Abstract—The area of wireless cooperation/relaying has recently been significantly enriched by the ideas of wireless network coding (NC), which bring substantial gains in spectral efficiency. These gains have mainly been demonstrated in scenarios with two-way relaying. Inspired by the ideas of wireless NC, recently we have proposed techniques for coordinated direct/relay (CDR) transmissions. These techniques embrace the interference among the communication flows to/from direct and relayed users, leveraging on the fact that the interference can be subsequently canceled. Hence, by allowing simultaneous transmissions, spectral efficiency is increased. In our prior work, we have considered CDR with non-regenerative relay that uses Amplify-And-Forward (AF). In this paper we consider the case of regenerative Decode-And-Forward (DF) relay. This refers also to joint decoding of the interfering flows received over a multiple-access channel. Our analysis shows that the assumption of regenerative relaying brings new parametrization of the CDR schemes, such that the transmission times used by each node are subject to optimization. We show how these parameters should be chosen if the sum-rate needs to be optimized. Our results confirm the high gains in spectral efficiency over the reference schemes.

Index Terms—Cooperative communications, relaying, analog network coding, interference cancelation, a priori information.

I. INTRODUCTION

Recently there have been extensive studies on cooperative, relay-based transmission schemes for extending cellular coverage or increasing diversity. Several basic relaying transmission techniques have been introduced, such as amplify-and-forward (AF) [3], decode-and-forward (DF) [4] and compress-and-forward (CF) [5]. These transmission techniques have been applied in one-, two- or multi-way relaying scenarios.

In particular, two-way relaying scenarios [1], [2], [6] have attracted a lot of attention, since it has been demonstrated that in these scenarios one can apply techniques based on NC in order to obtain a significant throughput gain. There are two basic principles used in designing throughput-efficient schemes with wireless NC: (1) aggregation of communication flows - NC operates by having the flows sent/processed jointly; (2) intentional cancellable interference: flows are allowed to interfere over the wireless channel, knowing a priori that the interference can be cancelled by the destination.

Using these insights, in [11] we have proposed schemes, depicted on Figs. 1 and 2 for traffic scenarios that are more general than the usual two-way relaying. These schemes are termed coordinated direct/relay (CDR) transmissions. In the scheme on Fig. 1, termed $S_1$, U receives downlink traffic from the BS, while V sends uplink traffic to the BS. For the scheme $S_1$ (Fig. 2, these traffic patterns are inverted), in the first step the BS transmits to the relay RS. In the second step, RS transmits to U and simultaneously V transmits to the BS. The reception of V’s signal at BS is interfered by the transmission of RS, however, since BS knows the signal of RS a priori, it can cancel it and get a “clean” message from V. Enabling such simultaneous transmissions improves the spectral efficiency. In scheme $S_2$, in the first step BS sends to V and simultaneously U sends to RS, such that RS receives interference of these two signals, such as in analog NC for two-way relaying. But, unlike two-way relaying, the signal sent by RS in the second step need only be decoded at BS, but not at U. This makes the link RS-U irrelevant and, as we will see later, deflecting the traffic to go BS-V instead of BS-RS-U, and combining it with the traffic U-RS-BS, can give advantages in the sum-rate.

In [11] we have considered RS that uses Amplify-and-Forward (AF). In this paper we consider schemes in which RS decodes the signals that it needs to relay. We will see that such an assumption significantly complicates the analysis compared to the AF operation, since the choice of the duration of different phases in the schemes $S_1$, $S_2$ is subject to optimization. In this paper, the optimization objective is the sum-rate for each of the respective schemes. In addition, we discuss the relation to the two-way relaying schemes with decoding at the relay and show the rate advantages brought by the generalized traffic patterns.

This paper is organized as follows. Section II describes the system model. The reference and CDR schemes are described and analyzed in Section III. Section IV presents the numerical results and the relation to the two-way relaying. Section V concludes the paper.

II. SYSTEM MODEL

We consider a scenario with one base station (BS), one relay (RS), and two users (U and V), see Fig. 1. All transmissions have a unit power and normalized bandwidth of 1 Hz. Each of the complex channels $h_i, i \in \{1, 2, 3, 4\}$, is reciprocal, known at the receiver. All the channels are known at BS. We use the following notation, with a slight abuse: $x_i$ may denote a packet or a single symbol, and it will be clear from the context. For example, the packet that BS wants to send to U is denoted by $x_1$; but if we want to express the received signal, then we use expressions of type $y = hx_1 + z$, where all variables denote symbols (received, sent, or Additive White Gaussian Noise (AWGN) noise $z \sim \mathcal{CN}(0, \sigma^2)$). We introduce further
Fig. 1. Time slots in Reference (a) and CDR $S_1$ Schemes (b, c).

notation: $x_4$ is the packet sent from BS to V, while the packets that BS needs to receive are $x_3$ from U and $x_2$ from V. Note that the example on Fig. 1 does not show traffic patterns that involve $x_3$ and $x_4$, but they are used on Fig. 2.

The direct channel BS–U is assumed weak and U gets the information from BS only through the decoded/forwarded signal from RS. If the reception of $x$ is additionally interfered by $w$, then the received signal is $y = h_i x + h_j w + z$. Denoting the capacity function as $C(\gamma) = \log_2(1 + \gamma)$, we can write the capacity of such a transmission as $C_{i-j} = C\left(\frac{|h_i|^2}{|h_i|^2 + \sigma^2}\right) = C\left(\frac{g_i}{g_i + 1}\right)$ with $g_i = \frac{|h_i|^2}{\sigma^2}$. In case there is no interfering signal the capacity is $C_i = \log_2(1 + g_i)$. If the receiver jointly decodes $x$ and $w$, the maximal sum rate for these two signals is $C_{ij} = \log_2(1 + g_i + g_j)$. It is straightforward to see that $C_{ij} = C_{ji} = C_i + C_j - C_{i-j}$.

In each scheme, the total time length is $2N$ symbols. $R_{U_i}$ and $R_{V_i}$, $i \in \{E, S_1, S_2\}$ are maximal rates for U and V respectively in scheme i. $E$ denotes the reference scheme, all schemes will be described in the next part. The sum-rate is therefore estimated as $R_{sum} = R_{U_i} + R_{V_i} = \frac{1}{2N}(D_{U_i} + D_{V_i})$, where $D_{U_i}, D_{V_i}$ represent the corresponding number of bits. The transmission for the direct user has a duration of $\lambda N$ symbols. In the following part, we analyze the choice of $\lambda$ with respect to the optimization of the sum-rate.

III. REFERENCE AND CDR SCHEMES

A. Reference Scheme

BS first transmits $x_1$ to RS, RS decodes $x_1$ and transmits it to U (see Fig. 1 (a)). V after that transmits $x_2$ to BS. Since the V–BS transmission’s length is pre-defined as $\lambda N$ symbols and all transmissions are performed separately, the total time length for U is therefore $(2 - \lambda)N$. We denote the number of symbols in the RS–U transmission as $\mu N$. The maximal data sent through the BS–RS, RS–U and V–BS transmissions are respectively $D_{U_1}^{E_1} = (2 - \lambda - \mu)NC_1$, $D_{U_2}^{E} = \mu NC_2$, $D_{V}^{E} = \lambda NC_3$. The total data transmitted for two users is

$$R_{sum} = \min(D_{U_1}^{E_1}, D_{U_2}^{E} + D_{V}^{E})$$

Since $D_{V}^{E}$ does not depend on $\mu$, $D_{U_2}^{E}$ is a decreasing function and $D_{U_1}^{E_1}$ is an increasing function of $\mu$, in order to get maximal $R_{sum}^E$, $\mu$ is selected such that $D_{U_1}^{E_1} = D_{U_2}^{E}$. Solving this equation we have the optimal $\mu = \mu_{opt}^E = \frac{(2 - \lambda)C_1}{C_1 + C_2}$. The data for U and V are respectively $D_{U_i}^{E} = (2 - \lambda)NC_1 + \lambda NC_2$, $D_{V}^{E} = \lambda NC_3$. The sum-rate is $R_{sum}^E = \frac{(2 - \lambda)C_1C_2 + \lambda NC_3}{2(C_1 + C_2)}$.

B. CDR Scheme 1

BS first transmits $x_1$ to RS (see Fig. 1 (b, c)). After that RS decodes $x_1$ and transmits it to U. In the meantime, V transmits $x_2$ to BS. The length of the transmission for the direct user, which is the V–BS transmission here, is pre-defined as $\lambda N$ symbols. Denote the number of symbols in the RS–U transmission as $\mu N$. Since BS and RS cannot transmit and receive at the same time, the BS–RS transmission cannot be performed simultaneously with any other transmission. Because the RS–U and V–BS transmissions do not completely coincide, the length of the BS–RS transmission is thus determined as $(2 - \max(\mu, \lambda))N$. In the following, we estimate the optimal value of $\mu$ for a pre-defined value of $\lambda$. Since BS knows $x_1$ thus BS cancels the contribution of $x_1$ in the received signal. The total data sent through the BS–RS, RS–U and V–BS transmissions are respectively

$$D_{U_1}^{S_1} = (2 - \max(\mu, \lambda))NC_1$$

$$D_{U_2}^{S_1} = \min(\mu, \lambda)NC_2 + (\mu - \min(\mu, \lambda))NC_2$$

$$D_{V}^{S_1} = \lambda NC_3$$

The total data for two users is therefore $R_{sum}^{S_1} = \min(D_{U_1}^{S_1}, D_{U_2}^{S_1}) + D_{V}^{S_1}$. Similar to Reference Scheme, since $D_{V}^{S_1}$ does not depend on $\mu$, $D_{U_2}^{S_1}$ is a decreasing function and $D_{U_1}^{S_1}$ is an increasing function of $\mu$, in order to get maximal $R_{sum}^{S_1}$, $\mu$ is selected such that $D_{U_1}^{S_1} = D_{U_2}^{S_1}$. We estimate optimal $\mu$ and sum-rate by considering two following cases:

- If $\mu \geq \lambda$: $D_{U_1}^{S_1} = (2 - \mu)NC_1$, $D_{U_2}^{S_1} = \lambda NC_2 + (\mu - \lambda)NC_2$. We set

$$D_{U_1}^{S_1} = D_{U_2}^{S_1}$$

and get $\mu = \mu_{opt}^{S_1} = \frac{C_1C_2 - C_3}{C_1 + C_2 - C_3}$. Condition $\mu \geq \lambda$ is satisfied when $\lambda \geq \lambda_0^{S_1} = \frac{C_1C_2 - C_3}{C_1 + C_2 - C_3}$.

$$R_{sum}^{S_1, \mu \geq \lambda} = \frac{\min(D_{U_1}^{S_1}, D_{U_2}^{S_1}) + D_{V}^{S_1}}{2N} = \frac{1}{2N}(\frac{(2 - \lambda)C_1 + \lambda NC_3}{2(C_1 + C_2)}).$$

- If $\mu < \lambda$: $D_{U_1}^{S_1} = (2 - \lambda)NC_1$, $D_{U_2}^{S_1} = \mu NC_2 - 4$. We set

$$D_{U_1}^{S_1} = D_{U_2}^{S_1}$$

and get $\mu = \mu_{opt}^{S_1} = \frac{(2 - \lambda)C_1}{C_1 - 4}$. Similar to the previous case, condition $\mu < \lambda$ is satisfied when $\lambda < \lambda_0^{S_1}$.

$$R_{sum}^{S_1, \mu < \lambda} = \frac{(2 - \lambda)C_1 + \lambda NC_3}{2}. $$

Solving $R_{sum}^{S_1, \mu \geq \lambda} \geq R_{sum}^{S_1, \mu < \lambda}$, we can get $\lambda \geq \lambda_0^{S_1}$. Thus in summary, we have

$$R_{sum}^{S_1} = \begin{cases} R_{sum}^{S_1, \mu \geq \lambda} & \text{if } \lambda \geq \lambda_0^{S_1} \\ R_{sum}^{S_1, \mu < \lambda} & \text{if } \lambda < \lambda_0^{S_1}. \end{cases}$$
Fig. 2. Time slots in CDR Scheme \( S_2 \).

\[ (2 - \max(x, \lambda))N \]

\[ (2 - \max(x, \lambda))N \]

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\[ (2 - \max(x, \lambda))N \]

C. **CDR Scheme 2**

First U transmits \( x_3 \) to RS in \( \mu N \) symbols and BS transmits \( x_4 \) in \( \lambda N \) symbols simultaneously (see Fig. 2). It is not necessary that the U–RS and V–BS transmissions completely coincide. During the first \( \min(\mu, \lambda)N \) symbols, both U and BS transmit. Denote the rates from U and from BS in this period as \( R_U \) and \( R_V \) respectively. \( R_U \) and \( R_V \) are selected such that RS can decode both

\[ R_U \leq C_2, \quad R_V \leq C_1, \quad R_U + R_V \leq C_{12} \]  

(5)

and V can decode \( x_4 \) treating \( x_3 \) as noise

\[ R_V \leq C_{3-4}. \]  

(6)

After that, if \( \mu > \lambda \), BS stops transmitting and U turns to transmit with rate \( C_2 \), the maximum rate over the U–RS channel achieved with no interference. Conversely, if \( \mu < \lambda \), U stops transmitting and BS transmits with rate \( C_3 \), the maximum rate over the BS–V channel achieved with no interference. Since BS and RS cannot transmit and receive at the same time, the RS–BS transmission cannot be performed simultaneously with any other transmission, it starts only after the first \( \max(\mu, \lambda)N \) symbols are finished. RS thus transmits \( x_3 \) to BS in \( (2 - \max(\mu, \lambda))N \) symbols.

The data transmitted in U–RS, RS–BS and BS–V transmissions are respectively

\[ D_{U_1}^{S_2} = \min(\mu, \lambda)R_U N + (\mu - \min(\mu, \lambda))C_2 N \]

\[ D_{U_2}^{S_2} = (2 - \max(\mu, \lambda))C_1 N \]

\[ D_{V}^{S_2} = \min(\mu, \lambda)R_V N + (\lambda - \min(\mu, \lambda))C_3 N. \]  

(7)

The total data transmitted \( D_{sum}^{S_2} = \min(D_{U_1}^{S_2}, D_{U_2}^{S_2}) + D_{V}^{S_2} \). With a pre-defined \( \lambda \), we derive \( \mu, R_U, R_V \) which give the highest \( D_{sum}^{S_2} \). Denote the set containing \( (R_U, R_V) \) points satisfying the conditions (5) and (6) are \( A_1 \) and \( A_2 \) respectively. \( A_1 \) here is pentagonal \( OO_3O_4O_5O_8 \) in Fig. 3 and \( A_2 \) is all the area below the line \( R_V = C_{3-4} \). The optimizing problem can be summarized as

\[ D_{sum}^{S_2} = \max_{0 \leq \mu \leq 2} \left( (R_U, R_V) \in A_1 \cap A_2 \right) D_{sum}^{S_2}. \]  

(8)

There are three different rate regions \( A_1 \cap A_2 \) corresponding to three cases in Fig. 3 (a) \( OO_1O_4O_6O_8 \) if \( C_{3-4} \leq C_1 \), (b) \( O0_3O_4O_5O_8 \) if \( C_{1-2} \leq C_{3-4} \), and (c) \( OO_3O_4O_5O_8 \) if \( 0 < C_{3-4} < C_{1-2} \).

Because \( D_{sum}^{S_2} \) is an increasing function of \( R_U \) and \( R_V \), it is straightforward to see that it achieves its maximum at a point in the line segment \( O_4O_6 \) because from this point we cannot move further to the right or higher. We therefore consider only points \( (R_U, R_V) \) in this line segment. These points satisfies the equation \( R_U + R_V = C_{12} \). Hence \( R_V \) can be written in terms of \( R_U \) as \( R_V = C_{12} - R_U \) with \( R_U \) varying correspondingly in one of the three regions \( [C_{2-1}, C_2], [C_{12} - C_{3-4}, C_{12}], [C_{2}, C_{3}] \). By substituting \( R_V \) to \( D_{sum}^{S_2} \) and re-arranging, we have

\[ D_{sum}^{S_2} = \min(D_{U_1}^{S_2}, D_{U_2}^{S_2}) + D_{V}^{S_2} \]

\[ = \min[\min(\mu, \lambda)N(R_U - C_2) + \mu NC_2, \]

\[ (2 - max(\mu, \lambda))NC_1] \]

\[ + \min(\mu, \lambda)N(C_{12} - C_3 - R_U) + \lambda NC_3. \]  

(9)

Maximizing this function for general channels is cumbersome because we have to consider several cases therefore we make some assumptions as follow which are close to a practical case \( C_{1-2} < C_{3-4} < C_1 \) (case (b) in Fig. 3) and \( C_{12} > C_3 \). This is because RS and BS are designed so as the channel between them \( (\gamma_1) \) is large and typically larger than the channel between V and BS \( (\gamma_2) \). Moreover, the channel between two mobile users \( (\gamma_3) \) is small and typically smaller than the channel between U and RS \( (\gamma_2) \). In summary, we need to find

\[ D_{sum}^{S_2} = \max_{\mu \in [0, 2]} \left( R_U \in [C_{12} - C_{3-4}, C_{12}] \right) D_{sum}^{S_2}. \]  

(10)

Because \( D_{sum}^{S_2} \) is a linear function of \( R_U \) and \( \mu \), all of its second derivatives are 0. Its maxima can be achieved at points where its first derivatives do not exist or at boundary points. First, \( (D_{sum}^{S_2})'_\mu \) does not exist at points where \( D_{U_1}^{S_2} = D_{U_2}^{S_2} \). Second, because there is function \( \min(\mu, \lambda) \) inside function \( D_{sum}^{S_2} \), at points where \( \mu = \lambda \), its first derivatives also do not exist. We consider three cases:

- If \( \mu > \lambda \), the equation \( D_{U_1}^{S_2} = D_{U_2}^{S_2} \) is equivalent to

\[ \lambda R_U N + (\mu - \lambda)C_2 N = (2 - \mu)C_1 N, \]

\[ \mu = \frac{2C_1 + \lambda C_2 - \lambda R_U}{C_1 + C_2}. \]  

(11)

We have

\[ D_{sum}^{S_2} = \lambda N \left( \frac{C_1}{C_1 + C_2} - 1 \right) R_U + \frac{(2 - \mu)NC_2}{C_1 + C_2} + \lambda NC_{12} \]  

(12)
therefore consider the lower boundary point to have $R_D$. We have

$$\mu_{opt} = \frac{2C_1 - \lambda C_1 + \lambda C_3 - 4}{C_1 + C_2}.\quad (13)$$

If $\mu < \lambda$, the equation $D_{U_1}^{S_2} = D_{U_2}^{S_2}$ is equivalent to

$$\mu N R_U = (2 - \lambda)C_1 N$$

We have $D_{sum}^{S_2} = (2 - \lambda)NC_1 (C_1 - C_3) + \lambda N C_3$. It is also a decreasing function since $C_{12} > C_3$ as assumed above. We therefore consider the lower boundary point $R_U = C_{12} - C_{34}$. Substituting it to (14), we have $\mu = \frac{(2 - \lambda) C_1}{C_{12} - C_{34}}$. In order to have $\mu < \lambda$, it has to satisfies $\lambda > \frac{C_1}{C_{12} - C_{34}}$. In order to have $\mu > \lambda$, $\lambda < \frac{C_1}{C_{12} - C_{34}}$. When the condition above is satisfied, $D_{sum}^{S_2} > \frac{2C_2 + \lambda (C_1 - C_3 - 4) - \lambda N C_3}{C_1 + C_2}$.

If $\mu < \lambda$, $D_{sum}^{S_2}$ does not depend on $R_U$

$$\begin{align*}
D_{sum}^{S_2} &= \min(\lambda R_U, (2 - \lambda)C_1 + \lambda (C_1 - R_U) \\
&= \min(\lambda C_{12}, (2 - \lambda)C_1 + \lambda C_{34}).
\end{align*}\quad (16)$$

Finally, $\mu$ is chosen as the value making the total data the highest and $R_{sum}^{S_2} = \frac{\max(D_{sum}^{S_2}, \mu < \lambda, D_{sum}^{S_2}, \mu > \lambda)}{2N}$.

IV. NUMERICAL RESULTS

In all simulations below, the channels are fixed $[g_1, g_2, g_3, g_4] = [15, 10, 40, -10]dB$ unless stated otherwise. Fig. 4 shows the sum–rate and rates for $U$ and $V$ in CDR and Reference Scheme 1 with respect to $\lambda$. While Reference Scheme’s sum–rate $R_{sum}$ is a linearly increasing function with respect to $\lambda$, CDR Scheme 1’s sum–rate $R_{sum}$ achieves a maximum at a certain value of $\lambda$. In Reference Scheme’s case, it is straightforward since when $\lambda$ increases data transmitted for $V$ increases and data transmitted for $U$ decreases but the former is with a higher speed due to a direct transmission compared to a two–hop transmission. When $\lambda = 0$, the whole time is used for $U$ and $\mu$ is fixed at a value to balance the data transmitted of two hops. When $\lambda$ increases, the time for $U$ in Reference Scheme is shortened accordingly. However in CDR Scheme 1, the time for $U$ is not changed with a slightly different balance point ($\mu$) because the $V$’s transmission slightly affects the $U$’s transmission. In the meantime, transmitted data for $V$ increases therefore the sum–rate increases with a high speed. When $\lambda$ reaches the balance point of $U$’s DF transmissions and continues to increases, the time for RS–$U$ has to decreases accordingly to balance with a small data transmitted in BS–RS transmission. With a small inter–user channel, the interference from a user to the other is negligible, CDR Scheme 2’s rates and sum–rate has a quite similar slopes as seen in Fig. 5. In the two figures, AF CDR schemes $S_1$, $S_2$ are worse than their DF CDR respective schemes. For AF CDR schemes, $\lambda$ is re–defined as $\in [0, 2]$ instead of $[-1, 1]$ as in [12].

In the part above, we consider a scenario in which $U$ or $V$ has a downlink or uplink only. In the following part, we assume that both have a downlink and an uplink. All the assumptions regarding the channels and packets are the same. The time length for the whole scheme is now $4N$ symbols long.

In Reference Scheme, while transmissions for $V$ are also separately conducted, Two–way Relay Network Coding can be applied for transmissions of $U$ (Fig. 6). We optimize the time slots of the three–phase scheme in the way that the data sent from BS to $U$ and from $U$ to BS are the same. It means that the data transmitted in all three phases are the
same. Denote \( \mu N \) as the number of symbols in BS–RS phase and \( D_{2w} \) as the data transmitted in each phase. Because the maximal rates in BS–RS, U–RS and broadcast phases are \( C_1, C_2, \min(C_1, C_2) \) respectively, the number of symbols in the corresponding phases are \( \frac{D_{2w}}{C_1}, \frac{D_{2w}}{C_2}, \frac{D_{2w}}{\min(C_1, C_2)} \). We have
\[
\frac{D_{2w}}{C_1} + \frac{D_{2w}}{C_2} + \frac{D_{2w}}{\min(C_1, C_2)} = (4 - 2\lambda)N.
\]
(17)

We can estimate \( D_{2w} \) and the number of symbols in BS–RS, U–RS and broadcast phases are
\[
\mu^{E-2W}_{opt} = \frac{D_{2w}}{C_1} = \frac{(4 - 2\lambda)N}{1 + \frac{C_1}{C_2} + \frac{C_1}{\min(C_1, C_2)}}.
\]
(18)

and \( \frac{C_1}{C_2} \mu^{E-2W}_{opt} = \frac{C_1}{\min(C_1, C_2)} \mu^{E-2W}_{opt} \). The rate for the whole scheme is thus
\[
R_{sum}^{E-2W} = \frac{2D_{2w} + 2NC_3}{4N} = \frac{\mu^{E-2W}_{opt} C_1 + C_3}{2}.
\]
(19)

In CDR Scheme, the scheme for two–way traffic is simply a combination between CDR Scheme 1 and CDR Scheme 2 thus the rate is \( R_{sum} = \frac{R_{sum}^{C_1} + R_{sum}^{NC_2}}{2} \).

Varying the inter-user channel and keeping the other channels, we compare the rates of Reference Scheme with Two-way Relay (TWR) Network Coding and Combined CDR Scheme in Fig. 7. With a small inter-user channel, Combined CDR Scheme provides a quite higher sum-rate than Reference Scheme with Two-way Relay NC because of combining different transmission flows and exploiting a priori information to cancel the interference.

Comparing with Joint-Decode-and-Forward (JDF) NC for Two-way Relaying we can see that the principle is somehow similar. JDF NC for TWR RS decodes both received messages and broadcasts the coded message. BS decodes the expected message based on the message sent from it. U carries out in the same manner. RS has to adapt the rate of the broadcasted message such that both BS and U can successfully receive it while in our CDR Scheme 2 here, because U does not need to receive any message, RS only needs to adapt the rate to RS–BS channel and therefore a higher rate for the transmission can be chosen considering the relay side of the network.

V. Conclusion

In this paper we have presented regenerative relaying schemes for applying coordinated direct and relay (CDR) transmissions in wireless cellular networks. The essence of the CDR schemes is that they allow simultaneous, interfering transmissions to/from a relayed user and a direct user, thus shortening the total time in which the transmissions take place. We have considered two schemes: (S1) CDR for downlink relayed traffic with uplink direct traffic and (S2) CDR for uplink relayed traffic with downlink direct traffic. Unlike the previously proposed CDR schemes, where the relay applied Amplify–and–Forward (AF) relaying, here we have considered Decode–and–Forward (DF) operation at the relay. The CDR schemes based on DF are non-trivial extension of the case with AF, since the transmission time used by each node becomes a subject of optimization, while in the AF schemes the transmission time of the relay is a priori determined by the duration of the transmission from the source. In that respect particularly interesting is the scheme S2, where the relay needs to carry out a joint decoding over a multiple access channel. We have shown how the time duration should be selected in order to optimize the sum-rate and the results clearly show rate improvements. We have also discussed the relation that these schemes have to the established two–way relaying schemes based on wireless NC. Future studies will consider the system–level issues, scheduling and resource allocation, that arise from the usage of the CDR schemes.

REFERENCES