

MIMO Skript - Wintersemester 2013

Kapitel 4

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4 Distributed MIMO

- This research topic emerged ca. 10 years ago and is still a very active area of research
- Simple relaying schemes have been included in recent standards such as IEEE 802.16 (WiMAX) and LTE-Advanced
- Advantages: relay-assisted communications:
 - Relays can help to reduce the effective overall pathloss
 - Relays can also combat small-scale fading effects
 - Relays can help to realize MIMO gains with single-antenna nodes
- Challenges in relays-assisted communication:
 - Network architectures are becoming more complex
 - Synchronization across different nodes may be necessary (*Anm.: untersch. Trägerfrequenzen der Relays \rightarrow Offset, Fehler, etc.*)
 - Exchange of channel state information (CSI) across nodes may be required

4.1 Half-Duplex One-Way Relaying

Basic Relay Network

- Relay R assists source S in communication with destination D
- Two basic nodes of transmission (at the relay):

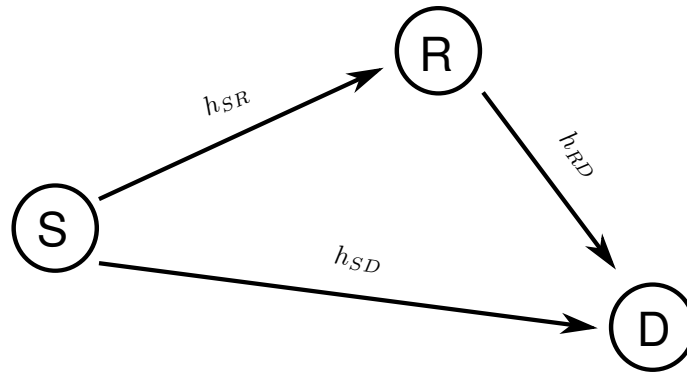


Figure 1: Basic Relay Network

Full - Duplex relaying: R can receive and transmit at the same time and in the same frequency band (*Anm.: effizient, da restliche Zeit und restliche Frequenzband von anderen genutzt werden kann*)

→ Since the TX signal power is orders of magnitude larger than the RX power, there is self-interference (at the relay)

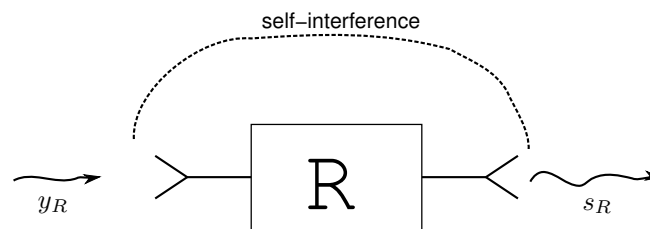


Figure 2: Relay with self-interference

→ Full-duplex relays are difficult to implement. The design of full-duplex relays is an active area of research.

→ Majority of existing literature assumes half-duplex relaying.

Half - duplex relaying: R transmits and receives in different time slots and/or different frequency bands. Typically, a two-phase protocol is used:

Phase 1: S transmits, R and D receive

Phase 2: R transmits, D receives, S may or may not transmit

There are different relaying strategies that differ in the processing applied at the relay. The most popular are:

- Decode - and - Forward
- Amplify - and - Forward
- (Compress - and - Forward)

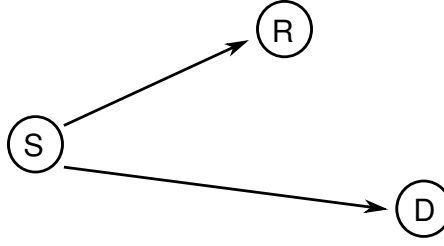


Figure 3: Half-duplex Relaying: Phase 1

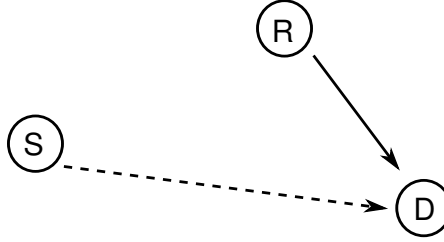


Figure 4: Half-duplex Relaying: Phase 2

4.1.1 Decode - and - Forward (DF) Relaying

In DF relaying, the relay detects and decodes the signal received from the source before encoding it and forwarding it to the destination.

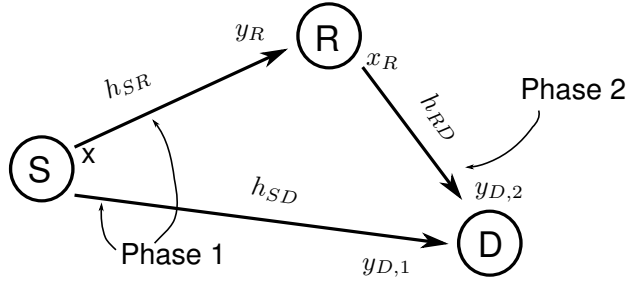


Figure 5: Block diagramm Decode - and - forward Relaying

Phase 1:

- R receives: $y_R = h_{SR}x + n_R$
- D receives: $y_{D1} = h_{SD}x + n_{D1}$
- with:
 - transmit signal $x, \mathcal{E}_s = \mathcal{E}\{|x|^2\}$
 - AWGN n_R and $n_{D1}, \sigma_n^2 = \mathcal{E}\{|n_R|^2\} = \mathcal{E}\{|n_{D1}|^2\}$

Phase 2:

- R decodes and forwards x_R (estimate of x)
- D receives: $y_{D2} = h_{RD}x_R + n_{D2}$
 - x_R is estimate of x after decoding at R
 - $\sigma_n^2 = \mathcal{E}\{|n_{D2}|^2\}$; $\mathcal{E}_R = \mathcal{E}\{|x_R|^2\}$
 - we assume: S is silent in Phase 2
- The capacity at the three node relay channel is not known!
- We provide an achievable rate under the following simplifying assumption: The direct source-relay link is not used/exploited.
- Achievable rate without S-D link:

$$C_{DF} = \frac{1}{2} \min \left\{ \log_2 \left(1 + \frac{\mathcal{E}_S |h_{SR}|^2}{\sigma_n^2} \right), \log_2 \left(1 + \frac{\mathcal{E}_R |h_{RD}|^2}{\sigma_n^2} \right) \right\}$$

- factor $\frac{1}{2}$ is due to the fact that we use two time slots to transmit one packet
- $\min\{\dots\}$ means we are limited by the weaker link (bottle-neck)
- If power allocation is possible, the total power $\mathcal{E} = \mathcal{E}_S + \mathcal{E}_R$ should be divided between S and R to guarantee:

$$\begin{aligned} \frac{\mathcal{E}_S |h_{SR}|^2}{\sigma_n^2} &= \frac{\mathcal{E}_R |h_{RD}|^2}{\sigma_n^2}, \\ \mathcal{E}_R &= \frac{|h_{SR}|^2}{|h_{SR}|^2 + |h_{RD}|^2} \cdot \mathcal{E}, \\ \mathcal{E}_S &= \frac{|h_{RD}|^2}{|h_{SR}|^2 + |h_{RD}|^2} \cdot \mathcal{E} \end{aligned}$$

- Outage-probability in fading:
 - We transmit with fixed rate R
 - An outage occurs, if:

$$\begin{aligned} \frac{1}{2} \log_2 \left(1 + \underbrace{\frac{\mathcal{E}_S |h_{SR}|^2}{\sigma_n^2}}_{=\gamma_{SR}} \right) &< R \quad \text{or} \\ \frac{1}{2} \log_2 \left(1 + \underbrace{\frac{\mathcal{E}_R |h_{RD}|^2}{\sigma_n^2}}_{=\gamma_{RD}} \right) &< R \end{aligned}$$

$$\gamma_{SR} < \underbrace{2^{2R} - 1}_{\gamma_T} \quad \text{or} \quad \gamma_{RD} < 2^{2R} - 1$$

$$\begin{aligned}
P_{\text{out}} &= \Pr\{\gamma_{SR} < \gamma_T \vee \gamma_{RD} < \gamma_T\} = \Pr\{\underbrace{\min\{\gamma_{SR}, \gamma_{RD}\}}_{=\gamma_{eq}} < \gamma_T\} \\
&= 1 - \Pr\{\gamma_{SR} > \gamma_T \wedge \gamma_{RD} > \gamma_T\} = 1 - \Pr\{\gamma_{SR} > \gamma_T\} \Pr\{\gamma_{RD} > \gamma_T\} = \\
&= 1 - (1 - F_{\gamma_{SR}}(\gamma_T))(1 - F_{\gamma_{RD}}(\gamma_T)) = \\
&= \underline{F_{\gamma_{SR}}(\gamma_T) + F_{\gamma_{RD}}(\gamma_T) - F_{\gamma_{SR}}(\gamma_T) \cdot F_{\gamma_{RD}}(\gamma_T)}
\end{aligned}$$

with CDFs: $F_{\gamma_{SR}}(\cdot)$ and $F_{\gamma_{RD}}(\cdot)$

– Rayleigh Fading:

$$\begin{aligned}
\rightarrow F_{\gamma_{SR}}(\gamma) &= 1 - \exp\left(\frac{-\gamma}{\bar{\gamma}_{SR}}\right); \quad \bar{\gamma}_{SR} = \mathcal{E}\{\gamma_{SR}\} \\
F_{\gamma_{RD}}(\gamma) &= 1 - \exp\left(\frac{-\gamma}{\bar{\gamma}_{RD}}\right); \quad \bar{\gamma}_{RD} = \mathcal{E}\{\gamma_{RD}\} \\
\rightarrow P_{\text{out}} &= 1 - \exp\left(\frac{-\gamma_T}{\bar{\gamma}_{SR}}\right) + 1 - \exp\left(\frac{-\gamma_T}{\bar{\gamma}_{RD}}\right) - \left(1 - \exp\left(\frac{-\gamma_T}{\bar{\gamma}_{SR}}\right)\right)\left(1 - \exp\left(\frac{-\gamma_T}{\bar{\gamma}_{RD}}\right)\right) = \\
&= 1 - \exp\left(-\frac{\bar{\gamma}_{SR} + \bar{\gamma}_{RD}}{\bar{\gamma}_{SR}\bar{\gamma}_{RD}} \cdot \gamma_T\right)
\end{aligned}$$

\rightarrow equivalent SNR $\gamma_{eq} = \min\{\gamma_{SR}, \gamma_{RD}\}$ is also exponentially distributed with $\bar{\gamma}_{eq} = \frac{\bar{\gamma}_{SR}\bar{\gamma}_{RD}}{\bar{\gamma}_{SR} + \bar{\gamma}_{RD}}$

– Diversity gain: Assume $\bar{\gamma}_{SR} = \alpha\bar{\gamma}$

$$\begin{aligned}
\rightarrow P_{\text{out}} &\xrightarrow{\bar{\gamma} \rightarrow \text{inf}} 1 - \left(1 - \frac{\alpha + \beta}{\alpha\beta} \cdot \frac{\gamma_T}{\bar{\gamma}}\right) + \mathcal{O}(\bar{\gamma}^{-1}) = \\
&= \frac{\alpha + \beta}{\alpha\beta} \cdot \frac{\gamma_T}{\bar{\gamma}} + \mathcal{O}(\bar{\gamma}^{-1}) = \\
&\rightarrow \boxed{G_d = 1}
\end{aligned}$$

• Bit error rate (BER) of BPSK (uncoded)

$$- \text{BER}(\gamma_{SR}, \gamma_{RD}) = \left(1 - \text{BER}_{SR}(\gamma_{SR})\right) \text{BER}_{RD}(\gamma_{RD}) + \left(1 - \text{BER}_{RD}(\gamma_{RD})\right) \text{BER}_{SR}(\gamma_{SR})$$

* with BER of the S - R link, $\text{BER}_{SR}(\gamma_{SR})$ and BER of the R - D link $\text{BER}_{RD}(\gamma_{RD})$

* for sufficiently high SNR $\rightsquigarrow \text{BER}_{SR}(\gamma_{SR}), \text{BER}_{RD}(\gamma_{RD}) \ll \text{BER}_{SR}(\gamma_{SR}) + \text{BER}_{RD}(\gamma_{RD})$

$$\rightarrow \underline{\text{BER}(\gamma_{SR}, \gamma_{RD}) \approx \text{BER}_{SR}(\gamma_{SR}) + \text{BER}_{RD}(\gamma_{RD})}$$

* to average BER (Rayleigh Fading):

$$\text{BER} = \mathcal{E}_{\gamma_{SR}, \gamma_{RD}} \left\{ \text{BER}(\gamma_{SR}, \gamma_{RD}) \right\} = \frac{1}{2} \left(1 - \sqrt{\frac{1}{1 + \frac{1}{\bar{\gamma}_{SR}}}} \right) + \frac{1}{2} \left(1 - \sqrt{\frac{1}{1 + \frac{1}{\bar{\gamma}_{RD}}}} \right)$$

* high SNR:

$$\begin{aligned}
\text{BER} &\approx \frac{1}{2} \left(1 - 1 + \frac{1}{2} \frac{1}{\bar{\gamma}_{SR}} \right) + \frac{1}{2} \left(1 - 1 + \frac{1}{2} \frac{1}{\bar{\gamma}_{RD}} \right) = \\
&= \frac{1}{4} \left(\frac{1}{\bar{\gamma}_{SR}} + \frac{1}{\bar{\gamma}_{RD}} \right)
\end{aligned}$$

\rightsquigarrow also indicates diversity gain $G_d = 1$

4.1.2 Amplify - and - Forward (AF) Relaying

- Relay does not decode signal received from source but only amplifies it before forwarding it to the destination

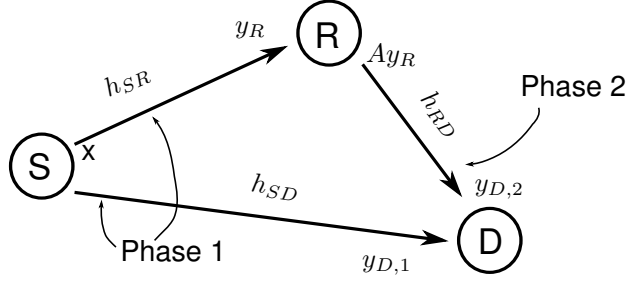


Figure 6: Block diagram AF - Relaying

- Amplification gain A may be constant or channel dependent and ensures a certain (average) transmit power

Phase 1:

- R receives: $y_R = h_{SR}x + n_R$
- D receives: $y_{D,1} = h_{SD}x + n_{D,1}$

Phase 2:

- R transmits: $s_R = Ay_R = A(h_{SR}x + n_R)$
- D receives: $y_{D,2} = h_{RD}Ay_R + n_{D,2}$

- We can use MRC to combine $y_{D,1}$ and $y_{D,2}$ at D: $y_{D,2} = Ah_{RD}h_{SR}x + h_{RD}An_R + n_{D,2}$, where: $h_{RD}An_R + n_{D,2}$ is effective noise n_{eff} with variance $\sigma_{n_{\text{eff}}}^2 = \sigma_n^2(|h_{RD}|^2A^2 + 1)$

→ make noise variances of both branches equal