Mitigating interference and reducing detection complexity in asynchronous cooperative relay network utilising new distributed space time block coding

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1 | INTRODUCTION

Using cooperative communication techniques in wireless networks has been recently shown to be an efficient way to improve the robustness against channel fading, extend the network coverage and mitigating the practical issues of implementing Virtual Antenna Arrays (VAA) [1–4]. These techniques achieve significant benefit in diversity gains so-called cooperative diversity as in multi-input multi-output (MIMO) systems without requiring multiple antennas at individual terminals. This is achieved by utilising the antennas of other neighbouring terminals as relay node by sharing their physical resources through a virtual transmit and receive antenna arrays. Additionally, the idea of space time block coding (STBC) developed for MIMO system [5], has been applied in a distributed manner for cooperative relay networks and has attracted much researcher interest throughout last decade. This results in what is known as a distributed STBC (D-STBC) which significantly improve the system performance without losing any spatial diversity order (cooperative diversity) [6–10].

Moreover, the design of D-STBC for cooperative relay networks has many challenges which are different from these associated with the design of STBC for point-to-point MIMO systems. All previous existing research assume that, the perfect synchronisation exists among the relay nodes. This means that all relay nodes transmitted their signals simultaneously and the destination node will receive all transmitted signal without any delay. However, in the real world environment, it is difficult or even impossible to achieve such an assumption due to the distributed nature of cooperative relay nodes. The received signal from different relay nodes at the destination node are not continuously aligned at symbol level. Therefore,
this lack of synchronisation in time results in intersymbol interference (ISI) among the received signals at the destination node [11–14]. This will negatively impacts of the network performance and makes it difficult to exploit full cooperative diversity.

In the reported literature, there are many schemes proposed to mitigate the effects of asynchronism. However most of previous approaches have high detection complexity at the destination node. The approaches presented in [15] and [16] for mitigating the effects of asynchronism in cooperative relay networks attain the fourth order of cooperative diversity by utilising orthogonal space time block coding (OSTBC) in [15] and closed-loop quasi-orthogonal space time block coding (CL QO-STBC) in [16], respectively. However, the approach in [15] only achieves three-quarter of the full data transmission rate throughout the network with simple linear decoding processing. Although in [16] approach achieves full data transmission rate throughout the network. However, this approach requires high decoding complexity due to the feedback information needed to exploit the full cooperative diversity order. Moreover, both approaches utilise the parallel interference cancellation (PIC) detection to mitigate the effect of inter-symbol interference (ISI) among the relay nodes at the destination node. The main drawback of the PIC detection is the computational complexity which is dependent upon the number of PIC detection iteration which leads to receiver complexity at the destination node. Recently, a sub-optimum detection approach is proposed which employs new efficient distributed OSTBC structure using pre-coding matrices at the relay nodes to achieve full data transmission rate and exploits full cooperative diversity order for dual-antenna cooperative relay networks without any feedback link between the source and the destination nodes. This proposed scheme overcome all the drawback of previous works in [15–17]. It is shown that, the new distributed OSTBC structure can achieve full data rate as well as full cooperative diversity order throughout the network with fast symbol-wise maximum likelihood decoding without requiring any feedback information from the destination node as presented in previous reported work. In addition to that this sub-optimum approach is effective at eliminating the lack of synchronisation at the destination node produced by ISI between the relay nodes with low detection complexity dependent only on the constellation size.

In this proposed model the following assumptions are valid:

(i) All the fading channels in this model are assumed to be Gaussian random variable distributed with $CN(0, 1)$. The fading channel from the transmitter side to cooperative relay nodes are denoted by $f_{ij}$, while the fading channel from cooperative relay nodes to the receiver side are denoted by $g_{ij}$, where $i, j \in 1, 2$. Moreover, the direct transmission (DT) connection link between the transmitter side and the receiver side is considered and it is denoted by $b_{ij}$.

(ii) The channel state information (CSI) is assumed; thus the transmitter-relay, transmitter–receiver and relay–receiver channel coefficients are estimated perfectly at the receiver side. This can be gained by transmitting training signal from transmitting cooperative relay nodes and the receiver side [9].

(iii) The distance between each pair of antenna on each relay node is assumed to be equal to half of transmitted wavelength, and all relay nodes are subjected to half-duplex constraint.\footnote{The received signal becomes practically uncorrelated, if the antenna at relay nodes are spaced equal to half of transmitted wavelength signals and half-duplex mode means that the relay nodes cannot transmit and receive signals simultaneously [17].}

(iv) The decode-and-forward (DF) scenario is adapted at all transmitting cooperative relay nodes in this model. That means the relaying will only take place, if the received

FIGURE 1 Asynchronous wireless cooperative relay network
signals from the transmitter side are perfectly detected at the relay nodes.

(v) Due to transmitting relay nodes movement and each relay node has its independent clock. It is assumed that, the transmitting relay node (R1) is fully synchronised to the receiver side.

Assuming time-division multiplexing, the transmission producer is carried out in two phases as follows.

2.1 First phase (transmitter to relay node)

In the first phase, at the transmitter side the information signals are encoded into $s(k)=[s(1,k), ..., s(4,k)]^T$, with normalisation $E\{s(k)^Hs(k)\}=1$, where $E$ indicates the expectation of random variable and $k$ represented the discrete index. Then the transmitter side broadcasts its information signals $s(k)$ over four different transmission periods, while the relay nodes and the destination node are in receive mode as shown in Figure 2. Therefore, the equivalent signal vector received at the receiver side through DT connection link over four transmission periods can be represented as follows

$$\mathbf{r}_{id}(k) = s(k)b_{id} + \mathbf{v}_{id}(k),$$

where $\mathbf{r}_{id}(k)=[r_{id}(1,k), ..., r_{id}(4,k)]^T$ is the received signal vector and each element of $\mathbf{v}_{id}(k)=[v_{id}(1,k), ..., v_{id}(4,k)]^T$ is assumed as Gaussian noise random vector at the receiver side with distribution $CN(0,1)$. At the receiver side the least squares (LS) method is used to estimate the transmitted signal $\hat{s}_{id}(t,i)$ through DT link as follows

$$\hat{s}_{id}(t,i) = \arg\min_{s \in \mathcal{S}} |b_{id}s - s_{id}|^2,$$

where $t \in 1, 2, 3, 4$ denotes the transmission periods and $\mathcal{S}$ is the alphabet containing $M$ symbols for transmitted signals. The estimated signals in (2) can still be utilised to initialise additional processing, even if the received signals in (1) over the DT connection link deliver limited end-to-end performance. Furthermore, the signals received by each antenna of each relay node can be expressed by

$$\mathbf{r}_{ij}(k) = s(k)f_{ij} + \mathbf{v}_{ij}(k),$$

where $\mathbf{r}_{ij}(k)=[r_{ij}(1,k), ..., r_{ij}(4,k)]^T$ is the received signal vector at the relay nodes, and each element of $\mathbf{v}_{ij}(k)=[v_{ij}(1,k), ..., v_{ij}(4,k)]^T$ is assumed as Gaussian noise random vector at the relay nodes with distribution $CN(0,1)$.

2.2 Second phase (relay nodes to receiver)

Each relay node linearly transmit their received signals after rearranging them as shown in Figure 3 over four different transmission periods. While the receiver side is in receive mode and the transmitter side is in idle mode.

Therefore, the received signal vector at the receiver side is referred to $\mathbf{y}(i)$ and can be represented as

$$\begin{bmatrix} y(1,k) \\ y(2,k) \\ y(3,k) \\ y(4,k) \end{bmatrix} = \mathbf{C}_{new}(k) \begin{bmatrix} \xi_1 \\ \xi_2 \\ \xi_3 \\ \xi_4 \end{bmatrix} + \mathbf{w}(k),$$

where $\mathbf{C}_{new}(k)$ is $4 \times 4$ matrix of the new efficient OSTBC which is transmitted from each antenna of each relay node over four different transmission periods as in (5). Each element of $\mathbf{w}(k)=[w(1,k), ..., w(4,k)]^T$ is assumed to be Gaussian noise random vector at the receiver side with distribution $CN(0,1)$.

3 Construction of new distributed OSTBC

$$\mathbf{C}_{new}(k) = \begin{bmatrix} \mathbf{C}_{new}(k)^T \\ \mathbf{C}_{new}(k)^T \end{bmatrix} =$$

$$= \begin{bmatrix} i(1,k) + i(2,k) & i(1,k) - i(2,k) & 0 & 0 \\ i'(1,k) - i'(2,k) & i'(1,k) + i'(2,k) & 0 & 0 \\ i(3,k) + i(4,k) & i(3,k) - i(4,k) & 0 & 0 \\ i'(3,k) - i'(4,k) & i'(3,k) + i'(4,k) & 0 & 0 \end{bmatrix}.$$
data transmission rate among the transmitting cooperative relay nodes and the receiver side. The following steps show the producer of constructing the new codeword \( C_{\text{new}}(k) \)

(i) **STEP 1**: After the relay nodes receive the transmitted signal \( s(k) \) from the transmitter side, the DF cooperation strategy is applied at both relay nodes. Then both relay nodes preform OSTBC encoding matrix as in (6).

\[
S_{j}(i) = \begin{bmatrix}
  s_{j}(1, k) & s_{j}(2, k) & s_{j}(3, k) & s_{j}(4, k) \\
  -s_{j}^{*}(2, k) & s_{j}^{*}(1, k) & -s_{j}^{*}(4, k) & s_{j}^{*}(3, k)
\end{bmatrix}, \quad (6)
\]

(ii) **STEP 2**: Multiplying the encoding matrix \( S_{j}(i) \) at each relay node with matrices \( D_{j} \), to generate the OSTBC \( C_{\text{new}}(i) = [C_{\text{new}}^{1}(i) \ C_{\text{new}}^{2}(i)] \) of \( 4 \times 4 \) order can be represented as follows

\[
D_{j} = A \otimes M, \quad (7)
\]

where \( j \in 1, 2 \) referred to the number of transmitting cooperative relay nodes, \( \otimes \) is the Kronecker product, \( A \) is fixed unitary matrix of \( 2 \times 2 \) order used at the relay nodes and can be designed as follows

\[
A = \begin{cases}
  \begin{bmatrix}
    1 & 0 \\
    0 & 0
  \end{bmatrix} & \text{if } j = 1 \\
  \begin{bmatrix}
    0 & 0 \\
    0 & 1
  \end{bmatrix} & \text{if } j = 2
\end{cases}, \quad (8)
\]

and \( M \) is the Hadamarad matrix of \( 2 \times 2 \) order and can be represented as

\[
M = \begin{bmatrix}
  1 & 1 \\
  1 & -1
\end{bmatrix}. \quad (9)
\]

**Definition 1** (Kronecker product): If \( A \) is \( m \times n \) matrix and \( M \) is a \( p \times q \) matrix then the Kronecker product of \( A \otimes M \) is \( mp \times np \) block matrix.

**Definition 2** (Hadamard matrix): An \( n \times n \) matrix \( M \) with all entries +1 or -1 and \( MM^{T} = nI_{n} \) is called Hadamard matrix of order \( n \), where \( M^{T} \) is the transpose of \( M \) and \( I_{n} \) is the order \( n \) identity matrix. The generating matrix of \( C_{\text{new}}(k) \) at each relay node can be expressed as

\[
C_{\text{new}}(k) = S_{j}(i)D_{j}, \quad (10)
\]

**Theorem**: An OSTBC is linear space time block coding \( C_{\text{new}}^{j}(i) \) that has the following unitary property \( C_{\text{new}}^{j}(i)C_{\text{new}}^{j}(i)^{T} = \sum_{j=1}^{2} 2|s_{j}|^2 \sum_{q=a}^{b} 2|s_{q}|^2 \sum_{q=a}^{b} 2|s_{q}|^2 \sum_{q=a}^{b} 2|s_{q}|^2 I_{4} \), where \( I_{4} \) is identity matrix of order 4.

(iii) Finally, The new codeword matrix \( C_{\text{new}}(k) \) in (10) is designed to achieve a property which enables the receiver side to detect the transmitted signal \( s(k) \) by a simple linear signal processing operation without requiring any closed-loop feedback scheme as in [16] and [17]. This new codeword achieves both full data rate and full cooperative diversity order of \( 2K \). The new distributed codeword formed at the receiver side has the same form as that represented in (5).

### 4 | NEW DISTRIBUTED OSTBC UNDER IMPERFECT SYNCHRONISATION

In this section, the new distributed OSTBC in (5) is considered in asynchronous cooperative scenario as represented in Figure 4. As stated earlier in Section 2, after successfully decoding of the received signal from the transmitter side. The relay nodes contracted and re-encoded the new distributed OSTBC as in (5) and then the resulting matrix code of \( C_{\text{new}}(i) \) in (5) is effectively forward to the receiver side in four different time transmission periods. The transmitted signal \( C_{\text{new}}^{j}(t, k) \) are transmitted from antennas of \( R_{1} \), while, the transmitted signal \( C_{\text{new}}^{j}(t, k) \) are transmitted from antennas of \( R_{2} \), where \( j \in 1, 2 \) denotes number of antennas and \( t \in 1, 2, 3, 4 \) denotes number of transmission period.

As mentioned earlier, due to the issues such as relay nodes movement and transmission delays, the exact synchronisation among relays nodes is difficult to achieve. Consequently, the full cooperative diversity order cannot be attained, and the system performance degradation is presented. This lack of synchronisation occurs among the received signals at the receiver side damages the orthogonality of broadcasted matrix code in (5). However, the perfect synchronisation among the relay node \( R_{1} \) and the receiver side is considered as reference. Therefore, the received signal in (4) can be re-written as follows

\[
y(t, k) = \sum_{j=1}^{2} C_{\text{new}}^{1j}(t, k)g_{1j} + \sum_{j=1}^{2} C_{\text{new}}^{2j}(t, k)g_{2j} + I(t, k) + w(t, k), \quad (11)
\]

where \( w(t, k) \) is assumed as Gaussian noise random variable over four different transmission periods at the receiver side distributed with \( CN(0, 1) \), and \( I(t, k) \), represented the ISI at the
receiver side and it can be expressed as follows
\[
I(1, k) = \sum_{j=1}^{2} C_{w^2j}(4, k-1)g_{2j}^{-1},
\]
(12)
and
\[
I(t, k) = \sum_{j=1}^{2} C_{w^2j}(t, k)g_{2j}^{-1},
\]
(13)
where \(t \in \{2, 3, 4\}\) and the coefficient of \(g_{2j}^{-1}\) reflects the time misalignments among the transmitting cooperative relay nodes. The amount of imperfect synchronisation \(g_{2j}^{-1}\) can be modelled as follows [15–17]
\[
\hat{g}_{2j} = g_{2j}^{-1} \quad \text{for} \quad j \in \{1, 2\}.
\]
(14)
By substituting (5) into (11) and applying the complex conjugate to received signals in the second and the fourth transmission periods. The received signal at receiver side node can be modelled as in (17) and the interference term in (12) and (13) can be represented as follows
\[
I(1, k) = s^* (3, k-1)(g_{21}^{-1} - g_{22}^{-1}) - s^* (4, k-1)(g_{21}^{-1} + g_{22}^{-1}),
\]
(15)
\[
I^*(4, k) = s^* (3, k)(g_{21}^{-1} + g_{22}^{-1}) + s^* (4, k)(g_{21}^{-1} - g_{22}^{-1}),
\]
(16)
Both sides of the received signal in (17) are multiplied by matched filter \(H^H\). Therefore, the estimated signals at receiver side can be expressed as follows
\[
\begin{bmatrix}
\hat{y}(1, k) \\
\hat{y}^*(2, k) \\
\hat{y}(3, k) \\
\hat{y}^*(4, k)
\end{bmatrix} = H^H \begin{bmatrix}
y(1, k) \\
y^*(2, k) \\
y(3, k) \\
y^*(4, k)
\end{bmatrix} = \Delta + H^H \begin{bmatrix}
w(1, k) \\
w^*(2, k) \\
w(3, k) \\
w^*(4, k)
\end{bmatrix},
\]
(18)
where \(\Delta = H^H H\) is a \(4 \times 4\) Grammian matrix and can be represented by
\[
\Delta = \begin{bmatrix}
\lambda_1 & 0 & 0 & 0 \\
0 & \lambda_1 & 0 & 0 \\
0 & 0 & \lambda_2 & 0 \\
0 & 0 & 0 & \lambda_2
\end{bmatrix},
\]
(19)
where \(\lambda_1 = 2(\sum_{k=1}^{2} |g_{2i}|^2)\) and \(\lambda_2 = 2(\sum_{k=1}^{2} |g_{2i}|^2)\) are the conventional channel gain for four transmit antenna. The resulting instantaneous received SNR at the receiver side for each symbol is given by
\[
\text{SNR} = \frac{\lambda_1 + \lambda_2}{4 \sigma_w^2}.
\]
(20)
Therefore, full cooperative diversity order of \(2R\) as well as full data transmission rate can be achieved with this a new distributed OSTBC approach. However, due to \(H^H I(k)\) term in (18), the system performance degradation and the above conventional detection will fail to obtain the full cooperative diversity gain of \(2R\) as in (19). The sub-optimum detection scheme is introduced in the following section to eliminate \(H^H I(k)\) term in (18) and achieve the desired channel gain.

5 | IMPROVED SUB-OPTIMUM DETECTION WITH NEW DISTRIBUTED OSTBC

In this section, the proposed scheme so-called sub-optimum detection is introduced to overcome synchronisation issue between transmitting cooperative relay nodes. It can be used to combat the interference term of \(H^H I(k)\) in (18), where
$s^i(3, k - 1)$ and $s^o(4, k - 1)$ are known if the detection procedure has been adjusted correctly [15–17]. Therefore, the interference term $I(1, k)$ in (15) can be removed before applying the linear transformer in (18). Therefore, the linear transformer process in (18) can be re-written as follows

\[
\hat{s}(k) = H^H y(k) \\
= \Delta s(k) + \Phi(k) + w(k),
\]

where

\[
\Phi = \begin{bmatrix}
\phi(1, k) \\
\phi(2, k) \\
\phi(3, k) \\
\phi(4, k)
\end{bmatrix} = H^H \begin{bmatrix}
0 \\
0 \\
0 \\
I^s(4, k)
\end{bmatrix}.
\]

Thus, (21) can be re-written as follows

\[
\hat{y}(t, k) = \lambda_1 s(t, k) + w(t, k) \quad \text{if} \quad t \in 1, 2,
\]

and

\[
\hat{y}(t, k) = \lambda_2 s(t, k) + \phi(t, k) + w(t, k) \quad \text{if} \quad t \in 3, 4,
\]

where

\[
\phi(3, k) = \phi_3 I^s(4, k) \quad \text{where} \quad \phi_3 = g_{21} - g_{22},
\]

\[
\phi(4, k) = \phi_4 I^s(4, k) \quad \text{where} \quad \phi_4 = -g_{21} - g_{22}.
\]

The estimated transmitted signals from DT link connection in (2) is next used to prepare only $\hat{s}(4, k) = \hat{s}_{sd}(4, k)$. ‘The reliability of these decisions is not critical to the performance of final detector next defined’ [17]. Therefore, The estimate of transmitted signal $\hat{s}(t, k) = [\hat{s}(1, k), ..., \hat{s}(4, k)]^T$ can be estimated by using LS detection approach as follows.

\[
\hat{s}(t, k) = \arg \min_{s, m \in S} \|\hat{y}(t, k) - \lambda_1 s_m\|^2 \quad \text{if} \quad t \in 1, 2,
\]

and

\[
\hat{s}(t, k) = \arg \min_{s, m \in S} \|\hat{y}(t, k) - \lambda_2 s_m - \phi(t, k)\|^2 \quad \text{if} \quad t \in 3, 4,
\]

where $\phi(3, k)$ in (23) can be re-written as follows to detect transmitted signal $\hat{s}(3, k)$

\[
\phi(3, k) = \phi_3 \left(s^o(\delta_{21}^{-1} + \delta_{22}^{-1}) + s^o(4, i)(\delta_{21}^{-1} - \delta_{22}^{-1})\right).
\]

Finally, by substituting $\hat{s}(3, k)$ in (24), when $t = 4$ to detect transmitted signal $\hat{s}(4, k)$, therefore the term $\phi(4, k)$ in (24) can be re-written as follows

\[
\phi(4, k) = \phi_4 \left(s^o(3, k)(\delta_{21}^{-1} + \delta_{22}^{-1}) + s^o(4, i)(\delta_{21}^{-1} - \delta_{22}^{-1})\right).
\]

It can be seen that from the above analysis, the detection complexity of sub-optimum scheme is low by using the innovative distributed OSTBC approach, and also this new approach does not require any feedback information from the receiver side to achieve full cooperative diversity order of $2R$ as compared with the approaches in [15] and [16].

6 | SIMULATION RESULTS

In this section, the simulation results also shows how the synchronisation error can cause a degradation in the BER performance. In this section, the bit probability performance of the new proposed scheme is investigated in asynchronous cooperative relay network. All channels are considered to be quasi-static fading channels. In each simulation figure, the horizontal axis shows the ratio of signal power to the noise power SNR and vertical axis shows the percentage of bits that have errors relative to the total number of bits received at the receiver side BER. SNR has been defined as $\text{SNR} = \frac{\sigma_n^2}{\sigma_i^2}$, and all transmitting cooperative relay antennas transmit at $\frac{1}{2R}$, where $R$ denotes the total number of transmitting cooperative relay nodes. Furthermore, all simulation results, which are presented in this section, are simulated by utilising the quadrature phase shift keying (QPSK) mapping scheme.

The simulation result in Figure 5, illustrates the BER performance of the new proposed scheme in the case of perfect synchronisation (PS) combined with and without received signal
through DT connection link. Moreover, the open-loop scheme for QO-STBC in [16] and [17] are included as reference. It can be observed from Figure 5, the new proposed approach including and not including the received signals through DT connection link are provided performance improvement over the distributed open-loop QO-STBC in [16] and [17]. For example, to reach BER at $10^{-3}$, the new proposed approach including received signals through DT connection link requires approximately 9 dB and approximately 14 dB without including receiver signals through DT connection link. While, the distributed open-loop QO-STBC approach in [16] and [17] requires approximately 32 dB. Therefore, this figure illustrates that when the SNR region between 6 dB and 40 dB the BER performance of the new proposed approach including DT connection link is considerably smaller by 23 dB than the BER performance distributed open-loop QO-STBC scheme.

Figures 6 and 7 illustrates the impact of synchronisation errors as result of changing the value of $\beta_{2k}$, which indicates the effect of time delay $\tau_{2j}$ from relay node $R_2$ at the receiver side and it can be computed as demonstrated in Table 1, where $j \in 1, 2$, indicates the number of antennas on each transmitting cooperative relay node.

Figure 6 presents the simulation result of the new proposed approach under imperfect synchronisation, also including PS as a reference. This figure shows that new distributed OSTBC is not effective in presence of synchronisation error even under insignificant time misalignments which corresponds to $\beta_{2k} = -6$ dB.

Figure 7 shows that the average BER performance of the proposed sub-optimum decoding scheme is greatly enhanced compared to conventional detector under imperfect synchronisation even under large time misalignments $\beta_{2k} = 6$ dB. For example, at average BER $10^{-3}$, approximately 15 dB of SNR is essential in the case of PS, nevertheless, in the case of sub-optimum detection approximately 16 dB of SNR is required when $\beta_{2k} = -6$ dB, approximately 17 dB of SNR is required when $\beta_{2k} = -3$ dB and approximately 19 dB, 21 dB and 33 dB is required when $\beta_{2k} = 0, 3, 6$ dB, respectively.

### Table 1

| $\beta_{2k}$ [dB] | $10(\beta_{2k}/10)$ | $\tau_{2k}$ |
|------------------|---------------------|-------------|
| 6                | 4                   | 2T          |
| 3                | 2                   | T           |
| 0                | 1                   | 0.5T        |
| -3               | 0.5                 | 0.25T       |
| -6               | 0.25                | 0.125T      |

### 7 CONCLUSION

A new distributed OSTBC employing sub-optimum detection scheme has been developed and evaluated in asynchronous wireless cooperative relay network. The new design of distributed OSTBC and the use of two dual-antenna at each relay node both contributed to minimise the inter-symbol interference at the destination node. The proposed scheme has been shown that the complexity of decoding is reduced by using only linear decoding process at the receiver side. Moreover, with no need for feedback information, both full cooperative diversity order of $2R$ and data transmission rate are attained as compared to existing approaches. Analysis of the simulation results showed that the sub-optimum approach with new distributed OSTBC is very effective at dealing with inter-symbol interference with low detection complexity process at the receiver side.
REFERENCES

1. Dohler, N.: Virtual Antenna Arrays - The Dawn of Cooperative Communications, 1st ed. Scholars’ Press (2014)
2. Choi, Y., Hong Lee, J.: A new cooperative jamming technique for a two-Hop Amplify-and-forward relay network with an eavesdropper. IEEE Trans. Veh. Technol. 67(12), 12447–14451 (2018)
3. Liu, Q., Leow, C.: Successive user relaying in cooperative NOMA system. IEEE Wireless Commun. Lett. 8(3), 921–924 (2019)
4. Darsena, D., et al.: Design and performance analysis of multiple-relay cooperative MIMO networks. IEEE J. Commun. Netw. 21(1), 25–32 (2019)
5. Alamouti, S.: A simple transmit diversity technique for wireless communications. IEEE J. Sel. Areas Commun. 16(8), 1451–1458 (1998)
6. Jing, Y., Jafarkhani, H.: Using orthogonal and quasi-orthogonal designs in wireless relay networks. IEEE Trans. Inf. Theory 53(11), 4106–4118 (2007)
7. Ikki, S., Ahmed, M.: Performance analysis of generalized selection combining for decode-and-forward cooperative-diversity networks. In: IEEE 72nd Vehicular Technology Conference (VTC), pp. 1–5. IEEE, Piscataway (2010)
8. Choi, M., et al.: Cooperative UAV networks based on distributed space-time block code. In: IEEE 13th International Conference on Ubiquitous Robots and Ambient Intelligence (URAL), pp. 454–458. IEEE, Piscataway (2016)
9. Liu, Y., et al.: Distributed space-time coding based on the self-coding of RLI for full-duplex two-way relay cooperative networks. IEEE Trans. Signal Process. 65(12), 3036–3047 (2017)
10. Zhong, F., et al.: Distributed linear convolutional space-time coding for two-hop full-duplex relay 2 X 2 X 2 cooperative communication networks. IEEE Trans. Wirel. Commun., 17(5), 2857–2868 (2018)
11. Zhang, X., Jafarkhani, H.: Asynchronous network coding for multiuser cooperative communications. IEEE Trans. Wirel. Commun. 16(12), 8250–8260 (2017)
12. Wang, H.: Full-diversity uncoordinated cooperative transmission for asynchronous relay networks. IEEE Trans. Veh. Technol. 66(1), 468–480 (2017)
13. Xiong, Y., et al.: Cooperative network synchronization: Asymptotic analysis. IEEE Trans. Signal Process. 66(3), 757–772 (2018)
14. Wang, J., et al.: Distributed space time block transmission and QRD based diversity detector in asynchronous cooperative communications systems. IEEE Trans. Veh. Technol. 67(6), 5111–5125 (2018)
15. Zheng, F., et al.: Distributed space time block coding for 3 and 4 relay nodes: Imperfect synchronisation and a solution. In: IEEE 18th International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), pp. 1–5. IEEE, Piscataway (2007)
16. Elazreg, A., et al.: Distributed closed-loop quasi-orthogonal space time block coding with four relay nodes: Overcoming imperfect synchronization. In: IEEE 5th International Conference on Wireless and Mobile Computing Networking and Communication (WiMob), pp. 320–325. IEEE, Piscataway (2009)
17. Elazreg, A., Kharaz, A.: Sub-optimum detection scheme for distributed closed-loop quasi orthogonal space time block coding in asynchronous cooperative two dual-antenna relay networks. In: Wireless Internet. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol. 146, pp. 217–228. Springer, Cham (2015)

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