
Agenda Item: 15.3
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Title: Spatial Multiplexing of Type-2 L1 and L2 Relays
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1 Introduction

This contribution proposes spatial multiplexing of type-2 [1] L1 and L2 relays. The L1 relay has the advantage of negligible delays [2] and the L2 relays can make the end-to-end link between eNodeB and UE more efficient [3]. The proposal further takes advantage of the extra antenna space and HARQ buffer capacity offered by the relay node (RN) to release the UE frequency-time resources that would be otherwise consumed by HARQ retransmissions. The hybrid L1/L2 relay effectively increases the rank of the UL MIMO system and is fully backward compatible with Rel-8 UE's.

2 System Description

The communication nodes under consideration include an eNodeB, an RN and a certain number of UE's. An L1 relay process does not demodulate the signal that is being relayed; hence it only involves amplify-and-forward operation. We further assume that the RN is

- (1) capable of monitoring downlink control signalling from the eNodeB to UE's,
- (2) aware of which UE to be amplified and forwarded,
- (3) capable of decoding the UE signal that was being amplified and forwarded,
- (4) capable of communicating its decoding success/failure with the eNodeB before the eNodeB sends ACK/NAK to UE,
- (5) able to re-encode previously decoded packets and spatially multiplex them with the UE signal under amplification and forwarding, and
- (6) able to receive the eNodeB ACK/NAK to the UE plus another special indicator to the RN itself.

The process of applying the adaptive amplify-and-forward operation with the above RN capabilities is called advanced hybrid L1/L2 relay.

The system is described as follows. The channel between the eNodeB and the RN is assumed to be relatively stable, i.e., the channel can be estimated by a relatively infrequent sounding, as illustrated in Figure 1..

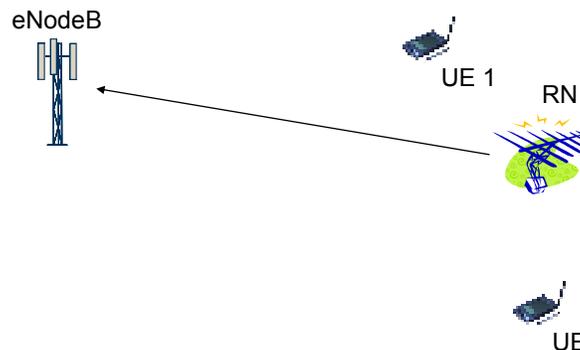


Figure 1: eNodeB learns RN's actual CSI without being affected by its sources

The channel response matrices involved in the advanced hybrid L1/L2 relay are denoted in Figure 2.

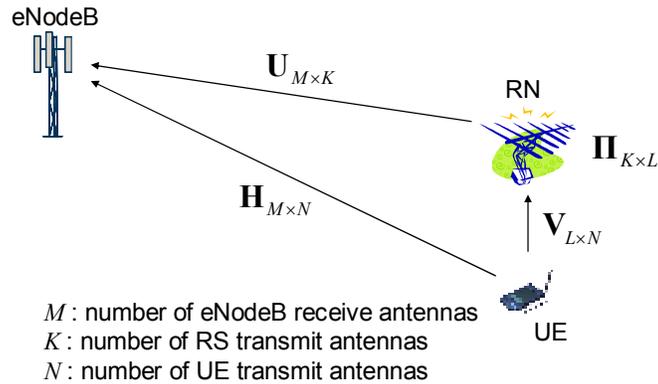


Figure 2: Mathematical notation of channel response matrices

As depicted in Figure 1, the eNodeB learns $\mathbf{U}_{M \times K}$ from the RN signals without relaying any UE's, and the eNodeB may inform the RN a certain form of the channel state information (CSI) $\mathbf{U}_{M \times K}$. If the DL and UL channels have reciprocal properties, such as in TDD systems, the CSI may be inferred solely by the RN itself.

Note that dimensions of the RN receive and transmit antennas can be different. As shown in Figure 2, the MIMO channel matrix between UE and RN is denoted by $\mathbf{V}_{L \times N}$, the number of RN receive antennas by L , and the receive-to-transmit antenna coupling by $\mathbf{\Pi}_{K \times L}$. Without loss of generality, we assume that the number of RN receive antennas is equal to that of RN transmit antennas in the sequel, i.e., $K = L$, since it is straightforward to generalize the result to unequal receive and transmit antenna dimensions.

One important step for the advanced hybrid L1/L2 relay is to learn which UE is being scheduled and controlled by the eNodeB. This can be accomplished by the RN monitoring eNodeB controlling signals to UE's. The RN generally has good reception conditions and hence can be assumed to decode all eNodeB signals at a reasonably high successful rate. This is illustrated in Figure 3.

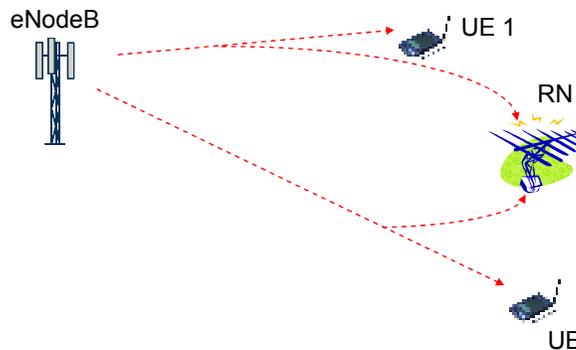


Figure 3: RN monitoring eNodeB control and scheduling signal to UE's

In this case, the RN is acting as a friendly eavesdropper of control and scheduling signals. It uses the obtained knowledge to decode the UE signals, as illustrated in Figure 4.

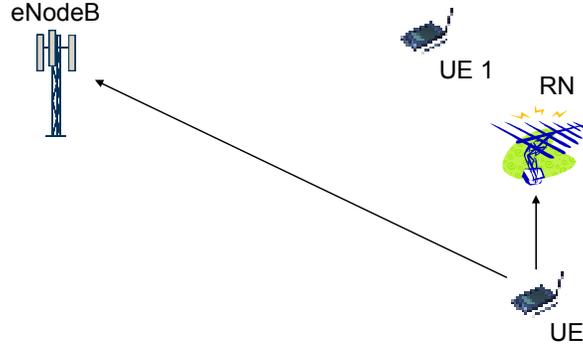


Figure 4: RN monitors and decodes the scheduled UE signal

In the situation depicted in Figure 4, the channel matrices $\mathbf{H}_{M \times N}$ and $\mathbf{V}_{K \times N}$ (defined in Figure 2) can be estimated by the eNodeB and the RN, respectively. When the UE in Figure 4 is scheduled for transmission, the RN can, at the same time, perform amplify-and-forward operation on received UE signal. This is illustrated in Figure 5.

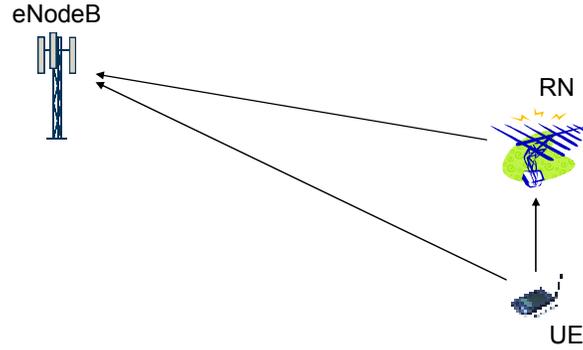


Figure 5: eNodeB schedules UE whose CSI is known to RN. RN performs amplify-and-forward and forms a composite transmitter

The amplify-and-forward operation in the L1 relay is characterized by the total MIMO matrix channel from the UE to the eNodeB via the RN. It is described next mathematically by using the notation in Figure 2. The RN signal component received at the eNodeB is denoted by

$$\mathbf{y}_{M \times 1}^{(RN)} = \mathbf{U}_{M \times K} \cdot \mathbf{\Pi}_{K \times K} \cdot \mathbf{V}_{K \times N} \cdot \mathbf{P}_{N \times D} \cdot \mathbf{d}_{D \times 1}$$

where $\mathbf{d}_{D \times 1}$ is the data symbol and $\mathbf{P}_{N \times D}$ is the precoder matrix. The UE signal component received at the eNodeB is denoted by

$$\mathbf{y}_{M \times 1}^{(UE)} = \mathbf{H}_{M \times N} \cdot \mathbf{P}_{N \times D} \cdot \mathbf{d}_{D \times 1}$$

The simple L1 relay is summarized in Figure 6.

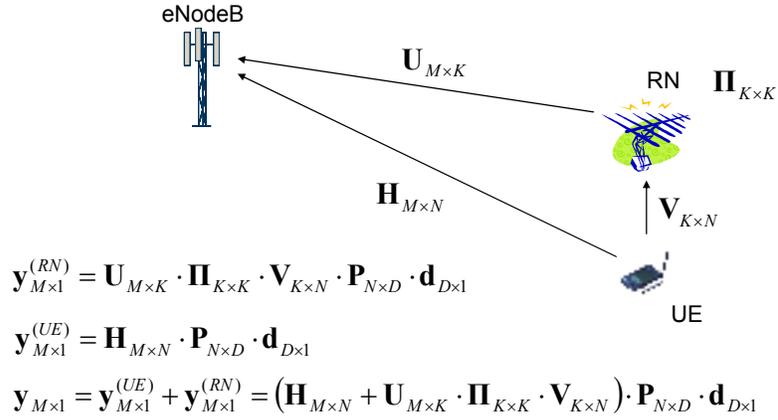


Figure 6: Simple L1 relay

3 Hybrid L1/L2 Relay

In addition to the simple L1 relay, the increased UL antenna dimension can be used for spatial multiplexing with a rank larger than the UE antenna dimension. In this case, the RN is acting as an external buffer for past unsuccessful UE packets. This is especially useful in an HARQ process because the retransmission can be sent from the RN and multiplexed spatially with new UE packets without consuming additional frequency and time resources. This is described as follows.

As the first step, the UE is scheduled by the eNodeB to transmit an initial packet. The RN, after its amplify-and-forward operation, also demodulates the signal and decodes the packet, at the same time as the eNodeB. There are possible four results from the RN and the eNodeB decoding.

1. Both RN and eNodeB fail, as illustrated in Figure 7.

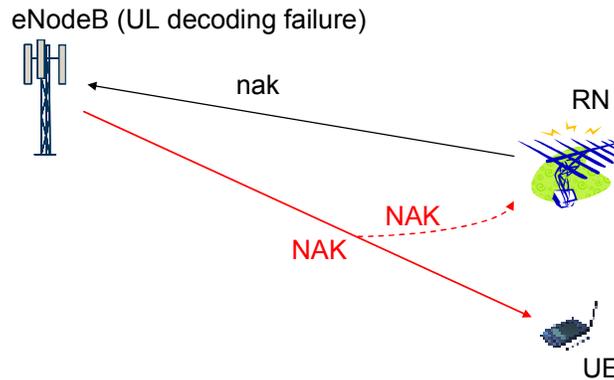


Figure 7: The eNodeB sends NAK after failing to decode the UE packet and receiving nak from the RN at the same time

In this case, the RN sends a nak indication (the lower case is to distinguish from the eNodeB ACK/NAK) to the eNodeB before the eNodeB decides its PHICH transmission. After receiving the RN nak, the eNodeB sends NAK to the UE and the UE continues the conventional HARQ retransmission. Note that the RN can perform HARQ soft combining similar to the eNodeB to increase its success probability in the next transmission. The RN provides diversity in HARQ decoding.

2. Both RN and eNodeB succeed in decoding, as illustrated in Figure 8.

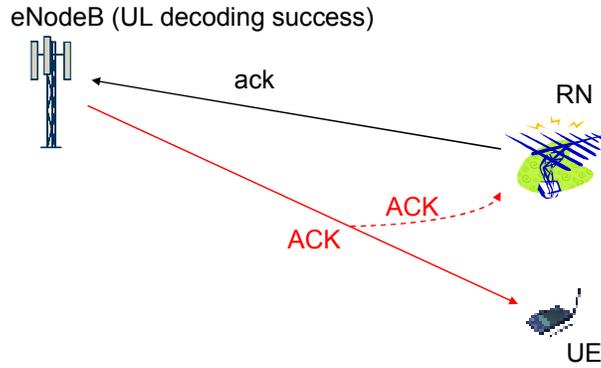


Figure 8: The eNodeB sends ACK after decoding the UL packet. The HARQ instance ends.

In this case, the RN sends an ack indication to the eNodeB and the eNodeB will send ACK on PHICH. The HARQ instance ends as the UL packet has been successfully received.

3. The eNodeB succeeds in decoding the UL packets while the RN fails, as illustrated in Figure 9.

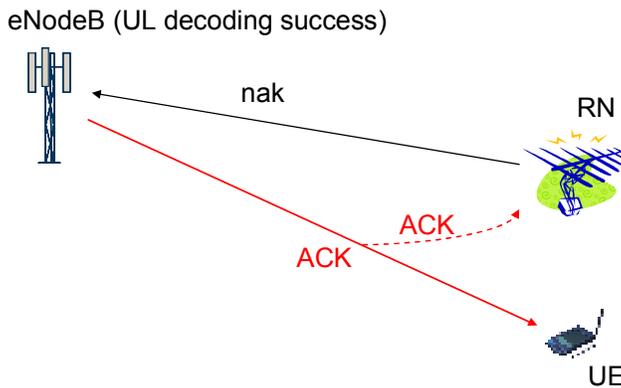


Figure 9: The eNodeB sends ACK after decoding the UL packet, although the RN fails. The HARQ instance ends.

In this case, the RN sends a nak indication to the eNodeB but the eNodeB will decide to send ACK on PHICH anyway. The HARQ instance ends as the UL packet is already received. The RN will clear its soft value buffer since there will be no more UE retransmission.

4. The eNodeB fails but the RN succeeds in decoding the UL packet. This is illustrated in Figure 10.

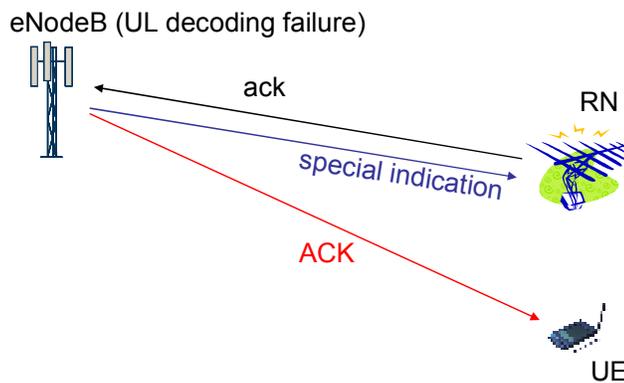


Figure 10: The eNodeB sends an ACK after failing to decode the UL packet but receiving the RN ack. The HARQ instance ends for the UE but the retransmission is taken over by the RN.

In this case, the RN sends an ack indication to the eNodeB before the eNodeB decides what to send on PHICH. Although the eNodeB itself fails to decode the packet, upon receiving the ack from the RN it will send an ACK on PHICH to UE to terminate the UE HARQ. At the same time, the eNodeB sends a special indicator to the RN that the RN shall take over the remaining HARQ retransmission in lieu of the UE. The mathematical expression of the joint RN HARQ retransmission (L2-relay) and UE packet amplify-and-forward (L1-relay) is given next.

We define, In addition to the mathematical notation in Figure 2,

$\mathbf{d}'_{D' \times 1}$: data from RN-stored UE packet for retransmission

$\mathbf{P}''_{K \times D'}$: precoder matrix for RN stored retransmission

D' : rank of RN stored retransmission, assuming $K > D$, $D' < K - D$

Then the hybrid L1/L2 MIMO relay results in a received signal at the eNodeB as follows

$$\mathbf{y}_{M \times 1} = \begin{bmatrix} \mathbf{U}_{M \times K} & \mathbf{H}_{M \times N} \end{bmatrix} \begin{bmatrix} \mathbf{P}''_{K \times D'} & \mathbf{P}'_{K \times D} \\ \mathbf{O}_{N \times D'} & \mathbf{P}_{N \times D} \end{bmatrix} \begin{bmatrix} \mathbf{d}'_{D' \times 1} \\ \mathbf{d}_{D \times 1} \end{bmatrix}$$

where the eNodeB assigns a dimension- $(K + N)$ precoder matrix that multiplexes the L1-relay data $\mathbf{d}_{D \times 1}$ and the L2-relay data $\mathbf{d}'_{D' \times 1}$, with the total UL MIMO rank of $(D + D')$. The matrix $\mathbf{P}'_{K \times D}$, which represents the UE precoding of $\mathbf{d}_{D \times 1}$ distorted by the UE-to-RN channel, is mathematically expressed as

$$\mathbf{P}'_{K \times D} = \mathbf{\Pi}_{K \times K} \cdot \mathbf{V}_{K \times N} \cdot \mathbf{P}_{N \times D}$$

As a result, the MIMO system for the advanced hybrid L1/L2 relay including eNodeB, RN, and UE becomes

$$\begin{aligned} \mathbf{y}_{M \times 1} &= \begin{bmatrix} \mathbf{U}_{M \times K} & \mathbf{H}_{M \times N} \end{bmatrix} \begin{bmatrix} \mathbf{P}''_{K \times D'} & \mathbf{P}'_{K \times D} \\ \mathbf{O}_{N \times D'} & \mathbf{P}_{N \times D} \end{bmatrix} \begin{bmatrix} \mathbf{d}'_{D' \times 1} \\ \mathbf{d}_{D \times 1} \end{bmatrix} \\ &= \begin{bmatrix} \mathbf{U}_{M \times K} & \mathbf{H}_{M \times N} \end{bmatrix} \begin{bmatrix} \mathbf{P}''_{K \times D'} & \mathbf{\Pi}_{K \times K} \cdot \mathbf{V}_{K \times N} \cdot \mathbf{P}_{N \times D} \\ \mathbf{O}_{N \times D'} & \mathbf{P}_{N \times D} \end{bmatrix} \begin{bmatrix} \mathbf{d}'_{D' \times 1} \\ \mathbf{d}_{D \times 1} \end{bmatrix} \end{aligned}$$

In the special case where the RN does not perform L1 relay, the RN coupling matrix $\mathbf{\Pi}_{K \times K}$ is set to zero.

The process of extending the UL MIMO rank beyond the number of UE antennas N to a maximum of $(N + K)$ by including the RN antenna space is summarized in Table 1.

Table 1: Summary of extending UL MIMO rank beyond the number of UE antennas with the antenna space and stored UE packets at the RN

Result of decoding current UE UL packets at eNodeB and RN		RN intermediate action	Feedback from eNodeB		Actions of different nodes		
UE→eNodeB	UE→RN	RN→eNodeB	eNodeB→UE	eNodeB→RN	eNodeB	RN	UE
Pass	Pass	ack	ACK	--	HARQ instance ends. RN, UE, eNodeB clears HARQ buffer		
Pass	Fail	-- (nak)	ACK	--			
Fail	Fail	-- (nak)	NAK	--	Regular HARQ continues as if only eNodeB and UE exist		
Fail	Pass	ack	ACK	special indicator	Schedule a new UL UE packet	Multiplex the new UL UE packet under L1 relay with HARQ reTx of previous packets stored at the RN	Transmit the new UL packet

Note: The lower case ack/nak and the special indicator are new overhead channels between eNodeB and RN. The lower case is used to distinguish from the existing eNodeB-UE PHICH. The "--" represents a possibility, not a restriction, of using on-off signaling for less interference.

Since the MIMO channel matrix $\mathbf{U}_{M \times K}$ is known to the eNodeB, the channel knowledge between the RN and the eNodeB does not require UE specific pilots. That is, utilizing the RN-to-eNodeB link for increased UL MIMO rank is done with full backward compatibility without introducing new reference signals in the UE UL transmission. The UE remains RN-agnostic.

4 Conclusions

In this contribution, we propose a spatially multiplexed type-2 L and L2 relays with help of the additional antenna space and HARQ buffer from the RN to increase the rank of UL MIMO. The proposal is fully backward compatible with legacy UE's and satisfies the requirement of type-2 relay [1]. With additional HARQ indicator channels between the RN and the eNodeB, the hybrid L1/L2 relay releases frequency-time resources that would be otherwise consumed by UE HARQ retransmission. The released frequency-time resources can be effectively used for improving system capacity.

5 References

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