TSG-RAN Working Group 1 meeting No. 15 **TSGR1#15(00)-1065**
August 22– 25, Berlin, Germany

Agenda item: 6

Source: Fujitsu

Title: **Enhance the Beamfoming Feature of the Multiple Antenna Tx Diversity**

Document for: Discussion

1. Introduction

Multiple antenna transmit diversity is one of the study items for UTRAN Release 2000. Nokia and Samsung proposed extended mode 1 and mode 2 scheme respectively [1][2]. These schemes assume that spatial correlations among antenna branches are small enough to get sufficient diversity gain. This assumption will add some restrictions on the Tx antenna configurations. The eigenbeamforming scheme proposed in [3] at WG1#14 is assumed to be a flexible solution for various antenna configurations and radio propagation environments. UE can determine an appropriate combination of Tx diversity and beamforming. Though no signaling from Node B to UE is required, the number of eigenbeams and the appropriate frame format shall be signaled to Node B from UE when these are determined in the UE.

We support to study a scheme, which can realize a combination of Tx diversity and beamforming for certain applications such as high data rate packet transmission. It is generally understood that high data rate transmission is targeted at quasi-static UEs. In this case, the beamforming weights can be updated at a lower rate than that of the diversity, which can lead to an increase of the diversity gain in moderately fast fading conditions.

It is desirable that the closed loop multiple antenna transmit diversity/beamforming scheme can support a variety of antenna configurations and beamforming algorithms. To achieve it efficiently, we propose to introduce higher layer signaling information about Tx antenna configurations of Node B to UE. As the spatial correlations largely depend on the Tx antenna configurations in most cases, it will greatly help UEs to determine how appropriately the diversity and beamforming be combined (e.g. the number of beams) and the feedback frame format. In addition, the eigenbeam estimation will not necessarily be required in UE anymore.

Unequal power allocation scheme for pilot sequences on CPICH is also presented that can improve performance of channel estimation in the UE.

2. Consideration on Transmit Antenna Configurations

Spatial correlation property depends on both the transmit antenna configuration and the radio propagation environments. The latter is unpredictable and performance depends on how feedback scheme match the channel. For example, in strong spatially correlated channels, frequent update of short-term diversity weights is not efficient. In spatially uncorrelated channels, feedback bits for long-term beamforming weights are useless. The former, selection of antenna configuration, is one of the design criteria for cellular operators. It is rather easy to control spatial correlation by choosing appropriate antenna configuration.

In theory, employing multiple transmit antenna elements can achieve both diversity gain and beamforming gain. If the antennas are placed far away from each other, maximum diversity gain can be achieved but, due to the grating lobe problem, the achievable beamforming gain is limited. On the other hand, if the inter-element spacing in the antenna array is small, maximum beamforming gain can be obtained but the diversity gain will be limited as signals from different antenna elements will be highly correlated.

Several Tx diversity/beam forming scenarios for typical Tx antenna configurations in Node B are considered as follows.

Scenario 1: Space diversity antenna array with large inter-element spacing (larger than spatial coherent length)

This is a straightforward extension of an assumption for current 2-branch Tx diversity technique and was also a starting assumption for Tx diversity enhancement discussed for Release 2000. For large angle spread environments, this might be a likely scenario. For macro cell environments, inter-element spacing to have signals with low spatial correlations will be around 20 wavelength (λ). In ideal condition (no feedback bit error, no feedback delay, no channel estimation error, no quantization error), full spatial diversity gain can be obtained by using this antenna configuration. Samsung and Nokia proposals are suitable for this scenario. Same antenna configuration can be used for uplink diversity reception in Node B. The net diversity gain achievable by increasing the number of branches will be less significant in combination with path (RAKE) diversity combining. Large physical space required to locate multiple antenna elements will not be attractive.

Scenario 2: Antenna array with small inter-element spacing (less than spatial coherent length)

In this scenario, spatial correlations between antenna elements are high and this is sufficient configuration to apply a beamforming. This can be used for environments with small angular spread. Same antenna can be used for uplink beamforming in Node B. For macro cell environments, typical antenna element spacing to have signals with high spatial correlations is less than 1λ. In this scenario, it is difficult to employ closed-loop and/or open-loop Tx diversity. It might be a problem that common control channels, which should be transmitted on non-directional beams, cannot have a benefit of STTD encoding. Eigenbeamforming scheme can be used even when there is no perfect spatial correlation between antennas.

Scenario 3: Space diversity array with sub-array antennas

Each diversity branch consists of a sub-array antenna. This can be used for environments with small angular spread. This will be a practical antenna configuration due to following reasons.

- Combined diversity and beamforming can be applied in both uplink and downlink.
- STTD encoding can be applied to downlink common control channels.
- Current specified closed-loop Tx diversity (mode-1 and mode-2) can be served for Release ’99 UEs.
- Physical antenna space required would not increase when 2-branch diversity system is already used in the uplink.
- Diversity gain of 2-branch seems to be sufficient due to the additional Rx diversity gain.

Eigenbeamforming scheme can be used for this scenario. However, it can be simplified by utilizing the paticular Tx antenna configuration.

The closed loop multiple antenna transmit diversity scheme should support a variety of antenna configurations as described above. Owing to such practical limitations as FBI field, however, careful consideration is needed before specifying the details for Release 2000.

3. Closed-loop Beam forming with Tx antenna diversity

We propose to introduce a combined transmit diversity and downlink beamforming scheme and a necessary signaling between Node B and UE. Following issues should be specified for it.

- Specifying the downlink pilot sequences and its power allocation. Our proposal is to use CPICHs with unequal power allocation.
- Specifying the way to allocate feedback fields to diversity and beamforming. Our proposal is to define a number of different formats for different channel conditions.
- Specifying the normative beamforming algorithms. The feedback signal should be able to handle a number of different algorithms.

3.1 Description of our solution

Our proposed scheme is a combination of Tx diversity and beam forming and its concept is very similar to the eigenbeamforming scheme. Major difference is that higher layer signaling information about Tx antenna configurations of Node B is utilized in the UE to determine how appropriately the diversity and beamforming be combined and the feedback frame format. This explicit signaling simplifies the algorithm and the procedure.

According to the transmit antenna configuration of the Node B, UE calculate short-term diversity weights and long-term beamforming weights. At least, configurations described in Section 2 should be supported. A hierarchical weighting is defined as shown in Figure 1.

Consider an *M* sub-arrays configuration in which each sub-array consists of *K*=*N/M* elements. Firstly, UE finds an *M*-dimensional short-term diversity weight vector $\underline{w}_D$, which maximize

$$P_D = \underline{w}_D{}^H H_D{}^H H_D \underline{w}_D \quad (1)$$

with $H_D = [\underline{h}_1, \underline{h}_{K+1}, \cdots, \underline{h}_{(M-1)K+1}]$

where, $\underline{h}_{(m-1)K+1}$ $(m = 1 \cdots M)$ is the channel response vector, which represents the *m*-th sub-array.

Secondly, UE finds a *K*-dimensional beamforming weight vector $\underline{w}_{B,m}$ for each sub-array which maximize

$$P_{B,m} = \underline{w}_{B,m}{}^H H_{B,m}{}^H H_{B,m} \underline{w}_{B,m} \quad (2)$$

with $H_{B,m} = [\underline{h}_{(m-1)K+1}, \underline{h}_{(m-1)K+2}, \cdots, \underline{h}_{(m-1)K+K}]$

where, $\underline{h}_{(m-1)K+k}$ $(k = 1 \cdots K)$ is the channel response vector of the *k*-th element in the *m*-th sub-array.

Then, short-term diversity weights $D_{1,m}$ and long-term beamforming weights $B_{m,k}$ for the hierarchical weighting are calculated from $\underline{w}_D$ and $\underline{w}_{B,m}$ as follows.

$$D_{1,m} = \frac{w_D(m)}{w_D(1)} \quad (m = 1 \cdots M) \tag{3}$$

$$B_{m,k} = \frac{w_{B,m}(k)}{w_{B,m}(1)} \quad (m = 1 \cdots M,\ k = 1 \cdots K) \tag{4}$$

$\{D_{1,m}\}$ corresponds to the M-branch Tx diversity weights and $\{B_{m,k}\}$ are beamformer weights for the m-th antenna group. The feedback frequency for $\{D_{1,m}\}$ is much higher than that for $\{B_{m,k}\}$ to suit for fast fading environment.

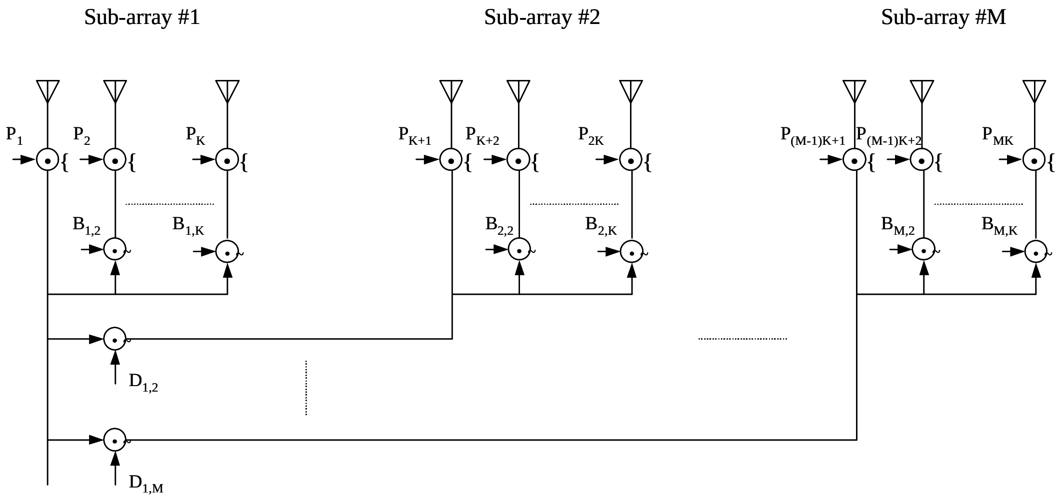

Figure 1. Hierarchical weighting for transmit antenna diversity/beamforming

3.2 Power allocation for pilot sequences on CPICH

One of the problems of multi antenna Tx diversity is its large overhead of CPICH for transmission of pilot sequences from each antenna. Increasing the number of antennas, decreasing channel estimation performance for each transmission antenna if the total CPICH power is constant, say -10dB of total transmit power.

We propose to employ unequal power allocation for the pilot sequences in order to mitigate the drawback by utilizing the spatial correlation property of the channel. In the case of N=4 and M=2 (i.e. two-sub-array antenna configuration), power of pilot sequences P_2 and P_4 can be reduced than that of pilot sequences P_1 and P_3. In the UE, P_2 and P_4 are used for calculation of $\underline{h}_2$ and $\underline{h}_4$ respectively. As these parameters are used only for calculation of beamforming weights $\{B_{m,k}\}$, long term averaging of $\{B_{m,k}\}$ can compensate the reduced SIR of $\underline{h}_2$ and $\underline{h}_4$.

For N=4 and M=1 (i.e. one array antenna with 4 branches), only one pilot sequence can be transmitted with larger power than that of the other 3 pilot sequences.

For N=4 and M=4 (i.e. 4-branch diversity antenna configuration), it is difficult to apply this unequal power allocation technique because fast channel estimation is necessary for all of the branches.

The proposed optimization of the power allocation for CPICH will result in the system capacity increase due to its low overhead of multiple pilot sequences transmission. Structure of the Node B with combined Tx diversity/beamforming (N=4, M=2) is shown in Figure 2.

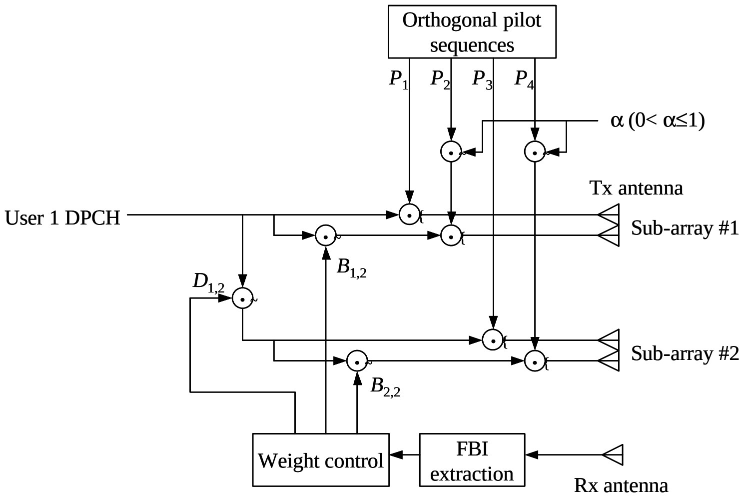

Figure 2. Structure of the combined Tx diversity/beamforming (N=4, M=2)

3.3 Example Format of Feedback Information

The following frame formats for the feedback information bits are proposed. These formats can be used for scenarios described in Section 2 respectively. Format 1 is for Tx diversity and it allow employing Nokia and Samsung proposal. Format 2 is for beamforming. All of 15 bits/frame for beamformer weights can be used for accurate control of the beam. Format 3 is for combination of diversity and beamforming. Single beamformer weight is quantized by 3 bits and fed back in a frame to Node B.

Table 1: Multiplexing format 1 of feedback information for scenario 1

Slot #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FB bits for D	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
FB bits for B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2: Multiplexing format 2 of feedback information for scenario 2

Slot #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FB bits for D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FB bits for B	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 3: Multiplexing format 3 of feedback information for scenario 3

Slot #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FB bits for D	1	1	1	1	0	1	1	1	1	0	1	1	1	1	0
FB bits for B	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1

4. Impacts to UE and UTRAN Implementation

Complexity impacts to UE

- Estimation of spatial channel vectors

  For all of the closed loop Tx diversity proposals, the UE should perform channel estimation over *N* antenna elements at *L* dominant temporal taps. This yields *N* channel estimation vectors of length *L*. Both channel estimation using CPICH for Tx diversity/beamforming control and channel estimation using DPCCH for antenna verification or RAKE combining will be necessary. $(N*L*10)+(N*L*N_{dp})$ complex additions are required for channel estimation (CPICH+DPCCH), where N_{dp} is the number of pilot symbols in DPCCH. $(M-1)*L$ complex multiplications is required for the antenna verification. In case of N=4 and M=2, the number of complex multiplications of *L* is identical to that of the conventional 2-branch diversity scheme.
- Calculation of diversity weights

  The weights are calculated by using *M* channel response vectors of length *L* in which one vector from each sub-array, where *M* is the number of sub-arrays. The calculation method described in Section 3.1 is same as that specified in the current closed-loop Tx diversity modes. In case of M=2, the complexity is same as that of the conventional 2-branch diversity scheme.
- Calculation of beamforming weights

  The weights are calculated by using $K=N/M$ channel response vectors of length *L* for each sub-array. In case of M=2 and N=2, $M*L*(K-1)$=8 complex multiplications are required.

The complexity of the case N=4, M=2 and the conventional 2-branch diversity are shown in Table 4, where L=4, N_{dp}=4. Most of the additional complexity comes from the channel estimation and the algorithm complexity is relatively small.

Table 4. Complexty of UE

	2-branch	4-branch (M=2)
Complex additions	116	232
Complex multiplications	4+4+0=8	4+8+8=20

Complexity impacts to Node B

- Orthogonal pilot symbol transmission

  For all of the closed loop Tx diversity proposals, the Node B transmits orthogonal CPICH pilot symbols on each antenna branch.
- Weighting operation

  The proposed hierarchical weighting has same complexity compared with that of the conventional weighting scheme.

5. Backward Compatibility to Release'99

When CPICH is used for control of the multiple antenna Tx diversity/beamforming scheme, one of the major backward compatibility issues to Release'99 is a selection of common pilot sequences on CPICH. Introduction of any interference from additional pilot sequences to the Release'99 UEs should be avoided or minimized.

An example of a set of pilot sequences for CPICH is shown in Figure 3 for a 4-antenna system. When a Release'99 UE calculates the channel estimation value slot by slot, orthogonality can be maintained among the pilot sequences because P_1 and P_3 are identical to the pilot sequences specified in Release'99 and are orthogonal to both P_2 and P_4 within a slot. However, an UE may not calculate the correlation with CPICH in slot basis because its implementation depends on the manufacturer of the UE. This matter should be further discussed in WG1.

A reduced SIR of each pilot sequence is another problem. The unequal CPICH power allocation for sub-array system proposed in Section 3.2 can minimize the channel estimation performance degradation for the Release'99 UEs due to the increased power of P_1 and P_3.

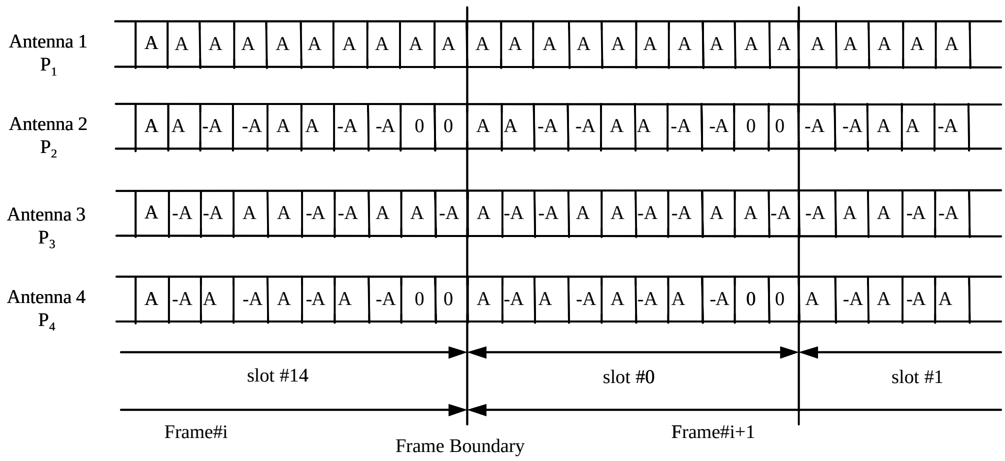

Figure 3. Pilot sequences of CPICH (4-antenna case)

6. Conclusions

We proposed an efficient method to enhance the beamforming feature of the multiple antenna close-loop Tx diversity, which have several advantages as follows:

- Combined diversity and beamforming capability works for various antenna configurations.
- Explicit signaling about Tx antenna configurations of Node B eases the UE to select the appropriate algorithm and the feedback operation.
- Unequal power allocation for pilot sequences of CPICH reduces the overhead of the multiple pilots and results in the capacity increase.

As Tx diversity/beamforming algorithms, various methods proposed by other companies could be used in combination with our proposed features. Further discussion to elaborate the concept is suggested in WG1.

References

[1] Nokia. Multipath Tx diversity simulation results for closed loop mode 1 extended for multiple antennas. TSG-R WG1 document, TSGR1#14(00)0914, 4-7th, July, 2000, Oulu, Finland.

[2] Samsung and Seoul National University. Preliminary version of algorithm and Simulation results for Tx Diversity with more than 2 Tx Antennas. TSG-R WG1 document, TSGR1#14(00)0882, 4-7th, July, 2000, Oulu, Finland.
[3] Siemens. Advanced closed loop Tx diversity concept (eigenbeamformer). TSG-R WG1 document, TSGR1#14(00)0853, 4-7th, July, 2000, Oulu, Finland.