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Agenda Item: **15.2**
Source: **Fujitsu**
Title: **Pseudo Transmission Timing Control using Cyclic Shift for Downlink CoMP Joint Transmission**
Document for: **Discussion and Decision**

1. Introduction

Coordinated multipoint (CoMP) transmission/reception is a key technology to improve spectrum efficiency for LTE-Advanced. The impacts on the L1 specifications have been investigated in [1-4]. The downlink CoMP is classified into the following two categories.

- Coordinated scheduling and/or beamforming
- Joint processing/transmission

In joint processing/transmission, data to a single UE is simultaneously transmitted from multiple transmission points. Even if, however, all the eNodeB are perfectly synchronized, an inevitable received timing difference occurs at the UE due to a distance offset between UE and coordinated cells. This timing difference, in general, may at least cause two issues. Firstly, from joint processing perspective, the impact of the received timing difference is fairly notable, which has been investigated in [5, 6]. Secondly, the received timing difference also affects reference signal structure for downlink CoMP joint transmission, which will be discussed in section 2.

In [7], we have shown how large the received timing difference is for the downlink CoMP transmission by means of system level simulation. In this contribution, we first discuss the issues caused by the received timing difference and then propose a simple solution which may efficiently mitigate the relevant impact.

2. Issues Caused by the Received Timing Difference

We consider a downlink joint transmission from K cells. Each cell has $N_t^{(k)}$ transmit antennas (k = 0, 1, 2, …, K), and UE has N_r received antenna. For simplicity and illustrative purpose, let $K = 2$, $N_t^{(0)} = N_t^{(1)} = 2$, $N_r = 2$, and the number of layer $L = 1$. We assume that the received timing difference is τ sample and less than the cyclic prefix (CP). It should be noted that the received timing difference could exceed the normal CP in some circumstance [7].

Two fundamental issues should be taken into account when a received timing difference occurs in CoMP transmission; one is related to the precoding collaborated from two cells, and the other is to the dedicated RS transmitted from two cells as well. In what follows, we detail these two issues.

2.1. Issue in Joint Processing

When a precoding as a joint processing is involved in CoMP, the received signal of UE#0 can be described as

$$Y = HWs + N\ ,$$

where $Y \in C^{2\times 2}$ are the received signal at the UE, $H \in C^{2\times 4}$ is the channel matrix between the cell and the UE, $W \in C^{4\times L}$ is the precoding matrix applied at the transmitter, $s \in C^{L\times 1}$ is the signal with L streams for the UE, $N \in C^{2\times 1}$ is the additive white Gaussian noise at UE. Here, we assumed that the per-subband precoding is employed, as used in LTE Rel.8 and the joint design [8]. Even for the disjoint design, so-called per-cell precoding [9], the same issues exist. The received signal with a received timing difference at the UE can be described as

$$\begin{pmatrix} y_0 \\ y_1 \end{pmatrix} = \begin{bmatrix} H^{(0)} & e^{-j2\pi\tau n/N_{FFT}} H^{(1)} \end{bmatrix} \begin{pmatrix} w_0 \\ w_1 \\ w_2 \\ w_3 \end{pmatrix} s + \begin{pmatrix} n_0 \\ n_1 \end{pmatrix},$$

where $H^{(p)} \in C^{2\times 2}$ is the channel matrix between cell #p and the UE. Due to the received timing difference, the channel between the collaborative cell and UE can be seen as a deep frequency-selective channel. Thus, a single preferable precoding matrix across a subband cannot be implemented effectively. As shown in Figure 1, the signals in frequency domain in (a) and (b) are received from the coordinated cells #0 and #1 by assuming the correct timing in (a) whereas incorrect time due to the time difference in (b). It should be noted that the signals depicted in figure belong to the output of FFT. By simply combining these two signals with a precoding vector (1, *A*), the resultant signal is shown in (c), from which a significant phase rotation and amplitude distortion can be observed.

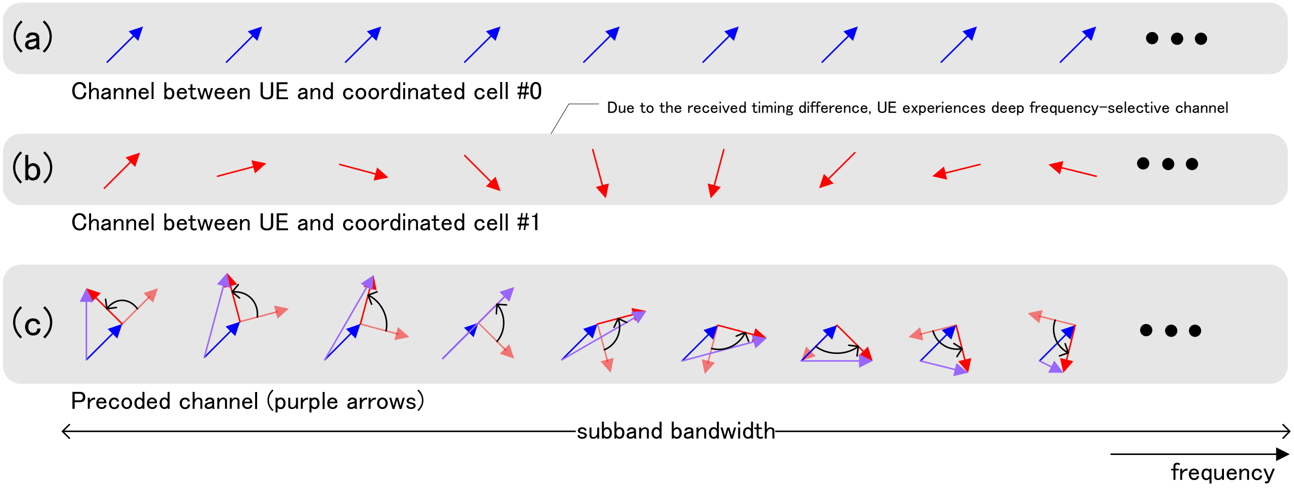

(a)
Channel between UE and coordinated cell #0
Due to the received timing difference, UE experiences deep frequency−selective channel
(b)
Channel between UE and coordinated cell #1
(c)
Precoded channel (purple arrows)
subband bandwidth
frequency

Figure 1 Issue on per-subband precoding

2.2. Issue in Dedicated RS

Moreover, if DRS overlapped on the same resources is employed for demodulation, another issue exists. In scattered structure employed for DRS as illustrated in Figure 2, for instance, the UE may estimate the channel on the non-DRS resources by mean of interpolation mechanism in both time and frequency domain. In such a case, the UE may smooth the channel estimates over the several DRS subcarriers. This could result in a deep frequency selective channel and cause inaccurate channel estimation for the UE because the UE always experiences a combined channel. Figure 3 gives an example with some distortion by using a linear interpolation, where a mismatch occurs between actual channel and estimated channel. It is worthwhile noting that the larger the received timing difference is, the deeper frequency selective channel the UE experiences. As a possible solution, the denser DRS in frequency domain can be exploited like MBSFN reference signals in Rel.8, but at the cost of undesirable overhead.

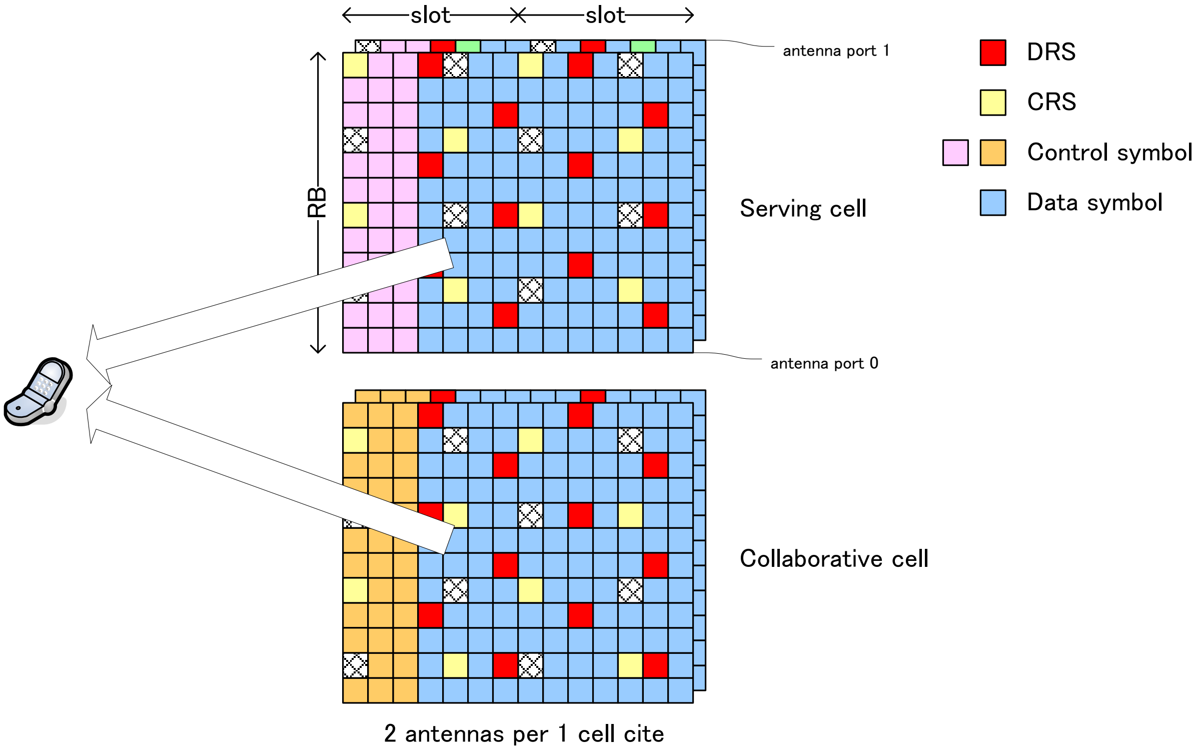


Figure 2 Example of the overlapped DRS with scattered structure

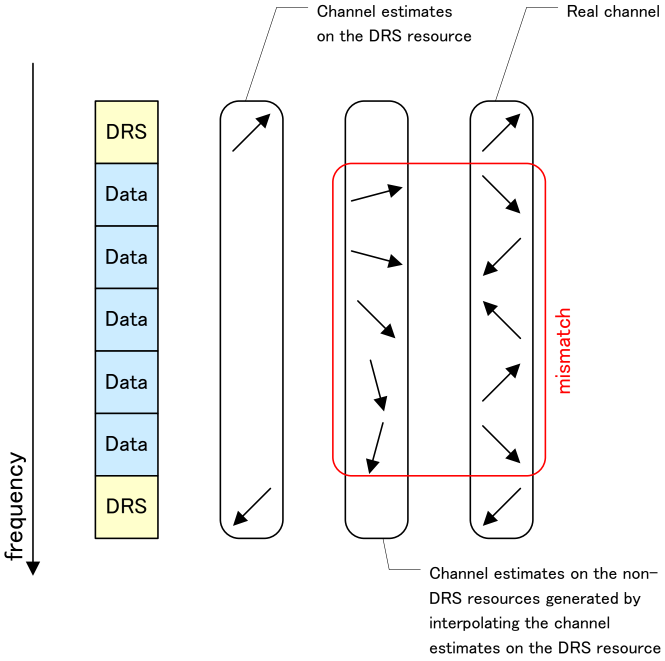

Channel estimates on the DRS resource
Real channel
DRS
Data
Data
Data
Data
Data
DRS
frequency
mismatch
Channel estimates on the non-DRS resources generated by interpolating the channel estimates on the DRS resource

Figure 3 Issue on channel estimation

3. Pseudo Transmission Timing Control using Cyclic Shift

In this section, we propose a simple solution to circumvent the above two issues. The transmission timing control as employed in Rel.8 uplink seems to be a natural solution. In downlink, however, it is infeasible to adjust the transmission timing for each UE. Thus, we consider a cyclic shift within an OFDM symbol. The proposed procedure is illustrated in Figure 4. The CoMP UE measures the received timing difference using the cell specific reference signals from each coordinated cell, for instance, and then feeds back the measures to the serving cell. As one alternative solution, the measured received timing difference is indicated to the collaborative cell through the network. The collaborative cell applies the cyclic shift to the data and DRS so that the received timing difference can be compensated. By doing this way, the UE receives the signals from coordinated cells as if they are aligned in time. Since the actual transmission timing is not physically changed, we term the proposed scheme pseudo transmission timing control (PTTC) using cyclic shift.

Since the cyclic shift corresponds to the phase rotation in the frequency domain, PTTC can be equivalently described as

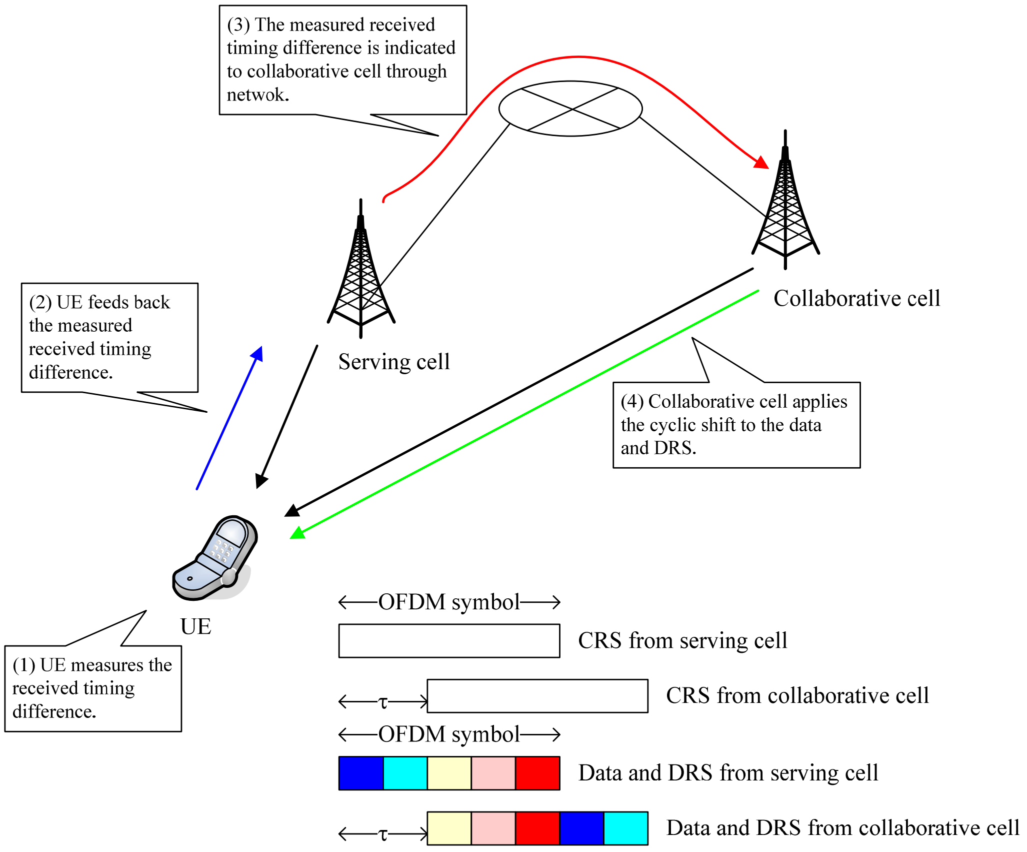
$$X = \Xi W s\,,$$

$$\Xi(t,n) = \begin{pmatrix} I & O \\ O & e^{2\pi n\Delta / N_{IFFT}} I \end{pmatrix},$$

where X is the transmitted signal, Ξ is the phase rotation matrix, $I \in C^{2\times 2}$ is the identity matrix, O is the zero matrix and Δ is the preferable cyclic shift fed back from the UE. This can be easily implemented for individual UE in each TTI.

From feedback overhead point of view, the feedback period is important. Considering the feedback frequency in the Rel.8 uplink transmission timing control, the feedback on MAC layer, i.e. several 100ms order, may be enough. Hence, the proposed scheme does not burden L1 feedback channel. As a further discussion, the preferable range and granularity for adjustment could be investigated at the later stage.

Although this proposed scheme is not capable of compensating for ISI when a received timing difference exceeds the CP, a significant gain still can be expected, that will be confirmed in the following section.


Serving cell
Collaborative cell
UE
⟵OFDM symbol⟶
CRS from serving cell
⟵τ⟶
CRS from collaborative cell
⟵OFDM symbol⟶
Data and DRS from serving cell
⟵τ⟶
Data and DRS from collaborative cell

(1) UE measures the received timing difference.

(2) UE feeds back the measured received timing difference.

(3) The measured received timing difference is indicated to collaborative cell through netwok.

(4) Collaborative cell applies the cyclic shift to the data and DRS.

Figure 4 Pseudo transmission timing control procedure

4. Simulation Results

In this section, we evaluate the performance for both the conventional and proposed scheme. The simulation parameters are tabulated in Table 1. For simplicity, the difference of averaged received powers between two coordinated cells is assumed to be 0 dB. It is further assumed that the eNBs perfectly know the received timing difference experienced at the UE so that the cyclic shift is always functioned well to compensate for the received timing difference. Moreover, the received timing difference is considered as a fixed parameter in the practical range shown in [7]. The overlapped DRS is employed and multiplexed on the 4th, 7th, 10th and 13th OFDM symbol with staggered 6 subcarrier spacing.

Table 1 Simulation Parameters

Carrier frequency	2 GHz
Subcarrier spacing	15 kHz
Number of allocated RBs	25
Number of RBs per precoding subband	5
Number of corrdinated cells	2
Number of transmit antennas per cell	1
Number of receive antennas at receiver	2
Number of MIMO layers	1
Precoding codebook	$\frac{1}{\sqrt{2}}\begin{pmatrix}1\\1\end{pmatrix}, \frac{1}{\sqrt{2}}\begin{pmatrix}1\\-1\end{pmatrix}, \frac{1}{\sqrt{2}}\begin{pmatrix}1\\j\end{pmatrix}, \frac{1}{\sqrt{2}}\begin{pmatrix}1\\-j\end{pmatrix}$
PMI feedback delay	6 ms
PMI feedback period	every 1 ms

Maximum number of HARQ retransmissions	3
Channel model	PA, TU
Maximum Doppler frequency	5 Hz
Averaged Received Power Offset	0dB

In our simulation, we attempt to figure out the required SNR at residual BLER of 1% by given the received time difference. Figure 5 and Figure 6 show the required SNR in both ideal and real channel estimation cases, respectively.

From Figure 5, the following observations can be made.

- The required SNR for the conventional scheme increases sharply up to around 1μs. This is because with such received timing difference, the frequency selectivity occurs within the subband of 900 kHz.
- The required SNR for the proposed scheme slightly increases up to around 5μs.
- The required SNR for both schemes degrades as the received timing difference increases more than the CP duration. This degradation is caused by ISI.

From Figure 6, it can be seen that the increase of the required SNR for the conventional scheme does not drop dissimilar to the case for ideal channel estimation. This is because the accurate channel estimation is not feasible.

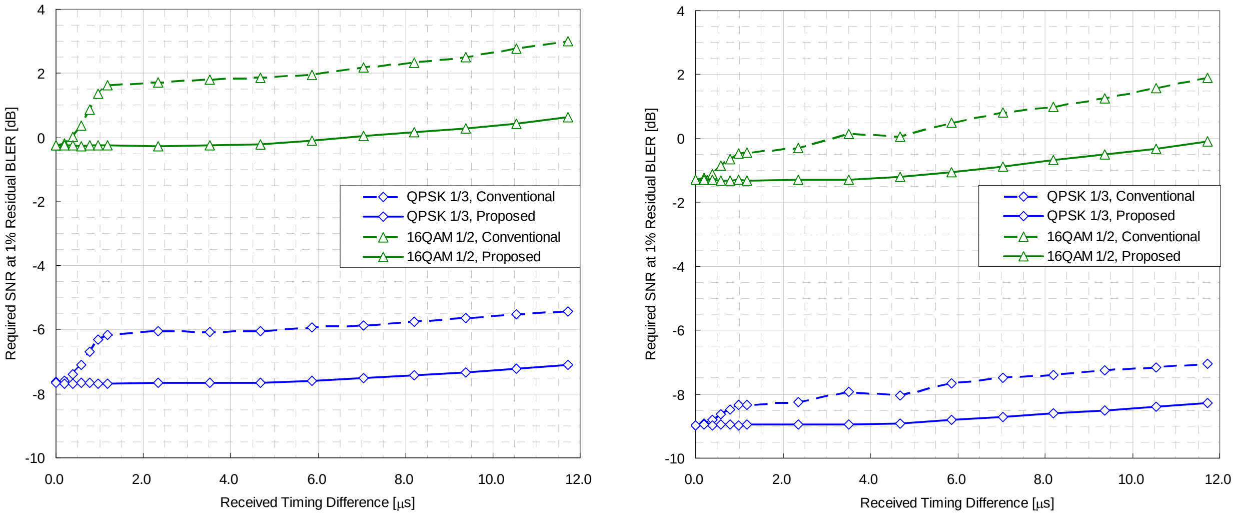


Figure 5 Required SNR at 1% residual BLER for ideal channel estimation (left :PA5Hz, right :TU5Hz)

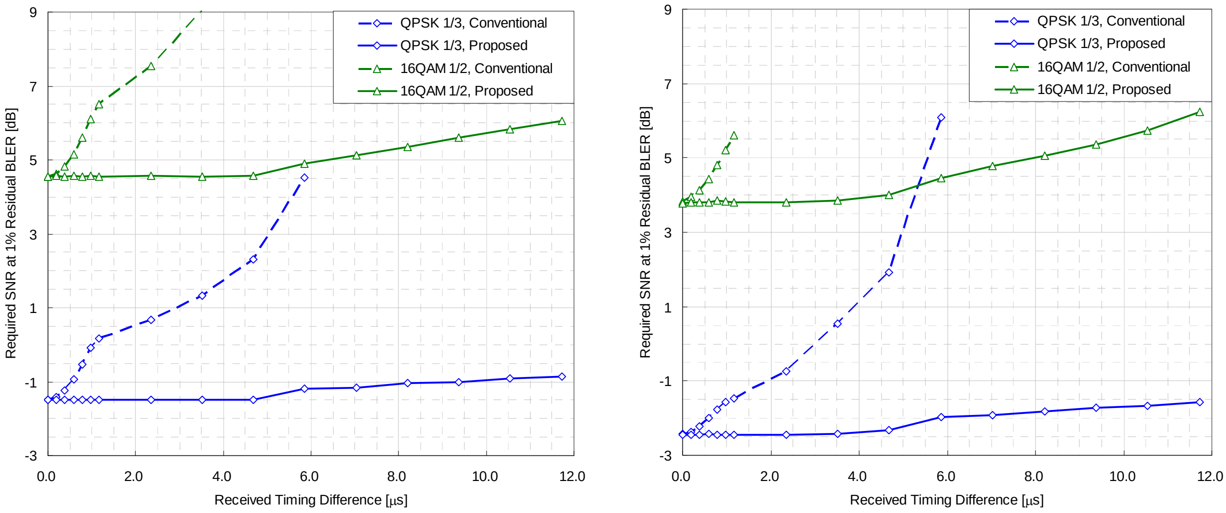


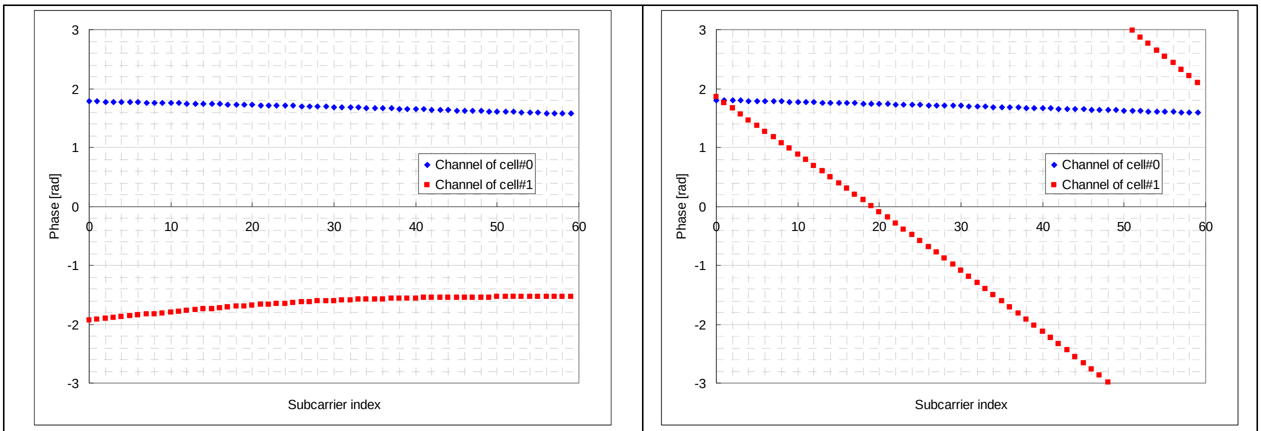
Figure 6 Required SNR at 1% Residual BLER for real channel estimation (left :PA5Hz, right :TU5Hz)

5. Conclusions

In this contribution, we proposed pseudo transmission timing control using cyclic shift for downlink CoMP joint transmission. We also showed the preliminary simulation results. The proposed scheme outperforms the conventional scheme even in the range more than the CP duration. In order to exploit the potential gain of the CoMP joint transmission, the proposed scheme should be considered.

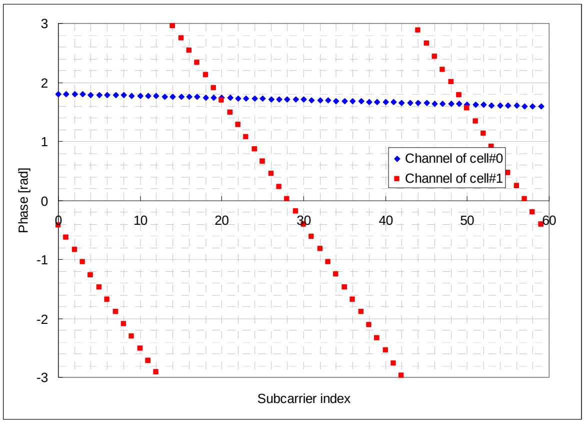
6. Appendix

The snapshots of the channel between the UE and each coordinated cell are shown in Figure 7 for just illustrative purpose. It is noted that only the phase is shown in the figure.



(a) 0 µs received timing difference

(b) T_{CP}/4 µs received timing difference



(c) T_{CP} /2 μs received timing differnece

Figure 7 Snapshots of the channel between the UE and each coordinated cell

Reference

[1] R1-084377, “Downlink coordinated transmission – Impact on specification”, Ericsson

[2] R1-090325, “Coordinated Multi-Point Transmission --- Coordinated Beamforming/Precoding and Some Performance Results”, Motorola

[3] R1-090366, “Impact of Downlink CoMP on the Air Interface”, Qualcomm Europe

[4] R1-090129, “Further Discussions on the Downlink Coordinated Transmission - Impact on the Radio Interface”, Huawei, CMCC

[5] R1-090142, “Performance evaluation of CoMP solutions”, Nortel

[6] R1-090193, “Aspects of Joint Processing in Downlink CoMP”, CATT

[7] R1-090950, “Received Timing Mismatch in Downlink CoMP Transmission”, Fujitsu

[8] R1-090286, “Joint Processing Coordinated Multi-point Transmission for LTE-A Downlink”, Texas Instruments

[9] R1-090273, “Per-cell precoding methods for downlink joint processing CoMP”, ETRI