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(54) **Title**: CHANNEL QUALITY INFORMATION PREDICTION METHOD, DEVICE AND SYSTEM

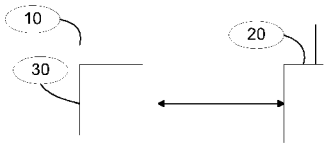


Figure 1A

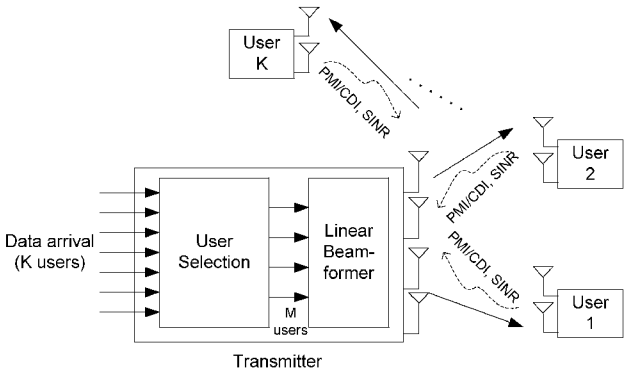


Figure 1B

(57) **Abstract**: A method of computing a channel quality indicator of a channel in a telecommunication network, said channel quality indicator characterizing the quality of the signal received on a channel by a device in said telecommunication network, said method comprising, for a device, the acts of monitoring the state of the channel; computing a prediction of the channel based on a past and the current state of the monitored channel; obtaining a channel variation indicator, said channel variation indicator characterizing the variation of the channel between a past and the current state of the channel; computing a channel quality indicator based on the channel prediction and the channel variation indicator.

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CHANNEL QUALITY INFORMATION PREDICTION METHOD, DEVICE AND SYSTEM

Field of the Invention

The present invention relates in general to telecommunication networks and more specifically to channel quality information prediction.

Background of the Invention

Telecommunication systems comprise a telecommunication network and devices (or downlink receivers) that may connect to the telecommunication network for communicating. The telecommunication network may comprise a network management entity or downlink transmitter (such as e.g. a base station) for managing the network resources (such as e.g. allocating network resources to the devices). In some telecommunication systems, each device may determine channel quality information using information (such as e.g. signals) received or monitored on the channel between the device and the network management entity. Each device may then communicate (i.e. feedback) said channel quality information to the network management entity in order for the network management entity to manage network resources. In other words the network management entity will further use the channel quality information received from the devices to allocate the network resources to said devices. An example of such a type of telecommunication system comprises a Multi-Users Multiple Inputs Multiple Outputs (MU MIMO) telecommunication network and devices that are user equipments. Multi-Users Multiple Inputs Multiple Outputs (MU MIMO) networks may be employed for example in Third Generation Partnership Project (3GPP) Long-Term Evolution-Advanced (LTE-A) (both Frequency Duplex Division (FDD) & Time Duplex Division (TDD)) and Institute of Electrical and Electronics Engineers (IEEE) 802.16m networks. In such networks, channel quality information which is fedback by a device to a network management entity may comprise for example Precoding Matrix Index (PMI), Channel Direction Information (CDI), Signal to Interference and Noise Ratio (SINR)... In MU-MIMO systems, several user equipments may be served simultaneously in frequency and time but can be separated in the spatial domain by adopting well designed precoding techniques. To realize known precoding techniques, such as e.g. Zero-Forcing BeamForming (ZFBF) and Zero-Forcing Dirty Paper Coding (ZF-DPC), the network management entity, e.g. Base Station or Access Point, should know accurate Channel State Information (CSI) of users. In Frequency Duplex Division (FDD) systems, a dedicated feedback channel between the network management entity and the user equipment is needed to provide CSI, which may comprise two

parts: Channel Direction Information (CDI) or Precoding Matrix Index (PMI), and Channel Quality Information, in the form of Signal To Interference to Noise Ratio (SINR). Since the downlink channel (i.e. between the network management entity and the user equipment) is always time variant and the feedback channel is always bandwidth limited, the design objectives of efficient feedback approach should cover at least two aspects. Firstly, the feedback overhead has to be minimized or restricted below a given bit rate. Secondly, the feedback delay effect needs to be considered and mitigated.

The document "Multi-antenna downlink channels with limited feedback and user selection", T. Yoo, et. Al, IEEE journal on selected areas in communications, vol. 25, No. 7, September 2007, describes how to compute CDI and SINR for ZFBF-based MU MIMO systems where each receiver is equipped with only one antenna. This solution does not take channel variation into account feeds back the channel quality indicator (e.g. SINR) which is computed solely on the current channel vector. It is obvious that if the channel does not change at all, the SINR fed back from the receiver would be very close to the real SINR when data are transmitted a few time slots later. On the other hand, when the channel changes a lot, the feedback SINR is absolutely different from the real SINR and makes the transmitter chose the wrong users.

The document "On transceiver design and channel quantization for downlink multiuser MIMO systems with limited feedback", M. Trivellato, et. al, IEEE journal on selected areas in communications, vol. 26, No. 8. October 2008, proposes a MU-MIMO transceiver architecture and methodology (including the computation of CDI and SINR) based on linear ZFBF and linear receiver combining for MU MIMO systems in which each receiver is equipped with more than one antenna. The document "Linear precoding in the downlink of limited feedback MU MIMO systems", G. Dietl and G. Bauch, Proc. IEEE Globecom 2007, describes two different feedback approaches. In the first one, users feed back the best entry of a precoder codebook (i.e. PMI) and in the second one, users provide the quantized channel information on a channel code book (i.e. CDI). The computation of SINR based on ZFBF and Minimum Mean Squared Error (MMSE) receiver combining is also presented.

These three documents "Multi-antenna downlink channels with limited feedback and user selection ", "On transceiver design and channel quantization for downlink MU MIMO systems with limited feedback", and "Linear precoding in the downlink of limited feedback MU MIMO systems" address the issue of limited or finite rate feedback design for MU MIMO systems. They describe how to determine and feedback CDI/PMI and SINR assuming that channels keep invariant. However,

if the time varying nature of wireless channels (induced by the mobility of user equipments) is not taken into account, CSI fed back to the transmitter easily becomes outdated and as a result, outdated CSI will lead to serious performance degradation and make CSI feedback useless at all.

The document "Robust design for multiuser block diagonalization MIMO downlink system with CSI feedback delay", Y. Chang and K. Araki, Proc. IEEE international symposium on personal, indoor and mobile radio communications 2009, proposes a wiener filter-based channel prediction approach for unquantized channel feedback to combat the performance degradation due to feedback delay. Robust computation of SINR which also accounts for feedback delay is provided. This document addresses the issue of mitigation of feedback delay by incorporating channel predication. Estimation of SINR is also carefully designed by introducing the so called robustness parameter to combat delay effect. However, unquantized channel feedback is employed which makes the design not usable for Frequency Duplex Division (FDD) systems as the SINR computed in this solution is inaccurate when quantization error is moderate or serious, which is the case and cannot be avoided in FDD systems. If quantization error is not taken into account, the downlink receiver could only feed back the magnitude of the channel vector as channel quality indicator. However, larger magnitude of channel vector does not mean lager receiving SINR which is the only parameter that could describe the receiving condition. So upon the magnitudes of channel vectors fed back from receivers, the downlink transmitter can not always select the proper users and the throughput would be degraded.

The document "Precoded spatial multiplexing systems in the presence of feedback delay using Kalman filter", A. Khrwat et. al, Proc. IEEE International conference on communications 2009, proposes a prediction method based on a Kalman filter to overcome the dynamics of the channels and mitigates the feedback delay effect for spatial multiplexing MIMO systems. Since a Single User (SU)-MIMO framework is considered in this solution, computation of SINR which is used for multiuser selection is not addressed. Therefore, such a solution does not allow computation of SINR for multiuser selection (the fundamental difference between MU-MIMO and SU-MIMO).

Challenges for SINR feedback in FDD MU MIMO includes how to evaluate the influence of channel quantization error induced by finite-rate (or limited) feedback and incorporate it in the formulation of SINR, and how to incorporate the influence of channel variation or uncertainty induced by feedback delay and terminal's mobility in the formulation of SINR. Unlike other systems, such as e.g. High Speed Downlink Packet Access (HSDPA) or SU MIMO, these two impairments are

crucial to MU MIMO, since they would significantly degrade the system's performance by introducing serious multiple access interference. For example, if the speed is large, the channel state is surely very uncertain. Under this situation, the receiver should have high probability to feed back very low SINR to indicate to the transmitter that its channel quality could be very poor due to the high mobility. If the user's speed is low, the channel state could be very certain or deterministic. In this situation, the receiver should feed back a SINR value that is close to the one that accurately indicates the current channel quality.

The document "Performance Evaluation of Opportunistic Beamforming with SINR Prediction for HSDPA", Markus Jordan et al., Proc. IEEE VTC- Spring 2007, describes a SINR prediction which is realized at base station by adaptively filtering a sequence of instantaneous SINR fed back from the user equipment. The coefficients of the filter can be adaptively adjusted based on the same SINR sequence. A major drawback of this solution is that a condition under which the prediction method can be applied is that the sequence of instantaneous SINR is stationary. This may hold for HSDPA systems but can not be satisfied in MU MIMO due to the multiuser interference induced by channel quantization error.

The European Patent EP1212839B1 "System and method for accurately predicting signal to interference and noise ratio to improve communication system performance", Wu Qiang et al. describes SINR prediction realized by using a filter bank to adaptively filter a sequence of instantaneous SINR estimated at the user equipment. As for the previous document, a major drawback of this solution is also that a condition under which the prediction method can be applied is that the sequence of instantaneous SINR is stationary. This may hold for HSDPA systems but can not be satisfied in MU MIMO due to the multiuser interference induced by channel quantization error.

The document "Predicting SINR conditions in mobile MIMO-OFDM systems by interpolation techniques", Malte Schellmann et al., Proc. 42nd Asilomar conference on signals, systems and computers, 2008, describes first the prediction of the future channel vector by linear interpolation, and then replaced the current channel vector in the expression of SINR with the predicted channel vector. A major drawback of this solution is that it does not allow solving the problem of channel uncertainty but just relieve the negative impact of channel variation compared with the method directly using current channel vector to calculate SINR.

Today there is no solution to efficiently compute channel quality indicators such as e.g. CDI/PMI and SINR which could mitigate the feedback delay effects

for MU-MIMO systems and thus improving efficiency of such wireless telecommunication systems.

Today there is a need for a channel quality indicator determination solution that can be easily implemented on the existing communication infrastructures.

Summary of Invention

It is an object of the present system to overcome disadvantages and/or make improvement over the prior art.

To that extend, the invention proposes a method of computing a channel quality indicator of a channel in a telecommunication network, said channel quality indicator characterizing the quality of the signal received on a channel by a device in said telecommunication network, said method comprising, for a device, the acts of:

- monitoring the state of the channel,
- computing a prediction of the channel based on a past and the current state of the monitored channel,
- obtaining a channel variation indicator, said channel variation indicator characterizing the variation of the channel between a past and the current state of the channel,
- computing a channel quality indicator based on the channel prediction and the channel variation indicator.

As opposed to existing methods, the method according to the invention allows a prediction, i.e. not based on the current channel, of a channel quality indicator based on a channel prediction and a channel variation indicator. Based on a stochastic and dynamic model which describes the relation between future and past channel vectors, channel quality indicator (such as e.g. SINR) prediction is realized by taking expectation on a random channel quality indicator, which is a function of the future channel vector (a random variable) and channel variation indicator (such as e.g. channel variation rate). In this invention, there is presented a method which is capable of predicting the channel direction as well as channel quality a few time slots ahead from the present time when data is really transmitted, on the basis of current and past channel observations. An advantage of the method according to the invention is that performance degradation induced by feedback delay effects may be alleviated. Another advantage is that accurately predicting a channel quality indicator of the moment when data is really transmitted allows preventing channel delay effect and avoid performance degradation. Conventional methods for SINR feedback including the formula given above rely only on the current channel (continuous

and quantized) but do not take the channel variation into account. The mismatch between current and future channel condition may easily make the transmitter overestimate the link quality and as a result schedule users of low throughput for data transmission. On the contrary, an advantage of the invention is that considering channel variation allows mitigating feedback delay effects.

The invention also proposes a method according to claim 2. An advantage is that channel quality indicator prediction is realized by taking expectation on a random channel quality indicator, which is a function of the future channel vector (a random variable) and channel variation indicator with respect to the sample space of the future channel vector determined by the stochastic model (according to the probability theory, the sample space is the set of all possible outcomes). Another advantage is that the formulation of predicted channel quality indicator is the average of a certain random variable (for instance, a random SINR), which allows deriving a more accurate and reliable prediction and therefore a more accurate and reliable value of channel quality indicator.

The invention also proposes a method according to claim 3. An advantage is that a robust and accurate channel feedback approach is designed, which includes channel quantization and channel quality indicator prediction to mitigate feedback delay effects induced by the mobility of downlink receivers. An advantage of taking quantization error into account is to accurately indicate the channel quality (such as e.g. signal to noise ratio (SINR)) at the user equipment (i.e. downlink receiver). Upon the value of channel quality indicators fed back from the user equipments, the downlink transmitter (e.g. eNode B or Base Station) may schedule the adequate user equipments whose channel quality indicators are larger than others to maximize the throughput of the communication channel between the downlink transmitter and the downlink receivers. Taking channel quantization error as well as channel variation allows to accurately indicate the channel quality of the time slot when data are really transmitted and help the transmitter (i.e. the network management entity) making the right managing (like e.g. scheduling) decision. Another advantage is that the formulation of predicted channel quality indicator integrating two important effects which are respectively channel quantization error and channel variation, allows an accurate prediction that takes into account channel quantization error and channel variation (i.e. channel uncertainty).

The invention also proposes a method according to claim 4. An advantage of taking channel variation into account is to accurately indicate the channel quality (e.g. SINR) at the time slot when data are really transmitted by the downlink transmitter. Another advantage is that drawbacks associated to channel

uncertainty, which may be due to channel variation a result of user's mobility, may be alleviated. Therefore, taking channel variation into account allows avoiding the drawbacks of the existing methods as the accuracy of the channel quality indicator is dramatically increased.

The invention also proposes a method according to claim 5. In this invention, a robust channel feedback approach which could mitigate feedback delay effects by predicting the future channel direction as well as channel quality is described. Firstly, downlink channel (e.g. vector or matrix) is predicted a few time slots ahead from the present time when data is transmitted on the basis of current and past channel observations. Secondly, channel quantization is performed on the predicted channel to provide more accurate estimation of channel direction than the traditional methods in which quantization is performed on the current channel. Thirdly, a SINR (an indicator of channel quality) of the moment when data is transmitted by the downlink transmitter is predicted by the downlink receiver (i.e. user equipment) by taking into account both quantization error and channel variation. Since the predicted SINR fed back to the transmitter accurately indicates the capacity of the channel when data is transmitted, the transmitter could select proper users of larger throughput. The function of predicting channel direction and SINR allows avoiding the mismatch between feedback and the true channel that widely exists in traditional feedback methods and achieve significant performance gain.

It is very likely that MU MIMO will be employed both by 3GPP LTE-A (both FDD & TDD) and 802.16m. Challenges for SINR feedback in FDD MU MIMO include 1) how to evaluate the influence of channel quantization error induced by finite-rate (or limited) feedback and incorporate it in the formulation of SINR, and 2) how to incorporate the influence of channel variation or uncertainty induced by feedback delay and terminal's mobility in the formulation of SINR. Unlike other systems, e.g. HSDPA or SU MIMO, the two impairments are crucial to MU MIMO, since they would significantly degrade the system's performance by introducing serious multiple access interference. An advantage is to provide an accurate SINR prediction method by taking into account both quantization error and channel variation/uncertainty in MU MIMO systems.

The invention also proposes a method according to claim 6. Claim 6 implies similar advantages to the ones of the claim 5.

The invention also proposes a method according to claim 7. Claim 7 implies similar advantages to the ones of the claim 5.

The invention also proposes a device according to claim 8. Devices claims imply similar advantages to the ones of the corresponding method claims. The

invention may be for instance utilized by a MIMO enabled receiver for predicting and transmitting channel quality information back to the transmitter.

The invention also proposes a system according to claim 14. Claim 14 implies similar advantages to the ones of the corresponding method claim 1 and device claim 8. The invention may be for example applied in any closed-loop MU MIMO systems including 3GPP Long Term Evolution (LTE)/LTE-advanced, 802.16m etc...

The invention also proposes a readable computer program according to claim 15: a computer-readable medium having computer-executable instructions to enable a computer system to perform the method of any one of claims 1 to 7. Claim 15 proposes similar advantages to the ones of the method claims.

Brief Description of the Drawings

Embodiments of the present invention will now be described solely by way of example and only with reference to the accompanying drawings, where like parts are provided with corresponding reference numerals, and in which:

Figure 1A schematically illustrates a system according to an embodiment of the present invention;

Figure 1B schematically illustrates a MU MIMO system according to an embodiment of the present invention;

Figure 2 schematically illustrates a device according to an embodiment of the present invention;

Figure 3 schematically illustrates a device according to an embodiment of the present invention;

Figure 4 schematically illustrates a device according to an embodiment of the present invention;

Figure 5 schematically illustrates a method according to an embodiment of the present invention;

Figure 6 schematically illustrates sum-rate performances of the method according to an embodiment of the present invention.

Description of Preferred Embodiments

The following are descriptions of exemplary embodiments that when taken in conjunction with the drawings will demonstrate the above noted features and advantages, and introduce further ones. In the following description, for purposes of explanation rather than limitation, specific details are set forth such as architecture, interfaces, techniques, devices etc..., for illustration. However, it will be apparent to those of ordinary skill in the art that other embodiments that

depart from these details would still be understood to be within the scope of the appended claims. Moreover, for the purpose of clarity, detailed descriptions of well-known devices, systems, and methods are omitted so as not to obscure the description of the present system. Furthermore, routers, servers, nodes, gateways or other entities in a telecommunication network are not detailed as their implementation is beyond the scope of the present system and method. Unless specified otherwise, the exemplary embodiment will be described hereafter in its application to a device of a telecommunication network. In addition, it should be expressly understood that the drawings are included for illustrative purposes and do not represent the scope of the present system.

Figure 1A describes an illustrative embodiment of the system according to the invention. The system according to the invention comprises a telecommunication network 10 and devices 20 that may connect to the telecommunication network 10 for communicating. The telecommunication network 10 comprises a network management entity 30 (such as e.g. a base station) for managing the network resources (such as e.g. allocating network resources to the devices 20). In the system according to the invention, a device 20 determines and then communicates channel quality information to the network management entity 30 in order for the network management entity 30 to manage network resources (i.e. the network management entity 30 uses the channel quality information received from the devices 20 to allocate the network resources to said devices 20).

The system according to the invention will be described here under in reference to a Multi-Users Multiple Inputs Multiple Outputs (MU MIMO) telecommunication network and wherein devices are user equipments. This is in no way limiting the scope of the present invention as the method, device and system according to the invention may be used in any telecommunication network wherein channel quality information needs to be fedback by a device 20 to a network management entity 30 of a telecommunication network 10. Multi-Users Multiple Inputs Multiple Outputs (MU MIMO) networks may be employed for example in Third Generation Partnership Project (3GPP) Long-Term Evolution-Advanced (LTE-A) (both Frequency Duplex Division (FDD) & Time Duplex Division (TDD)) and Institute of Electrical and Electronics Engineers (IEEE) 802.16m networks. In such networks, channel quality information which is fedback by a device 20 to a network management entity 30 may comprise for example Precoding Matrix Index (PMI), Channel Direction Information (CDI), Signal to Interference and Noise Ratio (SINR)...

Figure 1B describes an illustrative embodiment of a MU MIMO system according to the invention. A MU-MIMO system with linear precoding (e.g. ZFBF) is depicted in Fig. 1B, where the transmitter is equipped with M antennas while a user is equipped with N ($N \geq 1$) antennas. Each user equipment provides PMI/CDI and SINR of downlink through the dedicated feedback channel (denoted by dash line). Based on the CDI's and SINR's fed back from K users, the transmitter selects M out of the K users to form the transmitted set $S = \{\pi(1), \cdots, \pi(M)\}$ where $\pi(m)$ denotes the actual index of the mth selected user in S. Based on the PMI/CDI's of the users in S, the transmitter choose the unit-norm beamforming vectors $\mathbf{w}_i, i \in S$, and generate $\mathbf{x} = \sum_{i \in S} \mathbf{w}_i s_i$, where s_i is the information symbol of the ith user, as the transmitted signal which is then sent through the downlink channel (denoted by solid line).

Figure 2 describes an illustrative embodiment of the device according to the invention. The device allows computing a channel quality indicator of a channel in a telecommunication network, said channel quality indicator characterizing the quality of the signal received on a channel by a device in said telecommunication network.

A monitoring unit 205 allows monitoring the state of the channel.

A channel prediction unit 210 allows computing a prediction of the channel based on a past and the current state of the monitored channel.

A channel variation unit 220 allows obtaining a channel variation indicator, said channel variation indicator characterizing the variation of the channel between a past and the current state of the channel.

A channel quality unit 230 allows computing a channel quality indicator based on the channel prediction and the channel variation indicator.

In an illustrative embodiment of the device according to the invention, a channel quantization unit 215 allows quantizing the channel prediction and computing a channel quantization error of said quantized channel prediction, said channel quantization error being the error induced by the quantization of the channel prediction, and wherein the channel quality indicator is a function of the channel quantization error over a sample space of the channel prediction.

Figure 3 describes an illustrative embodiment of the device according to the invention. A wireless channel state is time-variant in nature due to the mobility between transmitter and receiver. Changes in the state of the channel will make feedback outdated and leads to severe performance degradation. Therefore, channel prediction allows mitigating the delay effect.

Linear channel predictor utilizes the linear combination of current and/or past channel realization to predict the future channel. It takes the following form:

$$\hat{\mathbf{h}}(n+T)=\sum_{i=0}^{L-1} w_i \mathbf{h}(n-i)$$

where $\mathbf{h}(n)$ denotes the channel at time *n* and $\hat{\mathbf{h}}(n+T)$ denotes the predicted channel *T* time slots ahead from the present time *n*.

The implementation of the predictor may be different if different order *L* and coefficients are chosen. Some examples are provided in the following:

a). First order: $\hat{\mathbf{h}}(n+T)=\rho\mathbf{h}(n)$, where ρ may be determined according to the correlation between $\mathbf{h}(n+T)$ and $\mathbf{h}(n)$, i.e. $E(\mathbf{h}(n+T)\cdot\mathbf{h}(n))$.

b). Second order: $\hat{\mathbf{h}}(n+T)=\rho_1\mathbf{h}(n)+\rho_2\mathbf{h}(n-1)$, where ρ_1 and ρ_2 may determined according to $E(\mathbf{h}(n+T)\cdot\mathbf{h}(n))$ and $E(\mathbf{h}(n+T)\cdot\mathbf{h}(n-1))$.

c). *N*th order minimum mean square error (MMSE) estimator: if the temporal evolution of channel $\mathbf{h}(n)$ may be described in terms of an *N*th order AR model as $\mathbf{h}(n+T)=\sum_{l=0}^{N-1}\rho_l\mathbf{h}(n-l)+\rho_u\mathbf{u}(n+T)$, where $\mathbf{u}(n+T)$ is a Gaussian vector with zero mean and correlation matrix *I* (denoted as $\mathbf{u}(n+T)\sim CN(0,I)$) and independent from $\mathbf{h}(n)$, ..., $\mathbf{h}(n-N+1)$, then the MMSE predictor is $\hat{\mathbf{h}}(n+T)=\sum_{l=0}^{N-1}\rho_l\mathbf{h}(n-l)$. An illustrative embodiment of a predictor is shown in Figure 3, in which *N* memory units consists of a memory chain to store the past *N* channel estimates from the current time. The predicted channel is then a linear combination of these values in the memory chain. In the device according to the invention, channel quality indicator (such as e.g. PMI/CDI and SINR etc...) that may be fed back to a transmitter for user selection as well as beamforming may be derived on the basis of the predicted channel $\hat{\mathbf{h}}(n+T)$ rather than the current channel $\mathbf{h}(n)$. So, any prediction methods other than the linear predictor described above, e.g. Kalman filter and non-linear filter are still within the scope of the present invention if they are adopted for the derivation of channel quality indicators such as e.g. PMI/CDI and SINR etc...

Figure 4 describes an illustrative embodiment of the device according to the invention. In an illustrative embodiment of the device according to the invention, a quantization unit 215 (in reference to Figure 2) may be used to quantize the channel and compute a quantization error.

Since a feedback channel is always bandwidth limited, feeding back accurate complex vector $\hat{\mathbf{h}}(n+T)$ or $\mathbf{h}(n)$ without any distortion may be difficult. Therefore, quantizing $\hat{\mathbf{h}}(n+T)$ or $\mathbf{h}(n)$ to constrain the continuous value of $\hat{\mathbf{h}}(n+T)$ or $\mathbf{h}(n)$ to a discrete or finite set may be necessary. The procedure of channel quantization is always based on a set of unit norm vectors, which is referred to as codebook whose volume (i.e. the number of the vectors in the codebook) *V* is related to the number of feedback bits *B* as $V = 2^B$.

A unit vector in a codebook may be interpreted as either the direction of a quantized channel or the preferred precoding vector under a certain channel condition. For the former, the index of the selected vector is termed CDI while for the latter, the index is termed PMI.

Denote a codebook $\mathbf{C}$ as $\mathbf{C} = \{\mathbf{c}_1, \cdots, \mathbf{c}_V\},\ V = 2^B$. Then, a channel quantization may be for instance:

$$\tilde{\mathbf{h}}(n+T) = Q[\hat{\mathbf{h}}(n+T)] = \arg\min_{\mathbf{c}_i} F(\hat{\mathbf{h}}(n+T), \mathbf{c}_i)$$

Where $F(\hat{\mathbf{h}}(n+T), \mathbf{c}_i)$ stands for any effective metric to describe the derivation between $\hat{\mathbf{h}}(n+T)$ and $\mathbf{c}_i$, $1 \le i \le V$. Some exemplary metrics are provided in the following:

a). Chordal distance: $F(\hat{\mathbf{h}}(n+T), \mathbf{c}_i) = \sqrt{1 - \| \mathbf{c}_i^H \hat{\mathbf{h}}(n+T) \|^2 / \| \hat{\mathbf{h}}(n+T) \|^2}$.

b). Inner product: $F(\hat{\mathbf{h}}(n+T), \mathbf{c}_i) = -\| \mathbf{c}_i^H \hat{\mathbf{h}}(n+T) \|$.

c). Singular value and mean square error: for channels described in terms of matrices rather than vectors, minimum singular value selection criterion (MSV-SC) and mean square error selection criterion (MSE-SC) may be applied with the predicted channel.

An illustrative embodiment of channel quantization is depicted in Figure 4, in which the input and output are respectively the predicted channel (unquantized channel) and CDI/PMI (quantized channel). ROM may be employed for recording the codebook. On the basis of the predicted channel and the data read from the ROM, metric computation unit may evaluate the derivation between them and a minimum metric selection unit may allow choosing as the output the index of the vector in the codebook whose derivation with the input is minimized. Although only these three exemplary metrics for channel quantization ar described, methods employing criteria other than those presented above are

still within the scope of the invention if quantization is performed on the predicted channel.

Figure 5 describes an illustrative embodiment of the method according to the invention. The method allows computing a channel quality indicator of a channel in a telecommunication network, wherein said channel quality indicator characterizes the quality of the signal received on a channel by a user equipment in said telecommunication network. The method comprises, for a user equipment, the following acts as described here under in reference to Figure 2.

In an act 505, a monitoring unit allows monitoring the state of the channel.

In an act 510, a channel prediction unit 210 allows computing a prediction of the channel based on a past and the current state of the monitored channel.

In an illustrative embodiment of the method according to the invention, in an act 515 and prior to the act of 530 of computing a channel quality indicator, a quantization unit 215 allows quantizing the channel prediction and computing a channel quantization error of said quantized channel prediction, said channel quantization error being the error induced by the quantization of the channel prediction.

In an act 520, a channel variation unit 220 allows obtaining a channel variation indicator, said channel variation indicator characterizing the variation of the channel between a past and the current state of the channel. In an illustrative embodiment of the method according to the invention, the channel variation indicator is the rate of variation of the channel.

In an act 530, a channel quality unit 230 allows computing a channel quality indicator based on the channel prediction and the channel variation indicator.

In the following illustrative embodiment, for the sake of clarity, the number of user antennas $N = 1$ is assumed. For a case where $N > 1$, only receiver filter is needed and the following invention described for $N = 1$ may be easily extended to such a case. So any arbitrary antenna deployment other than $N = 1$ still falls within the scope of the present invention.

The method according to the invention will be further described here using a SINR as channel quality indicator. This does not limit the scope of the present invention as other channel quality indicator may be used.

Definition of SINR

As described in the system model of MU-MIMO, the transmitted signal $\mathbf{x} = \sum_{i \in S} \mathbf{w}_i s_i$ is a linear combination of the data from selected users where precoding vectors $\mathbf{w}_i$'s act as the combination factors. If the channel between

the transmitter and the *k*th user is $\mathbf{h}_k \in C^{1\times M}$, then the signal received by user *k* may be represented as $y_k = \mathbf{h}_k \mathbf{x} + z_k$, or equivalently

$$y_k = (\mathbf{h}_k \mathbf{w}_k) s_k + \sum_{j\in S, j\neq k} (\mathbf{h}_k \mathbf{w}_j) s_j z_k + z_k$$

where the first term ($(\mathbf{h}_k \mathbf{w}_k) s_k$) stands for signal while the second ($\sum_{j\in S, j\neq k} (\mathbf{h}_k \mathbf{w}_j) s_j$) and the third term (z_k) respectively stand for interference and noise.

SINR, which describes the ratio of signal power and interference and noise power, is therefore formulated as $\mathrm{SINR} = \frac{\alpha |\mathbf{h}_k \mathbf{w}_k|^2}{1+\alpha \sum_{j\neq k} |\mathbf{h}_k \mathbf{w}_j|^2}$, where α is a parameter related to the ratio of the total signal power and noise power. P_t and P_n respectively denoting the transmitting power of the transmitter and the noise power, which may be estimated by the receiver upon the specific signals (e.g. broadcast channel or pilots) emitted by the transmitter, then, the total power is equally allocated to M users and therefore the power for each user is P_t / M. α is then defined as $P_t / (P_n M)$ which means the ratio of transmitting power per user and noise power. Since both P_t and P_n may be estimated, and M is the number of transmit antennas, α may be computed accordingly.

SINR prediction

As the future channel vector is a random variable, the function of which i.e. SINR is therefore also a random variable. In an illustrative embodiment of the method according to the invention, the SINR is predicted with respect to the sample space of the channel vector, as described here above in reference to act 530 of Figure 5. According to probability theory, the sample space of an experiment or random trial is the set of all possible outcomes. For example, if the experiment is tossing a coin, the sample space is the set {head, tail}. For tossing a single six-sided die, the sample space is {1, 2, 3, 4, 5, 6}. In probability theory and statistics, the expected value (or expectation value, or mathematical expectation, or mean, or first moment) of a random variable is the integral of the random variable with respect to its probability measure.

In an illustrative embodiment of the system according to the invention, a prediction of SINR is described here under. Using the time-variant channel being modeled in terms of a first order AR process (also referred to as Gauss-Markov process): $\mathbf{h}_k(n+T) = \rho \mathbf{h}_k(n) + \sqrt{1-\rho^2}\mathbf{u}_k(n+T)$, where $\mathbf{u}(n+T) \sim CN(0, I)$.

In the area of communication and signal processing, an autoregressive (AR) or autoregressive moving average (ARMA) model may be used for modeling random processes or time series. In this model, the deterministic part e.g. $\sum_{l=0}^{p-1}\rho_l \mathbf{h}(n-l)$ in $\mathbf{h}(n+T)=\sum_{l=0}^{p-1}\rho_l \mathbf{h}(n-l)+\rho_u \mathbf{u}(n+T)$ determines the dependency of $\mathbf{h}(n+T)$ and $\mathbf{h}(n-l)$ (l=0, 1, ..., p-1) while the random part, i.e. the Gaussian vector $\mathbf{u}(n+T)$ determines the modeling error and is introduced to make $\mathbf{h}(n+T)$ random. The precise value of $\mathbf{u}(n+T)$ (the outcome of $\mathbf{u}(n+T)$ may be for instance random) is not specified, since it disappears in the prediction of SINR when taking expectation with respect to $\mathbf{u}(n+T)$ as described here under.

The MMSE estimator is $\hat{\mathbf{h}}_k(n+T)=\rho \mathbf{h}_k(n)$, and the quantized channel is $Q[\hat{\mathbf{h}}_k(n+T)]=Q[\mathbf{h}_k(n)]$. The angle between $Q[\hat{\mathbf{h}}_k(n+T)]$ and $\hat{\mathbf{h}}_k(n+T)/\|\hat{\mathbf{h}}_k(n+T)\|$ is θ_k, which may stand for the quantization error. Then the received signal may be represented as:

$$y_k(n+T)=(\rho \mathbf{h}_k(n)+\sqrt{1-\rho^2}\mathbf{u}_k(n+T))\mathbf{w}_k s_k+\sum_{j\neq k}(\rho \mathbf{h}_k(n)+\sqrt{1-\rho^2}\mathbf{u}_k(n+T))\mathbf{w}_j s_j+z_k$$

and the SINR may be:

$$\mathrm{SINR}=\frac{\alpha|(\rho \mathbf{h}_k(n)+\sqrt{1-\rho^2}\mathbf{u}_k(n+T))\mathbf{w}_k|^2}{1+\alpha\sum_{j\neq k}|(\rho \mathbf{h}_k(n)+\sqrt{1-\rho^2}\mathbf{u}_k(n+T))\mathbf{w}_j|^2}.$$

In an illustrative embodiment of the method according to the invention, the channel variation indicator is the rate of variation of the channel ρ. On the basis of the pilots which are known to the receiver side, the channel vectors $\mathbf{h}_k(n)$ (n = 0, 1, ...) may be estimated. The determination of ρ becomes the estimation of the parameters of an AR model. Other existing solutions known from the prior art also exist to determine ρ.

As detailed in "Multi-antenna downlink channels with limited feedback and user selection", T. Yoo, et. Al, IEEE journal on selected areas in communications, vol. 25, No. 7, September 2007, the channel may be decomposed as: $\mathbf{h}_k(n)/\|\mathbf{h}_k(n)\|=\cos\theta_k\hat{\mathbf{h}}_k(n)+\sin\theta_k\mathbf{g}_k$, where θ_k denotes the angle between $\mathbf{h}_k(n)$ and

its unit-norm quantization $\hat{\mathbf{h}}_k(n)$, $\mathbf{g}_k$ is the unit norm vector which is orthogonal to $\hat{\mathbf{h}}_k(n)$ and therefore satisfies $\mathbf{g}_k\mathbf{w}_k = 0$.

Substituting the above equation into the expression of SINR allows deriving:

$$\mathrm{SINR}=\frac{\alpha[\rho^2 \| \mathbf{h}_k(n)\|^2 \cos^2\theta_k + 2\rho\sqrt{1-\rho^2}\,\mathrm{Re}\{\mathbf{h}_k(n)\mathbf{w}_k\left(\mathbf{u}_k(n+T)\mathbf{w}_k\right)^*\} + (1-\rho^2)|\mathbf{u}_k(n+T)\mathbf{w}_k|^2]}{1+\alpha[\rho^2 \| \mathbf{h}_k(n)\|^2 \sin^2\theta_k \cdot \sum_{j\neq k}|\mathbf{g}_k\mathbf{w}_j|^2 + (1-\rho^2)\sum_{j\neq k}|\mathbf{u}_k(n+T)\mathbf{w}_j|^2 + \Delta]}$$

where $\Delta = 2\rho\sqrt{1-\rho^2}\sin\theta_k\,\mathrm{Re}\{\sum_{j\neq k}\mathbf{g}_k\mathbf{w}_j\cdot\left(\mathbf{u}_k(n+T)\mathbf{w}_j\right)^*\}$.

Define $\mathbf{W}=[\mathbf{w}_1\ \mathbf{w}_2\ \cdots\ \mathbf{w}_M]\in C^{M\times M}$, $\mathbf{b}=[b_1\ b_2\ \cdots\ b_M]=\mathbf{u}_k(n+T)\mathbf{W}\in C^{1\times M}$. $\mathbf{b}$ is a Gaussian vector since the linear transformation of a Gaussian vector (i.e. $\mathbf{u}_k(n+T)$) is still Gaussian, and $E[\mathbf{b}^H\mathbf{b}]=E[\mathbf{Q}^H\mathbf{u}_k^H(n+T)\mathbf{u}_k(n+T)\mathbf{Q}]=I$. Therefore $\mathbf{b}\sim N_c(\mathbf{0},I)$ and b_1, $\cdots$, b_M are independent identically distributed (IID) Gaussian variables.

Conditioned on $\mathbf{W}$ and $\mathbf{g}_k$, the conditional expectation (i.e. prediction) may be derived as:

$$\begin{aligned}
E[\mathrm{SINR}\mid\mathbf{W},\mathbf{g}_k] &= E[E[\mathrm{SINR}\mid\mathbf{W},\mathbf{g}_k,\mathbf{b}/\{b_k\}]\mid\mathbf{W},\mathbf{g}_k] \\
&= E\left[\left.\frac{\alpha[\rho^2\|\mathbf{h}_k(n)\|^2\cos^2\theta_k+(1-\rho^2)]}{1+\alpha[\rho^2\|\mathbf{h}_k(n)\|^2\sin^2\theta_k\cdot\sum_{j\neq k}|\mathbf{g}_k\mathbf{w}_j|^2+(1-\rho^2)\sum_{j\neq k}|b_j|^2+\Delta]}\right|\mathbf{W},\mathbf{g}_k\right] \\
&\geq \frac{\alpha[\rho^2\|\mathbf{h}_k(n)\|^2\cos^2\theta_k+(1-\rho^2)]}{1+E\left[\alpha[\rho^2\|\mathbf{h}_k(n)\|^2\sin^2\theta_k\cdot\sum_{j\neq k}|\mathbf{g}_k\mathbf{w}_j|^2+(1-\rho^2)\sum_{j\neq k}|b_j|^2+\Delta]\mid\mathbf{W},\mathbf{g}_k\right]} \\
&= \frac{\alpha[\rho^2\|\mathbf{h}_k(n)\|^2\cos^2\theta_k+(1-\rho^2)]}{1+\alpha[\rho^2\|\mathbf{h}_k(n)\|^2\sin^2\theta_k\cdot\sum_{j\neq k}|\mathbf{g}_k\mathbf{w}_j|^2+(1-\rho^2)(M-1)]}
\end{aligned}$$

where $\mathbf{b}/\{b_k\}$ stands for any element in $\mathbf{b}$ other than b_k and the inequality follows from Jensen's inequality. Employing Jensen's inequality and the conclusion from the paper "Multi-antenna downlink channels with limited feedback and user selection" again,

$$\begin{aligned}
E[\mathrm{SINR}] &= E[E[\mathrm{SINR}\mid\mathbf{W},\mathbf{g}_k]] \\
&\geq \frac{\alpha[\rho^2\|\mathbf{h}_k(n)\|^2\cos^2\theta_k+(1-\rho^2)]}{1+\alpha[\rho^2\|\mathbf{h}_k(n)\|^2\sin^2\theta_k\cdot E[\sum_{j\neq k}|\mathbf{g}_k\mathbf{w}_j|^2]+(1-\rho^2)(M-1)]} \\
&= \frac{\alpha[\rho^2\|\mathbf{h}_k(n)\|^2\cos^2\theta_k+(1-\rho^2)]}{1+\alpha[\rho^2\|\mathbf{h}_k(n)\|^2\sin^2\theta_k+(1-\rho^2)(M-1)]}
\end{aligned}$$

$$E(\mathrm{SINR}) \approx \frac{\alpha[|\rho|^2 \|\mathbf{h}_k(n)\|^2 \cos^2(\theta_k) + 1 - |\rho|^2]}{1 + \alpha[|\rho|^2 \|\mathbf{h}_k(n)\|^2 \sin^2(\theta_k) + (M-1)(1-|\rho|^2)]}$$

different from the conventional estimation of SINR, e.g. $\mathrm{SINR} = \frac{\alpha\|\mathbf{h}_k(n)\|^2 \cos^2(\theta_k)}{1 + \alpha\|\mathbf{h}_k(n)\|^2 \sin^2(\theta_k)}$ which dependents only on the present channel and quantization error, the invention takes channel variation, i.e. ρ into consideration and incorporates ρ into the predictive estimation of SINR.

b). As a variational example, the channel may be modeled as $\sqrt{1-\rho^2}\mathbf{u}_k(n+T)\mathbf{w}_k s_k$ as the interference, i.e., decomposing the received signal as:

$$y_k(n+T) = \underbrace{\rho\mathbf{h}_k(n)\mathbf{w}_k s_k}_{\text{signal}} + \underbrace{\sqrt{1-\rho^2}\mathbf{u}_k(n+T)\mathbf{w}_k s_k + \sum_{j\neq k}(\rho\mathbf{h}_k(n) + \sqrt{1-\rho^2}\mathbf{u}_k(n+T))\mathbf{w}_j s_j}_{\text{interference}} + z_k$$

Then the predictive estimation of SINR may be:

$E(\mathrm{SINR}) \approx \frac{\alpha|\rho|^2 \|\mathbf{h}_k(n)\|^2 \cos^2(\theta_k)}{1 + \alpha[|\rho|^2 \|\mathbf{h}_k(n)\|^2 \sin^2(\theta_k) + M(1-|\rho|^2)]}$. The mathematical derivation of E(SINR) for case b) is similar to case a) here above.

c). As an another variational example, the channel may be modelled in terms of a pth order AR process: $\mathbf{h}(n+T) = \sum_{l=0}^{p-1}\rho_l\mathbf{h}(n-l) + \rho_u\mathbf{u}(n+T)$. Then the MMSE estimator $\hat{\mathbf{h}}_k(n+T) = \sum_{l=0}^{p-1}\rho_l\mathbf{h}(n-l)$, and the quantized channel $Q[\hat{\mathbf{h}}_k(n+T)] = Q[\sum_{l=0}^{p-1}\rho_l\mathbf{h}(n-l)]$. The angle between $Q[\hat{\mathbf{h}}_k(n+T)]$ and $\hat{\mathbf{h}}_k(n+T)/\|\hat{\mathbf{h}}_k(n+T)\|$ may be θ_k. The signal y may be derived by replacing the original representation of $\mathbf{h}(n+T)$ i.e. $\rho\mathbf{h}_k(n) + \sqrt{1-\rho^2}\mathbf{u}_k(n+T)$ with $\sum_{l=0}^{p-1}\rho_l\mathbf{h}(n-l) + \rho_u\mathbf{u}(n+T)$ which may be as follows:

$$y_k(n+T) = (\sum_{l=0}^{p-1}\rho_l\mathbf{h}(n-l) + \rho_u\mathbf{u}(n+T))\mathbf{w}_k s_k + \sum_{j\neq k}(\sum_{l=0}^{p-1}\rho_l\mathbf{h}(n-l) + \rho_u\mathbf{u}(n+T))\mathbf{w}_j s_j + z_k$$

and the prediction of SINR may be:

$$E(\mathrm{SINR}) \approx \frac{\alpha[\|\sum_{l=0}^{p-1}\rho_l\mathbf{h}(n-l)\|^2 \cos^2(\theta_k) + |\rho_u|^2]}{1 + \alpha[\|\sum_{l=0}^{p-1}\rho_l\mathbf{h}(n-l)\|^2 \sin^2(\theta_k) + (M-1)(|\rho_u|^2)]}$$

The mathematical derivation of E(SINR) for case c) is similar to case a) here above.

In the three examples a), b) and c) here above, ρ in the part of channel prediction and SINR prediction are the same. It describes the correlation between future channel and current as well as past channels in terms of variation (i.e. channel variarion indicator). In practice, depending on the nature of the time variant channel itself, the channel may be described using an Auto-Regressive (AR) model with different orders to decrease the modeling error, including 1st order $\mathbf{h}_k(n+T)=\rho\mathbf{h}_k(n)+\sqrt{1-\rho^2}\mathbf{u}_k(n+T)$, or a general pth order $\mathbf{h}(n+T)=\sum_{l=0}^{p-1}\rho_l\mathbf{h}(n-l)+\rho_u\mathbf{u}(n+T)$. For the 1st order AR model, the channel variation rate is ρ. However, for the pth order AR model, the channel variation rate is a function of ρ_l ($l=0,\cdots,p-1$). ρ_l may be called correlation coefficient while as a whole, they may be called parameters of channel variation. The parameters ρ or ρ_l may be determined using existing methods as described here above.

Although only these three examples of SINR feedback (i.e. E(SINR)) are presented here above, this does not limit the scope of the present invention as other similar methods may be used.

Based on a stochastic and dynamic model which describes the relation between future and past channel vectors, SINR prediction may be realized by taking expectation on the random SINR, which is a function of the future channel vector (a random variable) and channel quantization error, with respect to the sample space of the future channel vector determined by the stochastic model.

According to the probability theory, the sample space is the set of all possible outcomes. The sample space of the channel vector $\mathbf{h}_k(n+T)$ is the whole complex vector space i.e. C^N, where *N* is the dimension of the space, since $\mathbf{u}_k(n+T)$ is a Gaussian vector whose sample space is C^N. Taking the 1st order AR channel model $\mathbf{h}_k(n+T)=\rho\mathbf{h}_k(n)+\sqrt{1-\rho^2}\mathbf{u}_k(n+T)$ for example, $\mathbf{h}_k(n+T)$ may be any element in C^N, such as [1,1, ..., 1], [1.5, 3, ..., 10], etc. But the distribution of $\mathbf{h}_k(n+T)$ is concentrated around $\rho\mathbf{h}_k(n)$, and the probability that $\mathbf{h}_k(n+T)$ deviates far from $\rho\mathbf{h}_k(n)$ approaches 0.

In:

$$E(\mathrm{SINR})\approx\frac{\alpha[|\rho|^2\|\mathbf{h}_k(n)\|^2\cos^2(\theta_k)+1-|\rho|^2]}{1+\alpha[|\rho|^2\|\mathbf{h}_k(n)\|^2\sin^2(\theta_k)+(M-1)(1-|\rho|^2)]}$$

and

$$E(\mathrm{SINR}) \approx \frac{\alpha |\rho|^2 \|\mathbf{h}_k(n)\|^2 \cos^2(\theta_k)}{1+\alpha[|\rho|^2 \|\mathbf{h}_k(n)\|^2 \sin^2(\theta_k) + M(1-|\rho|^2)]},$$

θ_k denotes the quantization error effect, and ρ which is a key parameter of the stochastic model denotes the channel variation effect. The faster the channel varies, the smaller ρ is.

In $E(\mathrm{SINR}) \approx \frac{\alpha[\|\sum_{l=0}^{p-1} \rho_l \mathbf{h}(n-l)\|^2 \cos^2(\theta_k) + |\rho_u|^2]}{1+\alpha[\|\sum_{l=0}^{p-1} \rho_l \mathbf{h}(n-l)\|^2 \sin^2(\theta_k) + (M-1)(|\rho_u|^2)]}$, θ_k denotes the quantization error effect, and the combination of ρ_0, ..., ρ_{p-1} and ρ_u which are the key parameters of the stochastic mode (the pth order AR process) denotes the channel variation effect. The faster the channel varies, the bigger ρ_u is.

The predicted SINR, i.e. $E(\mathrm{SINR})$ may then be fed back to the network managing entity.

Figure 6 describes an illustrative embodiment of implementation of the method according to the invention.

The sum-rate performance of the method according to the invention is compared with that of the conventional (i.e. existing) feedback method. Time variant channel is assumed to be described using a first order AR model, i.e. $\mathbf{h}_k(n+T) = \rho \mathbf{h}_k(n) + \sqrt{1-\rho^2}\mathbf{u}_k(n+T)$. It is also assumed that the MU-MIMO system has a transmitter with four antennas and 100 receivers with one antenna each. For different receivers, we assume that ρ's are independent uniformly distributed random variables in the same interval [0.96 1]. Channel quantization (12bits for each receiver) and SINR feedback for the two approaches are listed in table 1.

Table 1 channel quantization and SINR feedback of the invention and conventional method

	Conventional method	Invention
Channel quantization	$Q[\mathbf{h}(n)]$	$Q[\hat{\mathbf{h}}(n+T)] = Q[\rho \mathbf{h}(n)]$
SINR feedback	$\frac{\alpha \|\mathbf{h}_k(n)\|^2 \cos^2(\theta_k)}{1+\alpha[\|\mathbf{h}_k(n)\|^2 \sin^2(\theta_k)]}$	$\frac{\alpha[\|\rho\|^2 \|\mathbf{h}_k(n)\|^2 \cos^2(\theta_k) + 1 - \|\rho\|^2]}{1+\alpha[\|\rho\|^2 \|\mathbf{h}_k(n)\|^2 \sin^2(\theta_k) + (M-1)(1-\|\rho\|^2)}$

Figure 6 shows the sum-rate vs. average SINR using both the method according to the invention and conventional method. The method according to the invention allows larger throughput/spectrum efficiency than the existing methods along the simulated SINR. Therefore performance degradation induced by feedback delay effects may be alleviated.

CLAIMS

1. A method of computing a channel quality indicator of a channel in a telecommunication network, said channel quality indicator characterizing the quality of the signal received on a channel by a device in said telecommunication network, said method comprising, for a device, the acts of:

- monitoring the state of the channel,

- computing a prediction of the channel based on a past and the current state of the monitored channel,

- obtaining a channel variation indicator, said channel variation indicator characterizing the variation of the channel between a past and the current state of the channel,

- computing a channel quality indicator based on the channel prediction and the channel variation indicator.

2. A method according to claim 1, wherein the channel quality indicator is a function of the channel prediction over a sample space of the channel prediction.

3. A method according to any of the preceding claims, said method further comprising, prior to the act of computing a channel quality indicator, the acts of quantizing the channel prediction and computing a channel quantization error of said quantized channel prediction, said channel quantization error being the error induced by the quantization of the channel prediction, and wherein the channel quality indicator is a function of the channel quantization error over a sample space of the channel prediction.

4. A method according to any of the preceding claims, wherein the channel variation indicator is the rate of variation of the channel.

5. A method according to any of the preceding claims, wherein the telecommunication network is a multiple users multiple input multiple output network, wherein the signal received by device k on the channel may be defined as:

$$y_k(n+T)=(\rho\mathbf{h}_k(n)+\sqrt{1-\rho^2}\mathbf{u}_k(n+T))\mathbf{w}_k s_k+\sum_{j\neq k}(\rho\mathbf{h}_k(n)+\sqrt{1-\rho^2}\mathbf{u}_k(n+T))\mathbf{w}_j s_j+z_k$$

and wherein the channel quality indicator is an estimation of signal to interference

and noise ratio over the sample space of the channel prediction defined, for device k, by:

$$E(\mathrm{SINR}) \approx \frac{\alpha[|\rho|^2 \|\mathbf{h}_k(n)\|^2 \cos^2(\theta_k) + 1 - |\rho|^2]}{1 + \alpha[|\rho|^2 \|\mathbf{h}_k(n)\|^2 \sin^2(\theta_k) + (M-1)(1-|\rho|^2)]}.$$

6. A method according to any of the preceding claims, wherein the telecommunication network is a multiple users multiple input multiple output network, wherein the signal received by device k on the channel may be defined as:

$$y_k(n+T) = \underbrace{\rho \mathbf{h}_k(n)\mathbf{w}_k s_k}_{\text{signal}} + \underbrace{\sqrt{1-\rho^2}\mathbf{u}_k(n+T)\mathbf{w}_k s_k + \sum_{j \neq k}(\rho \mathbf{h}_k(n) + \sqrt{1-\rho^2}\mathbf{u}_k(n+T))\mathbf{w}_j s_j}_{\text{interference}} + z_k$$

and wherein the channel quality indicator is an estimation of signal to interference and noise ratio over the sample space of the channel prediction defined, for device k, by:

$$E(\mathrm{SINR}) \approx \frac{\alpha |\rho|^2 \|\mathbf{h}_k(n)\|^2 \cos^2(\theta_k)}{1 + \alpha[|\rho|^2 \|\mathbf{h}_k(n)\|^2 \sin^2(\theta_k) + M(1-|\rho|^2)]}.$$

7. A method according to any of the preceding claims, wherein the telecommunication network is a multiple users multiple input multiple output network, wherein the signal received by device k on the channel may be defined as:

$$y_k(n+T) = (\sum_{l=0}^{p-1} \rho_l \mathbf{h}(n-l) + \rho_u \mathbf{u}(n+T))\mathbf{w}_k s_k + \sum_{j \neq k}(\sum_{l=0}^{p-1} \rho_l \mathbf{h}(n-l) + \rho_u \mathbf{u}(n+T))\mathbf{w}_j s_j + z_k$$

and wherein the channel quality indicator is an estimation of signal to interference and noise ratio over the sample space of the channel prediction defined, for device k, by:

$$E(\mathrm{SINR}) \approx \frac{\alpha[\|\sum_{l=0}^{p-1} \rho_l \mathbf{h}(n-l)\|^2 \cos^2(\theta_k) + |\rho_u|^2]}{1 + \alpha[\|\sum_{l=0}^{p-1} \rho_l \mathbf{h}(n-l)\|^2 \sin^2(\theta_k) + (M-1)(|\rho_u|^2)]}.$$

8. A device for computing a channel quality indicator of a channel in a telecommunication network, said channel quality indicator characterizing the quality of the signal received on a channel by a device in said telecommunication network, said device comprising:

- a monitoring unit for monitoring the state of the channel,

- a channel prediction unit for computing a prediction of the channel based on a past and the current state of the monitored channel,

- a channel variation unit for obtaining a channel variation indicator, said channel variation indicator characterizing the variation of the channel between a past and the current state of the channel,

- a channel quality unit for computing a channel quality indicator based on the channel prediction and the channel variation indicator.

9. A device according to claim 8, wherein the channel quality unit is further operable to compute the channel quality indicator as a function of the channel prediction over a sample space of the channel prediction.

10. A device according to claim 8 to 9, said device further comprising a quantization unit for quantizing the channel prediction and for computing a channel quantization error of said quantized channel prediction, said channel quantization error being the error induced by the quantization of the channel prediction, and wherein the channel quality unit is further operable to compute the channel quality indicator as a function of the channel quantization error over a sample space of the channel prediction.

11. A device according to any of the preceding claims 8 to 10, wherein the telecommunication network is a multiple users multiple input multiple output network, wherein the signal received by device k on the channel may be defined as:

$$y_k(n+T)=(\rho\mathbf{h}_k(n)+\sqrt{1-\rho^2}\mathbf{u}_k(n+T))\mathbf{w}_k s_k+\sum_{j\neq k}(\rho\mathbf{h}_k(n)+\sqrt{1-\rho^2}\mathbf{u}_k(n+T))\mathbf{w}_j s_j+z_k$$

and wherein the channel quality unit is further operable to compute a channel quality indicator which is an estimation of signal to interference and noise ratio over the sample space of the channel prediction defined, for device k, by:

$$E(\mathrm{SINR})\approx\frac{\alpha[|\rho|^2\|\mathbf{h}_k(n)\|^2\cos^2(\theta_k)+1-|\rho|^2]}{1+\alpha[|\rho|^2\|\mathbf{h}_k(n)\|^2\sin^2(\theta_k)+(M-1)(1-|\rho|^2)]}.$$

12. A device according to any of the preceding claims 8 to 10, wherein the telecommunication network is a multiple users multiple input multiple output network, wherein the signal received by device k on the channel may be defined as:

$$y_k(n+T)=\underbrace{\rho\mathbf{h}_k(n)\mathbf{w}_k s_k}_{\text{signal}}+\underbrace{\sqrt{1-\rho^2}\mathbf{u}_k(n+T)\mathbf{w}_k s_k+\sum_{j\neq k}(\rho\mathbf{h}_k(n)+\sqrt{1-\rho^2}\mathbf{u}_k(n+T))\mathbf{w}_j s_j}_{\text{interference}}+z_k$$

and wherein the channel quality unit is further operable to compute a channel quality indicator which is an estimation of signal to interference and noise ratio over the sample space of the channel prediction defined, for device k, by:

$$E(\mathrm{SINR})\approx\frac{\alpha|\rho|^2\|\mathbf{h}_k(n)\|^2\cos^2(\theta_k)}{1+\alpha[|\rho|^2\|\mathbf{h}_k(n)\|^2\sin^2(\theta_k)+M(1-|\rho|^2)]}.$$

13. A device according to any of the preceding claims 8 to 10, wherein the telecommunication network is a multiple users multiple input multiple output network, wherein the signal received by device k on the channel may be defined as:

$$y_k(n+T)=(\sum_{l=0}^{p-1}\rho_l\mathbf{h}(n-l)+\rho_u\mathbf{u}(n+T))\mathbf{w}_k s_k+\sum_{j\neq k}(\sum_{l=0}^{p-1}\rho_l\mathbf{h}(n-l)+\rho_u\mathbf{u}(n+T))\mathbf{w}_j s_j+z_k$$

and wherein the channel quality unit is further operable to compute a channel quality indicator which is an estimation of signal to interference and noise ratio over the sample space of the channel prediction defined, for device k, by:

$$E(\mathrm{SINR})\approx\frac{\alpha[\|\sum_{l=0}^{p-1}\rho_l\mathbf{h}(n-l)\|^2\cos^2(\theta_k)+|\rho_u|^2]}{1+\alpha[\|\sum_{l=0}^{p-1}\rho_l\mathbf{h}(n-l)\|^2\sin^2(\theta_k)+(M-1)(|\rho_u|^2)]}.$$

14. A system for computing a channel quality indicator of a channel in a telecommunication network, said channel quality indicator characterizing the quality of the signal received on a channel by a device in said telecommunication network, said system comprising:

- a telecommunication network, said telecommunication network comprising a network managing entity,
- a device comprising:
  - a monitoring unit for monitoring the state of the channel,
  - a channel prediction unit for computing a prediction of the channel based on a past and the current state of the monitored channel,
  - a channel variation unit for obtaining a channel variation indicator, said channel variation indicator characterizing the variation of the channel between a past and the current state of the channel,
  - a channel quality unit for computing a channel quality indicator based on the channel prediction and the channel variation indicator.

15. A computer-readable medium having computer-executable instructions to enable a computer system to perform the method of any one of claims 1 to 7.

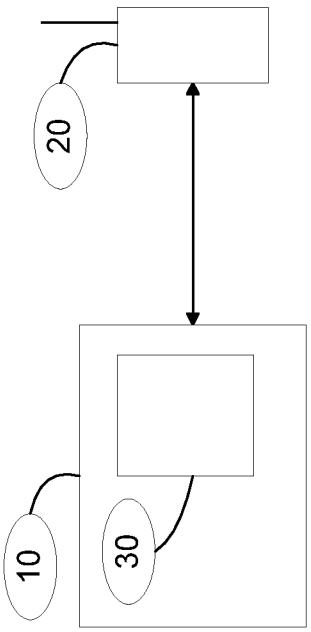


Figure 1A

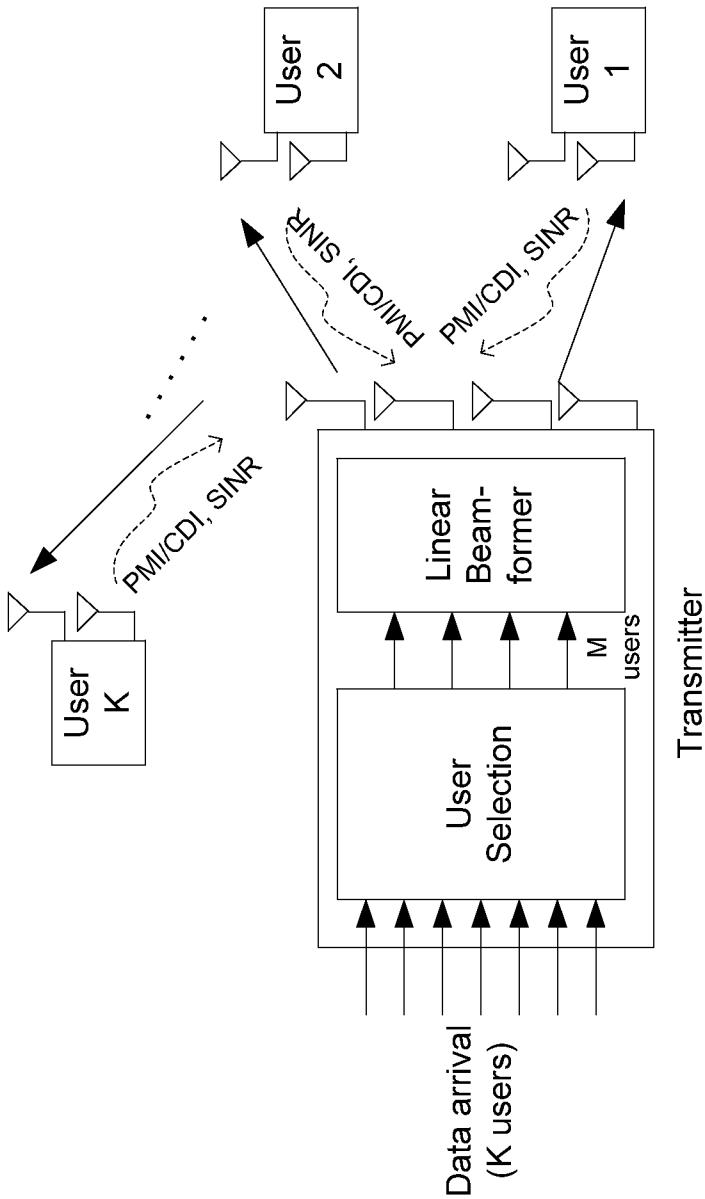


Figure 1B

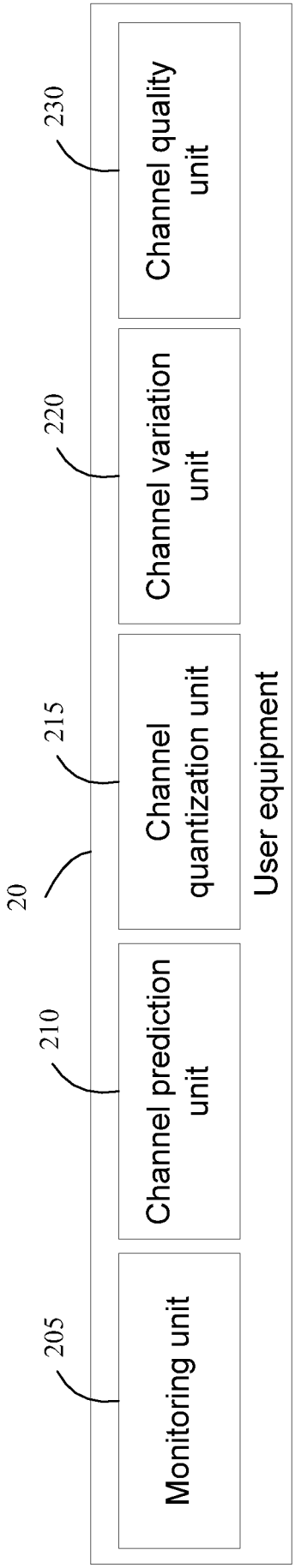


Figure 2

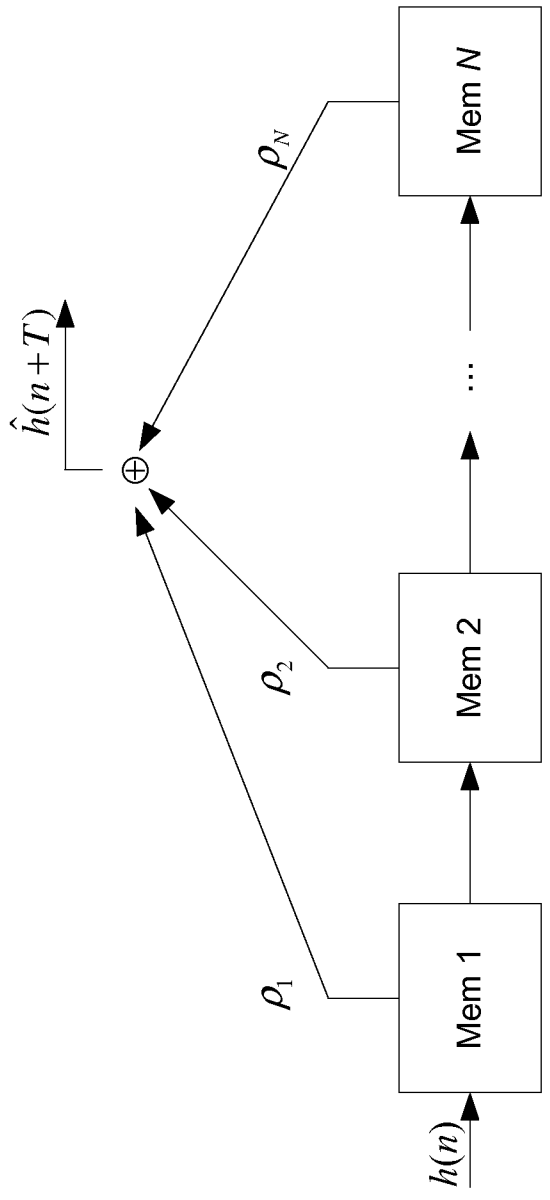


Figure 3

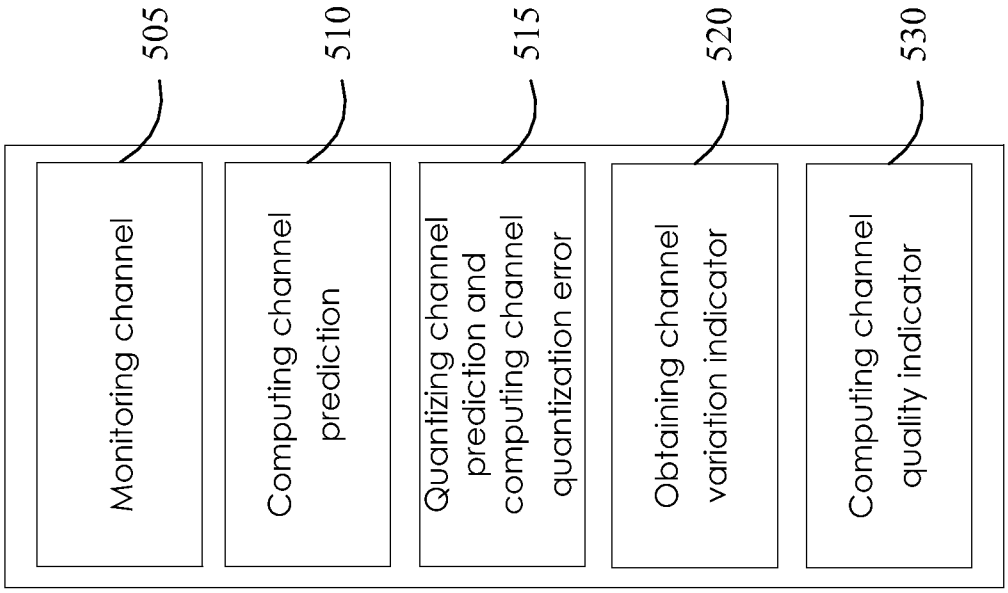


Figure 5

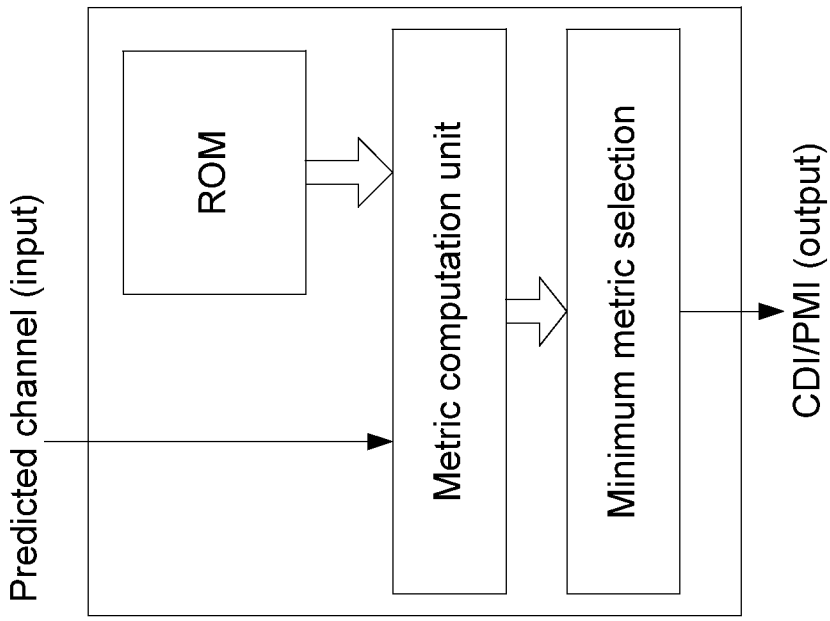


Figure 4

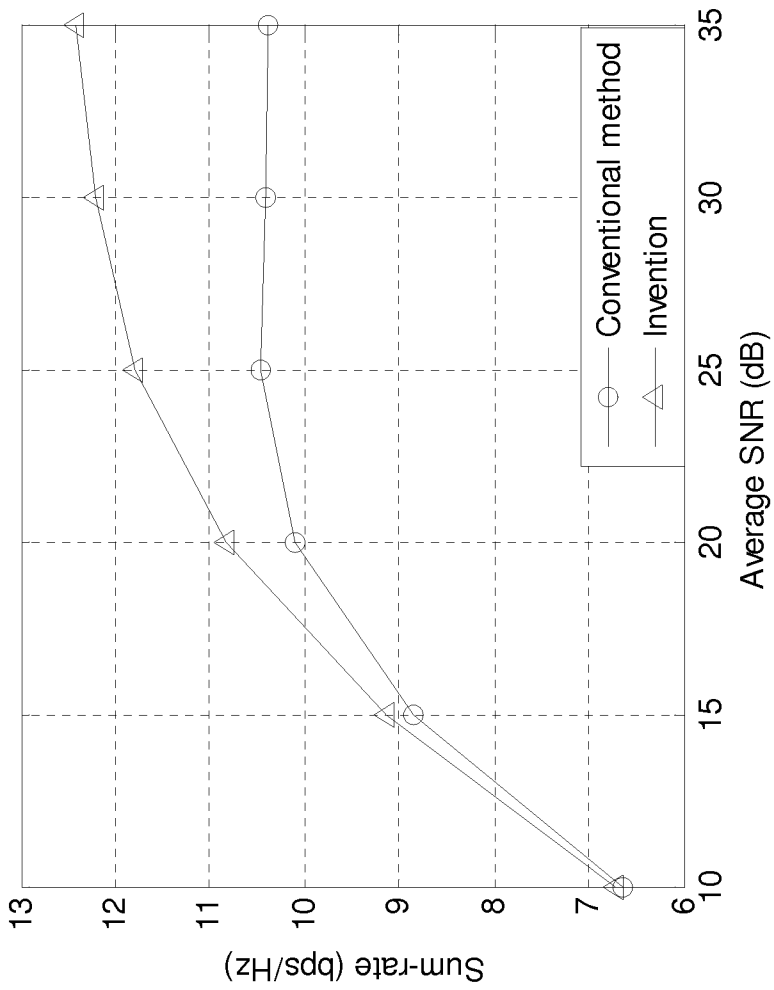

Sum-rate (bps/Hz)
Average SNR (dB)
Conventional method
Invention
13
12
11
10
9
8
7
6
10
15
20
25
30
35

Figure 6