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| Abstract | The use of cooperative relay allows for spatial diversity or multiplexing in the multi-hop network and benefits the inter relay handoff greatly due to the “virtual cell” concept. Adaptive Distributed Space Time/frequency Coding (ADSTC) is proposed and preferred for cooperative relaying due to its simplicity and its alignment with legacy 802.16. Two alternative approaches are also given: Interleaving based Macroscopic MIMO (IM-MIMO) and Collaborative Uplink Spatial Multiplexing (CUSM). |
| Purpose | [Description of what the author wants 802.16 to do with the information in the document.] |
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# Cooperative Relay Approaches in IEEE 802.16j

## I. Introduction

Cooperative relaying is principally a macroscopic or distributed multiple-in-multiple-out (MIMO) system in multi-hop environments. Multiple Relay Stations (RS) work collaboratively as a virtual array to improve signal quality or data rate, owing to spatial diversity or multiplexing respectively. Furthermore, cooperative relaying potentially simplifies handoff between RSs.

In this distributed MIMO system, factors such as path loss and shadow fading have great impact on available diversity or spectrum efficiency. The intention of this proposal is to find efficient solutions to cooperative relaying.

## II. System Description

Spatial diversity or multiplexing is expected to improve performance or throughput by means of cooperative relaying, as shown in Figure 1. This mechanism can apply to multiple hops in the relaying based network.

In this proposal, we first propose Adaptive Distributed Space Time Coding (ADSTC) method with minimum additional complexity introduced to the legacy 802.16 Base Station (BS). ADSTC is an adaptive selection of localized STC and distributed STC, and applies to both uplink and downlink for spatial diversity exclusively. The alternative approaches are also provided: Interleaving based Macroscopic MIMO (IM-MIMO) and Collaborative Uplink Spatial Multiplexing (CUSM). IM-MIMO is featured with the availability of either spatial diversity or multiplexing in both links, while only spatial multiplexing is available in uplink of CUSM.

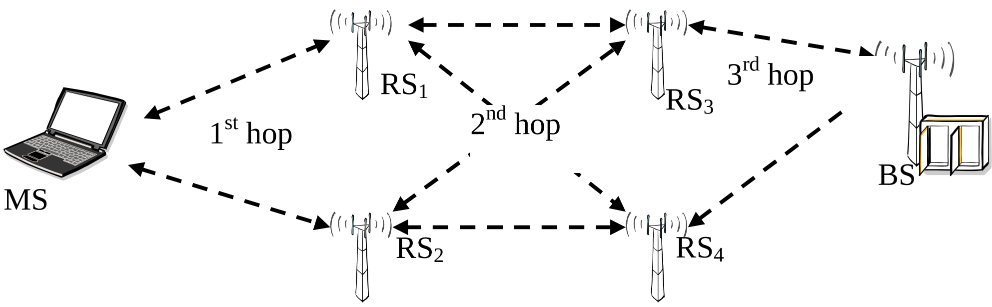


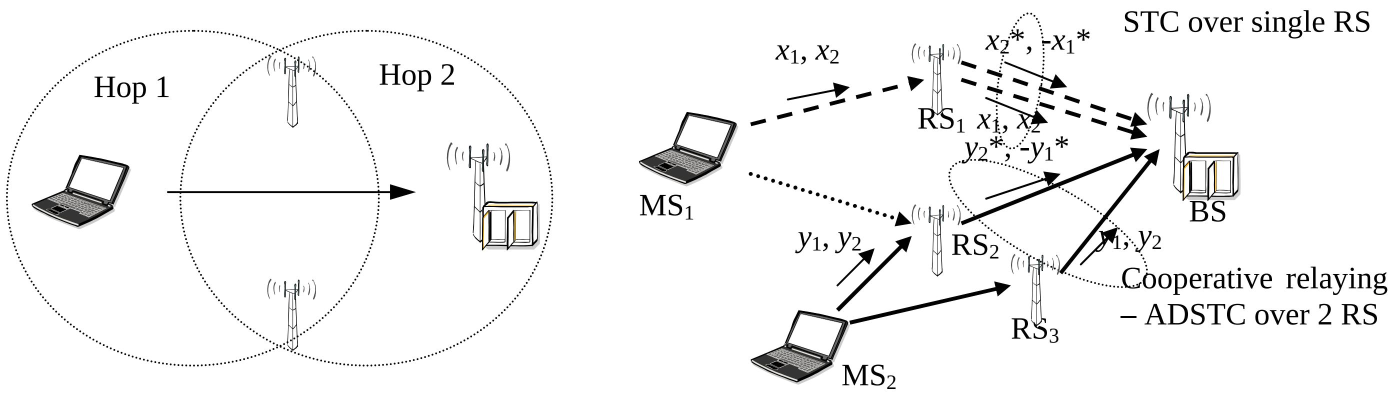

Fig. 1: Cooperative relay in multi-hop wireless networks

### 1. ADSTC

In this idea, neither the need to update the Mobile Stations (MS) nor significant modification of physical layer in the BS is required. RSs work as remote antennas of the BS and the MS. For example, the MS in Figure 2(a) transmits signals to two RSs and consequently these RSs forward signals cooperatively to the BS by using ADSTC techniques in the uplink.

For simplicity, the following description takes the Alamouti code for an example, but the other STC or space-frequency code (SFC) schemes is all supported in both uplink and downlink.

However, the RSs are not co-located which has impacts on the performance of ADSTC. The theoretical and mathematical analysis reveals that no diversity gain is available if received powers of RSs are seriously unbalanced. Furthermore, the symbol-level synchronization between the cooperative RSs is required according to the definition of space-time code.




(a) Virtual remote antenna array (b) A 2-hop uplink example of ADSTC

Fig. 2: ADSTC for cooperative relaying

With the concern of power balance and synchronization, the BS selects localized STC or distributed STC for cooperative relaying as illustrated in Figure 2(b). Criteria, i.e. the maximum SNR criterion, can be used to make the decision of approach selection and power control.

This scheme can be easily extended to the scenario with more hops.

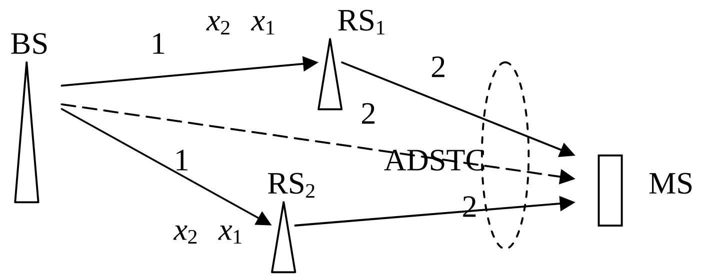



Fig.3: ADSTC method for the last hop in downlink

Figure 3 illustrates a downlink application example of the proposed ADSTC method for the last hop. In this example, the BS broadcasts signals that are going to be relayed to the MS at Phase ①.

During Phase ②, the involved RSs (potentially together with the BS by coherent combining or pre-coding) transmit signals to the MS cooperatively for diversity gain.

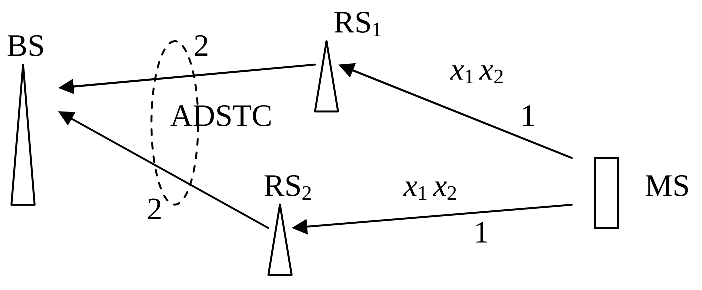



Fig.4: ADSTC method for the last hop in uplink

Figure 4 gives an uplink example corresponding to Figure 3, where the cooperation between the MS and the RSs is optional like that involving the BS.

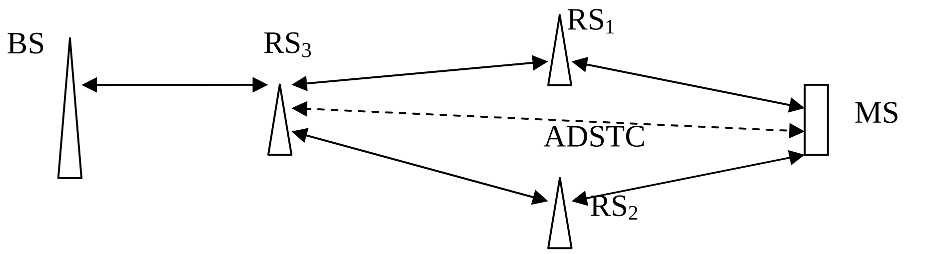



Fig. 5: ADSTC method for networks beyond two hops

Another application scenario of ADSTC is the Multi-Points-to-Point (MP2P) case as illustrated in Figure 5 where ADSTC is used not only for the last hop but also for the intermediate backhauling hops. By this idea, higher spatial diversity is expected for better performance and consequently improves capacity potentially.

As a summary of ADSTC, it is preferred generally because of its simplicity and its transparency to the MS. ADSTC is fully in alignment with existing IEEE 802.16e and no significant update on the physical layer of the BS is necessary.

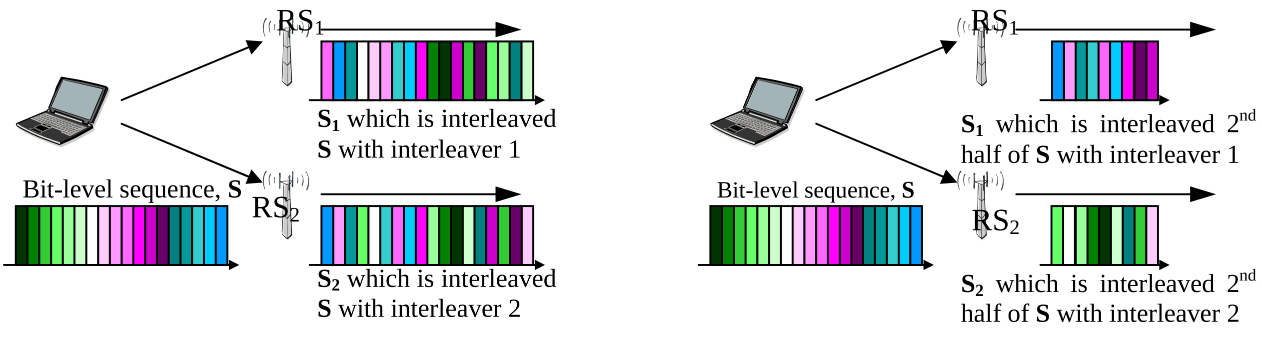
**2. Alternative Proposal (a): IM-MIMO**

If iterative detection/decoding can be employed at the BS and the RSs, IM-MIMO is an alternative scheme for cooperative relaying. In this scheme, bit-level interleaving that is regarded as a non-orthogonal STC acts as the signature waveform to identify and differentiate RSs similar to the IDMA [4] concept. The uplink transmission is illustrated in Figure 6.

Figure 6(a) explains how to achieve spatial diversity through this scheme. In this case, RSs within intermediate hops forward received signals simply after distinctly interleaving. So, in the receivers of this hop, "$S_1$" and "$S_2$" are detected separately as independent sources and then combined for spatial diversity.

Figure 6(b) illustrates the implementation of spatial multiplexing. With some predefined segment approach, each RS forwards some unique parts of received signals. By this means, resources for relaying are expected to decrease greatly. Similar to the case of diversity, reception and detection of signals from cooperative RSs are separate and after that concatenation is performed to retrieve original datum. Due to this efficient signature waveform, interference is suppressed ideally and the iterative detection can provide a performance almost the same as that of the non-interference case.

A mixed use of these two cases is also permitted and then both diversity and multiplexing are available simultaneously. As illustrated in Figure 7, this scheme can be employed in non-MS hops.




(a) The pattern for spatial diversity (b) The pattern for spatial multiplexing

Fig. 6: The principle of IM-MIMO

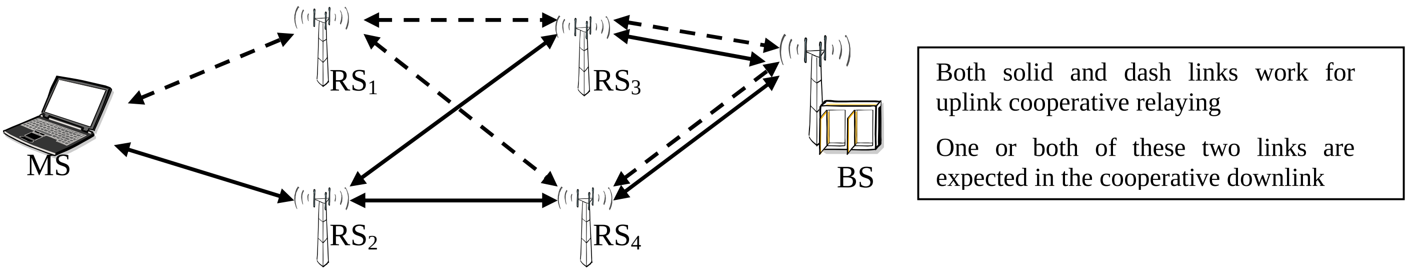



Fig. 7: Multi-hop cooperative relaying with IM-MIMO

The computational complexity is low (less then $O(n^2)$ [4]), especially if the number of cooperative RSs is small, i.e. 2 or 3. Furthermore, benefiting from separate detection of multiple relay stations, strict synchronization is not required.

**3. Alternative Proposal (b): CUSM**

The principle behind CUSM is utilizing spatial multiplexing to achieve higher data rate. Figure 8 illustrates a 2-hop example of the CUSM scheme.

In the second hop of Figure 8, the RSs are paired to comprise a CUSM transmission where two data streams are transmitted simultaneously through the identical radio resource. Then the BS detects spatially multiplexed data streams by using the classical spatial multiplexing detection algorithms.

The use of CUSM allows for the balance of the transmission capabilities between the first and the second hops. Since spatial correlation is likely to be weak, spatial multiplexing is a good solution to increase capacity. This scheme is also fully compliant with legacy 802.16 systems.

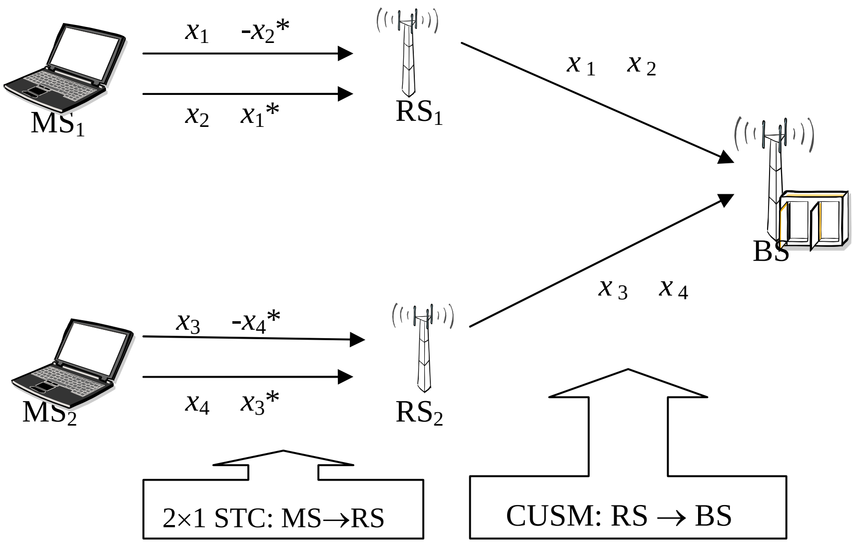



Fig.8: The illustration of CUSM

## III. Summary

In this document, cooperative relaying mechanisms are proposed on the purpose of achieving spatial diversity, multiplexing or both. With these schemes, RSs can work collaboratively for either better performance or higher data rate.

# IV. Proposed Text [3]

++++++++++++++++++++ *Start text proposal* ++++++++++++++++++++++

**6.3.2.3.62 Cooperative diversity configuration for RS (RS-CDC) message**

*[Change Table 109z as follows]*

Table 109z – RS-CRC message format

| Syntax | Size | Notes |
|---|---|---|
| RS-CRC_Message_Format( ) { | | |
| Management Message Type = 67 ? | 8 bits | |
| CRC Mode | 2 bits | 0b 00 indicates ADSTC<br>0b 01 indicates IM-MIMO<br>0b 10 indicates CUSM<br>0b 11 null |
| Antenna Assignment | 4 bits | Bit #0: Antenna #0<br>Bit #1: Antenna #1<br>Bit #2: Antenna #2<br>Bit #3: Antenna #3 |
| RS Encoding Method | 1 bit | If CRC Mode = 0b01<br>{<br>0b0 = Diversity mode<br>0b1 = Multiplexing mode<br>}<br>else {<br>0b0 = No encoding<br>0b1 = Encoding<br>} |
| Multiplexing Mode | 1 bits | If CRC Mode = 0b01 and RS Encoding Method = 0b1 or CRC Mode = 0b10<br>{<br>0b0 = First half<br>0b1 = Second half<br>} |
| } | | |

An MR-BS shall generate RS-CDC message in the form shown in Table 109z, including the following parameters:

*[Insert new paragraph as follows]*

**CRC Mode**

Indicates which cooperative relaying approach should be applied. For example, if this field is a 0b00, this RS shall use ADSTC.

**RS Encoding Method**

*[Insert new paragraphs at the end of this one]*

Diversity Mode means in case of IM-MIMO, the cooperative RSs/BS transmit simultaneously the totally same signal through the time-frequency resource for spatial diversity; Multiplexing Mode represents the different parts of the packet are transmitted simultaneously by the cooperative RSs/BS for multiplexing in the case of IM-MIMO.

Multiplexing Mode is activated only if the cooperative RSs work under IM-MIMO or CUSM for multiplexing, and it indicates which part to be transmitted in each RS/BS.

*[Change subclause 8.4.8.10]*

**8.4.8.10 Cooperative Relaying**

Cooperative relaying is principally a distributed MIMO system and can be applied to either access or relay links. ~~Cooperative relaying~~ It can be achieved within an MR-BS cell with BS and RS transmit cooperation, in the same manner as macro diversity with neighboring BS. It is possible to achieve diversity and multiplexing, and the pilot collision problem by sending correlated signals across different BS and RS transmit antennas during the transmission of a burst to a particular MS. Furthermore, cooperative relaying provides smooth handover between RSs. ~~The three modes of this operation are cooperative source diversity, cooperative transmit diversity, and cooperative hybrid diversity.~~

Adaptive Distributed Space Time Coding (ADSTC) method is a simple approach for cooperative relaying and it is an adaptive selection between localized STC and distributed STC. Diversity is available and maximized after the selection between distributed STC and localized STC. ADSTC applies to either uplink or downlink between multiple RSs or between the MR-BS and RSs. The three modes of this operation are cooperative source diversity, cooperative transmit diversity, and cooperative hybrid diversity.

In the following description, the transmission considered is the final hop from the multiple antennas at the BS/RS to the MS. For cooperative source diversity, the antennas simultaneously transmit the same signals using the same time-frequency resource. The cooperative transmit diversity mechanism uses STBC-encoded signals across the transmitting antennas using the same time-frequency resources (refer to Section 8.4.8 for a list of valid STBCs). Cooperative hybrid diversity uses a combination of source and transmit diversity. These three mechanisms can also be used in some relay links in both uplink and downlink.

Interleaving based Macroscopic MIMO (IM-MIMO) is an alternative for cooperative relaying, under the condition that iterative detection/decoding can be employed at the MR-BS and the RSs. In this scheme, bit-level interleaving that is regarded as a non-orthogonal STC acts as the signature waveform to identify and differentiate RSs.

Another alternative approach is Collaborative Uplink Spatial Multiplexing (CUSM). A pair of RSs is organized to comprise a CUSM transmission where two data streams are transmitted simultaneously to the destination, e.g. MR-BS, through the identical time-frequency resource. Then the MR-BS detects spatially multiplexed data streams by using the classical spatial multiplexing detection algorithms, so that higher data rate can be achieved.

These mechanisms can each be further subdivided into two categories describing the processing requirement at the RS. The relayed data at the RS may not require processing, which we have called Full Encoding (i.e. during the backhaul hop, the BS transmits the exact signals for the RS to relay). Alternatively, the relayed data at the RS may require some local processing, which we have called Half encoding (the backhaul hop contains uncoded data, and the RS decodes and re-encodes the data according to the STBC in use). In this last category, each RS shall be notified of its virtual antenna number(s).

+++++++++++++++++++++ *End of text proposal* ++++++++++++++++++++++