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(54) Title: EQUALIZING METHOD IN A RECEIVER NODE

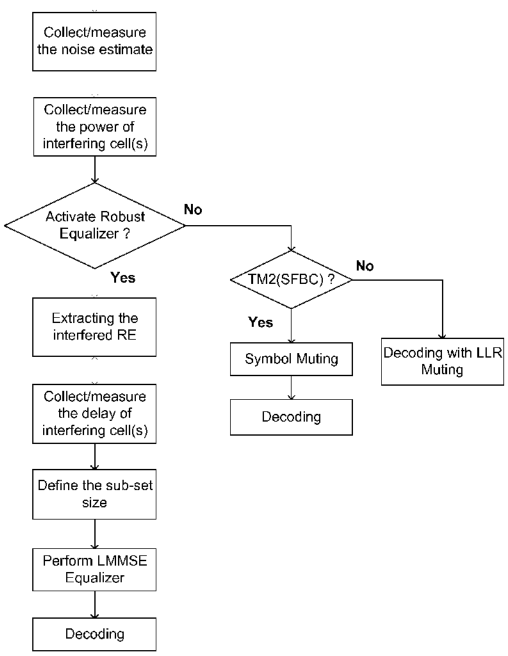

Fig. 5

(57) Abstract: The present invention relates to an equalizing method in a receiver node of a cellular wireless communication system, said cellular wireless communication system using time/frequency resource elements for transmission of radio signals comprising different channels and/or pilot symbols; said method comprising the steps of: a) receiving at least one radio signal comprising a plurality of resource elements; b) receiving interference information associated with said plurality of resource elements; c1) extracting resource elements carrying data of said plurality of resource elements into a first set based on said interference information so that said first set comprises resource elements carrying data and being affected by an interference; d) dividing the resource elements of said first set into one or more sub-sets; and e) equalizing the resource elements of said one or more sub-sets using a Linear Minimum Mean Square Error, LMMSE, estimator. Furthermore, the invention also relates to receiver node device, a computer program, and a computer program product thereof.

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EQUALIZING METHOD IN A RECEIVER NODE

Technical Field

The present invention relates to an equalizing method in a receiver node. Furthermore, the invention also relates to an equalizer device, a computer program, and a computer program product thereof.

Background of the Invention

Heterogeneous network is a strategy introduced in 3GPP LTE-Advanced with the purpose to improve network capacity. In a heterogeneous network as illustrated in Figure 1, many pico-cells with low transmit power (~ 250 mW) overlay on a macro-cell with higher transmit power (1-40 W). The advantage is to perform off-loading macro-cell data traffic to smaller pico-cells and thus improving network capacity. Moreover, those cells are using the same frequency resources which mean that User Equipments (UEs) can suffer high interference from macro-cell(s) which can lead to performance degradation. Therefore, interference management is a crucial aspect in heterogeneous network deployments.

3GPP LTE Release 10 has adopted enhanced-inter-cell interference coordination (e-ICIC) as part of the interference management. One key features in e-ICIC is the time domain interference management or also known as Almost Blank Sub-frame (ABS) transmission. An ABS contains Common Reference Symbols (CRS), Broadcast Channel (BCH), and synchronization signals (PSS/SSS). A shown in Figure 1, while the UE in cell range expansion maintains data transmission to a pico-cell (serving cell), the macro cell (neighbour cell) transmit ABS sub-frames. Depending on the cell-IDs, the CRS of neighbour cell can be colliding with CRS of serving cell (known as colliding CRS scenario) or it can also be colliding with data/control channels of serving cell (known as non-colliding CRS scenario). Thus, in a *non-colliding CRS* scenario, the interference level to the control/data channel of downlink serving cell is limited to the CRS from macro/neighbour cell(s).

Successive Interference Cancellation (SIC) is a well-known technique in CRS interference cancellation (CRS-IC) field. SIC performs interference cancellation from dominant interferences (neighbour cells) successively. The typical operation of a UE with CRS-SIC is:

1. Estimate the Channel Frequency Response (CFR) of the first dominant neighbour

cell;

2. Create a replica of the dominant interference by multiplying the locally generated CRS of neighbour cell with the estimated CFR;
3. Remove the dominant interference by subtract the received signal with the re-created/replica of the dominant interference;
4. Repeat the previous steps whenever there is a need to cancel the second or subsequent dominant interference; and
5. Once the interference(s) have been removed, the UE continues to perform demodulation of desired signal from the serving cell.

Successive interference cancellation technique however has the following technical drawbacks: The interference cancellation is depending on the accuracy of the neighbour cell(s) channel estimation technique; The error in the first cancellation is propagated to the subsequent cancellation and thus increasing the residual error which leads to performance degradation; Implementation complexity and latency are expected to be linearly increased with the number of cell(s) to be cancelled using successive interference cancellation.

Another alternative is to use Log-Likelihood Ratio (LLR) muting. This method requires only a negligible computational effort at the UE but can improve the performance in comparison to a UE that is not aware of the interference. Basically, the set of LLR corresponding to the interfered data symbols will be just simply set to zero. LLR muting is however expected to reduce the performance since the muting operation will set the data/information to zero. The degradation would be even worse in cases where are more resource elements interfered by neighbour cell(s).

Summary of the Invention

An object of the present invention is to provide a solution which mitigates or solves the drawbacks and problems of prior art solutions.

Another object is to provide a solution which has improved performance compared to prior art solutions.

According to a first aspect of the invention, the above mentioned objects are achieved by a equalizing method in a receiver node of a cellular wireless communication system, said cellular wireless communication system using time/frequency resource elements for transmission of radio signals comprising different channels and/or pilot symbols; said method comprising the steps of:

a) receiving at least one radio signal comprising a plurality of resource elements;

b) receiving interference information associated with said plurality of resource elements;

c1) extracting resource elements carrying data of said plurality of resource elements into a first set based on said interference information so that said first set comprises resource elements carrying data and being affected by an interference;

d) dividing the resource elements of said first set into one or more sub-sets; and

e) equalizing the resource elements of said one or more sub-sets using a Linear Minimum Mean Square Error, LMMSE, estimator.

Different embodiments of the above method are defined in the appended dependent claims. Further, the invention also relates to a computer program and a computer program product corresponding to the method.

According to a second aspect of the invention the above mentioned objects are achieved with a equalizing device for a cellular wireless communication system using time/frequency resource elements for transmission of radio signals comprising different channels and/or pilot symbols, and

said equalizing device comprising input means, communication means and signal processing means; and

said input means being arranged to receive at least one radio signal comprising a plurality of resource elements and arranged to receive interference information associated with said plurality of resource elements, and

said signal processing means being arranged to extracting resource elements carrying data of said plurality of resource elements into a first group based on said interference information so that said first group comprises resource elements carrying data and being affected by interference and further being arranged to equalise the resource elements of said first group using a Linear Minimum Mean Square Error, LMMSE, estimator.

The equalizing device may preferably be arranged in a receiver node device, and may further be modified, mutatis mutandis, according to the different embodiments of the present method.

The present invention provides a solution which implicitly cancels the dominant CRS interference(s), especially in non-colliding CRS heterogeneous network scenarios. This will improve the performance at the receiver node.

Further, in case of more than one interfering cell the proposed solution does not require the successive estimation and cancellation of each interference source and thus the implementation complexity and latency can be kept very low.

Further applications and advantages of the invention will be apparent from the following detailed description.

Brief Description of the Drawings

The appended drawings are intended to clarify and explain different embodiments of the present invention in which:

- Fig. 1 illustrates a heterogeneous network scenario;
- Fig. 2 illustrates a UE receiver chain comprising an equalizer according to the present invention;
- Fig. 3 illustrates the time domain coordination between serving and neighbouring eNode-Bs and its resource element allocations;
- Fig. 4 illustrates the grouping of resource elements according to the present invention;
- Fig. 5 is a flow chart of an embodiment of the present invention;
- Fig. 6 illustrates an equalizer device according to an embodiment of the present invention;
- Fig. 7 shows performance results; and
- Fig. 8 shows further performance results.

Detailed Description of the Invention

To achieve the aforementioned and further objects, the present invention relates to an equalizing method in a receiver node of a cellular wireless communication system. The cellular system is a system that uses time/frequency Resource Elements (REs) for transmission of radio signals which may comprise different channels and/or pilot symbols. The channels may e.g. be broadcast channels, control channels, synchronisation channels and data channels, while the symbols may be CRS or any other pilot symbols used in the system. The cellular system may preferably be a system specified by the 3GPP such as LTE or LTE Advanced.

The present method comprises the steps of receiving at least one radio signal comprising a plurality of REs and further receiving interference information associated with the plurality of REs. Thereafter, REs carrying data of the plurality of REs are extracted into a first set (set 1) based on the interference information so that the first set comprises REs carrying data and being affected by interference (from one or more interfering cells/sources). Thereafter the REs of the first set are divided into one or more sub-sets. Finally, all REs of the one or more sub-sets are in, each sub-set, concurrently equalized by mean of a Linear Minimum Mean Square Error, LMMSE, estimator.

REs affected by interference means that these REs are colliding with the REs of interfering (often neighbouring) cells which has strong interference. In LTE-Advanced system, there is a time domain interference mechanism which minimizes the interference impact as illustrated in Figure 3. The UE at the cell-edge or cell range expansion area are allocated by the serving cell to use the resources in sub-frame 2, 10. In that particular sub-frame, the neighbour cell transmit sub-frame 4, 12 which are the ABS sub-frames.

In case of heterogeneous network with non-colliding CRS scenario, the CRS interferences from interfering cell(s) are colliding with the control/data channels of the downlink signal from the serving cell. Figure 4 (left) illustrates the LTE 2x2 MIMO RE allocation within one RB pair in a non-colliding CRS scenario. The serving cell cell-ID is 0 and the neighbour cell cell-ID is 1 and thus the CRS from two cells are not colliding. The CRS interferences are located in certain REs in the OFDM symbols carrying CRS from the serving cell and colliding with control and data channels. The present robust equalizer performs the data demodulation on the interfered/colliding RE (and the adjacent REs carrying data in the frequency domain if the transmission is SFBC which is needed due to the detection process in SFBC which requires at least a pair of REs). SFBC is also known as Transmission Mode 2 (TM2) in LTE context. The REs for equalizing is illustrated in Figure 4 (right). The task of resource de-mapping unit in the receiver is to extract the resource elements based on its allocation (e.g. CRS to assist channel estimation, PDCCH, PDSCH, etc.) and then assign to other units in the receiver to be further processed.

In a typical receiver, all REs carrying data (e.g. PDSCH) are extracted and then passed to a MIMO detection block for detection purpose. In the present invention all REs carrying data are divided into two sets according to the following grouping principal:

- REs affected by interference from other cell(s) CRS;
- The remaining REs carrying data (PDSCH) which also belongs to the plurality of REs.

This can be illustrated as shown in Figure 4. The REs in the first set (set 1) is used as the input to the equalizer unit after division into one or more sub-sets, while the REs in the second set (set 2) is used as the input to the ordinary MIMO detection unit. The output of both units are thereafter multiplexed and used as the input to the data decoder unit of the receiver device. From the above it is noted that according to an embodiment of the invention the present method further comprises the step of extracting the remaining REs carrying data of the plurality of REs into a second set (set 2).

The sub-set size of the REs (i.e. the number of REs in each sub-set) should also be determined. The receiver needs to ensure that the REs within the sub-set are experiencing almost the same channel conditions to get the benefit of grouping processing from multiple REs within a sub-set. The sub-set size can be determined based on the following principals:

- Adaptive sub-set size based on channel conditions: in this case the sub-set size is determined based on the coherence time and coherence bandwidth of the radio channel. The coherence time and coherence bandwidth ensure that the REs in the sub-sets experience almost the same radio channel conditions. Accordingly, the number of REs in each sub-set is based on channel conditions for a radio channel, and preferably coherence bandwidth and coherence time of the radio channel; or

- Fixed sub-set size allocation: the sub-set size is pre-configured and fixed, e.g. the sub-set size can be 1 RB pair size as shown in Figure 4. However, the system designer needs to ensure the optimum group size which is applicable to all common radio channel conditions. Accordingly, the number of REs in each sub-set is predetermined and fixed according to this embodiment. The value(s) for the sub-set size could be predetermined based on channel propagation conditions as defined in a specification for a wireless communication system, such as 3GPP systems.

Robust equalizer activation can be determined based on the following criteria: measured interference power and/or noise estimate parameters are above certain thresholds. For example, if both the interfering power and noise estimate are extremely high and above the thresholds then it is expected that robust equalizer operation does not help to improve the performance and thus it is better to activate other methods with low computational load such as muting. The value of the thresholds is design parameters, and the noise estimate parameter may be obtained from the channel estimation unit. The size of RE set must be determined which can be based on the channel coherence bandwidth and coherence time as described above. A UE is typically equipped with means for channel parameters estimation which provide such information. If the coherence bandwidth and coherence time is large, a large RE group size is expected to further improve the performance however with the cost of implementation complexity. The receiver must estimate the interference power of interfering cell(s) prior to the above equalization process. In addition, even in synchronous networks, there is still a relative time delay between the interfering cell and the serving cell which must be estimated so that the delay is taken into account by rotating/de-rotating the regenerated CRS of interfering (e.g. neighbouring) cell(s).

The receiver can have dedicated units for estimating interfering cell(s) power and delay. In some systems (e.g. LTE) there are other units in the receiver which essentially performs the aforementioned estimation. For example the Reference Signal Received Power (RSRP) measurement unit in LTE provides the interference power of interfering cell(s) and LTE Cell search unit provides the delay timing information.

According to yet another embodiment of the present invention, the equalization is combined with muting technique(s) so that the either equalization or muting is activated depending on suitable condition(s). This operation is to avoid robust equalization in case both interference and noise estimate are high. In such scenario, robust equalization does not provide additional performance gain over muting and thus, it is better to keep low UE computational load.

Preferably, according to an embodiment of the invention symbol muting is employed if the radio signal comprising the REs are transmitted in transmit diversity mode or in SFBC mode. Yet further, LLR muting may be activated instead of the symbol muting if the radio signal is transmitted in non-transmit diversity mode. Symbol muting can only be applied to the transmit diversity transmissions due to the unique signal processing of transmit diversity.

The activation/deactivation of the present equalizer can be based on a threshold value so that the equalizer is deactivated if an interference value and/or a noise estimate value is greater than the threshold value. Another deactivation condition can be that the equalizer is deactivated if there is no capacity left in the CPU to perform equalizing (heavy load), e.g. if the CPU is used by other functionalities/purposes or already is in high computational load use.

Symbol muting is an interference avoidance method specifically for transmit diversity scheme/Space Frequency Block-Coded (SFBC) scheme. Symbol muting is performed by muting (set to zero) the received symbol which has been contaminated by interference and its corresponding channel and noise estimate. Typical received signal model for 2x2 MIMO SFBC is as follows:

$$\begin{bmatrix} y_0(k0) \\ y_0^*(k1) \\ y_1(k0) \\ y_1^*(k1) \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} h_{00}(k0) & -h_{01}(k0) \\ h_{01}^*(k1) & h_{00}^*(k1) \\ h_{10}(k0) & -h_{11}(k0) \\ h_{11}^*(k1) & h_{10}^*(k1) \end{bmatrix} \begin{bmatrix} s_0 \\ s_1^* \end{bmatrix} + \begin{bmatrix} w_0(k0) \\ w_0(k1) \\ w_1(k0) \\ w_1(k1) \end{bmatrix}$$

Where $y_n(k0)$ is the signal at received antenna n and at sub-carrier $k0$. In case the interfering CRS collide with received signal at sub-carrier $k1$, then the symbol muting signal model can be written as:

$$\begin{bmatrix} y_0(k0) \\ 0 \\ y_1(k0) \\ 0 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} h_{00}(k0) & -h_{01}(k0) \\ 0 & 0 \\ h_{10}(k0) & -h_{11}(k0) \\ 0 & 0 \end{bmatrix} \begin{bmatrix} s_0 \\ s_1^* \end{bmatrix} + \begin{bmatrix} w_0(k0) \\ 0 \\ w_1(k0) \\ 0 \end{bmatrix}$$

Furthermore, the interference information may according to an embodiment of the invention indicate the time/frequency location of the REs of the first set so that mentioned REs can be identified. This interference information can be obtained from a higher layer, such as layer 3 (also known as Radio Resource Control, RRC, layer), which means that the layer responsible for the equalization, i.e. the physical layer 1 in this case, receives the interference information from layer 3.

In heterogeneous networks both the e-NodeB of the serving cell and the e-NodeB(s) of the interfering cell(s) perform time domain interference coordination. It is known as time domain enhanced-inter-cell interference coordination (e-ICIC) in LTE release 10. The serving cell always transmits with full payload and most of the sub-frames are allocated to the UE receivers which are relatively close to the serving cell e-NodeB. The UE receivers at the cell edge or Cell Range Expansion (CRE) area are allocated to the serving cell sub-frame no.2 and no.10. In order to minimize the interference from the interfering cell(s), mentioned interfering cell(s) transmits ABS on that particular sub-frame. Both e-NodeBs perform interference coordination and exchange the scheduling information. This allows the interfering cell(s) to inform about the ABS pattern to the serving cell. The serving cell then utilizes and forwards the ABS pattern information to the UE at the cell edge.

The interference caused by ABS is the CRS of the interfering cell. The UE receiver can easily identify the position of the CRS interference by simple post-processing of serving cell cell-ID and interfering cell's cell-ID. By knowing the ABS pattern and CRS position of the interfering cell(s) from higher layer 3, the UE is then able to identify the interfered serving cell resource elements and thus group them together into the first group for equalization. Hence, according to an embodiment of the invention the interference information comprises information about ABS transmissions from interfering cell(s).

As for the LMMSE estimation that is used in the present equalizer two embodiments are preferred. The received signal from the serving cell and *N* interfering cell(s) can be written as follows:

$$\boldsymbol{Y} = \boldsymbol{D}_{sc}\boldsymbol{H}_{sc} + \sum_{m=1}^{M} \sqrt{q_m}\boldsymbol{D}_m \boldsymbol{H}_m + \boldsymbol{w}$$

(Eq. 1)

where is $\boldsymbol{D}_{sc}$ the diagonal data matrix, $\boldsymbol{H}_{sc}$ is the radio channel to the serving cell, q_m is the interference power, $\boldsymbol{D}_m$ is the CRS of interfering cell m, $\boldsymbol{H}_m$ is the channel of interfering cell-m, and $\boldsymbol{w}$ is the diagonal matrix of thermal noise and other interference modelled as white Gaussian noise.

According to an embodiment the LMMSE estimator uses the following model for the estimated data:

$$\widetilde{\boldsymbol{D}}_{sc} = \widetilde{\boldsymbol{H}}_{sc}^{H}\left(\widetilde{\boldsymbol{H}}_{sc}\widetilde{\boldsymbol{H}}_{sc}^{H} + \sum_{m=1}^{M} q_m \boldsymbol{D}_m E\left(\boldsymbol{H}_m\boldsymbol{H}_m^{H}\right)\boldsymbol{D}_m^{H} + \sigma^2\boldsymbol{I}\right)^{-1}\boldsymbol{Y},$$

(Eq. 2)

where $\widetilde{\boldsymbol{D}}_{sc}$ is estimated data from the serving cell, $\widetilde{\boldsymbol{H}}_{sc}$ is estimated radio channel from the serving cell, q_m is interference power from m-th dominant interfering cell relative to the noise estimate, $E\left(\boldsymbol{H}_m\boldsymbol{H}_m^{H}\right)$ is channel correlation matrix of m-th dominant interfering cell, $\boldsymbol{D}_m$ is regenerated CRS of m-th dominant interfering cell, σ^2 is noise estimate, and $\boldsymbol{Y}$ is received signal at the receiver node, and M is the number of dominant interfering cells. A very important component is the channel correlation matrix of interfering cell(s) which can be computed offline assuming that the UE knows the channel characteristic of the neighbouring cell. Eq. 2 can be extended in case of multi-cell CRS interference. It should be noted that typically all cells exhibit the same channel conditions and thus the same channel correlation matrix can be reused. This embodiment is denoted as the robust equalizer in the present application.

Example:

SFBC 2x2 with equalizer RE group within 1 RB utilizes 12 colliding REs and its adjacent RE as depicted in Figure 4.

$$\underbrace{\tilde{\mathbf{D}}_{\mathbf{sc}}}_{24x1} = \underbrace{\tilde{\mathbf{H}}_{\mathbf{sc}}^{H}}_{24x48} \underbrace{\left(\tilde{\mathbf{H}}_{\mathbf{sc}}\tilde{\mathbf{H}}_{\mathbf{sc}}^{H} + q_1\mathbf{D}_1 E\left(\mathbf{H}_1\mathbf{H}_1^{H}\right)\mathbf{D}_1^{H} + \sigma^2\mathbf{I}\right)^{-1}}_{48x48} \underbrace{\mathbf{Y}}_{48x1}$$

(Eq. 2)

This requires an online 48x48 matrix inversion for each RB process. This can however result in quite high computation load at the UE.

Therefore, according to another embodiment of the present invention the LMMSE estimator uses the following model for the estimated data:

$$\tilde{\boldsymbol{D}}_{sc} = \frac{1}{q_1}\tilde{\boldsymbol{H}}_{sc}^{H}\boldsymbol{D}_1\left(E\left(\boldsymbol{H}_1\ \boldsymbol{H}_1^{H}\right) + \frac{(\sigma^2+1)}{q_1}\boldsymbol{I}\right)^{-1}\boldsymbol{D}_1^{H}\boldsymbol{Y},$$

,(Eq. 4)

where $\tilde{\boldsymbol{D}}_{sc}$ is estimated data from said serving cell, $\tilde{\boldsymbol{H}}_{sc}$ is estimated radio channel from said serving cell, q_1 is interference power from dominant interfering cell , $E\left(\boldsymbol{H}_1\ \boldsymbol{H}_1^{H}\right)$ is channel correlation of dominant interfering cell, $\boldsymbol{D}_1$ is regenerated CRS of dominant interfering cell, σ^2 is noise estimate, and $\boldsymbol{Y}$ is received signal at said receiver node. Eq. 4 above is obtained by modifying Eq. 2 according to the following equation:

$$\tilde{\boldsymbol{D}}_{sc} = \tilde{\boldsymbol{H}}_{sc}^{H}\left(E\left(\boldsymbol{H}_{sc}\boldsymbol{H}_{sc}^{H}\right) + \sum_{m=1}^{M} q_m\boldsymbol{D}_m E\left(\boldsymbol{H}_m\boldsymbol{H}_m^{H}\right)\boldsymbol{D}_m^{H} + \sigma^2\boldsymbol{I}\right)^{-1}\boldsymbol{Y}.\text{(Eq. 5)}$$

Since $E\left(\boldsymbol{H}_{sc}\boldsymbol{H}_{sc}^{H}\right)$ is an identity matrix for spatially uncorrelated channels, Eq. 4 is obtained. This embodiment has the advantage that online matrix inversion is avoided since the inverted part can be pre-computed offline according to different channel type, noise and interference power level. Therefore a less complex equalizer is provided in this case, and is hence denoted robust low complex equalizer.

Figure 5 shows a flow chart of an embodiment of the present invention incorporating symbol and LLR muting. Firstly, the equalizing device collects interference power measurement and noise estimate from other units. If mentioned parameters are above certain thresholds then the

UE performs a simple muting operation or LLR muting if the radio signal is transmitted in non-transmit diversity mode. Otherwise, the UE performs robust equalizing as follows:

1. Separating the REs affected by interference from the REs not affected into set 1 and set 2, respectively;
2. Collecting the time delay of the dominant interference relatively to the serving cell. This delay will be used later in the LMMSE operation of set 1.
3. Defining the sub-set size of LMMSE operation for set 1. It can be based on channel coherence time/frequency as described above.
4. Performing separate LMMSE operation for each set 1 and set 2. LMMSE operation of set 1 is performed repeatedly for every sub-set while the LMMSE operation for set 2 can be performed repeatedly for every RE,
5. Multiplexing the output of set 1 and set 2, and then performing data decoding on the outputs.

Further, the equalizing methods above may be implemented in an equalizing device. The device comprises all suitable means for performing the equalisation according to the above described methods, such as memory means, input means, output means, communication means, signal processing means, register means, etc. Specifically, the input means being arranged to receive at least one radio signal comprising a plurality of REs and arranged to receive interference information associated with the plurality of resource elements, and the signal processing means being arranged to extracting Res carrying data of the plurality of REs into a first set based on the interference information so that the first set comprises REs carrying data and being affected by interference and dividing the REs of the first set into one or more sub-sets. Further being arranged to equalise the REs of the one or more sub-sets using a Linear Minimum Mean Square Error, LMMSE, estimator. The equalizing device may preferably be arranged in a receiver node device such as in a mobile station or a relay station.

An implementation of the proposed equalizer is preferably in a software based Digital Signal Processing (DSP) to allow flexible implementation. The equalizer implementation block diagram is depicted in Figure 6. This figure is an example of an implementation block diagram of the equalizer for the data in set 1. The matrix inverse operation is avoided by storing the filter coefficients in a Look-Up Table (LUT) form. The LUT selection is based on the interference power estimation, channel parameter estimation, and noise estimation. The detection process is the LMMSE operation as described in Eq. 4.

It should be realised that the equalizing device may be modified, *mutatis mutandis*, according to all embodiments of the equalizing method in the receiver node.

Figures 7 and 8 show the (normalized) throughput performance versus SNR for two test scenarios as defined by 3GPP LTE. The performance results of SFBC with modulation and coding QPSK ½ in EVA5 Medium correlation channel is shown in Figure 7. The interference power is 6 dB above noise level. The results indicate that the proposed robust equalizer performance is as good as the performance results with ideal cancellation (CRS-IC (Ideal)). Most importantly, the low complexity version of the equalizer (Eq. 4) is also achieving the same performance. Symbol muting is also performing better than LLR muting. All of the proposed algorithms provide significant gain compared to the case without cancellation.

Figure 8 shows the results in case of transmission mode 3 (open loop spatial multiplexing) with modulation and coding 16QAM ½ in EVA70 Low correlation channel. The performance results indicate the same trend as the results shown in Figure 7. The proposed robust equalizer performance is almost as good as the performance results with ideal cancellation (CRS-IC (Ideal)). The low complexity version of equalizer (using Eq. 4) is also achieving almost the same performance with negligible degradation. All of the proposed algorithms provide significant gain compared to the case without cancellation.

Furthermore, as understood by the person skilled in the art, any method according to the present invention may also be implemented in a computer program, having code means, which when run by processing means causes the processing means to execute the steps of the method. The computer program is included in a computer readable medium of a computer program product. The computer readable medium may comprises of essentially any memory, such as a ROM (Read-Only Memory), a PROM (Programmable Read-Only Memory), an EPROM (Erasable PROM), a Flash memory, an EEPROM (Electrically Erasable PROM), or a hard disk drive.

Finally, it should be understood that the present invention is not limited to the embodiments described above, but also relates to and incorporates all embodiments within the scope of the appended independent claims.

CLAIMS

1. Equalizing method in a receiver node of a cellular wireless communication system, said cellular wireless communication system using time/frequency resource elements for transmission of radio signals comprising different channels and/or pilot symbols; said method comprising the steps of:

a) receiving at least one radio signal comprising a plurality of resource elements;

b) receiving interference information associated with said plurality of resource elements;

c1) extracting resource elements carrying data of said plurality of resource elements into a first set based on said interference information so that said first set comprises resource elements carrying data and being affected by an interference;

d) dividing the resource elements of said first set into one or more sub-sets; and

e) equalizing the resource elements of said one or more sub-sets using a Linear Minimum Mean Square Error, LMMSE, estimator.

2. Method according to claim 1, further comprising the step of:

c2) extracting the remaining resource elements carrying data of said plurality of resource elements into a second set.

3. Method according to claim 1, wherein said interference information indicates time/frequency location of the resource elements of said first set.

4. Method according to claim 3, wherein steps a, b, c1, d, and e are performed in physical layer 1 and said interference information is received from a higher layer, such as layer 3.

5. Method according to claim 4, wherein said receiving node is served by a serving cell, and said interference information comprises information about Almost Blank Sub-frame, ABS, transmissions from interfering cell(s).

6. Method according to claim 1, wherein said first set comprises the resource elements carrying data and being affected by interference and its adjacent resource elements in the frequency domain.

7. Method according to claim 1, wherein the number of resource element in said one or more sub-sets is: based on channel conditions for a radio channel, or predetermined and fixed.

8. Method according to claim 7, wherein the channel conditions are coherence bandwidth and coherence time for said radio channel.

9. Method according to claim 1, wherein said plurality of resource elements are allocated in one or more Resource Block, RB, pairs.

10. Method according to claim 1, wherein said receiving node is served by a serving cell, and said LMMSE estimator uses:

$$\widetilde{\boldsymbol{D}}_{sc} = \widetilde{\boldsymbol{H}}_{sc}^{H}\left(\widetilde{\boldsymbol{H}}_{sc}\widetilde{\boldsymbol{H}}_{sc}^{H} + \sum_{m=1}^{M} q_m \boldsymbol{D}_m E\left(\boldsymbol{H}_m \boldsymbol{H}_m^{H}\right)\boldsymbol{D}_m^{H} + \sigma^2 \boldsymbol{I}\right)^{-1} \boldsymbol{Y}$$

,

where $\widetilde{\boldsymbol{D}}_{sc}$ is estimated data from said serving cell, $\widetilde{\boldsymbol{H}}_{sc}$ is estimated radio channel from said serving cell, q_m is interference power from m-th dominant interfering cell, $E\left(\boldsymbol{H}_m \boldsymbol{H}_m^{H}\right)$ is channel correlation of m-th dominant interfering cell, $\boldsymbol{D}_m$ is regenerated Common Reference Symbols, CRS, of m-th dominant interfering cell, σ^2 is noise estimate, and $\boldsymbol{Y}$ is received signal at said receiver node, and M is the number of dominant interfering cells.

11. Method according to claim 1, wherein said receiving node is served by a serving cell, and said LMMSE estimator uses:

$$\widetilde{\boldsymbol{D}}_{sc} = \frac{1}{q_1}\widetilde{\boldsymbol{H}}_{sc}^{H}\boldsymbol{D}_1\left(E\left(\boldsymbol{H}_1\ \boldsymbol{H}_1^{H}\right) + \frac{(\sigma^2+1)}{q_1}\boldsymbol{I}\right)^{-1}\boldsymbol{D}_1^{H}\boldsymbol{Y},$$

where $\widetilde{\boldsymbol{D}}_{sc}$ is estimated data from said serving cell, $\widetilde{\boldsymbol{H}}_{sc}$ is estimated radio channel from said serving cell, q_1 is interference power from dominant interfering cell, $E\left(\boldsymbol{H}_1\ \boldsymbol{H}_1^{H}\right)$ is channel correlation of dominant interfering cell, $\boldsymbol{D}_1$ is regenerated Common Reference Symbols of dominant interfering cell, σ^2 is noise estimate, and $\boldsymbol{Y}$ is received signal at said receiver node.

12. Method according to claim 1, wherein said equalizing step is deactivated if an interference power of said interference and/or a noise estimate is greater than a threshold value(s) and replaced by the step of:

employing a muting technique on said plurality of resource elements.

13. Method according to claim 12, wherein symbol muting is employed if said radio signal is transmitted in transmit diversity mode or in space frequency block code, SFBC, mode.

14. Method according to claim 13, wherein LLR muting is employed if said radio signal is transmitted in non-transmit diversity mode.

15. Method according to claim 1, wherein the equalization of the resource elements within each sub-set is performed concurrently.

16. Method according to claim 1, wherein said cellular wireless communication system is a 3GPP communication system.

17. Method according to claim 16, wherein said receiver node is a relay station or a mobile station such as a User Equipment, UE, and said radio signal is transmitted in the downlink.

18. Computer program, **characterised in** code means, which when run by processing means causes said processing means to execute said method according to any of claims 1-17.

19. Computer program product comprising a computer readable medium and a computer program according to claim 18, wherein said computer program is included in the computer readable medium, and comprises of one or more from the group: ROM (Read-Only Memory), PROM (Programmable ROM), EPROM (Erasable PROM), Flash memory, EEPROM (Electrically EPROM) and hard disk drive.

20. Equalizing device for a cellular wireless communication system using time/frequency resource elements for transmission of radio signals comprising different channels and/or pilot symbols, and

said equalizing device comprising input means, communication means and signal processing means; and

said input means being arranged to receive at least one radio signal comprising a plurality of resource elements and arranged to receive interference information associated with said plurality of resource elements, and

said signal processing means being arranged to extracting resource elements carrying data of said plurality of resource elements into a first set based on said interference information so that said first set comprises resource elements carrying data and being affected by interference, dividing the resource elements of said first set into one or more sub-sets, and further being arranged to equalise the resource elements of said one or more sub-sets using a Linear Minimum Mean Square Error, LMMSE, estimator.

21. Receiver node device comprising at least one equalizing device according to claim 20.

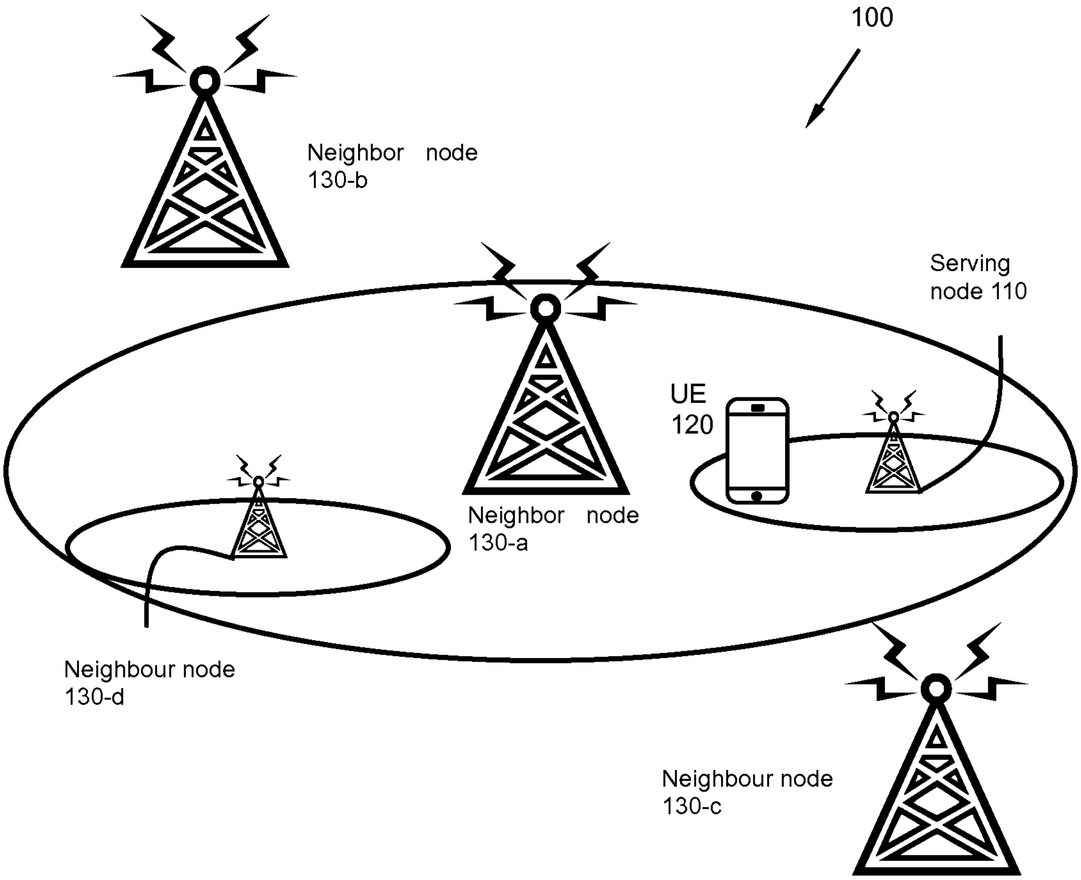

100
Neighbor node
130-b
Serving
node 110
UE
120
Neighbor node
130-a
Neighbour node
130-d
Neighbour node
130-c

Fig. 1

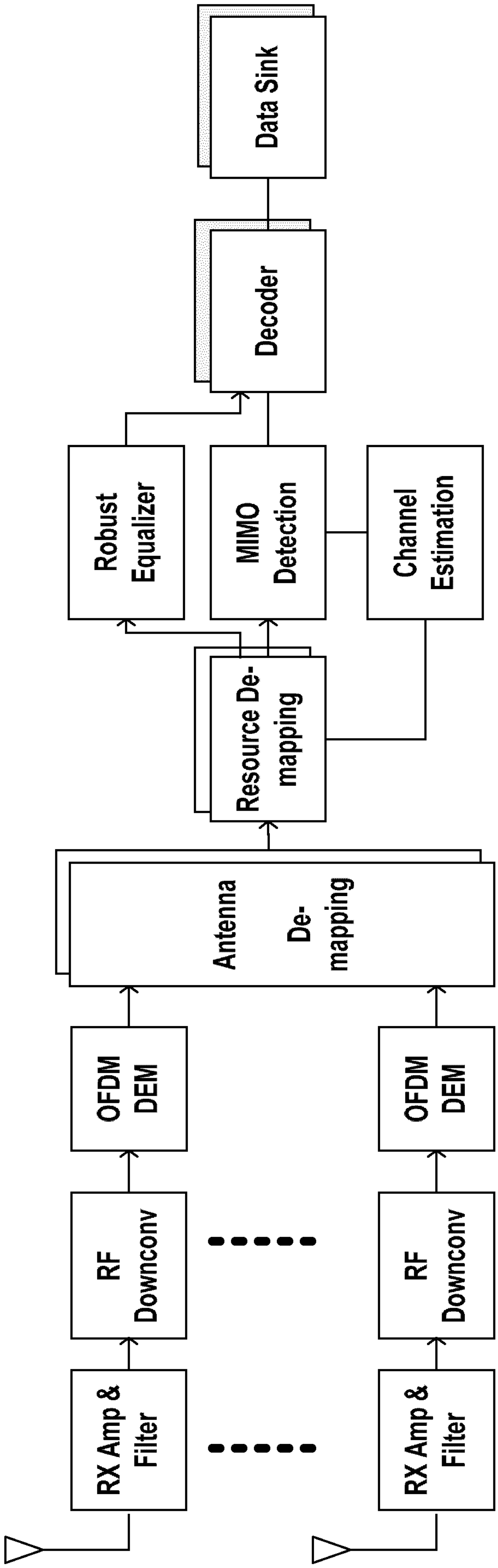

Data Sink
Decoder
Robust Equalizer
MIMO Detection
Channel Estimation
Resource De-mapping
Antenna De-mapping
OFDM DEM
RF Downconv
RX Amp & Filter
OFDM DEM
RF Downconv
RX Amp & Filter

Fig. 2

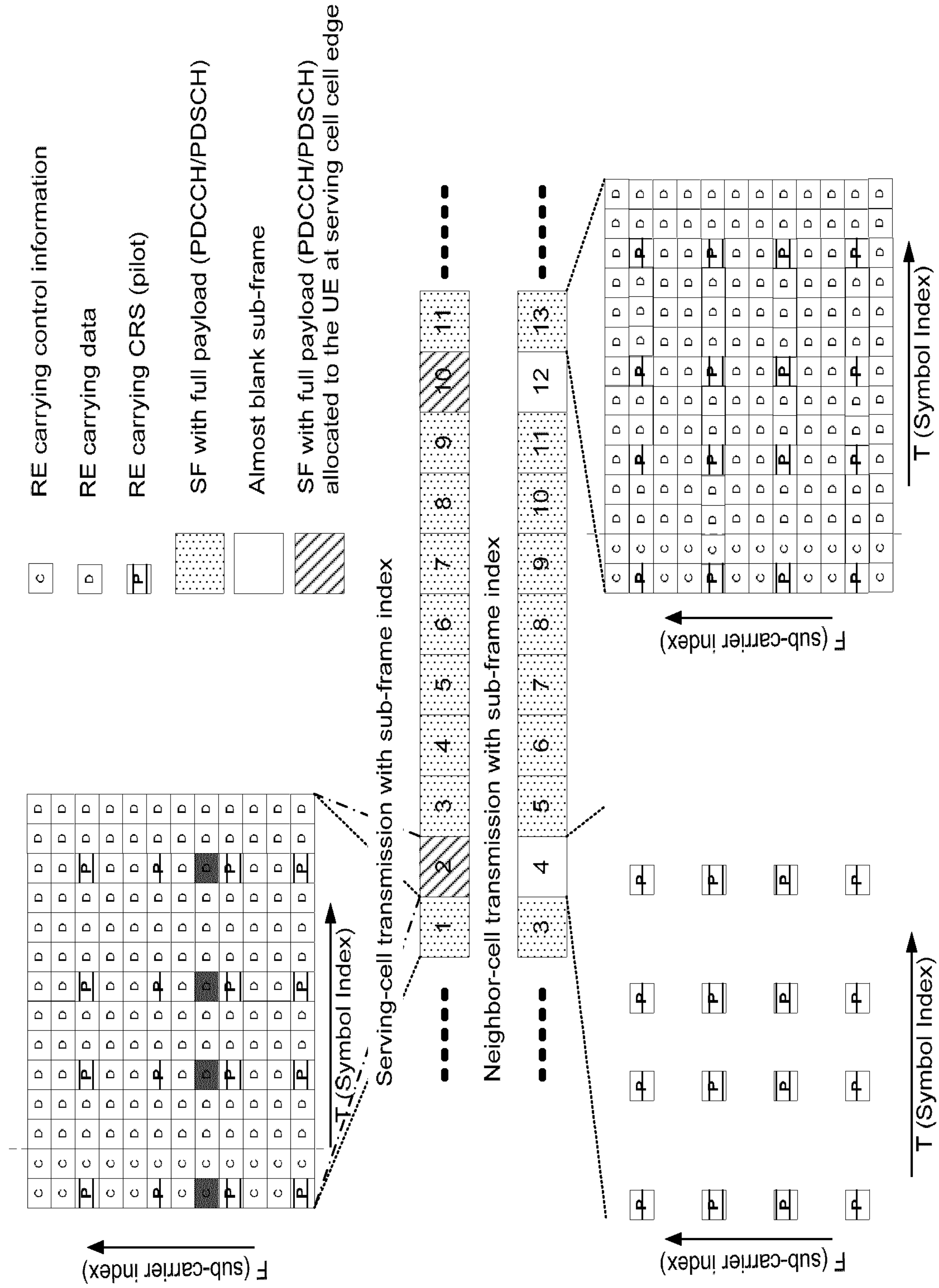
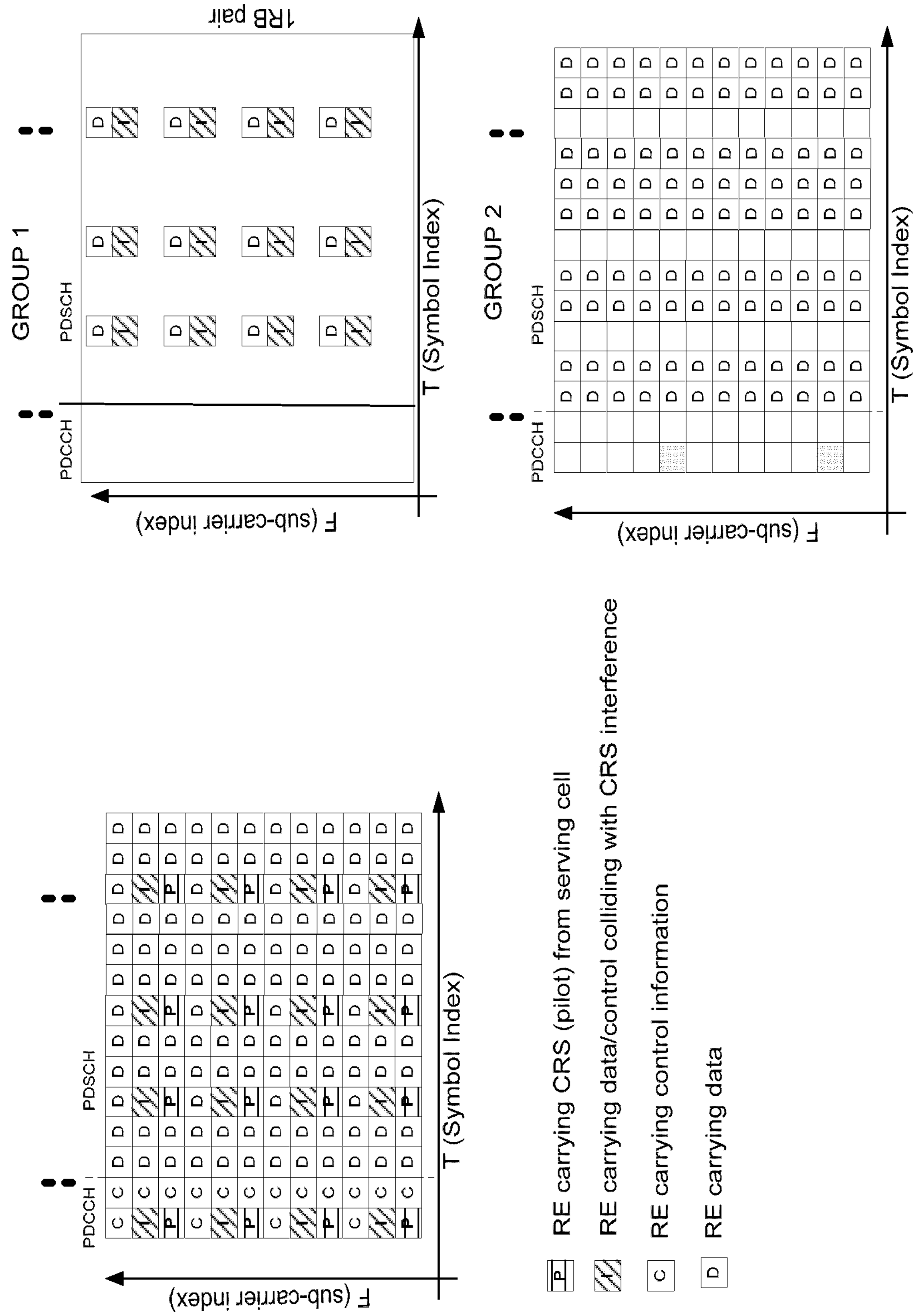

RE carrying control information
RE carrying data
RE carrying CRS (pilot)
SF with full payload (PDCCH/PDSCH)
Almost blank sub-frame
SF with full payload (PDCCH/PDSCH) allocated to the UE at serving cell edge
Serving-cell transmission with sub-frame index
Neighbor-cell transmission with sub-frame index
F (sub-carrier index)
T (Symbol Index)

Fig. 3



GROUP 1
GROUP 2
PDCCH
PDSCH
1RB pair
T (Symbol Index)
F (sub-carrier index)
RE carrying CRS (pilot) from serving cell
RE carrying data/control colliding with CRS interference
RE carrying control information
RE carrying data

Fig. 4

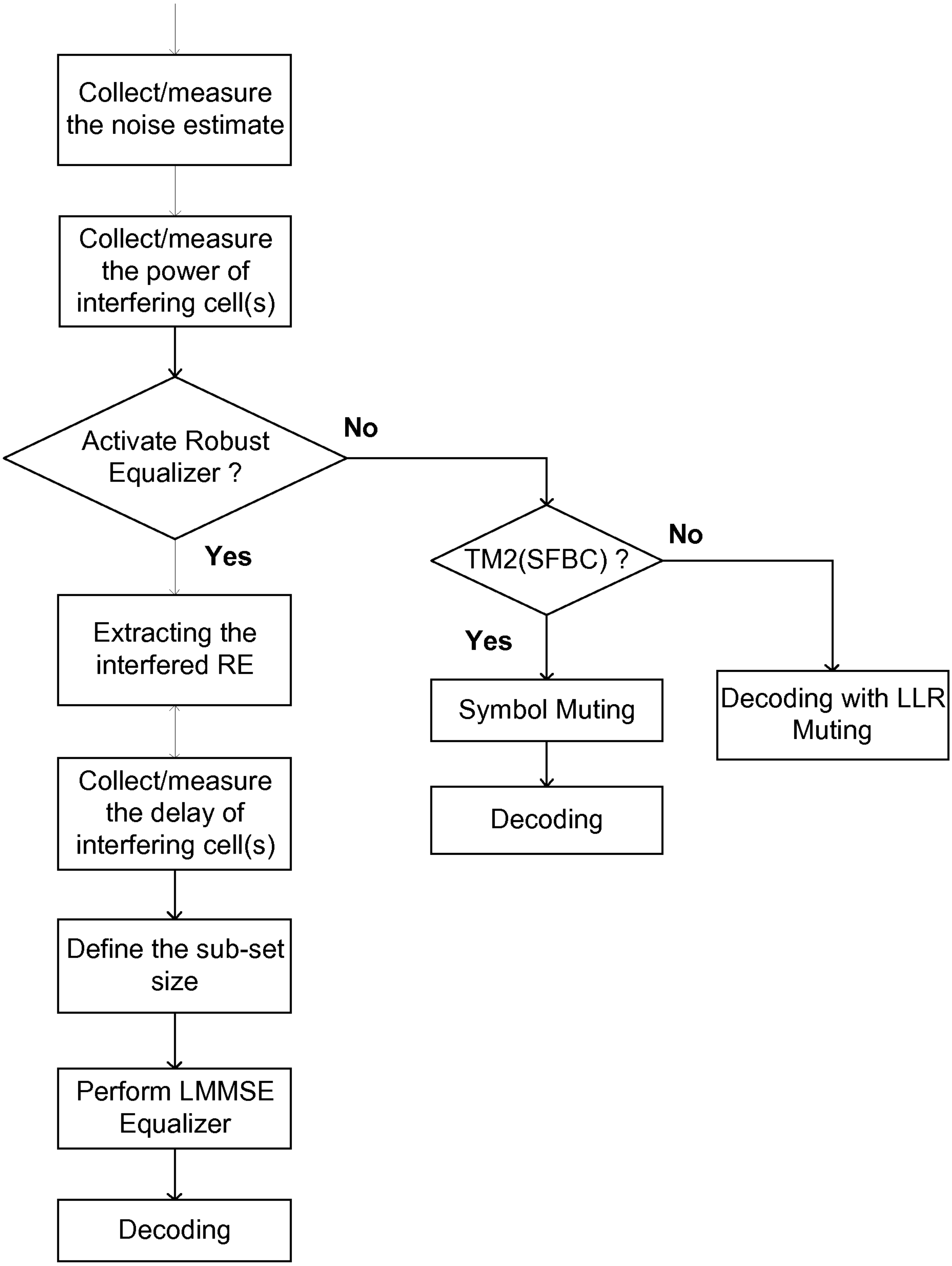

Collect/measure the noise estimate
Collect/measure the power of interfering cell(s)
Activate Robust Equalizer ?
No
Yes
TM2(SFBC) ?
No
Yes
Extracting the interfered RE
Symbol Muting
Decoding with LLR Muting
Decoding
Collect/measure the delay of interfering cell(s)
Define the sub-set size
Perform LMMSE Equalizer
Decoding

Fig. 5

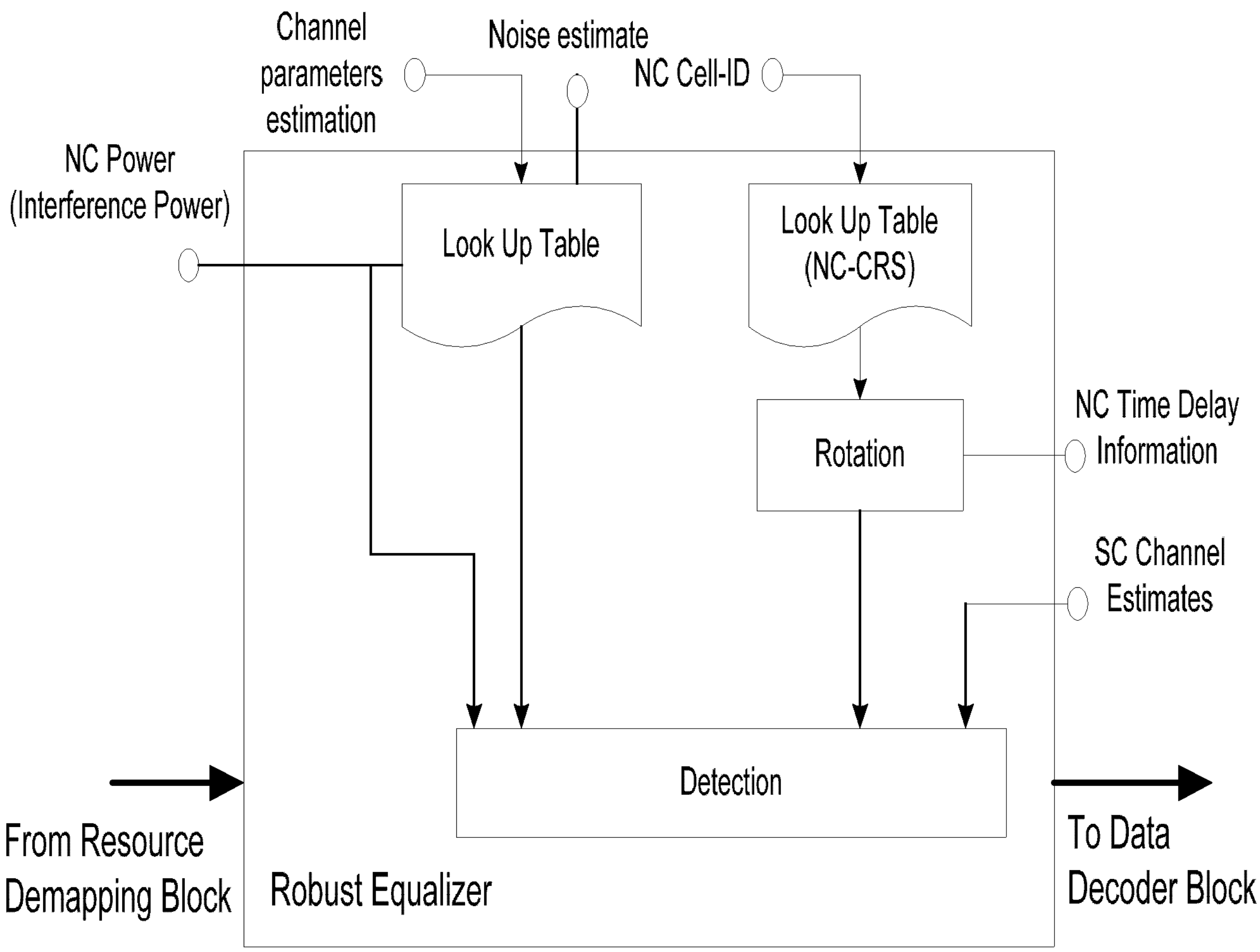

Channel parameters estimation
Noise estimate
NC Cell-ID
NC Power (Interference Power)
Look Up Table
Look Up Table (NC-CRS)
Rotation
NC Time Delay Information
SC Channel Estimates
Detection
From Resource Demapping Block
Robust Equalizer
To Data Decoder Block

Fig. 6

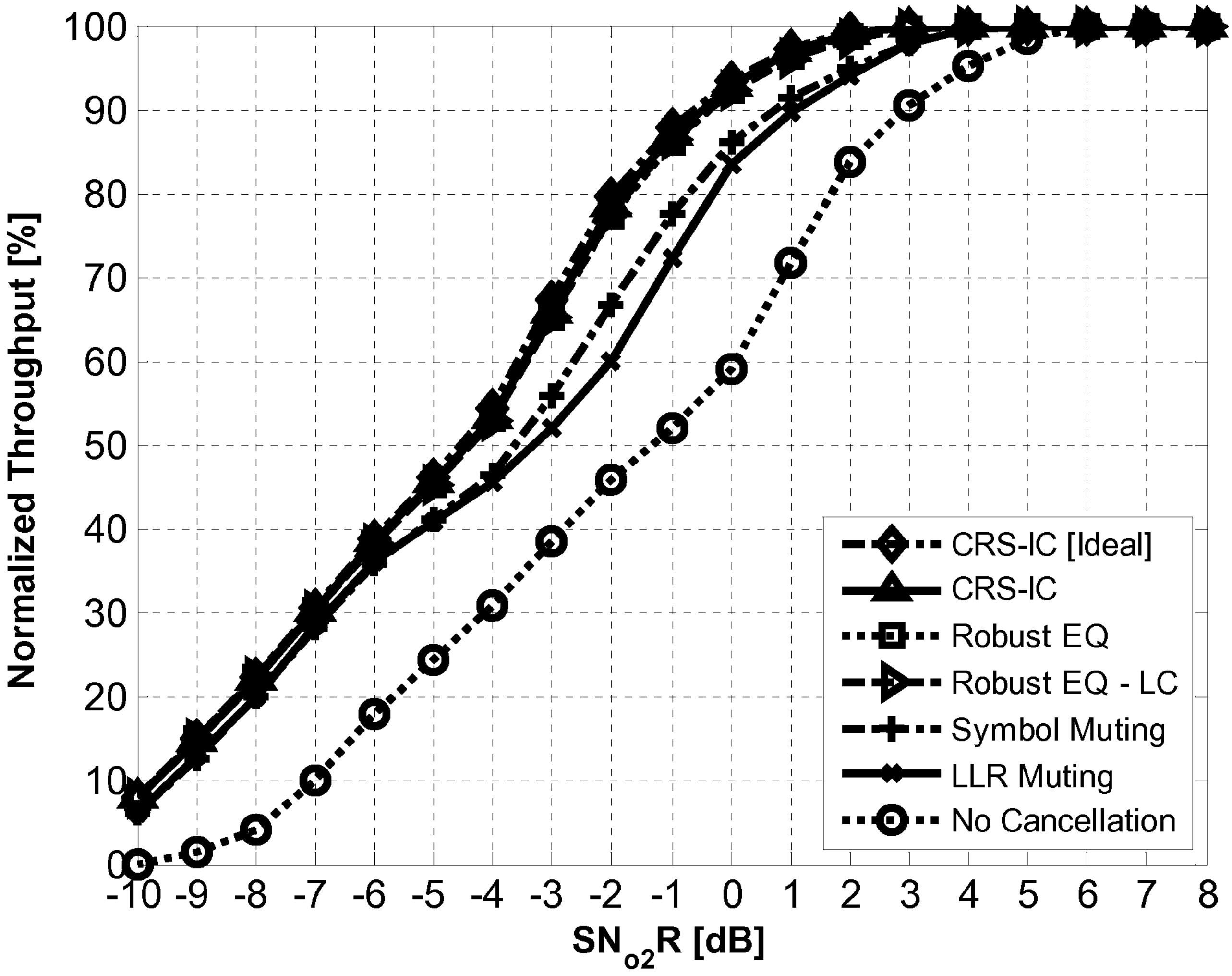

100
90
80
70
60
50
40
30
20
10
0
Normalized Throughput [%]
-10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8
SNo2R [dB]
CRS-IC [Ideal]
CRS-IC
Robust EQ
Robust EQ - LC
Symbol Muting
LLR Muting
No Cancellation

Fig. 7

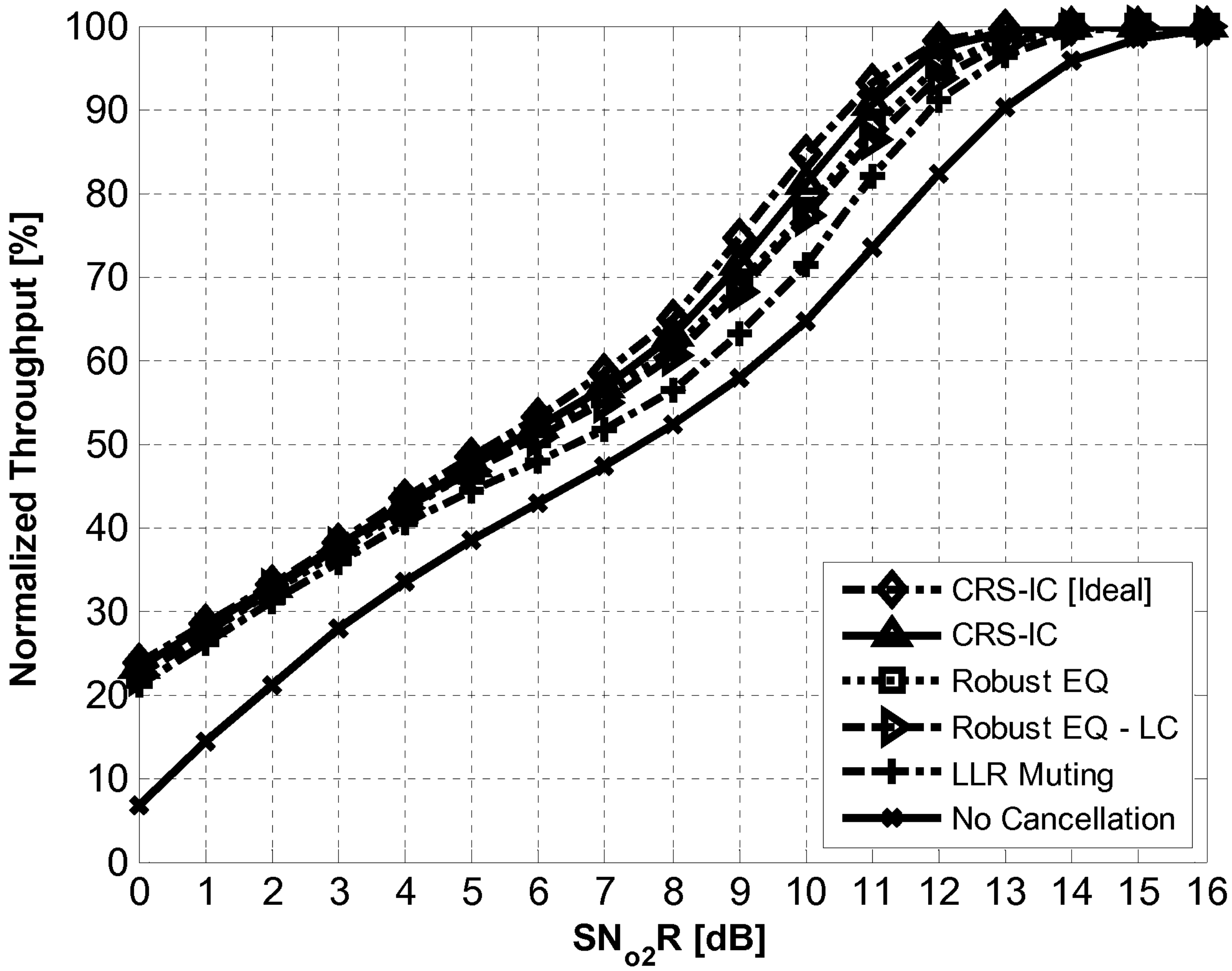

Normalized Throughput [%]
100
90
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
SN$_{o2}$R [dB]
CRS-IC [Ideal]
CRS-IC
Robust EQ
Robust EQ - LC
LLR Muting
No Cancellation

Fig. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/053495

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04L25/02 H04L25/03
ADD.

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

B. FIELDS SEARCHED

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

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	YUSUKE OHWATARI ET AL: "Investigation on advanced receiver employing interference rejection combining for space-frequency block code transmit diversity in LTE-Advanced downlink", PERSONAL INDOOR AND MOBILE RADIO COMMUNICATIONS (PIMRC), 2012 IEEE 23RD INTERNATIONAL SYMPOSIUM ON, IEEE, 9 September 2012 (2012-09-09), pages 2414-2420, XP032272953, DOI: 10.1109/PIMRC.2012.6362761 ISBN: 978-1-4673-2566-0 the whole document -----	1-21

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

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 October 2013	14/10/2013

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Haas, Hans

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JINGHUI XIE ET AL: "A Novel Method to Solve CRS/PDSCH RE Collision in Joint Transmission in LTE-A", CONNECTED VEHICLES AND EXPO (ICCVE), 2012 INTERNATIONAL CONFERENCE ON, IEEE, 12 December 2012 (2012-12-12), pages 66-70, XP032411035, DOI: 10.1109/ICCVE.2012.20 ISBN: 978-1-4673-4705-1 the whole document -----	1-21
A	NTT DOCOMO: "Performance of Interference Rejection Combining Receiver for LTE", 3GPP DRAFT; R4-113528, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE, vol. RAN WG4, no. Roma; 20110627, 24 June 2011 (2011-06-24), XP050542912, [retrieved on 2011-06-24] the whole document -----	1-21
A	NAGA SEKHAR KSHATRIYA S ET AL: "On interference management based on subframe blanking in Heterogeneous LTE networks", COMMUNICATION SYSTEMS AND NETWORKS (COMSNETS), 2013 FIFTH INTERNATIONAL CONFERENCE ON, IEEE, 7 January 2013 (2013-01-07), pages 1-7, XP032332926, DOI: 10.1109/COMSNETS.2013.6465557 ISBN: 978-1-4673-5330-4 the whole document -----	1-21
A	NOKIA CORPORATION: "Advanced UE Receiver Modelling based on LMMSE", 3GPP DRAFT; R4-114961, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE, vol. RAN WG4, no. Zhuhai; 20111010, 3 October 2011 (2011-10-03), XP050544072, [retrieved on 2011-10-03] the whole document -----	1-21
A	US 2010/009705 A1 (BUDIANU PETRU C [US] ET AL) 14 January 2010 (2010-01-14) abstract; figures 1-9 paragraph [0008] - paragraph [0010] paragraph [0037] - paragraph [0041] paragraph [0061] -----	1-21

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2013/053495

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		WO 2010005640 A2	14-01-2010
		WO 2010011410 A2	28-01-2010