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(54) **RELIABLE CHANNEL STATE INFORMATION IN MULTI-BEAM SATELLITE COMMUNICATIONS.**

(57) The invention provides a method for determining the reliability of estimated channel state information for each carrier/beam in a multi-beam satellite communication system, wherein the signals are transmitted using aggressive frequency reuse among the carriers/beams. The proposed method allows to reduce the complexity of the receiver as compared to known systems, as the detection of interfering carriers is shifted towards the end of the workflow, when the signal of the reference carrier has already been frequency, phase, and time compensated.

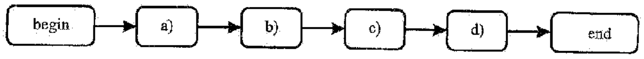

Fig. 1

RELIABLE CHANNEL STATE INFORMATION IN MULTI-BEAM SATELLITE COMMUNICATIONS

Technical field

The invention lies in the field of satellite communication systems, and relates in particular to a method and device for providing reliable channel state information for a plurality of carriers in a multi-beam satellite communication system relying on aggressive frequency reuse among its available carriers.

Background of the invention

Communication satellites have evolved to provide broadband data transfer from a transmitting ground station via the satellite to a geographical area on the ground, which is defined by the area covered by the satellite's transmission beam. Multibeam architectures have been proposed, in which information is simultaneously transmitted to a plurality of spot beams on the ground.

In known approaches, all of the satellite's beams are used to transmit data at the same time, while adjacent beams transmit at different frequencies and/or using different polarizations in order to reduce the co-channel interference. This approach fails to cope with heterogeneous data traffic demands in each ground spot, as the satellite resources are equally distributed over the beams, so that the per-beam offered capacity is fixed and the same for all beams.

It has also been proposed to use beam hopping techniques, in which a first subset of beams, serving a first set of ground spots, is active at a given time and transmitting at a given frequency. Subsequently, the first subset of beams is not transmitting, and a second subset of beams, preferably serving a second set of ground spots, transmits at the same frequency. This approach allows to flexibly allocate scarce on-board resources over the service coverage.

As an alternative, aggressive frequency reuse relies on the simultaneous transmission of signals on all available satellite beams, to receivers in all ground spots, on the same frequency. In order to mitigate spatial interference as well as co-channel interference, it has been suggested to use precoding at the transmitter gateway. Precoding takes the estimated interference levels into account, which the signal that is to be transmitted on a beam is likely to suffer. If, during transmission of the signal, the signal is indeed subject to the estimated interference, the precoding allows for a high probability of correct detection of the signal at a receiver located within the corresponding ground spot. For this approach to work efficiently, the channel state information that is estimated by the receivers and made available at the transmitter or at the gateway where the precoding step if performed, must be as reliable as possible. The more accurate the available channel state information is, the more efficient the quality of the received signal using precoding will be. Moreover, any system using precoding benefits from accurate and reliable channel state information.

Patent document WO 2015/192995 A1 describes a method for synchronization and channel estimation in a DVB-S2x system (see ETSI EN 302 307-2 DVB "*Second Generation framing structure, channel coding and modulation systems for Broadcasting, interactive Services, news gathering and other broadband satellite applications, Part II: S2-Extensions*", www.etsi.org). A complete chain for precoding is described and the method is designed to work even for asynchronous co-channel carriers. However, it has the drawback of detecting the interference carriers as a first step, when signals are not synchronized and, as a consequence, most of the impairments are not compensated. Aside from being computationally expensive, this considerably limits the possibility of detecting carrier at very low signal-to-noise plus interference ratios. A known sequence-based detection method is proposed for the detection of the adjacent co-channel carriers, which occurs in the presence of strong timing/phase impairments.

Technical problem to be solved

It is an objective to present a method and device, which overcome at least some of the disadvantages of the prior art.

Summary of the invention

In accordance with a first aspect of the invention, a method for generating reliable channel state information in a wireless multi-user multiple input single output, MISO, satellite communication system employing precoding is provided. The method comprises the following steps:

a) at a receiver, receiving a signal comprising a plurality of waveform components, each waveform component being subdivided into frame units, wherein each frame unit comprises a first field that is not subjected to precoding and that indicates a start of the respective frame unit and at least one second field that is not subjected to the precoding, said second field comprising a pilot sequence;

b) for a waveform component of the plurality of waveform components, determining the start of a frame unit of the waveform component, and determining positions of said plurality of second fields;

c) for said waveform component, determining phase values of said plurality of second fields;

d) if the standard deviation of said plurality of phase values is lower than a predetermined threshold value, generating a reliable channel coefficient corresponding to the waveform component based on the determined phase values, otherwise, discarding the phase values as being unreliable.

Preferably, the predetermined threshold value may be $\pi/2$. Alternatively, the threshold may be selected as a function of the carrier noise levels.

Preferably, only for a reference waveform component of the plurality of waveform components, step b) may comprise :

b1) estimating a frequency value of the waveform component, time-synchronizing said waveform component and re-sampling the waveform component, to obtain a re-sampled reference waveform component;

Further preferably, only for said reference waveform component, step c) may comprise:

c1) determining the absolute phase values of said plurality of second fields in the frame unit of the re-sampled reference waveform component.

Step b) may further preferably comprise a step of applying a matched filter on said received signal in order to increase the signal-to-noise ratio SNR. The matched filter may be determines based on the estimated frequency of the references waveform component.

Preferably, for each of waveform components other than said reference waveform component, step c) may comprise determining a phase offset value for said second fields of said the waveform component, relative to the phase value of said reference waveform component.

Preferably, the received signal may have been transmitted from a multi-beam satellite using aggressive full frequency reuse, wherein each beam serves a different ground spot. Preferably, said reference waveform may have said receiver as its destination, while said remaining waveform components may have receivers located in different ground spots as their respective destinations.

Said phase offset value may preferably be determined based on an average value of said phase values determined for the plurality of said second fields of said waveform component. The offset value may preferably be determined with respect to an average of the absolute phase values that are determined for said second fields of said reference waveform component.

Said determination of phase values may preferably be made based on the second fields within one frame unit of a waveform component. Alternatively, said determination of phase values may preferably be made based on the second fields within a plurality of subsequent frame units of a waveform component.

It may be preferred that information identifying said first and second fields of said waveform components is pre-provided at the receiver.

Preferably, said waveform components of the received signal are substantially synchronized in time with respect to each other.

Said second fields may preferably not be subjected to precoding.

The method may preferably comprise a subsequent step of transmitting said reliable channel coefficient using a data communication channel to a transmission gateway of said satellite communication system.

In accordance with another aspect of the invention, a device for generating reliable channel state information in a wireless multi-user MISO satellite communication system employing precoding is provided. The device comprises signal receiving means, for example an antenna for receiving satellite transmitted signals and/or a wireless receiving interface, signal processing means, for example a signal processor, and a memory element, for example a random-access memory, RAM, device, a Hard Disk, a solid-state drive, SDD, or other data storage devices. The receiving means are configured for receiving a signal comprising a plurality of waveform components, each waveform component being subdivided into frame units, wherein each frame unit comprises a first field that is not subjected to precoding and that indicates a start of the respective frame unit and at least one second field, said second field comprising a pilot sequence, and wherein the signal processing means are configured for

- determining for a waveform component comprised in said received signal, the start of a frame unit of the waveform component, and determining positions of said plurality of second fields;
- for said waveform component, determining phase values of said plurality of second fields;
- if the standard deviation of said plurality of phase values is lower than a predetermined threshold value, generating a reliable channel coefficient corresponding to the waveform component based on the determined phase values, otherwise, discarding the phase values as being unreliable.

Preferably, the signal processing means are further configured to perform the method in accordance with aspects of the invention.

In accordance with yet another aspect of the invention, a computer program comprising computer readable code means is provided, which when run on a computer, causes the computer to carry out the method according to aspects of the invention.

According to a final aspect of the invention, a computer program product is provided, comprising a computer-readable medium on which the computer program according to the previous aspect of the invention is stored.

Aspects of the present invention allow for providing reliable channel state information, CSI, in scenarios where a receiver obtains a signal that comprising multiple waveforms: a reference waveform, the destination of which is the receiver at hand, and a plurality of interfering waveforms, having other receivers as their intended destination. This is typically the case in signals transmitted via broadband satellites using full frequency reuse among a plurality of satellite beams, each beam serving different ground spots. The receiver is able to estimate the reliability of the computed channel state information for the reference channel as well as for the interfering channels. This reliability indicator substitutes the detection and verification procedure over interferer carriers. Only if the reliability is estimated to be sufficiently high, the channel state information is eventually provided o the transmitter gateway for further use, for example as input to a precoding step. Embodiments of the present invention allow to reliably estimate co-channel carriers with very low signal to noise plus interference ratio. As a consequence, precoding gain in terms of throughput are larger and the degradation due to non-perfect CSI is smaller as compared to known solutions. In accordance with embodiments of the invention, when a signal including a reference signal and interferer signals is received, the reference signal only is synchronized and as a consequence, the complexity of the receiver for the synchronization part is reduced compared to known solutions. Further, as only the difference in phase between the interferer carrier phase and the reference carrier is preferably reported, coherent accumulation pilots and correct estimation of the channel coefficients becomes feasible. In addition, the procedure facilitate the phase compensation of the precoded fields since, by reporting the phase difference, the phase of the precoded and the not precoded fields become the same.

Brief description of the drawings

Several embodiments of the present invention are illustrated by way of figures, which do not limit the scope of the invention, wherein:

- figure 1 provides a workflow diagram illustrating the main steps of a method in accordance with a preferred embodiment of the invention;
- figure 2a provides a schematic view of a communication system in which a method in accordance with a preferred embodiment of the invention may be put to use;
- figure 2b provides an illustration of the structure of various components comprised in a received signal, in accordance with an embodiment of the invention;
- figure 3 provides a schematic view of steps involved in implementing a method in accordance with a preferred embodiment of the invention.

Detailed description

This section describes aspects of the invention in further detail based on preferred embodiments and on the figures, without being limited thereto.

The proposed method assumes a broadband multi-beam satellite system where each i-th beam has an associated area of coverage or ground spot, and an associated signature in terms of pilot sequences. While the invention is not limited to such systems, it finds particular use in a system having a structure and using transmission signals as defined in Annex E, format 2 and 3 of the DVB-S2x specification, which is hereby incorporated by reference in its entirety: ETSI EN 302 307-2 DVB "*Second Generation framing structure, channel coding and modulation systems for Broadcasting, interactive Services, news gathering and other broadband satellite applications, Part II: S2-Extensions*", www.etsi.org. The multiple carriers are supposed to be aligned in time.

Figure 1 illustrates the main steps of a method according to a preferred embodiment of the invention. The method aims at generating reliable channel state information, CSI, in a wireless multi-user MISO satellite communication system employing precoding. With reference to figure 2a, a plurality of signals 1, ... , N_{beam} is generated at one or at a plurality of gateway stations 10 in the communication system, which relay the signals to a broadband multi-beam satellite 20. Each of the signals is due to be transmitted on one of the N_{beam} beams the satellite is forming, and serves receivers located within a corresponding ground spot, covered by said beam. In the non-limiting illustration, three beams are represented, but the invention extends of course to a different plurality of beams, for example up to tens or hundreds of beams. Beam 1 serves receivers in the first ground spot, such as receiver 100, beam 2 serves receivers 100(2), beam *i* serves receivers 100(i), and so on. The satellite may for example use aggressive frequency reuse on all its beams, so that the signal actually received by a receiver suffers from both spatial and co-channel interference. For example, the signal 110 received at receiver 100 not only comprises the reference waveform component 1 that it wants to decode, but it also comprises interference from waveform components 2, .. i, ... N_{beam}, that are transmitted on the same channel frequency.

In order to pre-empt this interference, the gateways 10 use a precoding technique. Precoding is as such known in the art and will not be explained in details in the context of the present invention. Details may for example be found in patent document WO 2015/192995 A1. In order to form the adequate precoding matrix that is multiplying the data signals formed at the gateways, the latter have to know channel state information describing the behaviour of each one the communication channels formed by each of the satellite's beams, as observed by the respective receivers.

As illustrated in figure 2b, each of the waveform components 1, 2, ..., i, ..., N_{beam} comprises a first field Start(1), Start(i), ... that marks the start of a frame unit within the waveform component. Further, each waveform component comprises a sequence of second fields, or pilot fields Pil(1), Pil(i), ..., that comprise respective pilot sequences. At step a) as shown in Figure 1, the signal 110 comprising the plurality of waveform components is received at the receiver 100, for which only the reference waveform component 1 is intended. Of course the signal also comprises a data payload, which will however not be described in the context of the present invention.

At step b), for a selected waveform component of the plurality of components included in the received signal 110, the start of the frame unit and of the pilot sequences are determined. Typically, the locations of the ground spots are static and the receiver 110 knows the signatures/pilot sequences for each beam.

At step c), for the selected waveform component, the phase values of the pilot sequences are determined, and at step d), the reliability of the estimated values is evaluated. Only if he phase values are deemed to be reliable, the corresponding channel state coefficient for the selected waveform component (corresponding to one of the beam channels) is generated, and eventually fed back 120 to the gateway(s) 10, either via a terrestrial or a satellite communication channel.

Preferably, the receiver 100 estimates a frequency value, time-synchronizes the waveform component and resamples it to obtain a re-sampled waveform component only for the reference waveform component 1, which was intended for reception by receiver 100. For this reference component 1, the absolute phase values of the pilot sequences in the frame unit of the re-sampled waveform component are determined.

These additional steps are not performed for those waveform components that are interfering with the reference waveform component. As these components may be assumed to be synchronized in time with the reference waveform component, finding the respective pilot sequences of these remaining waveform components, and estimating the corresponding phase values, is shifted towards the end of the workflow, when the received signal has already bean "cleaned" and compensated for based on the reference waveform's signature. This approach allows to reduce the complexity of the receiver.

Frequency misalignments amongst carriers/beams can in practice be mitigated through the use of an Ultra Stable Oscillator on the payload of the satellite, which drives all the downconverters. If the payload cannot incorporate it, a frequency calibration procedure, similar to the one used for timing, can be performed through dedicated terminals, see for example S. Andrenacci et al, "*Exploiting orthogonality in DVB-S2X through timing pre-compensation*", 2016 8th Advanced Satellite Multimedia Systems Conference and the 14th Signal Processing for Space Communications Workshop, pp.1-9. In that case, the most relevant impairment in frequency at the receiver is the frequency offset/drift experienced by the receiver, which affects the superimposed signal in the same way.

Further, timing misalignments amongst carriers are effective only for large baudrates of carriers. When timing misalignments are relevant, a pre-compensation procedure shall preferably be used to limit the degradation effects on both the channel estimations and the precoding gains.

The reliability test at step d) relies on the finding that when a co-channel carrier is present in the received signal, the phase estimation on successive pilot fields should yield a value which has a small standard deviation window, while on the other hand, when the signal is not present, the phase estimation should vary randomly between π and $-\pi$. According to these considerations, a coefficient is classified as being reliable (and, as a consequence, the corresponding carrier is detected at receiver 100) if the standard deviation of the estimated phase is below a certain predetermined value, for example but not limited to $\pi/2$. For the interfering waveform components received in the signal 110 at the receiver 100, the phase values are determined as offset values with respect to the absolute phase value that has been determined for the reference waveform 1. The offset value is for example computed by computing the difference between the average of the reference waveform component's sequence of pilot field phase values, and the average of an interfering waveform component's sequence of pilot field phase values.

Since each beam is defined by its own signature (in a frequency-reuse fashion for large systems since the number of Walsh-Hadamard sequences is limited) and since the beams are fixed (in terms of coverage over the earth), the receiver shall know the signature of the neighbour beams and it should try to estimate ideally all of them. In order to have an accurate estimation of the channel value, all SF-Pilot fields in a superframe should be used (for example, in format 2 of DVB-S2x, 639 pilot fields are included in one superframe).

In what follows a formal description of the detection/reliability estimation of step d) in accordance with embodiments with the invention is provided. Assuming that $\boldsymbol{c}_{ij}=[c_{ij}(1), \dots, c_{ij}(L_{pil})]$ is the j-th signature (first field) of the i-th beam, j=1,..., N_{pil} and i=1,..., N_{beam}, where N_{pil} is the number of pilot sequences (second field) in one frame (or alternatively, the number of pilot sequences contained in the desired length to be considered for the procedure) and L_{pil} is the length of the SF-Pilot for which orthogonality is maintained for up to N_{beam} beams.

In the particular case of format 2 and 3 of the annex E option of DVB-S2x, for example, c_{ij} is composed by a Walsh-Hadamard sequence $\boldsymbol{w}_i=[w_i(1),\dots,w_i(L_{pil})]$, one for each beam, and a scrambling sequence $\boldsymbol{s}_j=[s_j(1), \dots, s_j(L_{pil})]$, which is common for all beams but is changes depending on the pilot sequence in the frame.

Let $\bar{\boldsymbol{r}}_i^{(k)}$ be the received and compensated signal (based on the reference signal) of the k-th receiver in the i-th beam, before the CSI estimation procedure, as;

$$\bar{\boldsymbol{r}}_k^{(i)} = \sum_{n=1}^{N_{beam}} |h_{kn}^{(i)}| e^{-i(\theta_{kn}^{(i)} - \theta_{kk}^{(i)})} \boldsymbol{x}_n + \boldsymbol{n}_k^{(i)}$$

where $|h_{kn}|$ is the amplitude of the channel coefficient from the n-th antenna to the k-th user terminal, $\theta_{kn}^{(i)}$ is the phase of the channel from the n-th antenna to the k-th user terminal or receiver, $\theta_{kk}^{(i)}$ is the phase of the reference signal of the k-th user, x_n is the transmitted signal from the n-th antenna, which can be precoded or not precoded depending on the index of the symbol according to the DVB-S2x specification.

The received signal is given by the superposition of co-channel carriers, each of them coming from the n-th antenna. Since in one frame (for example the superframe duration) there are more pilot fields, the number of estimations for each co-channel coefficient is equal to N_{pil}. We define $\hat{\boldsymbol{\alpha}}_{kn}^{(i)} = [\hat{\alpha}_{kn}^{(i)}(1),\dots,\hat{\alpha}_{kn}^{(i)}(N_{pil})]$ and $\hat{\boldsymbol{\varphi}}_{kn}^{(i)} = [\hat{\varphi}_{kn}^{(i)}(1),\dots,\hat{\varphi}_{kn}^{(i)}(N_{pil})]$ the set of N_{pil} carrier estimates for, respectively, amplitude and phase of the k-th receiver in the i-th beam coming from the n-th antenna. It is worth noting that $\hat{\varphi}_{kn}^{(i)}(j) = \hat{\theta}_{kn}^{(i)}(j) - \hat{\theta}_{kk}^{(i)}(j)$.

Each estimate can be calculated using a pilot aided based correlation procedure: $\hat{\alpha}_{kn}^{(i)}(j) = \left|\overline{\boldsymbol{r}}_k^{(i)}(j)\boldsymbol{c}_{ij}^*\right|/L_{pil}$ and $\hat{\varphi}_{kn}^{(i)}(j) = \arg\,(\overline{\boldsymbol{r}}_k^{(i)}(j)\boldsymbol{c}_{ij}^*/L_{pil})$, where $\overline{\boldsymbol{r}}_k^{(i)}(j)$ is the portion of the received symbols corresponding to the j-th pilot field as defined in in the DVB-S2x specification, hence, for which $\boldsymbol{x}_n(j) = \boldsymbol{c}_{ij}$.

Focussing on the phase estimates, an estimated coefficient is defined as reliable, and as a consequence correctly detected, if:

$$\sigma_{kn}^{(i)} = \sqrt{\mathrm{E}\left[\hat{\boldsymbol{\varphi}}_{kn}^{(i)2}\right] - (\mathrm{E}\left[\hat{\boldsymbol{\varphi}}_{kn}^{(i)}\right])^2} < \varphi_{Th}$$

where φ_{Th} is defined according to the desired detection performance in terms of false alarm.

Of course, when carriers at very low signal to noise ratio are considered, the standard deviation of estimations based on a single pilot field, according to Cramer Rao Bounds, could not be as limited as desired. As a consequence, the method in accordance with aspects of the invention assumes that each estimation is based on a group of pilot fields in one superframe, as it follows:

$$\hat{\boldsymbol{\alpha}}_{kn}^{(i)} = [\hat{\alpha}_{kn}^{(i)}(1),\ldots,\hat{\alpha}_{kn}^{(i)}(N_{pil}/N_{acc})]\ ;\ \hat{\boldsymbol{\varphi}}_{kn}^{(i)} = [\hat{\varphi}_{kn}^{(i)}(1),\ldots,\hat{\varphi}_{kn}^{(i)}(N_{pil}/N_{acc})]$$

where $\hat{\alpha}_{kn}^{(i)}(l)$ and $\hat{\varphi}_{kn}^{(i)}(l)$ are the l-th estimate (l=1,…, N_{pil}/N_{acc}), $N_{acc}<N_{pil}/20$ is the number of pilots coherently accumulated inside the frame according to:

$$\hat{\alpha}_{kn}^{(i)}(l) = \left|\sum_{m=1}^{N_{acc}}\overline{\boldsymbol{r}}_k^{(i)}(p)\boldsymbol{c}_{ip}^*/L_{pil}\right|/N_{acc};\ \hat{\varphi}_{kn}^{(i)}(l) = \arg\,(\sum_{m=1}^{N_{acc}}\overline{\boldsymbol{r}}_k^{(i)}(p)\boldsymbol{c}_{ip}^*/L_{pil});$$

being $p = (l-1) * N_{acc} + m$.

CSI coefficients can be also calculated accordingly:

$$\hat{\alpha}_{kn}^{(i)} = \frac{1}{N_{pil}/N_{acc}}\sum_{l=1}^{N_{pil}/N_{acc}}\hat{\alpha}_{kn}^{(i)}(l);$$

$$\hat{\varphi}_{kn}^{(i)} = \frac{1}{N_{pil}/N_{acc}}\sum_{l=1}^{N_{pil}/N_{acc}}\hat{\varphi}_{kn}^{(i)}(l)$$

As already mentioned, no verification procedure at the beginning of the architecture is needed since the test operates directly on the CSI estimates. In order to make the procedure work, the estimation through pilot symbols for interferer carriers shall be almost coherent, so that the gaussian noise is almost completely mitigated thanks to the coherent accumulation over various pilot fields. To this aim, the reference signal is used to estimate the frequency/phase noise errors and then the tracking can be applied on the interferer carriers to compensate for frequency errors.

The procedure assumes the interferer carriers to be synchronous in frequency amongst beams. If the frequency coherence cannot be guarantee, a pre-compensation procedure similar to the one used for synchronize the timing misalignments is needed.

Figure 3 illustrates how the method that has been described is implemented in particularly preferred embodiment of the invention. In accordance with this embodiment, the receiver 200 implements the following steps:

- coarse frequency acquisition, 250, by means of frequency estimation algorithm: while the use of the quadricorrelator is one option, any coarse carrier frequency offset algorithm can be used. The aim is to reduce the frequency uncertainty and, as a consequence, increase the coherence window for the start of superframe detection procedure;
- a matched filtering, 251, through a Square Root Raised Cosine, SRRC, filter as specified in the DVB-S2x specification;
- a start of superframe detection of the reference signal only, 252, through its own signature. The start of superframe detection, depending on the considered Baudrate of the signal, can make use of the post detection integration procedure to account for the residual frequency offset. The start of superframe detection provides also a coarse timing synchronization in terms of samples, to be used to find the positions of the different fields;
- a timing synchronization for the reference signal only, 253, based on the known signature. For this step, a modified Early Late Gate working on the correlation function instead of the received waveform can be used. The timing estimation drives the re-sampling procedure through interpolation, 254;
- a downsampling procedure, 255;
- a fine frequency estimation and phase noise tracking procedure on the reference signal only, 256, based on the estimates over pilots.
- a channel state information estimation for each cannel coefficient, 257: the estimation is based on the synchronization with the reference signal only for frequency, timing and phase. Only the phase difference between the i-th carrier and the reference signal is reported. Using this procedure, an almost coherent accumulation over pilot fields can be implemented, which drastically reduce the bias of the estimation when low signal to noise plus interference carriers are considered;
- a detection of the channel state coefficient through evaluation of the reliability of the estimate, 258: the procedure is mandatory to decide whether the estimated coefficient comes from a carrier or not.

While the below description is provided for the exemplary case of a communication system employing the DVB-S2 (or DVB-S2X) standard, the present invention is not limited to such communication systems. The receiver 200 comprises a frequency acquisition unit 250 (a frequency estimation unit), a matched filter 251 (a matched filter unit), one frame synchronization unit 252, one symbol re-sampling unit 254 (resampling units), one demultiplexer (demultiplexer units), one time recovery unit 253 (time offset determination units), and a decoding unit for the reference waveform 260 comprising an SNIR estimation unit. The receiver further comprises a fine frequency tracking unit and phase noise tracking unit 256, a channel estimation unit 257 as well as a reliability test/detection unit 258. It is to be noted that as for the frequency acquisition unit 250 and the matched filter 251, all other units except for the channel estimation and the detection unit, commonly process all waveform components. This method relates to estimating a channel (channel state vector, channel vector) between a transmitter and a receiver, the transmitter wirelessly transmitting a plurality of first signals in a plurality of beams through a plurality of transmit feeds in accordance with a weighting procedure (precoding), wherein each of the plurality of first signals is subdivided into frame units (e.g. super-frames) each having a first field that is not subjected to the weighting (precoding) and that indicates a start of the respective frame unit (i.e. that comprises a (symbol) sequence indicating the start of the respective frame unit, e.g. the SoSF field of the super-frame) and one or more second fields that each comprise a predetermined pilot sequence, the receiver receiving a second signal resulting from transmission of the plurality of first signals through the plurality of transmit feeds in accordance with the weighting procedure and subsequent interference at the receiver location, wherein the second signal comprises a waveform component for each of the plurality of transmit feeds. In other words, this method relates to estimating a channel vector (channel state vector) in a wireless MISO (satellite) communication system employing precoding, wherein a receiver receives a signal comprising a plurality of waveform components, each waveform component being subdivided into frame units, wherein each frame unit has a first field that is not subjected to precoding and that indicates a start of the respective frame unit and one or more second fields and that each comprise a predetermined pilot sequence. In a preferred embodiment, the frame unit comprises two or more second fields, and the steps described below are applied to said two or more second fields.

After reception of the signal, the signal is sampled in a sampling unit (not shown in Fig.3) to obtain a sequence of samples corresponding to the received signal. A first frequency estimation (coarse frequency estimation) of the carrier frequency of the received signal is performed. The coarse frequency estimation may be performed for instance by the algorithm proposed in Kim et al. in "Robust frame synchronization for the DVB-S2 system with large frequency offsets," Int. J. Satell. Commun. Network., vol. 27, no. 1, pp. 35-52, 2009, which is hereby incorporated by reference. Of course, also other algorithms for performing the coarse frequency estimation are feasible, such as by a quadri-correlator as proposed in D'Andrea, A.N.; Mengali, U., "Design of quadricorrelators for automatic frequency control systems", IEEE Transactions on Communications, vol.41, no.6, pp.988-997, Jun 1993, which is hereby incorporated by reference. This step is performed at the frequency acquisition unit 250. Matched filtering is performed in order to increase the SNIR of the received signal. Therein, the matched filter is determined based on the frequency estimated in the frequency acquisition unit 250. Methods for performing matched filtering are known in the art. This step is performed in the matched filter 251. Frame synchronization is performed by searching the received signal for the known sequences of symbols (codewords) indicating the start of the super-frames (frame units) in the respective beams (i.e. respective waveform components). In other words, a start of a frame unit of a waveform component, e.g. waveform component m, is determined by searching (using a correlator), in the received signal, for a first field indicating the start of the respective frame unit. The received signal contains, in each waveform component, first fields indicating the starts of respective frame units, wherein the first fields in different waveform components are mutually orthogonal. Accordingly, the start of a frame unit in a given waveform component can be determined by correlating the received signal with a known codeword corresponding to the content of the first field of the frame units of the given waveform component.

Demultiplexing (de-framing) is performed for the reference waveform component in order to separate the start of the super-frame (SoSF, i.e. a first field indicating a start of the frame unit), the pilots (i.e. one or more second fields each indicating (comprising) non-precoded pilot sequences), the precoded pilots (PLH and P2, i.e. one or more third fields each indicating (comprising) precoded pilot sequences), and data (according to the SF structure contained in the SFFI field, i.e. a fourth field containing data). Having knowledge of the structure of the frame unit through signalling, i.e. the locations of the second, third and fourth fields with respect to the start of the frame unit, and moreover having knowledge of the position of the start of the frame unit, the first, second and third fields as well as actual data (fourth field) can be separated and extracted. That is, the first field and the one or more second fields (and optionally also the one or more third fields and further optionally also the fourth field) are separated (extracted) from the received signal on the basis of the determined start of the frame unit and a known (predetermined) structure of the frame unit. This step is performed in the illustrated demultiplexer.

Data aided time tracking and resampling is performed on the basis of the SoSF and precoded pilots of the reference waveform. In other words, a time offset of the waveform component is determined by referring to the first field and the one or more second fields. In other words, this step relates to (data aided) determining a time offset of the waveform component by referring to the first field in the frame unit and the one or more second fields in the frame unit. In more detail, this is achieved by correlating the demultiplexed waveform component with a known codeword corresponding to the content of the first field and known codewords corresponding to the contents of the one or more second fields, respectively, e.g. using a (pilot-aided) early/late gate. Thereby, a refined estimate of the time offset can be determined. It is to be noted that frame synchronization as previously described prerequisite for this step. Further the reference waveform component is resampled on the basis of the determined time offset, whereby the time offset is eliminated from the resampled waveform component, i.e. the frame units in the reference waveform component are aligned with a local clock of the receiver 200. This step is performed in the symbol re-sampling and time recovery units 253, 254.

Frequency and phase tracking on precoded pilots of the reference waveform component is performed. This step relates to (data-aided) determining a frequency offset and a phase offset of the re-sampled waveform component by referring to the one or more second fields in the frame unit. In more detail, the known codewords corresponding to the contents of the one or more second fields are compared to the one or more second fields in the frame unit (same for the one or more third fields, if applicable), and the frequency offset and phase offset are determined on the basis of the comparison. For example, the algorithm proposed in Luise, M.; Reggiannini, R., "Carrier frequency recovery in all-digital modems for burst- mode transmissions," Communications, IEEE Transactions on , vol.43, no.2/3/4, pp.1169, 1178, Feb./March/April 1995, which is hereby incorporated by reference, may be employed to this purpose. This step is performed in the frequency/phase tracking unit 256.

Channel estimation is performed on the basis of the non-precoded or precoded pilots (i.e. the one or more second fields) for each waveform component, wherein the estimated channel is to be sent back to the gateway only if it is deemed to be reliable, as it has been described in the context of the previous embodiments.

It should be noted that features described for a specific embodiment may be combined with the features of other embodiments, unless the contrary is explicitly mentioned. Based on the description and figures that have been provided, a person with ordinary skills in the art will be able to construct a computer program for implementing the described method steps without undue burden.

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It should be understood that the detailed description of specific preferred embodiments is given by way of illustration only, since various changes and modifications within the scope of the invention will be apparent to the person skilled in the art. The scope of protection is defined by the following set of claims.

Claims

1. Method for generating reliable channel state information (120) in a wireless multi-user MISO satellite communication system employing precoding, the method comprising the following steps:

   a) at a receiver (100), receiving a signal (110) comprising a plurality of waveform components (1, 2, i,...), each waveform component being subdivided into frame units (SF(1), SF(2), ...), wherein each frame unit comprises a first field (Start(1), Start(i)) that is not subjected to precoding and that indicates a start of the respective frame unit and at least one second field (Pil(1), Pil(i)) that is not subjected to the precoding, said second field comprising a pilot sequence;

   b) for a waveform component of the plurality of waveform components, determining the start of a frame unit of the waveform component, and determining positions of said plurality of second fields;

   c) for said waveform component, determining phase values of said plurality of second fields;

   d) if the standard deviation of said plurality of phase values is lower than a predetermined threshold value, generating a reliable channel coefficient corresponding to the waveform component based on the determined phase values, otherwise, discarding the phase values as being unreliable.

2. The method according to claim 1, wherein only for a reference waveform component (1) of the plurality of waveform components, step b) comprises :

   b1) estimating a frequency value of the waveform component (1), time-synchronizing said waveform component and re-sampling the waveform component, to obtain a re-sampled reference waveform component;

   and wherein only for said reference waveform component, step c) comprises:

   c1) determining the absolute phase values of said plurality of second fields in the frame unit of the re-sampled reference waveform component.

3. The method according to claim 2, wherein step b) further comprises a step of applying a matched filter on said received signal in order to increase the signal-to-noise ratio, SNR.

4. The method according to any of claims 2 or 3,wherein for each of waveform components (2, ...) other than said reference waveform component (1), step c) comprises determining a

phase offset value for said second fields of said the waveform component, relative to the phase value of said reference waveform component.

5. The method according to claim 4, wherein said phase offset value is determined based on an average value of said phase values determined for the plurality of said second fields of said waveform component.

6. The method according to any of claims 1 to 4, wherein information identifying said first and second fields of said waveform components are pre-provided at the receiver (100).

7. The method according to any of claims 1 to 6, wherein said waveform components of the received signal are substantially synchronized in time with respect to each other.

8. The method according to any of claims 1 to 7 wherein said second fields are not subjected to precoding.

9. The method according to any of claims 1 to 8, further comprising the subsequent step of transmitting said reliable channel coefficient using a data communication channel to a transmission gateway of said satellite communication system.

10. A device (100, 200) for generating reliable channel state information in a wireless multi-user MISO satellite communication system employing precoding, the device comprising signal receiving means, signal processing means and a memory element, wherein the receiving means are configured for receiving a signal comprising a plurality of waveform components, each waveform component being subdivided into frame units, wherein each frame unit comprises a first field that is not subjected to precoding and that indicates a start of the respective frame unit and at least one second field, said second field comprising a pilot sequence, and wherein the signal processing means are configured for

- determining for a waveform component comprised in said received signal, the start of a frame unit of the waveform component, and determining positions of said plurality of second fields;
- for said waveform component, determining phase values of said plurality of second fields;
- if the standard deviation of said plurality of phase values is lower than a predetermined threshold value, generating a reliable channel coefficient

corresponding to the waveform component based on the determined phase values, otherwise, discarding the phase values as being unreliable.

11. The device according to claim 10, wherein the signal processing means are further configured to perform the method in accordance to any of claims 2 to 9.

12. A computer program comprising computer readable code means, which when run on a computer, causes the computer to carry out the method according to any of claims 1 to 9.

13. A computer program product comprising a computer-readable medium on which the computer program according to claim 12 is stored.

Revendications

1. Procédé pour générer des d'informations d'état de canal fiables (120) dans un système de communication multi-utilisateurs sans fil par satellite de type MISO utilisant du précodage, le procédé comprenant les étapes suivantes:
   a) au niveau d'un récepteur (100), recevoir un signal (110) comprenant une pluralité de composantes de forme d'onde (1, 2, i, ...), chaque composante de forme d'onde étant subdivisée en unités de trame (SF (1), SF (2)...), dans lequel chaque unité de trame comprend un premier champ (Start (1), Start (i)) qui n'est pas soumis au précodage et qui indique un début de l'unité de trame respective et au moins un deuxième champ (Pil (1), Pil (i)) qui n'est pas soumis au précodage, ledit second champ comprenant une séquence pilote;
   b) pour une composante de forme d'onde de la pluralité de composantes de forme d'onde, déterminer le début d'une unité de trame de la composante de forme d'onde, et déterminer des positions de ladite pluralité de deuxièmes champs ;
   c) pour ladite composante de forme d'onde, déterminer des valeurs de phase de ladite pluralité de seconds champs;
   d) si l'écart type de ladite pluralité de valeurs de phase est inférieur à une valeur de seuil prédéterminée, générer un coefficient de canal fiable correspondant à la composante de forme d'onde sur la base des valeurs de phase déterminées, sinon, rejeter les valeurs de phase comme non fiables.

2. Procédé selon la revendication 1, dans lequel uniquement pour une composante de forme d'onde de référence (1) de la pluralité de composantes de forme d'onde, l'étape b) comprend:
   b1) estimer une valeur de fréquence de la composante de forme d'onde (1), synchroniser temporellement ladite composante de forme d'onde et ré-échantillonner la composante de forme d'onde, pour obtenir une composante de forme d'onde de référence ré-échantillonnée;

   et dans lequel uniquement pour ladite composante de forme d'onde de référence, l'étape c) comprend:
   c1) déterminer les valeurs de phase absolues de ladite pluralité de deuxièmes champs dans l'unité de trame de la composante de forme d'onde de référence ré-échantillonnée.

3. Procédé selon la revendication 2, dans lequel l'étape b) comprend en outre une étape d'application d'un filtre adapté sur ledit signal reçu afin d'augmenter le rapport signal sur bruit, SNR.

4. Procédé selon l'une quelconque des revendications 2 ou 3, dans lequel pour chacun des composantes de forme d'onde (2, ...) autres que ladite composant de forme d'onde de référence (1), l'étape c) comprend la détermination d'une valeur de décalage de phase pour lesdits deuxièmes champs de ladite composante de forme d'onde, par rapport à ladite valeur de phase absolue de ladite composante de forme d'onde de référence.

5. Procédé selon la revendication 4, dans lequel ladite valeur de décalage de phase est déterminée sur la base d'une valeur moyenne desdites valeurs de phase déterminées pour la pluralité desdits deuxièmes champs dudit composant de forme d'onde.

6. Procédé selon l'une quelconque des revendications 1 à 4, dans lequel des informations identifiant lesdits premier et deuxièmes champs desdites composantes de forme d'onde sont mises à disposition au niveau du récepteur (100).

7. Procédé selon l'une quelconque des revendications 1 à 6, dans lequel lesdites composantes de forme d'onde du signal reçu sont sensiblement synchronisées dans le temps les unes par rapport aux autres.

8. Procédé selon l'une quelconque des revendications 1 à 7, dans lequel lesdits dexièmes champs ne sont pas soumis à un précodage.

9. Procédé selon l'une quelconque des revendications 1 à 8, comprenant en outre l'étape suivante consistant à transmettre ledit coefficient de canal fiable en utilisant un canal de communication de données à une passerelle de transmission dudit système de communication par satellite.

10. Dispositif (100, 200) pour générer des informations d'état de canal fiables dans un système de communication par satellite MISO multiutilisateur utilisant du précodage, le dispositif comprenant des moyens de réception de signaux, des moyens de traitement de signal et un élément de mémoire, dans lequel les moyens de réception sont configurés pour recevoir un signal comprenant une pluralité de composantes de forme d'onde, chaque composante de forme d'onde étant subdivisée en unités de trame, chaque unité de trame comprenant un

premier champ qui n'est pas précodé et qui indique un début de l'unité de trame respective et au moins un deuxième champ comprenant une séquence pilote, et dans lequel les moyens de traitement de signal sont configurés pour

- déterminer pour une composante de forme d'onde comprise dans ledit signal reçu, le début d'une unité de trame de la composante de forme d'onde, et déterminer des positions de ladite pluralité de deuxièmes champs;
- pour ladite composante de forme d'onde, déterminer des valeurs de phase de ladite pluralité de deuxièmes champs;
- si l'écart type de ladite pluralité de valeurs de phase est inférieur à une valeur de seuil prédéterminée, générer un coefficient de canal fiable correspondant à la composante de forme d'onde sur la base des valeurs de phase déterminées, sinon, rejeter les valeurs de phase comme non fiables.

11. Dispositif selon la revendication 10, dans lequel les moyens de traitement de signal sont en outre configurés pour exécuter le procédé selon l'une quelconque des revendications 2 à 9.

12. Un programme d'ordinateur comprenant des moyens de code lisibles par ordinateur, qui lorsqu'il est exécuté sur un ordinateur, amène l'ordinateur à exécuter le procédé selon l'une quelconque des revendications 1 à 9.

13. Produit programme d'ordinateur comprenant un support lisible par ordinateur sur lequel le programme d'ordinateur selon la revendication 12 est stocké.

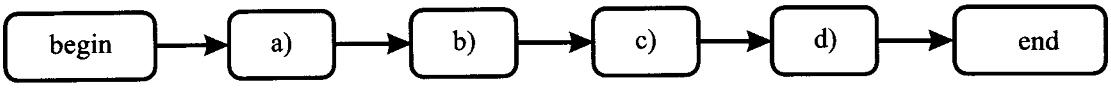

Fig. 1

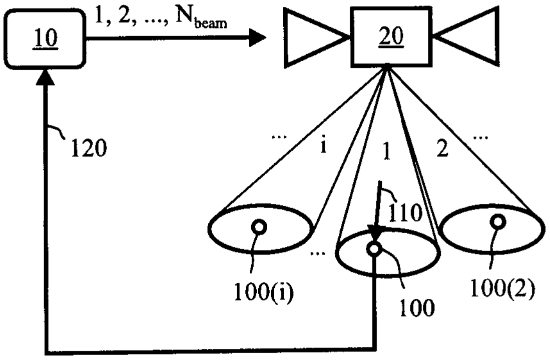

Fig. 2a

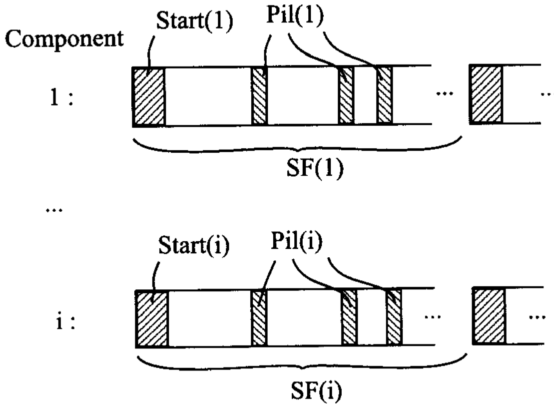

Fig. 2b

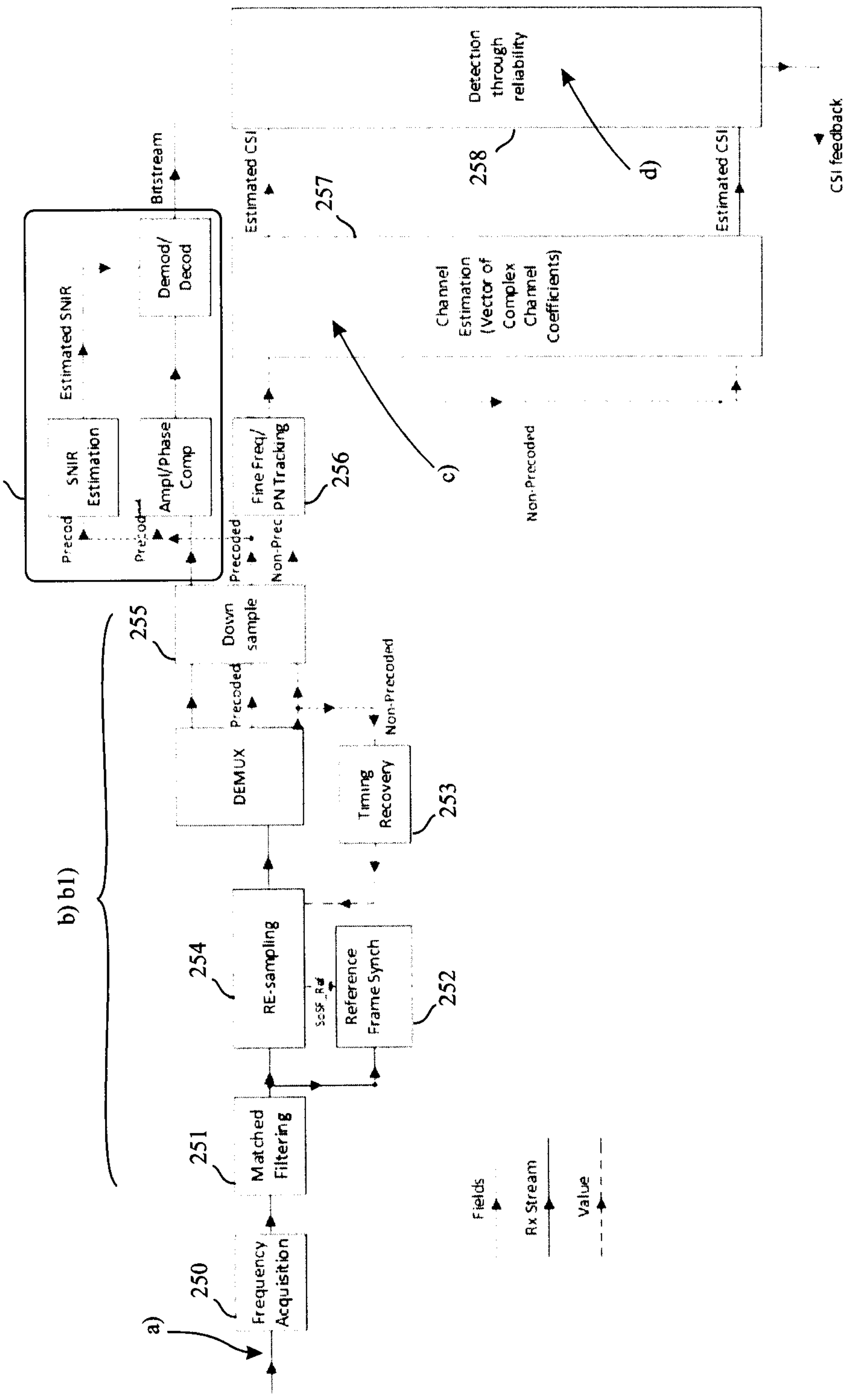
a)
250
Frequency Acquisition
251
Matched Filtering
b) b1)
254
RE-sampling
SoSF_Ref
Reference Frame Synch
252
DEMUX
Timing Recovery
253
Precoded
Non-Precoded
255
Down sample
Precoded
Non-Prec
260
Precod
Precod
SNIR Estimation
Ampl/Phase Comp
Estimated SNIR
Demod/ Decod
Bitstream
Fine Freq/ PN Tracking
256
c)
Non-Precoded
Estimated CSI
257
Channel Estimation (Vector of Complex Channel Coefficients)
Estimated CSI
258
d)
Detection through reliability
CSI feedback
Fields
Rx Stream
Value

Fig. 3