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**Title:** Text proposal for WG 1 report on Tx diversity for multiple antennas

**Document for:** Discussion and approval

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***Summary:***

This paper contains a text proposal for the eigenbeamformer to be included in the TR "RAN WG1 report on Tx diversity solutions for multiple antennas". The outline of this TR was originally intended for Release 2000 and is kept here for the new target Release 5.

The extension of Tx diversity for multiple antennas is currently discussed in WG 1. The results of the studies in WG1 shall be incorporated in this TR and presented in RAN #12.

The contents of the proposed text is taken from the following references:

?? Siemens, "Channel model for Tx diversity simulations using correlated antennas", Tdoc R1-00-1067

?? Siemens, "Simulation parameters for Tx diversity simulations using correlated antennas", Tdoc R1-00-1180

?? Siemens, "Description of the eigenbeamformer concept (update) and performance evaluation", Tdoc R1-01-0203

# 3G TR ab.cde V0.0.0(2000-07)

*Technical Report*

# 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; RAN WG1 report on Tx diversity solutions for multiple antennas (Release ~~2000~~5)

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# Contents

# Foreword

This Technical Specification has been produced by the 3rd Generation Partnership Project (3GPP).

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y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

z the third digit is incremented when editorial only changes have been incorporated in the document.

# 1 Scope

# 2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- ?? References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- ?? For a specific reference, subsequent revisions do not apply.
- ?? For a non-specific reference, the latest version applies.

[<seq>] <doctype> <#>[ ([up to and including]{yyyy[-mm]|V<a[.b[.c]]>}[onwards])]: "<Title>".

[11] 3G TS 25.123: "Example 1, using sequence field".

[2] 3G TR 29.456 (V3.1.0): "Example 2, using fixed text".

[5] Nokia. Recommended simulation parameters for Tx diversity simulations. TSG-R WG1 document, TSGR1#14(00)0867, July 4-7, 2000, Oulu, Finland, 5 pp.

[6] Siemens. Description of the eigenbeamformer concept (update) and performance evaluation. TSG-R WG 1 document, TSGR1#19(01)0203, February 27 – March 2, 2001, Las Vegas, USA.

[7] Siemens. Channel model for Tx diversity simulations using correlated antennas. TSG-R WG 1 document, TSGR1#15(00)1067, August 22-25, 2000, Berlin, Germany.

[8] Siemens. Simulation parameters for Tx diversity simulations using correlated antennas. TSG-R WG 1 document. TSGR1#16(00)1180, October 10-13, 2000, Pusan, Korea.

# 3 Definitions, symbols and abbreviations

## 3.1 Definitions

For the purposes of the present document, the [following] terms and definitions [given in ... and the following] apply.

*Definition format*

***<defined term>****: <definition>.*

**example:** text used to clarify abstract rules by applying them literally.

## 3.2 Symbols

For the purposes of the present document, the following symbols apply:

*Symbol format*

<symbol> <Explanation>

## 3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

*Abbreviation format*

<ACRONYM> <Explanation>

# 4 Background and Introduction

# 5 Descriptions of studied concepts

## 5.1 Description of the eigenbeamformer concept

With increasing the number of antenna elements by using an extension of the Release-99 TxD modes, the amount of necessary feedback is increased. When keeping the uplink bandwith the same the antenna weights cannot be adjusted fast enough to account for fast fading. Hence, for higher velocities of the UE the gain due to the additional antenna elements is low.

However there are ways to reduce the necessary feedback bandwith if the antenna channel paths are correlated. One possible concept to achieve a lower feedback bandwith is the eigenbeamformer concept which takes advantage of the correlated antenna paths. The general idea behind the eigenbeamformer is a decorrelation of the antenna signal paths to achieve a reduction in dimension of the spatial space. This enables subsequent short term processing at the UE to sufficiently mitigate fast fading.

This decorrelation is performed by exploiting the long term properties of the propagation paths based on an eigenanalysis of its long term spatial covariance matrix. The eigenvectors (in the sequel also called eigenbeams) with the largest eigenvalues (largest average UE receive power) are determined and fed back step by step to the Node B. This process takes place on the same time scale as the physical UE movement. Accordingly, the required operations in the UE as well as required feedback bits are distributed over a very large number of slots.

In addition, a short term selection between the eigenbeams is carried out at the UE to account for fast fading. This information is fed back to the Node B on (almost) every slot.

By this technique it is possible to address a larger number of antenna elements providing large beamforming gains at higher velocities.

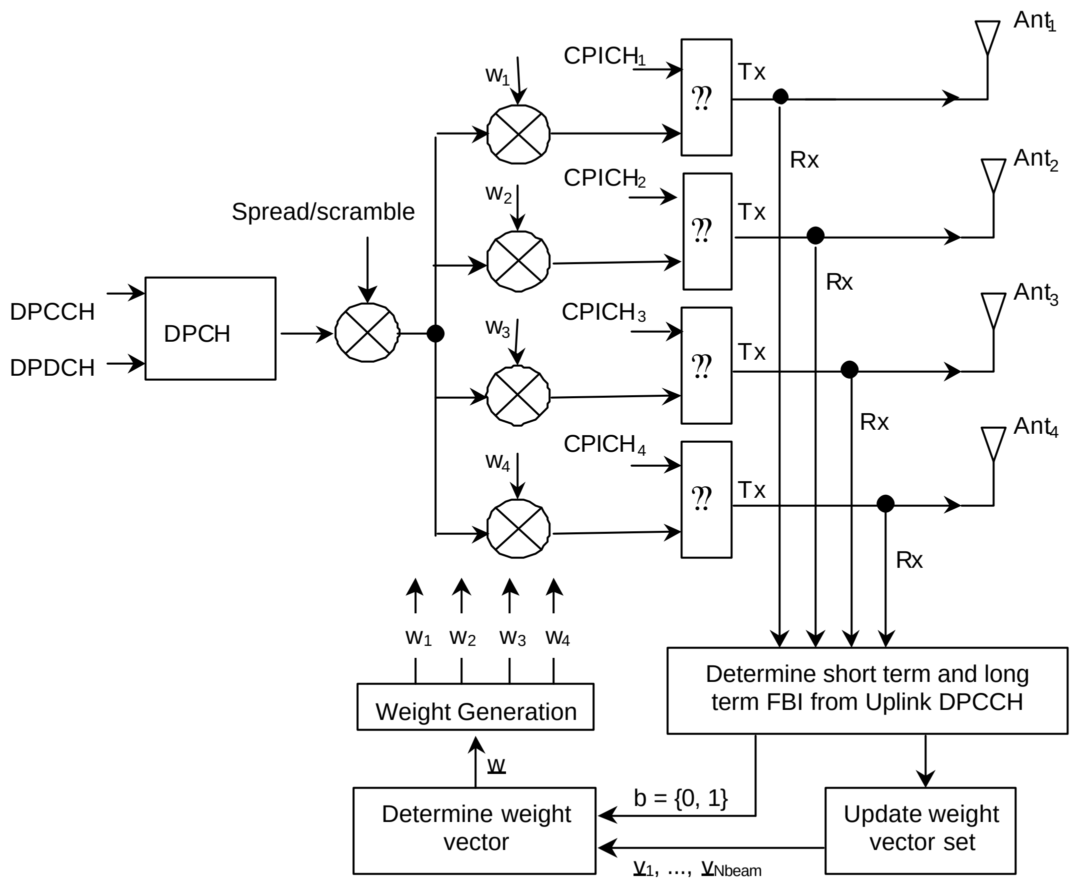


Figure 1: Generic Downlink transmitter at the Node B with M = 4 antenna elements

Figures 1 and 2 show the generic architecture of the eigenbeamformer concept at the Node B and the UE. In the following sections the focus is on a system with M = 4 antenna elements and Nbeam = 2 or 4 eigenvectors. However the eigenbeamformer is easily extendable to more antenna elements.

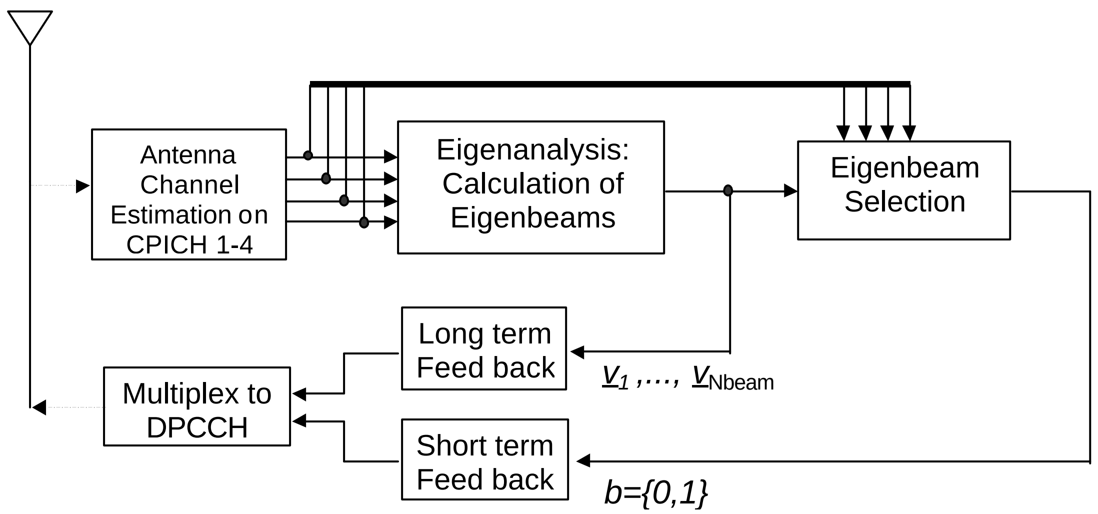


Figure 2: Generic eigenbeamformer structure at the UE for M = 4

### 5.1.1 Calculation of the Dominant Eigenvectors

Using orthogonal pilot sequences transmitted from the Node B antenna elements, the UE estimates the short term spatial covariance matrix averaged over the temporal taps of the channel.

$$\mathbf{R}_{\mathrm{ST}} = \sum_{n=1}^{N} \mathbf{h}_n \mathbf{h}_n^H \qquad (1)$$

The column vector $\mathbf{h}_n = [h_{n1}, h_{n2}, \ldots, h_{nM}]^T$ denotes the channel vector of the n-th temporal tap. The number of taps is denoted by N; M = 4 antenna elements are assumed. The long term spatial covariance matrix is obtained by averaging the short term matrix using a forgetting factor $\rho$.

$$\mathbf{R}_{\mathrm{LT}}(i) = \rho \mathbf{R}_{\mathrm{LT}}(i-1) + (1-\rho)\,\mathbf{R}_{\mathrm{ST}}(i) \qquad (2)$$

The symbol i denotes the time index. It is sufficient to perform an update once every frame or even in larger intervals.

Decorrelation in space is achieved by an eigenanalysis of the long term spatial covariance matrix according to

$$\mathbf{R}_{\mathrm{LT}}\,\mathbf{V} = \mathbf{V}\,\mathbf{T} \qquad (3)$$

The eigenvectors (eigenbeams) to be found are columns of $\mathbf{V}$. Since the matrix $\mathbf{T}$ is diagonal by definition, transmission on different eigenbeams leads to uncorrelated fast fading. The diagonal entries indicate the long term UE received power of each beam.

Note that the eigenbeamformer automatically adjusts to various propagation environments (spatially correlated or uncorrelated). If the channel is spatially correlated, the channel can accurately be described by a small number of eigenbeams. If, on the other hand, the channel has a spatial correlation of zero, no long term spatial channel information can be exploited and each eigenvector addresses only one antenna element.

### 5.1.2 Long Term Feedback Scheme

From the set of M = 4 eigenbeams in $\mathbf{V}$, Nbeam vectors with the largest eigenvalues will be chosen to be transmitted in the long term feedback.

Each weight vector is a vector of complex numbers. The size of this vector equals the number of antenna elements (M = 4). Each complex vector element is quantized by a number of bits. There are different ways for quantization. For example, the absolute value and the phase can be quantized with 3 and 5 bits respectively. Hereby, the amount of bits can be reduced if the phase of the first vector element is set to zero. Thus, for the transmission of one eigenbeam 4*3+3*5 = 27 bits are necessary.

This number applies for the direct feedback of the eigenbeams from the UE to the Node B. Also methods with progressive refinement could be used that transmit only the difference to the previously sent vector. This could reduce the subsequent update period and an increased quantization / resolution is possible.

More advanced long term feedback concepts could be used which require less feedback bits.

The implementation of mechanisms to protect the long term bits from bit errors are for further study.

### 5.1.3 Short Term Feedback Scheme

A short term estimate of the UE received power is performed for each eigenbeam by calculating

$$P_m = \mathbf{v}_m^H \mathbf{R}_{\mathrm{ST}}^T \mathbf{v}_m = \sum_{n=1}^{N} \left|\mathbf{v}_m^T \mathbf{h}_n\right|^2 \qquad (4)$$

where m characterizes the eigenbeam. The eigenbeam that results in the maximum value for the received power Pm is selected and signalled to the Node B.

For two (four) eigenbeams 1 (2) bit(s) is (are) transmitted to indicate the selection.

The overlaying long term processing makes it possible to switch between eigenbeams instead of antenna elements. An increasing number of antenna elements can be addressed without reducing the UE velocity threshold.

Note that the pilot symbols of the DPCCH may be used for eigenbeam verification similar to the closed loop modes in Release-99.

### 5.1.4 Format of Feedback Information

The feedback rate for the eigenbeamformer is kept at the same rate as in Release-99 and is 1500 bit/s. The long term information bits (for feedback of eigenbeams) and the short term information bits (for feedback of eigenbeam selection) are multiplexed. The following frame format for the feedback information bits is proposed:

| Slot # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| short term FB bits | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| long term FB bits | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

Table 1: Multiplexing of long term / short term feedback information

In this multiplexing format the transmission of two eigenbeams would take 2*27=54 frames or 540 ms (see section 5.1.2). The eigenbeam selection of the previous slot is applied in the slots where no short term feedback information is received by the Node B (slot #15).

This format is confined to one radio frame. Thus, no counting over frame boundaries is necessary.

In a later extension with more than 4 antenna elements other formats could be used, e.g. using 3 long term feedback bits within one frame. This is for further study.

| Slot # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| short term FB bits | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 |
| long term FB bits | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |

Table 2: Multiplexing format of long term / short term information for more than 4 antenna elements

Since no long term channel information is available at the Node B for a user at the start of transmission, initial weight vectors may, for instance, address only one of the antenna elements, e.g.,

$\mathbf{v}_1 = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}, \quad \mathbf{v}_2 = \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix},$ for M = 4 antenna elements.

# 6 Performance

## 6.1 Link level simulation assumptions

### 6.1.2 Additional simulation assumptions for the eigenbeamformer

?? The feedback error rate for short term bits for switching the eigenbeams was 4%. The long term feedback to transmit the eigenvectors was assumed to be error free [simulations with 4% error rate on long term feedback will be provided in future].

?? The eigenvectors were quantized with 5 bits for phase and 3 bits for amplitude of each vector element.

?? Ideal antenna verification was assumed at the UE.

?? Correlation between antennas was assumed as described in the following section.

#### 6.1.2.1 Channel model for correlated antennas

The channel model described in [5] is extended by incorporating spatial correlation between the signals from antennas m and n of the base station, denoted by $?_{m,n}$, which are general complex numbers. The corresponding matrix capturing all correlation coefficients is denoted by $\mathbf{R}\ ?\ [\,?_{m,n}]$ of size M? M when M antennas are used. Assuming Rayleigh fading for each antenna, the receive vector $\mathbf{x}(t)$ at the UE can be expressed by an overlay of M independent and normalized complex Gaussian fading processes $\mathbf{g}(t)\ ?\ [g_1(t) \quad g_2(t) \quad \ldots \quad g_M(t)]^T$, with Jakes power density spectrum, i.e.,

$$\mathbf{x}(t)\ ?\ \sqrt{P}\,\mathbf{h}(t)u(t) \qquad (5)$$

where

$$\mathbf{h}(t)\ ?\ \mathbf{R}^{1/2}\mathbf{g}(t) \qquad (6)$$

is the M-dimensional channel vector. Here, u(t) and P denote the transmitted signal and the transmit power per antenna, respectively. Figure 3 shows the applied model.

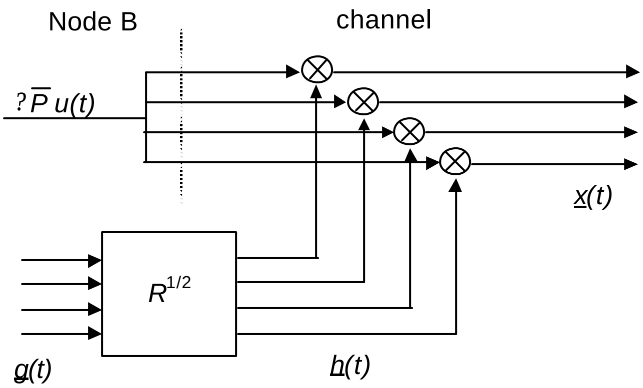


Figure 3: Correlated channel model. Here, the Node B is shown without channel weights applied to the antennas.

By taking the expected value of the receive vector, it can be verified: $E\{\mathbf{x}\mathbf{x}^H\}/P\ ?\ \mathbf{R}$ (Note: $\mathbf{R}^{1/2}\mathbf{R}^{1/2H}\ ?\ \mathbf{R}$ ).

#### 6.1.2.2 Parameters for micro and macro cell scenarios

Based on a comparison with mathematical descriptions of propagation models [7] two parameters sets for the correlation coeficients have been defined. These correspond to a micro cell scenario and a macro cell scenario.

- Micro cell

$$R = \begin{bmatrix} 1 & a & b & c \\ a^* & 1 & a & b \\ b^* & a^* & 1 & a \\ c^* & b^* & a^* & 1 \end{bmatrix}, \quad \text{where } a = 0.7\,e^{-j2.2},\ b = 0.1\,e^{j1.2},\ c = 0.2\,e^{-j3.0}$$

The correlation coefficients of this matrix correspond to planar waves which power is uniformly distributed in an angular spread of 45°.

- Macro cell

$$R = \begin{bmatrix} 1 & a & b & c \\ a^* & 1 & a & b \\ b^* & a^* & 1 & a \\ c^* & b^* & a^* & 1 \end{bmatrix}, \quad \text{where } a = 0.97\,e^{-j0.8}, b = 0.94\,e^{-j1.6},\ c = 0.88\,e^{-j2.4}$$

The correlation coefficients of this matrix correspond to planar waves which power is uniformly distributed in an angular spread of 10°.

Details on the derivation of these parameters can be found in [7, 8].

## 6.2 Link level simulation results

### 6.2.1 Link level simulation results of the eigenbeamformer

#### 6.2.1.1 Uncorrelated case

In Figure 4 the performance of the eigenbeamformer with switching between Nbeam = 4 eigenvectors compared to the Release-99 mode 1 with two antennas is shown. The eigenbeamformer performs about 2.2 dB better than Release-99 mode 1 for the UE velocity of 3 km/h and 10 km/h. Using four eigenbeams in an uncorrelated scenario has the result that each antenna element is addressed by one eigenbeam and effectively switching between antenna elements is done.

For higher velocities the Release-99 mode 1 with only two antennas will have the same or better performance. This can be explained with the increased number of feedback bits for 4 antenna elements which cannot be transmitted fast enough.

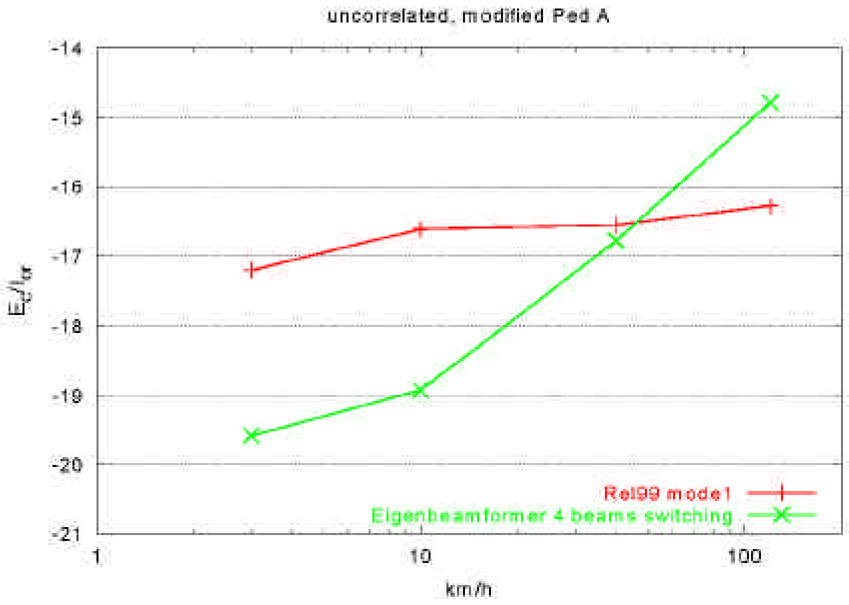


Figure 4: Simulation results for 0 dB geometry and uncorrelated antenna paths

Note that the velocity of 120 km/h is shown here for explanation of the behaviour and is quite unrealistic for the assumed Pedestrian A channel model.

### 6.2.1.2 Micro cell scenario

For the micro cell scenario switching between Nbeam = 2 eigenbeams was done. For all simulated velocities the eigenbeamformer performs with an advantage of about 3 dB compared to Release-99 mode 1.

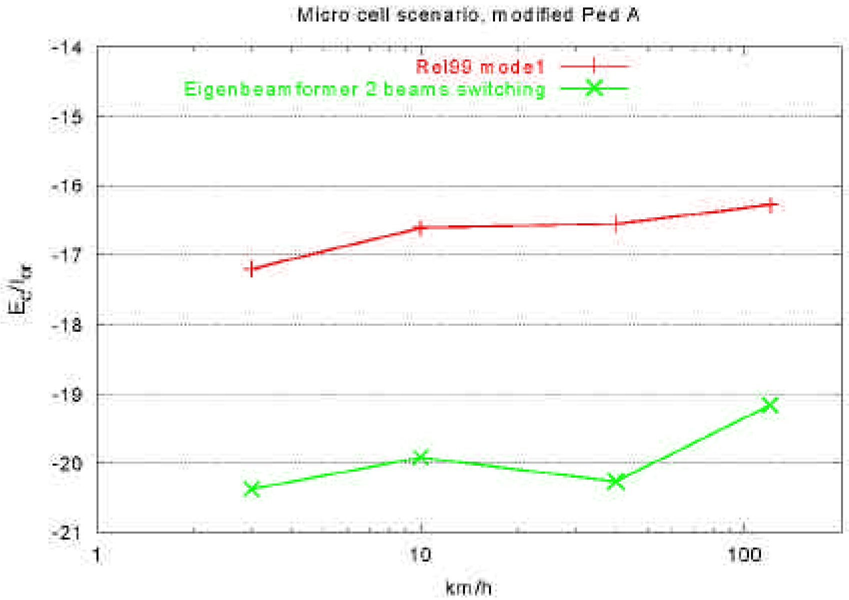


Figure 5: Simulation results for 0 dB geometry and micro cell scenario

Note that the velocity of 120 km/h is shown here for explanation of the behaviour and is quite unrealistic for the assumed Pedestrian A channel model.

#### 6.2.1.3 Macro cell scenario

For the macro cell scenario also switching between Nbeam = 2 eigenbeams was done. For all simulated velocities the eigenbeamformer performs with an advantage of about 3 dB compared to Release-99 mode 1.

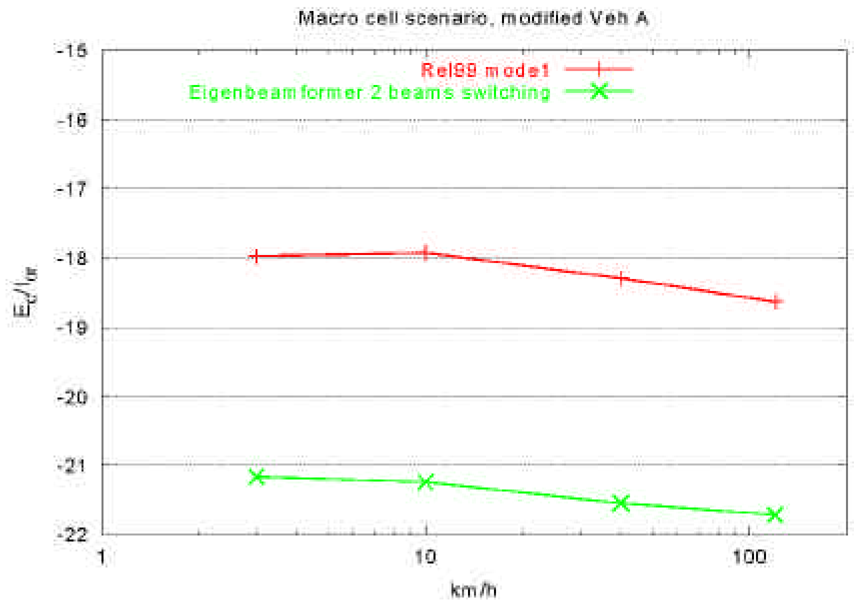


Figure 6: Simulation results for 0 dB geometry and macro cell scenario

# 7 Impacts to UE and UTRAN implementation

## 7.1 Impacts to UE implementation

### 7.1.2 Complexity evaluation of the eigenbeamformer concept

This evaluation is done by estimating the necessary complex multiplications. The numbers given can be regarded as the upper limit of complexity, since the actual implementation can still reduce the computational effort.

?? Channel estimation

For all the proposed concepts on closed loop Tx diversity with M = 4 antenna elements, the UE has to perform a short term channel estimate over the antenna elements at N dominant temporal taps. To calculate for example N = 4 spatial channel estimation vectors $\mathbf{h}_n$ of length M from the global pilots, N*M = 16 complex multiplications per slot are necessary regardless of the diversity concept used.

?? Calculation of matrix update

It is assumed that the update in equation (2) is calculated every 5th frame to be used for the long term averaging. The covariance matrix $\mathbf{R}_{ST}$ is symmetric, so for each tap (M+1)?M/2 complex multiplications (and additions) are needed. Over all taps

$\frac{(M+1)M}{2} \cdot \frac{N}{5 \cdot 15}$ complex multiplications (and additions) per slot are needed. Assuming N = 4 taps this results in 0.53 complex multiplications per slot.

?? Calculation of eigenbeams (long term processing)

The power method can be used for the calculation of the eigenbeams. It is assumed that 4 iterations are sufficient to yield one dominant eigenbeam. Thus, the complexity approximately equals 4*M*M multiplications for each eigenbeam.

Further, it is assumed that for each eigenbeam this calculation is done every 300 ms which equals to 30 frames (each frame consists of 15 slots). So this concludes to

4*M*M / 15*30 (= 0.14) complex multiplications per slot in average.

Advanced methods could be used based on subsequent updating of the eigenbeams which significantly reduce the computational effort.

?? Eigenbeam selection (short term processing)

For each eigenbeam the UE receive power has to be calculated, e.g. using equation (4). This implies about 2*M*N (= 32) complex multiplications per slot. The eigenbeam which yields the highest power is selected. Since for the other proposals a similar processing as the short term selection has to be performed, about 32 complex multiplications would be also necessary. If progressive refinement is used, the complexity would be higher for these proposals.

Thus, the eigenbeamformer comes at the cost of 0.53 + 0.14 = 0.67 complex multiplications per slot (matrix update and calculation of eigenbeams) which is relatively low with respect to 16 + 32 = 48 complex multiplications that are necessary in any case for an extension of the closed loop Tx diversity concept.

## 7.2 Impacts to UTRAN implementation

### 7.2.2 Eigenbeamformer concept

A small memory for storing the current eigenvector set at the UTRAN would be needed.

# 8 Impacts to physical layer operation

## 8.2 Eigenbeamformer concept

The procedures for initialization and compressed mode singularities will be defined for the eigenbeamformer concept in a straightforward way.

# 9 Backwards compatibility to Release-99

## 9.1 Eigenbeamformer concept

With the eigenbeamformer no backward compatibility problem is identified for Release-99.

# 109 Conclusions

# History

| Document history |
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| Date | Version | Comment |
|---|---|---|
| | 0.0.0 | |
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