L27/34 H04L1/00
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

<table>
<thead>
<tr>
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<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No</th>
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Further documents are listed in the continuation of Box C

D 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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