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Re:	<p>IEEE 802.16m-08/024- Call for comments and contributions on project 802.16m system description document (SDD)</p> <p>Topic: HARQ (PHY aspects)</p>	
Abstract	This contribution proposes an enhanced HARQ retransmission scheme for 802.16m	
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Symbol-Combining Retransmission Schemes for HARQ

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Introduction

In this contribution, we propose a simple and efficient retransmission scheme for HARQ (Hybrid Automatic Retransmission reQuest), which can be adopted in both DL and UL. This scheme could significantly reduce the radio resources required for retransmission while maintaining the comparable decoding gain with chase combining (CC), especially when the channel responses of transmission and retransmissions are almost the same. Thus, the spectrum efficiency and system capacity could be improved. Moreover, the computation complexity of the decoding procedure of the proposed scheme is not high and, hence, it is practical for implementation

Proposed Symbol-combining Retransmission Scheme

The proposed symbol-combining retransmission scheme could be adopted in both DL and UL. For simplicity, we only consider downlink (DL) in this contribution. The scheme can be easily applied to uplink (UL).

In the original DL HARQ CC procedure, BS transmits a sub-burst to MS, which contains symbols S_1 , S_2 , and so on. When the MS receives the sub-burst, the MS starts to check the CRC of the received sub-burst. If the received sub-burst passes the CRC check, the MS should feedback an ACK to the BS and forward the decoded sub-burst to the upper layer. Otherwise, the MS should feedback a NAK to the BS when the received sub-burst cannot pass the CRC check. Upon receiving the NAK from the MS, the BS performs retransmission procedure by sending the same sub-burst to the MS.

Our proposal is to modify the retransmission procedure when the BS received a NAK from the MS. Instead of retransmitting the same sub-burst to the MS, the BS retransmits a sub-burst, where each symbol is a linear combination of two symbols in the first transmitted sub-burst. A simple combination could be that one symbol subtracted by its adjacent symbol in the first transmitted sub-burst. That is, the symbols of the retransmitted sub-

burst are (S_1-S_2) , (S_3-S_4) , (S_5-S_6) , and so on. Fig. 1 illustrates our proposed HARQ retransmission scheme.

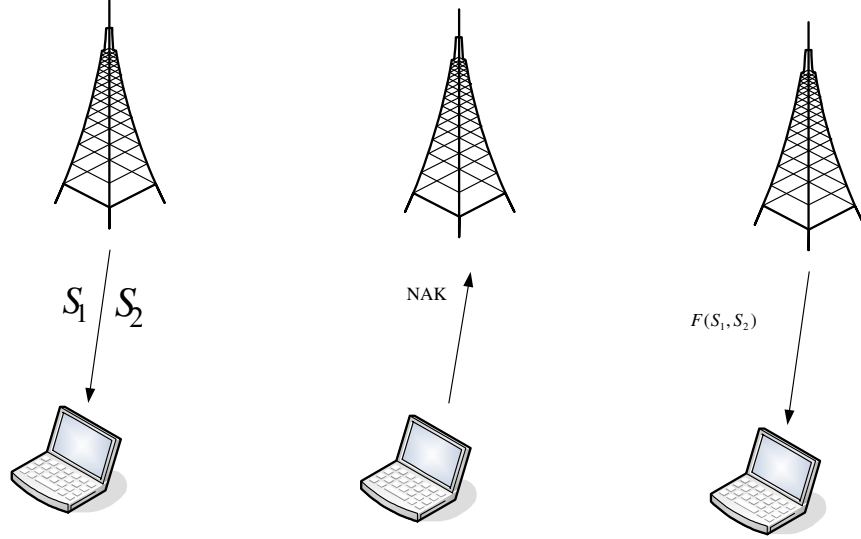


Fig. 1 The basic structure of the proposed retransmission scheme

Obviously, the re-transmitted sub-burst takes almost half symbols of the re-transmitted sub-burst by the traditional HARQ procedure when the number of symbols in the sub-burst is large. Upon receiving the re-transmitted sub-burst, the decoding procedure at the MS is given below. In order to illustrate the decoding procedure, we use the adjacent symbols S_1 and S_2 as an example, and the linear combining function $F(S_1, S_2)$ is defined as S_1-S_2 .

First, the MS adds the two adjacent symbols in the first-time received sub-burst and obtains $(h_1S_1+h_1S_2)$, where h_1 is the corresponding channel response of S_1 and S_2 in the first transmission. Note that S_1 and S_2 are two adjacent symbols, so we could assume the channel responses are approximately the same. On the other hand, we could obtain the combined symbol $(h_2S_1-h_2S_2)$ in the retransmitted sub-burst, where h_2 is the corresponding channel response in the re-transmission. The expression of the received symbols is presented as follows.

$$X = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} h_1S_1 + h_1S_2 \\ h_2S_1 - h_2S_2 \end{bmatrix} = \begin{bmatrix} h_1 & h_1 \\ h_2 & -h_2 \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + \begin{bmatrix} n_1 + n_2 \\ n_3 \end{bmatrix} = HS + N \quad (1)$$

In order to estimate S_1 and S_2 from the above equation, a straightforward approach is using zero forcing. However, zero forcing, in general, may cause higher gain loss. Thus we suggest the following approaches.

Approach 1: Maximum Likelihood (ML)

In ML, it is to find the column vector S satisfying that:

$$\hat{S} = \arg \min_s \|X - HS\|$$

By the ML, we can obtain the optimal solution of (1). It, however, causes a lot of computation overheads. The next approach is then proposed to find the sub-optimal solution of (1) with much less computation complexity.

Approach 2: QR decomposition (QRD)

This approach using QR decomposition method to decompose the matrix H into the multiplication of two matrices, namely Q and R , where Q is a unitary matrix and R is an upper triangular matrix. By multiplying the received symbol vector X with Q^H , there is no cross term for S_2 by the property of the upper triangular matrix R .

Thus we can decode S_2 first. Afterwards, S_1 can be decoded by either using the decision feedback (a.k.a. interference cancellation) or applying the same QR decomposition approach by reversing the signal vector \mathbf{X} . A derivation of decoding procedure by using QR decomposition is shown as follows.

$$\begin{aligned} \mathbf{X} &= \begin{bmatrix} h_1 & h_1 \\ h_2 & -h_2 \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + N = \mathbf{QRS} + N \\ \mathbf{Q} &= \begin{bmatrix} \frac{h_1}{\sqrt{|h_1|^2 + |h_2|^2}} & \frac{|h_2|h_1}{|h_1|\sqrt{|h_1|^2 + |h_2|^2}} \\ \frac{h_2}{\sqrt{|h_1|^2 + |h_2|^2}} & \frac{-|h_1|h_2}{|h_2|\sqrt{|h_1|^2 + |h_2|^2}} \end{bmatrix} \\ \mathbf{R} &= \begin{bmatrix} \sqrt{|h_1|^2 + |h_2|^2} & \frac{|h_1|^2 - |h_2|^2}{\sqrt{|h_1|^2 + |h_2|^2}} \\ 0 & \sqrt{|h_1|^2 + |h_2|^2} - \frac{(|h_1|^2 - |h_2|^2)^2}{|h_1|^2 + |h_2|^2} \end{bmatrix} \\ \mathbf{Q}^H \mathbf{X} = \mathbf{RS} + N' &= \begin{bmatrix} |h_1|^2 + |h_2|^2 & \frac{|h_1|^2 - |h_2|^2}{\sqrt{|h_1|^2 + |h_2|^2}} \\ 0 & \sqrt{|h_1|^2 + |h_2|^2} - \frac{(|h_1|^2 - |h_2|^2)^2}{|h_1|^2 + |h_2|^2} \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + N' \end{aligned}$$

From the above equation, we can obtain the gain of $S_2 = \sqrt{|h_1|^2 + |h_2|^2} - \frac{(|h_1|^2 - |h_2|^2)^2}{|h_1|^2 + |h_2|^2}$

From (1), the noises in company with S_1 and S_2 are summed. Therefore, it causes a higher noise power in the decoding procedure, which degrades the decoding performance. In order to resolve the problem, we alternatively express the received signal as follows.

$$\mathbf{X}' = \begin{bmatrix} h_1 & 0 \\ 0 & h_1 \\ h_2 & -h_2 \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix} \quad (2)$$

Similarly, we can apply QRD to get the sub-optimal solution and obtain the gain of S_2 equal to

$$\sqrt{|h_1|^2 + |h_2|^2} - \frac{|h_2|^4}{|h_1|^2 + |h_2|^2}$$

Approach 3: Sphere decoding algorithm (SDA)

SDA is another approach to obtain the near-optimal solution of (1) at the reduced computation complexity.

Approach 4: Maximum Ratio Combining (MRC)

By linearly combining the three received symbols (e.g. S_1, S_2, S_1-S_2) as shown in Fig. 2, the MRC can provide the near-optimal solution with considerably low complexity. Basically, the MRC is to find the coefficients which maximize the SINR of the linear combination. It is obvious that the output of the combiner is

$$(\alpha_1 h_1 + \alpha_3 h_2)S_1 + (\alpha_2 h_1 - \alpha_3 h_2)S_2 + \sqrt{(|\alpha_1|^2 + |\alpha_2|^2 + |\alpha_3|^2)}n', \quad n' \sim CN(0, N)$$

where $CN(0, N)$ denotes the complex normal distribution with zero mean and variance N .

From S_1 point of view, the SINR can be represented as

$$\begin{aligned} \gamma_{s_1} &= \frac{|\alpha_1 h_1 + \alpha_3 h_2|^2 A^2}{|\alpha_2 h_1 - \alpha_3 h_2|^2 A^2 + (|\alpha_1|^2 + |\alpha_2|^2 + |\alpha_3|^2)N} \\ &= \frac{|\alpha_1 h_1 + \alpha_3 h_2|^2 SNR}{|\alpha_2 h_1 - \alpha_3 h_2|^2 SNR + (|\alpha_1|^2 + |\alpha_2|^2 + |\alpha_3|^2)} \end{aligned} \quad (3)$$

where SNR is defined as $\frac{A^2}{N}$ and the amplitudes of S_1 and S_2 are assumed to be the same and denoted by A .

In order to find the coefficients $\alpha_1, \alpha_2, \alpha_3$ which maximize γ_{s_1} , two observations on (3) are given in the following.

Observation 1:

By applying Cauchy-Schwartz inequality to the numerator of (3), we can obtain $\alpha_1 = \frac{h_1^* \alpha_3}{h_2^*}$.

Observation 2:

To minimize $|\alpha_2 h_1 - \alpha_3 h_2|^2$ in denominator of (3), we obtain

$$\angle \alpha_2 h_1 = \angle \alpha_3 h_2 \longrightarrow \angle \alpha_2 = \angle \alpha_3 + \angle h_2 - \angle h_1.$$

From observation 1 & 2 and by setting $|\alpha_2| = x|\alpha_3|$, where x is a real number, (3) can be further expressed as

$$\begin{aligned} \gamma_{s_1} &= \frac{\left| \frac{h_1^* h_1}{h_2^*} \alpha_3 + h_2 \alpha_3 \right|^2 SNR}{(x^2 |h_1|^2 - 2x |h_1| |h_2| + |h_2|^2) SNR + (|\alpha_1|^2 + |\alpha_2|^2 + |\alpha_3|^2)} \\ &= \frac{\frac{(|h_1|^2 + |h_2|^2)^2}{|h_2|^2} |\alpha_3|^2 SNR}{(x^2 |h_1|^2 - 2x |h_1| |h_2| + |h_2|^2) |\alpha_3|^2 SNR + (|\alpha_1|^2 + |\alpha_2|^2 + |\alpha_3|^2)} \end{aligned} \quad (3)$$

Assuming $|\alpha_1|^2 + |\alpha_2|^2 + |\alpha_3|^2 = K$, we can obtain

$$|\alpha_3|^2 = \frac{|h_2|^2 K}{|h_1|^2 + (1+x^2)|h_2|^2}.$$

and then

$$\begin{aligned}
\gamma_{s_1} &= \frac{\frac{(|h_1|^2 + |h_2|^2)^2}{|h_2|^2} * \frac{|h_2|^2 K}{|h_1|^2 + (1+x^2)|h_2|^2} SNR}{(x^2|h_1|^2 - 2x|h_1||h_2| + |h_2|^2) \frac{|h_2|^2 K}{|h_1|^2 + (1+x^2)|h_2|^2} SNR + K} \\
&= \frac{(|h_1|^2 + |h_2|^2)^2 SNR * K}{(x^2|h_1|^2 - 2x|h_1||h_2| + |h_2|^2)|h_2|^2 K * SNR + K|h_1|^2 + (1+x^2)|h_2|^2} \\
&= \frac{(|h_1|^2 + |h_2|^2)^2 * SNR}{(SNR|h_1|^2|h_2|^2 + |h_2|^2) \left\{ x - \frac{|h_1||h_2|^3 SNR}{|h_1|^2|h_2|^2 SNR + |h_2|^2} \right\}^2 - \frac{|h_1|^2|h_2|^6 SNR^2}{|h_1|^2|h_2|^2 SNR + |h_2|^2} + \frac{|h_1|^2|h_2|^4}{|h_1|^2} SNR + |h_1|^2 + |h_2|^2}
\end{aligned}$$

To obtain the maximum SINR, we can set $x = \frac{|h_1||h_2|^3 SNR}{|h_1|^2|h_2|^2 SNR + |h_2|^2}$.

Consequently, we can obtain the relationship of the coefficients $\alpha_1, \alpha_2, \alpha_3$ as follows.

$$\alpha_1 = \frac{h_1^*}{h_2} \alpha_3, \quad \alpha_2 = \frac{|h_1||h_2|^3 SNR}{|h_1|^2|h_2|^2 SNR + |h_2|^2} \alpha_3 * e^{j(\angle h_2 - \angle h_1)}, \text{ and}$$

$|\alpha_1|^2 + |\alpha_2|^2 + |\alpha_3|^2 = K$, where K is an arbitrary positive constant.

If $SNR \gg |h_2|^2$, we obtain $x \approx \frac{|h_2|}{|h_1|}$, and $\gamma_{s_1} \approx (|h_1|^2 + |h_2|^2) SNR$. Note that the gain of the symbol-combining scheme is the same as CC. The set of coefficients to decode S_2 can be obtained by similar derivation as above.

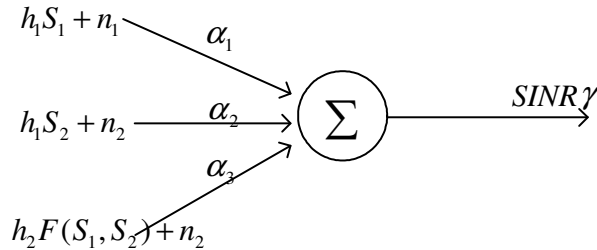


Fig. 2 The architecture of maximum ratio combining decoding scheme

In order to generalize the symbol-combining, a simple precoding approach can be used in the symbol-combining as shown in Fig. 3. When retransmission is required, the S_1 and S_2 can be combined by a pre-defined phase shift θ in opposite direction. That is, the retransmitted symbol becomes $F(e^{-j\theta}S_1, e^{j\theta}S_2) = e^{-j\theta}S_1 - e^{j\theta}S_2$. It can be shown that the simple precoding will not introduce any gain loss when QR decomposition method is adopted for decoding.

$$X' = \begin{bmatrix} h_1 & h_1 \\ h_2 e^{-j\theta} & -e^{j\theta} h_2 \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + N = \begin{bmatrix} e^{j\theta} h_1 & h_1 \\ h_2 & -e^{j\theta} h_2 \end{bmatrix} \begin{bmatrix} e^{-j\theta} S_1 \\ S_2 \end{bmatrix} + N = H' S' + N = Q' R' S' + N$$

$$Q' = \begin{bmatrix} \frac{h_1}{\sqrt{|h_1|^2 + |h_2|^2}} & \dots \\ \frac{h_2 e^{-j\theta}}{\sqrt{|h_1|^2 + |h_2|^2}} & \dots \end{bmatrix}$$

$$R' = \begin{bmatrix} |h_1|^2 + |h_2|^2 & \dots \\ 0 & g \end{bmatrix}$$

Let $H' = [v_1 \ v_2]$,

where v_1 and v_2 are the first and second column vectors of H' , respectively. Now we can obtain the value of g as follows.

$$g = \sqrt{\|v_2\|^2 - \left| \frac{\langle v_1, v_2 \rangle}{\|v_1\|} \right|^2} = |h_1|^2 + |h_2|^2 - \frac{\left| |h_1|^2 e^{j\theta} - |h_2|^2 e^{j\theta} \right|^2}{|h_1|^2 + |h_2|^2}$$

$$= |h_1|^2 + |h_2|^2 - \frac{(|h_1|^2 - |h_2|^2)^2}{|h_1|^2 + |h_2|^2}$$

It is shown that the gain keeps the same no matter if the precoding is used or not.

Since transmitting a sum of signals such as $e^{-j\theta} S_1 - e^{j\theta} S_2$ will usually increase the peak-to-average power ratio (PAPR), a method to avoid this problem is to perform a modulo operation based on the peak value of $e^{-j\theta} S_1 - e^{j\theta} S_2$ to clamp the transmitted signal values to within the range of $\pm S_i$, where $i = 1, 2$, for both the real part and the imaginary part. The presence/absence of this modulo operation can be detected by suitable techniques in the receiver and its effect properly remove

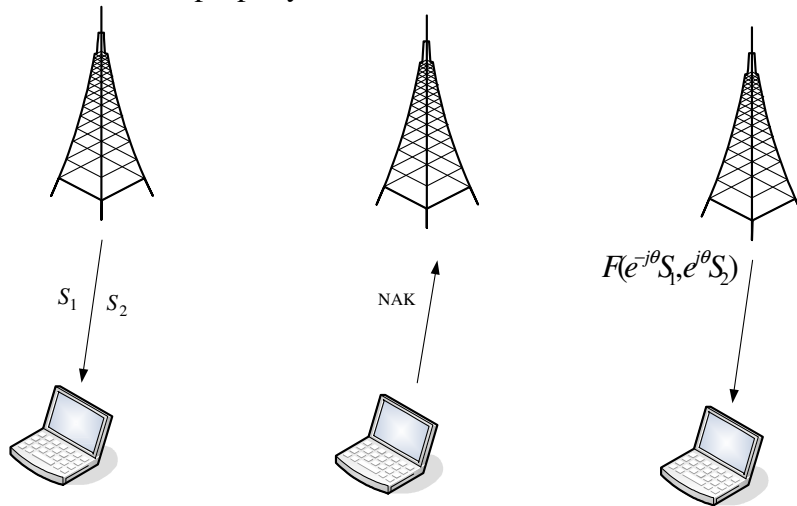


Fig.3 The structure of the proposed retransmission scheme with precoding

Proposed scheme in dealing with more than one retransmissions

When the sub-burst cannot be decoded successfully after the first retransmission, the MS should feedback a NAK again and the BS should perform the second retransmission before the retransmission timeout and retry count exhausted. When more than one retransmissions are required, the patterns of retransmissions are given in Table 1. In the more than one retransmission case, the MS may select one odd and one even retransmitted sub-bursts. Then, the MS adopts the proposed approaches, namely ML, QRD, SDA and MRC to estimate the symbols in the sub-bursts. It can be easily shown that decoding the odd and the even retransmission patterns by QRD does not cause any gain loss. Based on the estimated symbols, the MS can further use chase combining procedure to get the final versions of the symbols.

Table 1 The retransmission patterns of proposed scheme

	Symbol 1	Symbol 2	Symbol 3	Symbol 4
Original sub-burst	S_1	S_2	S_3	S_4
Odd Retransmitted sub-burst	$e^{-j\theta} S_1$ $- e^{j\theta} S_2$	$e^{-j\theta} S_3$ $- e^{j\theta} S_4$	N/A	N/A
Even Retransmitted sub-burst	$e^{j\theta} S_1$ $+ e^{-j\theta} S_2$	$e^{j\theta} S_3$ $+ e^{-j\theta} S_4$	N/A	N/A

The issue of increased PAPR can be addressed by performing modulo operation in the transmitter and a corresponding de-modulo operation in the receiver, as indicated in the case of one retransmission.

A special case of the proposed scheme for more than one receivers

Consider two MS which are denoted as MS 1 and MS 2. When the BS transmits two bursts to MS 1 and MS 2, respectively, the two MSs could decode the two bursts simultaneously. If the two MSs cannot decode the burst destined to itself but decode the burst for the other's, the BS may re-transmit the two bursts for the two MSs by combining the original symbols into $e^{-j\theta} S_1^1 + e^{j\theta} S_1^2$, $e^{-j\theta} S_2^1 + e^{j\theta} S_2^2$, where S_n^m denote the n -th symbol for MS m . In this case, the gain when decoding the symbols will be increased in comparison with the proposed re-transmission scheme for single receiver and is approximately equal to the gain of chase combining. Note that the resource for the retransmission scheme here is $\max(L_1, L_2)$ instead of L_1+L_2 , where L_n is the number of symbols of the original burst of MS n .

Proposed Text in SDD

[Insert the following subclause in 10.x]

10.x Symbol-combining retransmission scheme

In order to increase the efficiency of HARQ retransmission with comparable decoding gain with chase combining, symbol-combining HARQ retransmission schemes should be used. Two types of symbol-combining retransmission schemes are described as follows. In either type of retransmission, a modulo operation may be performed on the transmitted signal so as to limit the PAPR.

10.x.1 Type I symbol-combining retransmission scheme:

Type I symbol-combining retransmission scheme may be adopted in both DL and UL for the case of a single transmitter and receiver pair. When retransmissions are required, the symbol-combining retransmission patterns shown in Table xxx may be used instead of the original retransmission patterns used in the chase combining procedure, where S_i denotes the i -th symbol in the sub-burst and θ is a pre-defined phase shift in the symbol-combining retransmission scheme.

Table xxx The retransmission pattern of Type I symbol-combining retransmission scheme

	<u>Symbol 1</u>	<u>Symbol 2</u>	<u>Symbol 3</u>	<u>Symbol 4</u>
<u>Original sub-burst</u>	<u>S_1</u>	<u>S_2</u>	<u>S_3</u>	<u>S_4</u>
<u>Odd retransmitted sub-burst</u>	<u>$e^{-j\theta} S_1$</u> <u>$- e^{j\theta} S_2$</u>	<u>$e^{-j\theta} S_3$</u> <u>$- e^{j\theta} S_4$</u>	<u>N/A</u>	<u>N/A</u>
<u>Even retransmitted sub-burst</u>	<u>$e^{j\theta} S_1$</u> <u>$+ e^{-j\theta} S_2$</u>	<u>$e^{j\theta} S_3$</u> <u>$+ e^{-j\theta} S_4$</u>	<u>N/A</u>	<u>N/A</u>

10.x.2 Type II symbol-combining retransmission scheme:

Type II symbol-combining retransmission schemes may be adopted in DL for the case of more than one receivers if the receivers cannot decode the burst destined to itself but successfully decode the burst for the other's. In this case, the BS may performs retransmissions using the symbol-combining retransmission patterns shown in Table yyy instead of the original retransmission patterns used in the chase combining procedure, where S_n^m denotes the n -th symbol for receiver m in the sub-burst and θ is a pre-defined phase shift in the symbol-combining retransmission scheme.

Table yyy The retransmission pattern of Type II symbol-combining retransmission scheme

	<u>Symbol 1</u>	<u>Symbol 2</u>	<u>Symbol 3</u>	<u>Symbol 4</u>
<u>Original sub-burst</u>	<u>$S_1^1(S_1^2)$</u>	<u>$S_2^1(S_2^2)$</u>	<u>$S_3^1(S_3^2)$</u>	<u>$S_4^1(S_4^2)$</u>
<u>Odd retransmitted sub-burst</u>	<u>$e^{-j\theta} S_1^1$</u> <u>$- e^{j\theta} S_1^2$</u>	<u>$e^{-j\theta} S_2^1$</u> <u>$- e^{j\theta} S_2^2$</u>	<u>$e^{-j\theta} S_3^1$</u> <u>$- e^{j\theta} S_3^2$</u>	<u>$e^{-j\theta} S_4^1$</u> <u>$- e^{j\theta} S_4^2$</u>
<u>Even retransmitted sub-burst</u>	<u>$e^{-j\theta} S_1^1$</u> <u>$+ e^{j\theta} S_1^2$</u>	<u>$e^{-j\theta} S_2^1$</u> <u>$+ e^{j\theta} S_2^2$</u>	<u>$e^{-j\theta} S_3^1$</u> <u>$+ e^{j\theta} S_3^2$</u>	<u>$e^{-j\theta} S_4^1$</u> <u>$+ e^{j\theta} S_4^2$</u>