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Agenda item: **AH26: Tx Diversity**

Source: **Fujitsu**

Title: **Text Proposal for the Tx Diversity Scheme with Beamforming Feature**

Document for: **Approval**

Summary

This document proposes the Tx diversity scheme with beamforming feature for the TR on Tx diversity solutions for multiple antennas. The content of this text proposal is on the basis of the following references, although the simulation result of unequal CPICH power allocation in Table 5 has been updated from that in reference [3].

[1] Fujitsu. Enhance the beamforming feature of the multiple antenna Tx diversity. TSG-R WG1 document, TSGR1#15(00)1065, 22-25, August, 2000, Berlin, Germany.
[2] Fujitsu. Simulation results of the Tx diversity scheme with beamforming feature. TSG-R WG1 document, TSGR1#18(01)0103, 15-18, January, 2001, Boston, USA.
[3] Fujitsu. Further simulation results of the Tx diversity scheme with beamforming feature. TSGR1#19(01)0287, 27 February–2 March, 2001, Las Vegas, USA.

5. Descriptions of studied concepts

5.4. Tx diversity scheme with beamforming feature

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, the higher layer signaling information about Tx antenna configurations of Node B to UE is necessary. As the spatial correlation largely depends 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.

Spatial correlation property depends on both the transmit antenna configuration and the radio propagation environment. The latter is unpredictable and performance depends on how feedback scheme matches 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 are highly correlated.

5.4.1. Description of our solution

According to the transmit antenna configuration of the Node B, UE calculate short-term diversity weights and long-term beamforming weights. The 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

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

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

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

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

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

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.

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

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

$\{D_{1,m}\}$ 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.

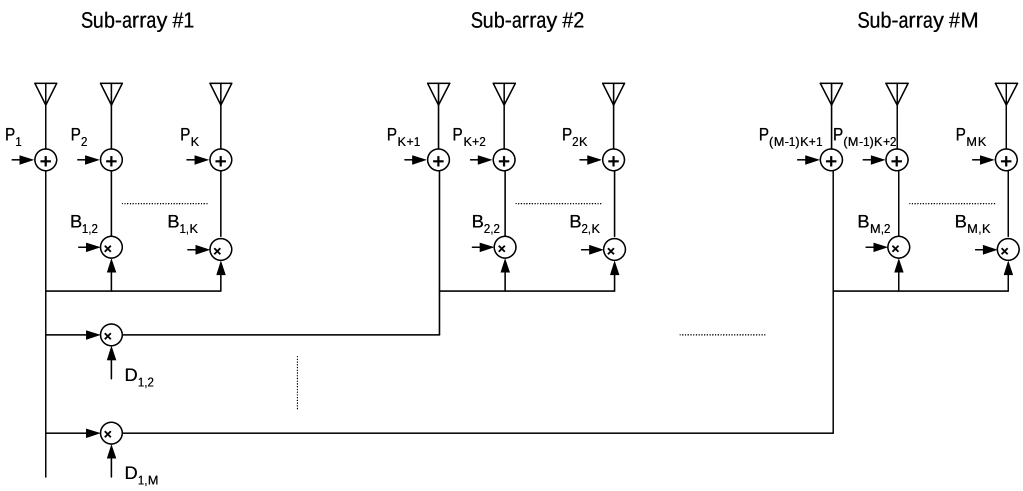

Figure 1. Hierarchical weighting for the transmit antenna diversity/beamforming

5.4.2. Power allocation for pilot sequences on CPICH

One of the problems of multiple antenna Tx diversity is its large overhead of CPICH for transmission of pilot sequences from each antenna. As the number of antenna elements increases, the additional CPICH power will be needed. If the total CPICH power is constant, the channel estimation performance for each transmission antenna will be degraded.

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

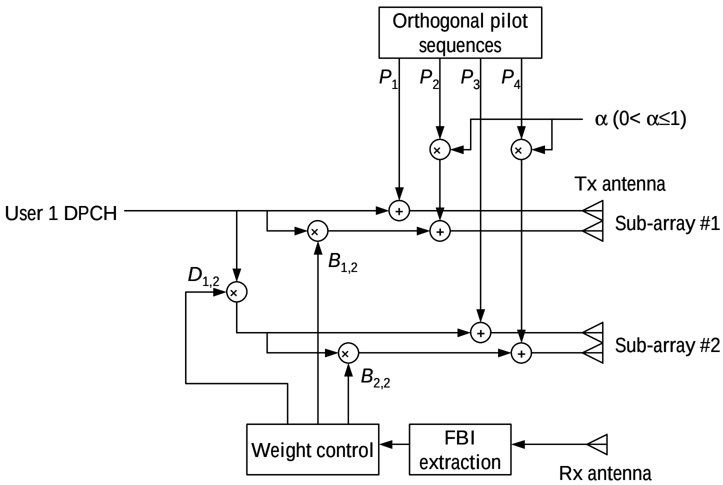

Figure 2. Structure of the combined Tx diversity/beamforming (N=4, M=2)

5.4.3. Example format of feedback information

The following frame formats for the feedback information bits are desirable. Format 1 is for Tx diversity and it allows employing the scheme without beamforming features. Format 2 is for beamforming with small inter-element spacing less than spatial correlation length. 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, which is suitable for the sub-array antenna configuration. Single beamformer weight is quantized by 3 bits and fed back in a frame to Node B. In case of two-sub-array system, the beamformer weight of sub-array #1 is transmitted in the first frame, then the beamformer weight of sub-array #2 is transmitted in the second frame. The number of antenna elements in each sub-array can be increased, as long as the feedback delay is permissible for updating the beamformer weights.

Table 1. Multiplexing format 1 of feedback information for Tx diversity

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 beamforming

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 combination of diversity and beamforming

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

6. Performance

6.1. Link level simulation assumptions

6.1.4. Additional simulation parameters for the Tx diversity scheme with beamforming feature

Table 4 lists the additional simulation parameters that should be used for the Tx diversity scheme with beamforming feature. The frame format for the feedback information bits shown in Table 3 are used for the simulation.

Table 4. Additional simulation parameters

Channel estimation	from CPICH with ideal weight verification
Correlation between antennas	0: between diversity branches 1: among each sub-array
UE location	preserving 0° direction from Node B
Multipath angular spread	0°
BF weight step size	45°
BF element space	$\lambda/2$

6.2. Link level simulation results

6.2.3. Link level simulation results of the Tx diversity scheme with beamforming feature

6.2.3.1. Comparison with other schemes

Five different antenna schemes were simulated and compared as follows.

- **1 Ant.**
  - Number of Tx antennas = 1
  - Without closed loop Tx diversity
- **2 Ant. Mode 1**
  - Number of Tx antennas = 2
  - Closed loop Tx diversity Mode 1 (Release'99)
- **4 Ant. Mode 1**
  - Number of Tx antennas = 4
  - Extension of closed loop Tx diversity Mode 1
- **2x2 Ant. Mode 1**
  - Number of Tx antennas = 4 (two-sub-array configuration)
  - Extension of closed loop Tx diversity Mode 1
- **2x2 Ant. BF**
  - Number of Tx antennas = 4 (two-sub-array configuration)
  - Proposed weight adaptation, see Table 3

Figure 3–Figure 5 show the simulation results for three different channel models with 0dB geometry.

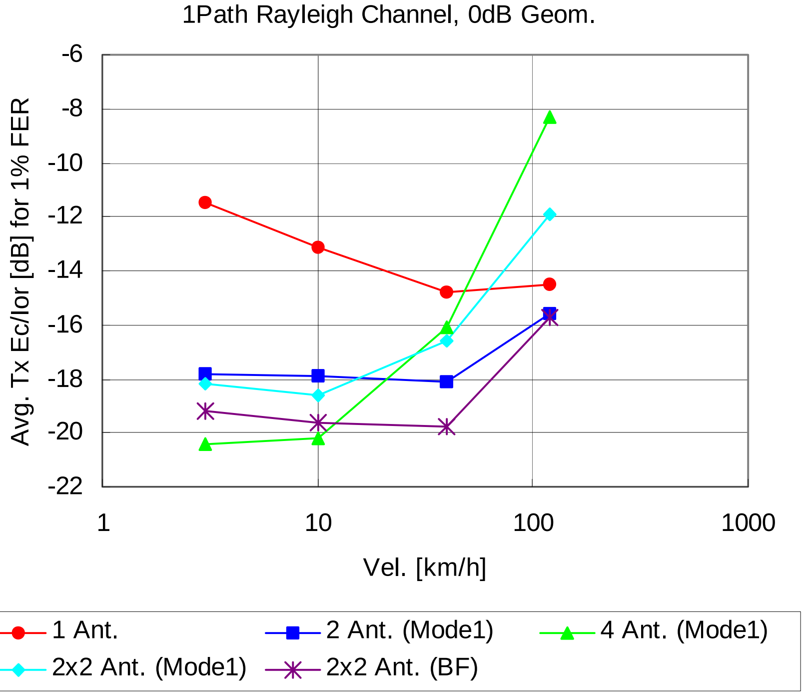

Figure 3. 1 path Rayleigh channel, 0 dB geometry

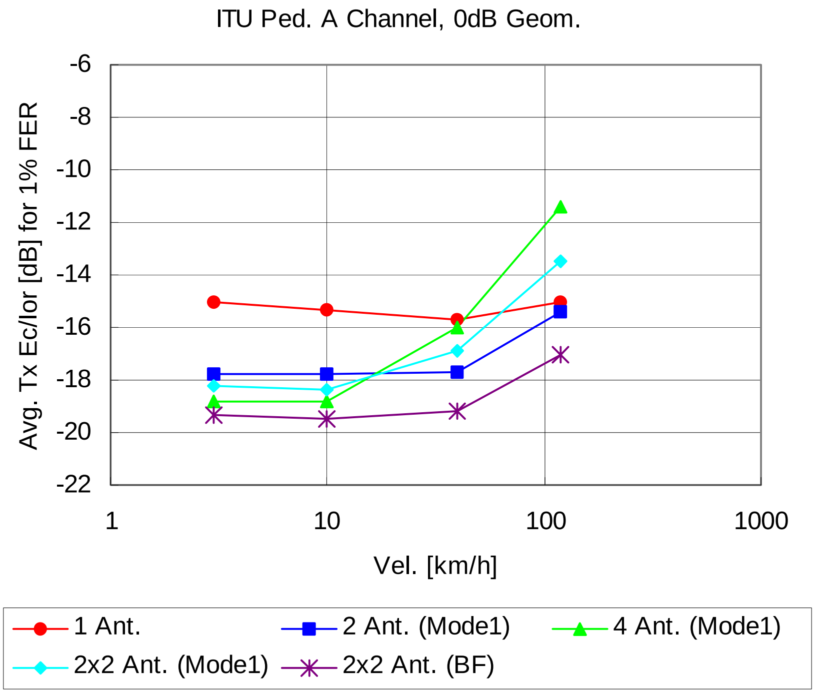

Figure 4. ITU Pedestrian A channel, 0 dB geometry

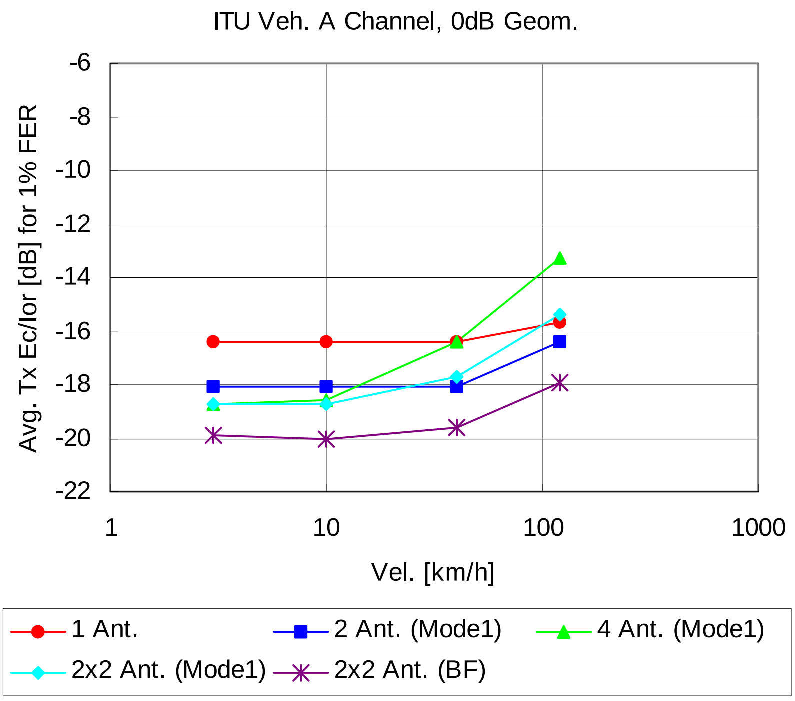

Figure 5. ITU Vehicular A channel, 0 dB geometry

6.2.3.2. Unequal CPICH power allocation

In Table 5, the CPICH power ratio of P_1 to P_2 (P_3 to P_4) was changed and the average Tx Ec/Ior performance were calculated for both the proposed scheme and the Release'99 UE. As the pilot power allocation for P_2 (P_4) decreases, the performance of the proposed scheme is gradually degraded. On the other hand, the performance for the Release'99 UE is improved, since the pilot sequences of only P_1 and P_3 are used for channel estimation.

Table 5. Performance with CPICH unequal power allocation (G=–3dB, V=40km/h)

CPICH power ratio	Tx Ec/Ior [dB]	
	2x2 Ant BF	2 Ant CL1 (R99)
5 : 5	-16.66	-14.70
6 : 4	-16.68	-14.77
7 : 3	-16.64	-14.84
8 : 2	-16.47	-14.98
9 : 1	-16.25	-15.04
10: 0	•	-15.04

6.2.3.3. Feedback weight filtering

If the feedback delay of the long-term beamformer weights is permissible, the feedback error reduction by filtering will be applicable. For example, when the same feedback information bits are detected consecutively, Node B may change the beamformer weight. If the feedback bit error occurs randomly, this filtering method can reduce the feedback error effectively. Moreover, the verification for beamformer weights will be unnecessary, if the feedback error is negligible. In Figure 6, the average Tx Ec/Ior performance assuming 4% feedback error rate for Tx diversity and 0% feedback error rate for closed loop beamforming is demonstrated. Results show that the extra beamforming gain of about 0.7 dB can be obtained by the feedback weight filtering.

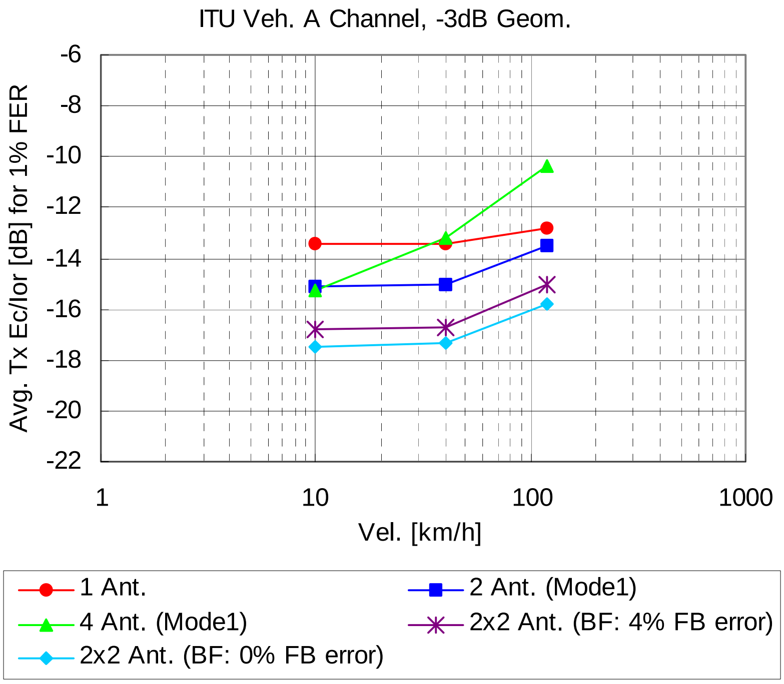

Figure 6. Performance with feedback filtering

7. Impacts to UE and UTRAN implementation

7.1. Impacts to UE implementation

7.1.4. Complexity evaluation of the Tx diversity scheme with beamforming feature

- 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 the channel estimation using CPICH for Tx diversity/beamforming control and the 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 6, where L=4, N_{dp}=4. Most of the additional complexity comes from the channel estimation and the algorithm complexity is relatively small.

Table 6. Complexity of UE

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

7.2. Impacts to UTRAN implementation

7.2.3. Tx diversity scheme with beamforming feature

The higher layer signaling information about Tx antenna configurations of Node B to UE is necessary to achieve efficient multiple antennas diversity/beamforming gain. An appropriate feedback frame format information should also be transmitted through higher layer signaling.

The procedure in soft handover is one of the most important issues for the feasibility study. Two handover methods were proposed for the Tx diversity scheme with beamforming feature.

- The common feedback weight is used to control the beamformer weights of active set of Node B.
- The individual beamformer weight is calculated and fed back in sequence among active set of Node B.

The former is the same method as described in Release'99 specification. In the latter method, the feedback delay occurs in proportion to the number of Node Bs. Since the UE in handover mode generally locates at cell edge, it is expected that the permissible feedback delay becomes much longer. However, this method needs higher layer signaling to assign the order of Node B, whose beamformer weights are transmitted in sequence from UE. On the other hand, the Tx diversity weight, that is vulnerable to feedback delay, is calculated and fed back to Node B in the same manner as described in Release'99 specification.

9. Backwards compatibility to Release-99

9.4. Tx diversity scheme with beamforming feature

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 7 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. In this method, additional OVSF code is not required for the additional CPICH.

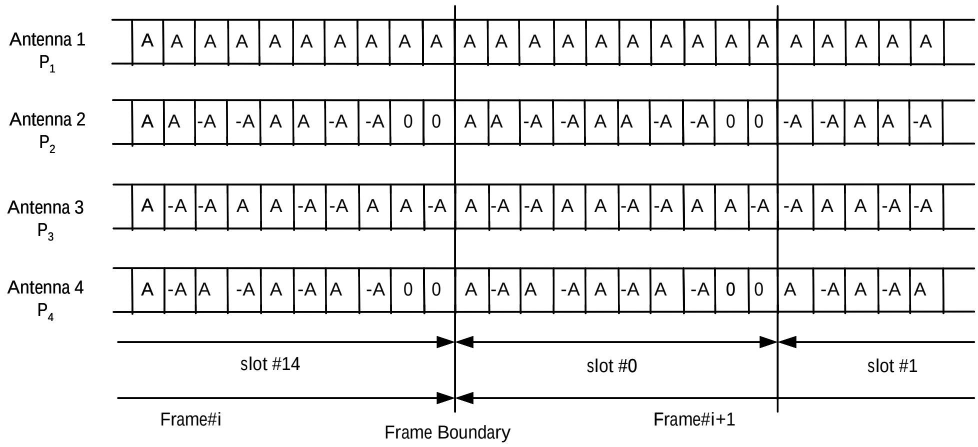

Figure 7. Pilot sequences of CPICH (4-antenna case)

The case should be considered, in which the Node Bs with different types of Tx diversity mode are mixed in the same active set during soft handover. In this case, only one feedback frame format should be shared to transmit the feedback information bits. For example, when the Node B with 2-sub-array antenna Tx diversity and the Node B with conventional 2-antenna Tx diversity exist in the same active set, the feedback frame format shown in Table 3 can be used as the common feedback frame format. Table 7 shows the active slots in a frame for each Tx diversity mode. Single Tx diversity weight is quantized by 2 bits, while single beamformer weight is quantized by 3 bits. Since only three slots per frame are clipped for the 2-antenna Tx diversity, the performance degradation seems to be negligible. Table 8 is the case where the Node Bs with 2-sub-array, 2-antenna and 4-antenna Tx diversity are mixed in the same active set. Since the 4-antenna Tx diversity should control three different diversity weights, the feedback rate for 2-antenna mode severely decreased. Thus there seems to be a significant performance degradation in a fast fading condition.

Table 7. Active feedback slots for 2-sub-array and 2-antenna Tx diversity in SHO

Slot #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2-sub-array	w_1	w_1	w_1	w_1	w_B	w_1	w_1	w_1	w_1	w_B	w_1	w_1	w_1	w_1	w_B
2-antenna	w_1	w_1	w_1	w_1	–	w_1	w_1	w_1	w_1	–	w_1	w_1	w_1	w_1	–

(w_1: feedback weight for Tx diversity. w_B: feedback weight for beamforming)

Table 8. Active feedback slots for 2-sub-array, 2-antenna and 4-antenna Tx diversity in SHO

Slot #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2-sub-array	w_1	w_1	–	–	w_B	–	–	w_1	w_1	w_B	–	–	–	–	w_B
2-antenna	w_1	w_1	–	–	–	–	–	w_1	w_1	–	–	–	–	–	–
4-antenna	w_1	w_1	w_2	w_2	–	w_3	w_3	w_1	w_1	–	w_2	w_2	w_3	w_3	–

(w_1, w_2, w_3: feedback weight for Tx diversity. w_B: feedback weight for beamforming)