A Solution for Improving BER Performance of OFDM based Simple Cooperative Relaying

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Abstract—**In this paper we present a solution for improving BER performance of orthogonal frequency division multiplexing (OFDM) based simple cooperative relaying which is used for achieving 4th order diversity. The proposed solution is implemented in OFDM based simple cooperative relaying schemes with virtual orthogonal space time block coding (OSTBC) and quasi orthogonal space time block coding (QOSTBC). Each of these two schemes includes one base station with two antennas, two relay stations with a single antenna and one mobile station with a single antenna. The aim of the proposed solution is to improve bit error rate (BER) performance of the OFDM based cooperative scheme with virtual OSTBC and QOSTBC, by mapping subcarriers at relay stations (RS). It is shown that the schemes with included subcarrier mapping obviously outperform BER performance of simple cooperative relaying schemes without subcarriers mapping.**

Keywords-BER; OSTBC; QOSTBC; subcarriers mapping

I. INTRODUCTION

With ever increasing demands for multimedia services and web-related content, a high data rate is becoming one of the major features in the next generation of wireless communication systems. However, channel fading, an inherent property of wireless communication links, severely limits the increase of the data rate. Among many diversity techniques that can be used for improving communication performances and combat channel fading, spatial diversity techniques are particularly attractive since they provide diversity gain without incurring extra costs of transmission time and bandwidth.

Traditionally, spatial diversity is achieved by using multiple antennas at the transmitter and/or receiver, where the spacing among antennas is with the order of a half of wavelength. These multiple-input multiple-output (MIMO) systems are known as collocated MIMO. Because of the diversity gain, collocated MIMO architectures are effective in improving bit error rate (BER), system capacity, spectrum efficiency, energy efficiency, etc [1], [2]. Apart from being employed in a point-to-point communication link between mobile station (MS) and base station (BS), MIMO systems are also implemented in a distributed mode, with a goal to improve performance in cooperative and relay networks, where every node can be equipped with only one antenna, [3]. Further, the benefits of the collocated MIMO technique can be improved with a distributed or virtual MIMO. Problem with nodes size limitation, i.e. problem with providing sufficient space separation between antennas with a purpose to achieving uncorrelated channels can be overcome with virtual MIMO. The major difference between the virtual and collocated MIMO is that multiple antennas are distributed among widely separated nodes. In a virtual MIMO system, each node may be only equipped with one antenna.

In this paper, we present a solution for improving BER performance of OFDM based simple cooperative relaying which is used for achieving 4th order diversity. This solution is implemented in simple cooperative relaying schemes with virtual orthogonal space time block coding (OSTBC) and quasi orthogonal space time block coding (QOSTBC), [4]. We provide a detailed description of the distributed coding procedure for OSTBC and QOSTBC. Each of previously mentioned schemes assumes one BS with two antennas, two relay stations (RS) with a single antenna and one MS with a single antenna. In these 2-hop schemes, the procedure in the RSs is reduced due to omitting the coding process. None of the RSs need detection and space-time coding. Their procedure is just permutation and forwarding of the signal sequences. As a solution for improving BER performance we proposed subcarriers mapping at RSs in best to worst (BW) manner. The simulation results show that BW subcarriers mapping provides evidently better BER performance in comparison with schemes without this mapping.

This paper is composed in the following order. In Sect. 2 the simple cooperative relaying with virtual QOSTBC and OSTBC is described. The simulation results for the proposed schemes with subcarriers mapping and without it are presented in Sect. 3. Conclusions are drawn in Sect. 4.

II. SIMPLE COOPERATIVE RELAYING WITH SPACE-TIME CODING FOR ACHIEVING4TH-ORDER DIVERSITY

In this section simple cooperative relaying schemes with virtual QOSTBC and OSTBC are described.

A. A Simple Cooperative Relaying with virtual QOSTBC

QOSTB code for system with four transmit antennas is extension of Alamoutu's code for systems with two transmit antennas, [5]. QOSTB is defined with next relation, [6]:

$$QuasiOrth\mathbf{X}_4 = \frac{1}{\sqrt{4}} \begin{bmatrix} a_1 & -a_2^* & -a_3^* & a_4 \\ a_2 & a_1^* & -a_4^* & -a_3 \\ a_3 & -a_4^* & a_1^* & -a_2 \\ a_4 & a_3^* & a_2^* & a_1 \end{bmatrix} \quad (1)$$

Here, a_i, i=1,…,4, are input symbols in QOSTB encoder. Average power spent per data symbol is fixed with scaling factor of $1/\sqrt{4}$.

This QOSTB code can be virtually realized with cooperative relaying.

The system model for simple cooperative relaying with virtual QOSTBC defined with relation (1) is presented in Fig. 1. The system includes one BS, two RSs and one MS. BS is equipped with two transmit antennas, while the two RSs and MS are equipped with one antenna.

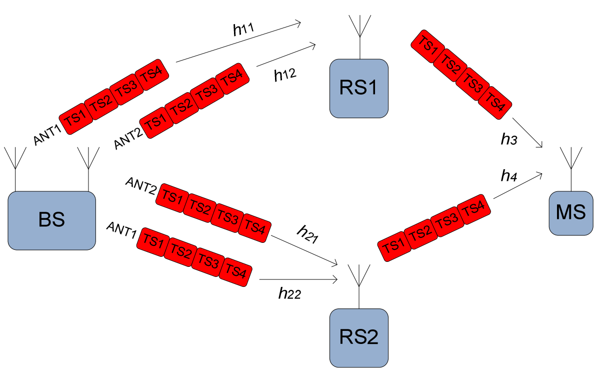

Fig. 1.Simple cooperative relaying with virtual QOSTBC

BS transmits symbol sequences and the MS receives symbol sequences via two coordinated RSs. Symbol sequences are treated as fourth order vectors. Also, it is assumed that every symbol belonging to same sequence is subject to suffering same fading.

For every four data symbols a_i, i=1,…,4, BS generates two symbol sequences. The symbol sequence transmitted from the first antenna is:

$$\begin{bmatrix} Ant1(TS_1) & Ant1(TS_2) & Ant1(TS_3) & Ant1(TS_4) \end{bmatrix} = \\ = \frac{1}{\sqrt{2}} \begin{bmatrix} a_1 & -a_2^* & -a_3^* & a_4 \end{bmatrix} \quad (2)$$

The symbol sequence transmitted from the second antenna is:

$$\begin{bmatrix} Ant2(TS_1) & Ant2(TS_2) & Ant2(TS_3) & Ant2(TS_4) \end{bmatrix} = \\ \frac{1}{\sqrt{2}} \begin{bmatrix} a_2 & a_1^* & -a_4^* & -a_3 \end{bmatrix} \quad (3)$$

Symbol sequences consist of four symbols transmitted over four time slots (TS_i, i=1,…,4). Average power spent per data symbol is fixed with scaling factor of $1/\sqrt{2}$.

The channel coefficients between the first antenna at BS (BSAnt1) and RS1, the second antenna at BS (BSAnt2) and RS1, BSAnt1 and RS2 and BSAnt2 and RS2 are h_{11}, h_{12}, h_{21} and h_{22}, respectively.

Receive symbols at RS1 in four time slots TS_i, i=1,…,4, are:

$$\begin{aligned} RS1_{in}(TS_1) &= \frac{1}{\sqrt{2}} a_1 h_{11} + \frac{1}{\sqrt{2}} a_2 h_{12} + n_{R11} \\ RS1_{in}(TS_2) &= \frac{1}{\sqrt{2}} a_1^* h_{11} - \frac{1}{\sqrt{2}} a_2^* h_{12} + n_{R12} \\ RS1_{in}(TS_3) &= \frac{1}{\sqrt{2}} - a_4^* h_{11} - \frac{1}{\sqrt{2}} a_3^* h_{12} + n_{R13} \\ RS1_{in}(TS_4) &= \frac{1}{\sqrt{2}} - a_3 h_{11} + \frac{1}{\sqrt{2}} a_4 h_{12} + n_{R14} \end{aligned} \quad (4)$$

Here, n_{R1i}, i=1,…,4, represents additive white Gaussian noise (AWGN) at RS1 in i-th TS.

RS1 generates the symbol sequence:

$$RS1_{out}(TS_i) = \frac{1}{\sqrt{2}} RS1_{in}(TS_i), \; i=1,...,4 \quad (5)$$

Average power spent per data symbol is fixed with scaling factor of $1/\sqrt{2}$.

The second relay, RS2, receives symbol sequence:

$$\begin{aligned} RS2_{in}(TS_1) &= \frac{1}{\sqrt{2}} a_1 h_{21} + \frac{1}{\sqrt{2}} a_2 h_{22} + n_{R21} \\ RS2_{in}(TS_2) &= \frac{1}{\sqrt{2}} a_1^* h_{21} - \frac{1}{\sqrt{2}} a_2^* h_{22} + n_{R22} \\ RS2_{in}(TS_3) &= \frac{1}{\sqrt{2}} - a_4^* h_{21} - \frac{1}{\sqrt{2}} a_3^* h_{22} + n_{R23} \\ RS2_{in}(TS_4) &= \frac{1}{\sqrt{2}} - a_3 h_{21} + \frac{1}{\sqrt{2}} a_4 h_{22} + n_{R24} \end{aligned} \quad (6)$$

Here, n_{R2i}, i=1,…,4 is AWGN at RS2 in TS_i.

Relay RS2, permutes the received symbol sequence, and generates output symbol sequence:

$$RS2_{out}(TS_1) = \frac{1}{\sqrt{2}}(-RS2_{in}(TS_3))^*$$
$$RS2_{out}(TS_2) = \frac{1}{\sqrt{2}}(-RS2_{in}(TS_4))^*$$
$$RS2_{out}(TS_3) = \frac{1}{\sqrt{2}}(RS2_{in}(TS_1))^*$$
$$RS2_{out}(TS_4) = \frac{1}{\sqrt{2}}(RS2_{in}(TS_2))^* \tag{7}$$

Average power spent per data symbol is fixed with scaling factor of $1/\sqrt{2}$.

The channel coefficients between RS1 and MS and RS2 and MS are h_3 and h_4, respectively. The received symbol sequence at MS is:

$$MS_{in}(TS_i) = RS1_{out}(TS_i)h_3 + RS2_{out}(TS_i)h_4 + n_{MSi},\ i=1,...,4 \tag{8}$$

Here, n_{MSi}, i=1,…,4 is AWGN at MS in TS_i.

With this cooperative relaying between BS and MS virtual, 4x1 multiple input single output (MISO) channel is created.

The main QOSTBC advantage in comparison with OSTBC is code rate. Its code rate is 1. The price for that is BER performance degradation in comparison with OSTBC. The only OSTBC with code rate 1 is Alamouti's code, which is dedicated for systems with two transmit antennas. For schemes with larger number of transmit antennas there is no full orthogonal code with code rate 1.

In the next part of this section simple cooperative relaying with virtual OSTBC is described.

B. *A Simple Cooperative Relaying with virtual OSTBC*

OSTBC for system with four transmit antennas is defined with next relation, [5]:

$$Orth\mathbf{X}_4 = \frac{1}{\sqrt{8}}\begin{bmatrix} a_1 & -a_2 & -a_3 & -a_4 & a_1^* & -a_2^* & -a_3^* & -a_4^* \\ a_2 & a_1 & a_4 & -a_3 & a_2^* & a_1^* & a_4^* & -a_3^* \\ a_3 & -a_4 & a_1 & a_2 & a_3^* & -a_4^* & a_1^* & a_2^* \\ a_4 & a_3 & -a_2 & a_1 & a_4^* & a_3^* & -a_2^* & a_1^* \end{bmatrix} \tag{9}$$

Here, a_i, i=1,…,4, are input symbols in OSTB encoder. Average power spent per data symbol is fixed with scaling factor of $1/\sqrt{8}$. As it can be seen, the code rate is 1/2.

This code can be virtually realized with cooperative relaying.

The system model for simple cooperative relaying with OSTBC defined with relation (9) is presented in Fig. 2. The system includes one BS, two RSs and one MS. BS is equipped with two transmit antennas, while the two RSs and MS are equipped with one antenna.

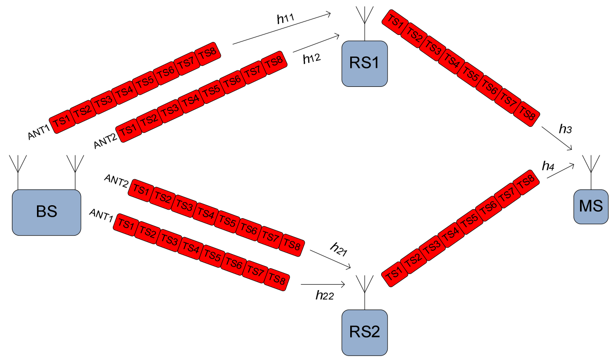

Fig. 2.Simple cooperative relaying with virtual OSTBC

As it was in previous case, BS transmits symbol sequences and the MS receives symbol sequences via two coordinated RSs. Also, it is assumed that every symbol belonging to same sequence is subject to suffering same fading.

For every four data symbols a_i, i=1,…,4, BS generates two symbol sequences. The symbol sequence transmitted from the first antenna is:

$$\left[Ant1(TS_1)\quad Ant1(TS_2)\quad ...\quad Ant1(TS_7)\quad Ant1(TS_8)\right] = = \frac{1}{\sqrt{4}}\left[a_1\quad -a_2\quad -a_3\quad -a_4\quad a_1^*\quad -a_2^*\quad -a_3^*\quad -a_4^*\right] \tag{10}$$

The symbol sequence transmitted from the second antenna is:

$$\left[Ant2(TS_1)\quad Ant2(TS_2)\quad ...\quad Ant2(TS_7)\quad Ant2(TS_8)\right] = = \frac{1}{\sqrt{4}}\left[a_2\quad a_1\quad a_4\quad -a_3\quad a_2^*\quad a_1^*\quad a_4^*\quad -a_3^*\right] \tag{11}$$

Symbol sequences consist of eight symbols transmitted over eight TS_i, i=1,…,8. Average power spent per data symbol is fixed with scaling factor of $1/\sqrt{4}$.

The channel coefficients between BSAnt1 and RS1, BSAnt2 and RS1, BSAnt1 and RS2 and BSAnt2 and RS2 are h_{11}, h_{12}, h_{21} and h_{22}, respectively.

In time slots TS_i, i=1,…,8, receive symbols at RS1 are:

$$RS1_{in}(TS_1) = \frac{1}{\sqrt{4}}a_1 h_{11} + \frac{1}{\sqrt{4}}a_2 h_{12} + n_{R11}$$
$$RS1_{in}(TS_2) = -\frac{1}{\sqrt{4}}a_2 h_{11} + \frac{1}{\sqrt{4}}a_1 h_{12} + n_{R12}$$
$$RS1_{in}(TS_3) = -\frac{1}{\sqrt{4}}a_3 h_{11} + \frac{1}{\sqrt{4}}a_4 h_{12} + n_{R13}$$
$$RS1_{in}(TS_4) = -\frac{1}{\sqrt{4}}a_4 h_{11} - \frac{1}{\sqrt{4}}a_3 h_{12} + n_{R14}$$

$$
\begin{aligned}
RS1_{in}(TS_5) &= \frac{1}{\sqrt{4}}a_1^* h_{11} + \frac{1}{\sqrt{4}}a_2^* h_{12} + n_{R15} \\
RS1_{in}(TS_6) &= -\frac{1}{\sqrt{4}}a_2^* h_{11} + \frac{1}{\sqrt{4}}a_1^* h_{12} + n_{R16} \\
RS1_{in}(TS_7) &= -\frac{1}{\sqrt{4}}a_3^* h_{11} + \frac{1}{\sqrt{4}}a_4^* h_{12} + n_{R17} \\
RS1_{in}(TS_8) &= -\frac{1}{\sqrt{4}}a_4^* h_{11} - \frac{1}{\sqrt{4}}a_3^* h_{12} + n_{R18}
\end{aligned} \tag{12}
$$

RS1 generates the symbol sequence:

$$RS1_{out}(TS_i) = \frac{1}{\sqrt{2}} RS1_{in}(TS_i),\ i=1,...,8 \tag{13}$$

Average power spent per data symbol is fixed with scaling factor of $1/\sqrt{2}$.

The second relay, RS2, receives symbol sequence:

$$
\begin{aligned}
RS2_{in}(TS_1) &= \frac{1}{\sqrt{4}}a_1 h_{21} + \frac{1}{\sqrt{4}}a_2 h_{22} + n_{R21} \\
RS2_{in}(TS_2) &= -\frac{1}{\sqrt{4}}a_2 h_{21} + \frac{1}{\sqrt{4}}a_1 h_{22} + n_{R22} \\
RS2_{in}(TS_3) &= -\frac{1}{\sqrt{4}}a_3 h_{21} + \frac{1}{\sqrt{4}}a_4 h_{22} + n_{R23} \\
RS2_{in}(TS_4) &= -\frac{1}{\sqrt{4}}a_4 h_{21} - \frac{1}{\sqrt{4}}a_3 h_{22} + n_{R24} \\
RS2_{in}(TS_5) &= \frac{1}{\sqrt{4}}a_1^* h_{21} + \frac{1}{\sqrt{4}}a_2^* h_{22} + n_{R25} \\
RS2_{in}(TS_6) &= -\frac{1}{\sqrt{4}}a_2^* h_{21} + \frac{1}{\sqrt{4}}a_1^* h_{22} + n_{R26} \\
RS2_{in}(TS_7) &= -\frac{1}{\sqrt{4}}a_3^* h_{21} + \frac{1}{\sqrt{4}}a_4^* h_{22} + n_{R27} \\
RS2_{in}(TS_8) &= -\frac{1}{\sqrt{4}}a_4^* h_{21} - \frac{1}{\sqrt{4}}a_3^* h_{22} + n_{R28}
\end{aligned} \tag{14}
$$

Relay RS2, permutes the received symbol sequence, and generates output symbol sequence:

$$
\begin{aligned}
RS2_{out}(TS_1) &= \frac{1}{\sqrt{2}}(-RS2_{in}(TS_4)) \\
RS2_{out}(TS_2) &= \frac{1}{\sqrt{2}}(-RS2_{in}(TS_3)) \\
RS2_{out}(TS_3) &= \frac{1}{\sqrt{2}} RS2_{in}(TS_2) \\
RS2_{out}(TS_4) &= \frac{1}{\sqrt{2}} RS2_{in}(TS_1)
\end{aligned}
$$

$$
\begin{aligned}
RS2_{out}(TS_5) &= \frac{1}{\sqrt{2}}(-RS2_{in}(TS_8)) \\
RS2_{out}(TS_6) &= \frac{1}{\sqrt{2}}(-RS2_{in}(TS_7)) \\
RS2_{out}(TS_7) &= \frac{1}{\sqrt{2}} RS2_{in}(TS_6) \\
RS2_{out}(TS_8) &= \frac{1}{\sqrt{2}} RS2_{in}(TS_5)
\end{aligned} \tag{15}
$$

Average power spent per data symbol is fixed with scaling factor of $1/\sqrt{2}$.

The channel coefficients between RS1 and MS and RS2 and MS are h_3 and h_4, respectively. The received symbol sequence at MS is:

$$MS_{in}(TS_i) = RS1_{out}(TS_i)h_3 + RS2_{out}(TS_i)h_4 + n_{MSi},\ i=1,...,8 \tag{16}$$

With this cooperative relaying between BS and MS, virtual 4x1 multiple input single output (MISO) channel is created and achieved 4thorder diversity.

This was a detailed description of coding procedure for simple cooperative schemes.

In the case when OFDM is implemented in previously described cooperative relaying schemes BER performance can be further improved. For the sake of improving BER performance of OFDM based simple cooperative relaying schemes we proposed subcarriers mapping at RSs in BW manner. This BW subcarriers mapping means that subcarrier on the first hop with the greatest value of $|h_{11}|^2 + |h_{12}|^2 + |h_{21}|^2 + |h_{22}|^2$ is paired with subcarrier on the second hop with the lowest value of $|h_3|^2 + |h_4|^2$, and so on.

III. Simulation Results

In this section BER performance of the OFDM based simple cooperative relaying schemes with and without proposed BW subcarriers mapping are compared.

It is assumed that the propagation conditions between BS and RSs are defined with Ricean fading statistics, while the propagation conditions between RSs and MS are defined with Rayleigh fading statistics. Also, perfect estimation of channel coefficients and no direct link between BS and MS are assumed. The information bits are mapped into QPSK symbols at the BS. The number of OFDM subcarriers is 64.

For the given Ricean channel parameter between BS and RSs, K_{dB}=4dB and 6dB, BER performance in function of signal to noise ratio (SNR) per bit, of the OFDM based simple cooperative relaying schemes with and without BW subcarriers mapping are presented in Fig. 3 and 4, respectively.

It can be seen that the simple cooperative relaying schemes with BW subcarriers mapping obviously outperforms simple cooperative schemes without BW subcarriers mapping.

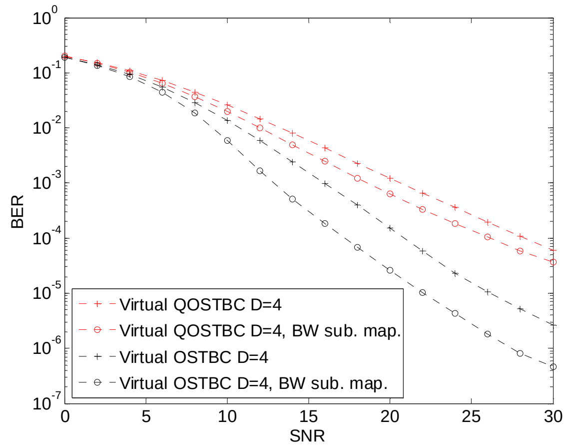

Fig. 3. BER performance of the simple cooperative relaying schemes with and without BW subcarriers mapping, K_{dB}=4 dB

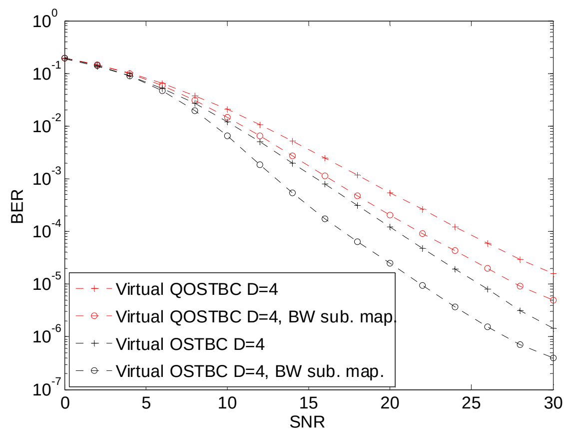

Fig. 4. BER performance of the simple cooperative relaying schemes with and without BW subcarriers mapping, K_{dB}=6 dB

From Fig. 3 we can see that for the BER value of 10^{-4} BW subcarriers mapping provides SNR gain of 2 dB in the case of simple cooperative relaying with OSTBC, while in the case of QOSTBC this SNR gain amounts 1 dB.

Also, it can be seen from Fig. 4 that with increasing the Ricean channel parameter between BS and RSs, K_{dB}, BER performance of simple cooperative relaying with QOSTBC and BW subcarriers mapping approaches to the BER performance of simple cooperative relaying with OSTBC and without BW subcarriers mapping. This is especially important because the code rate of QOSTBC is two times greater than for OSTBC. The main advantage of QOSTBC in comparison with OSTBC is its code rate, but with BER performance degradation as a price for that. The scheme with QOSTBC, BW subcarriers mapping and with two times less occupied time slots can approach to the schemes with virtual OSTBC and without subcarriers mapping, with regard to the BER performance.

IV. Conclusions

In this paper, we present a solution for improving BER performance of the OFDM based simple cooperative relaying which is used for achieving 4th order diversity. BER of the OFDM based simple cooperative relaying schemes with and without proposed BW subcarriers mapping are compared. These cooperative relaying schemes assume one BS with two antennas, two relay stations (RS) with single antenna and one MS with single antenna. For improving BER performance we proposed subcarriers mapping at RSs, in best to worst manner. In these 2-hop schemes, the procedure at the RSs is just permutation, forwarding of the signal sequences and BW subcarriers mapping. It is assumed that the propagation conditions between BS and RSs are defined with Ricean fading statistics, while the propagation conditions between RSs and MS are defined with Rayleigh fading statistics.

The simulation results show that the cooperative relaying schemes with the proposed BW subcarriers mapping has evidently better BER performance than cooperative relaying schemes without this subcarriers mapping. Also, it is shown that with increasing the Ricean channel parameter between BS and RSs, BER performance of the scheme with QOSTBC and BW subcarriers mapping approaches to the BER performance of the scheme with OSTBC and without subcarriers mapping, but with a benefit of two times less occupied time slots.

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