Double Relay Communication Protocol with Power Control for Achieving Fairness in Cellular Systems

Rodolfo Torrea-Duran[1], Fernando Rosas[1], Paschalis Tsiaflakis[2], Sofie Pollin[1], Aldo Orozco[3], Luc Vandendorpe[4], Marc Moonen[1]

[1]KU Leuven, Department of Electrical Engineering (ESAT), Leuven, Belgium
[2]Bell Labs, Nokia, Copernicuslaan 50, B-2018, Antwerp, Belgium
[3]Center for Research and Advanced Studies of IPN, Communications Section, Mexico City, Mexico
[4]Université Catholique de Louvain (UCL), ICTEAM Institute, Digital Communications Group, LLN, Belgium

Motivation

- Achieving fairness is critical in cellular systems, where the service that each user receives can be severely degraded by the variability of the wireless channel.
- Fairness can be improved by introducing spatial degrees of freedom through the use of relays.
- The Double Relay Communication Protocol (DRCP) achieves fairness without a backhaul connection nor relay deployment since it uses base stations (BSs) as relays.
- DRCP does not require any channel state information at the transmitter (CSIT). However, when CSIT is available, the fairness of DRCP can be further improved by controlling the transmit power at each BS.

System Model

- Each BS transmits to one user.
- Half-duplex. No backhaul link.
- BSs can overhear transmissions.

Baseline Approaches

1) TDMA: Communication is done in turns: BS k transmits s_k to user k in time-slot (TS) k.

2) DIV: Exploits overhearing of the transmitted symbols by using dedicated TSs.

3) INTF: All the BSs transmit continuously regardless of the interference.

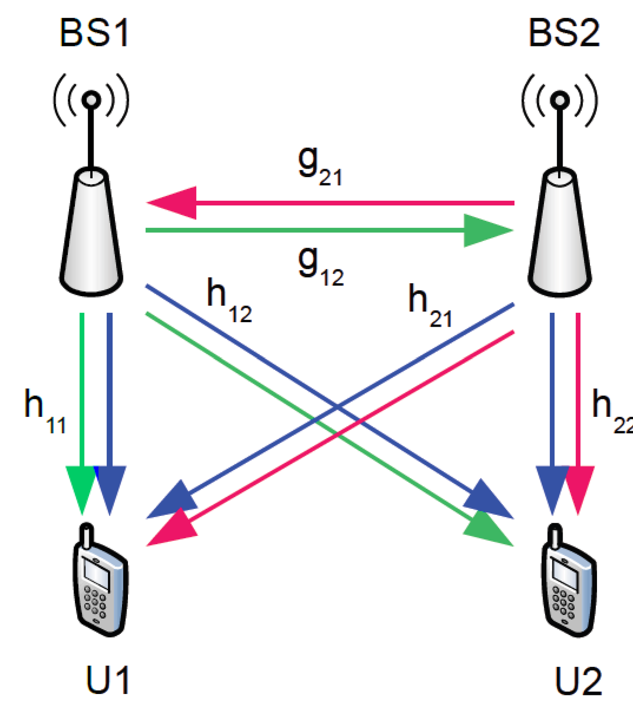
Double Relay Communication Protocol (DRCP)

- In TS1, BS1 transmits s_1. In TS2, BS2 transmits s_2. Finally, in TS3 each BS transmits simultaneously the overheard symbols.
- MMSE receiver.

$$y_{\mathrm{U}l}^{(1)} = \sqrt{P_1^{(1)}} h_{1l} s_1 + n_{\mathrm{U}l}^{(1)}$$

$$y_{\mathrm{U}l}^{(2)} = \sqrt{P_2^{(2)}} h_{2l} s_2 + n_{\mathrm{U}l}^{(2)}$$

$$y_{\mathrm{U}l}^{(3)} = \sqrt{P_1^{(3)}} h_{1l} z_{21} + \sqrt{P_2^{(3)}} h_{2l} z_{12} + n_{\mathrm{U}l}^{(3)}$$

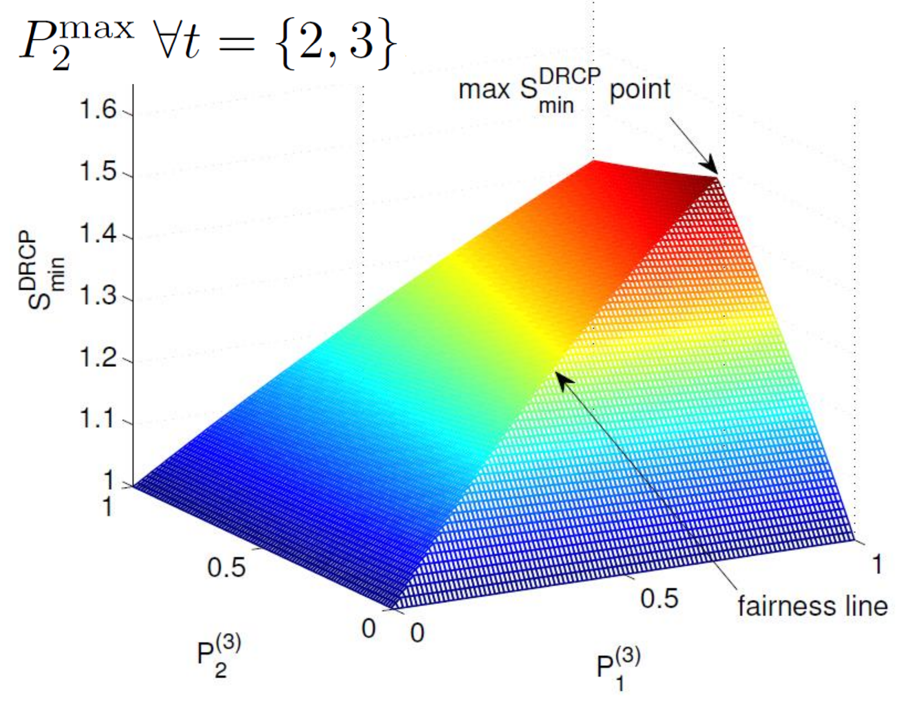


$$\mathrm{SNR}_{\mathrm{U}l}^{\mathrm{DRCP}} = \gamma_{ll}^{(l)} + \frac{\gamma_{ml}^{(3)}}{\frac{\gamma_{ll}^{(3)}}{\gamma_{ml}^{(m)}+1} + \frac{\gamma_{ll}^{(3)}}{\xi_{ml}^{(m)}} + \frac{\gamma_{ml}^{(3)}}{\xi_{lm}^{(l)}} + 1}$$

Minimum DRCP Spectral Efficiency Maximization

$$\begin{aligned} \underset{P_1^{(t)}, P_2^{(t)}\ \forall t}{\text{maximize}} \quad & S_{\min}^{\mathrm{DRCP}} = \min\{S_{\mathrm{U1}}^{\mathrm{DRCP}}, S_{\mathrm{U2}}^{\mathrm{DRCP}}\} \\ \text{s.t.} \quad & 0 \le P_1^{(t)} \le P_1^{\max}\ \forall t = \{1,3\} \\ & 0 \le P_2^{(t)} \le P_2^{\max}\ \forall t = \{2,3\} \end{aligned}$$

$$\begin{aligned} \underset{P_1^{(t)}, P_2^{(t)}\ \forall t}{\text{maximize}} \quad & v \\ \text{s.t.} \quad & 1 + \mathrm{SNR}_{\mathrm{U1}}^{\mathrm{DRCP}} \ge v \\ & 1 + \mathrm{SNR}_{\mathrm{U2}}^{\mathrm{DRCP}} \ge v \\ & 0 \le P_1^{(t)} \le P_1^{\max}\ \forall t = \{1,3\} \\ & 0 \le P_2^{(t)} \le P_2^{\max}\ \forall t = \{2,3\} \end{aligned}$$



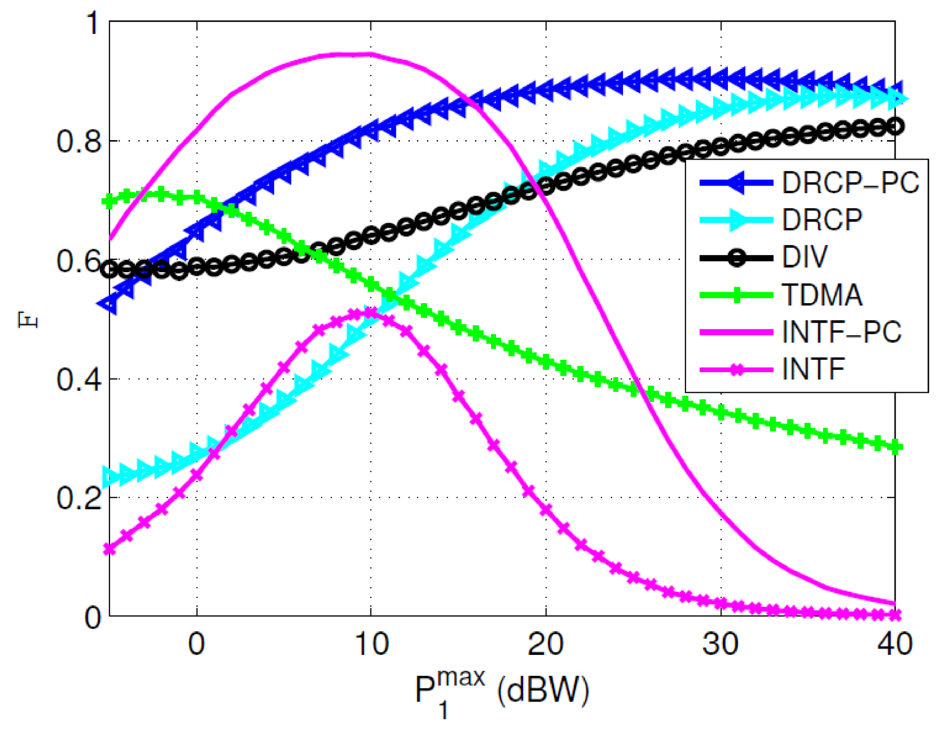
Finding the Fairness Line

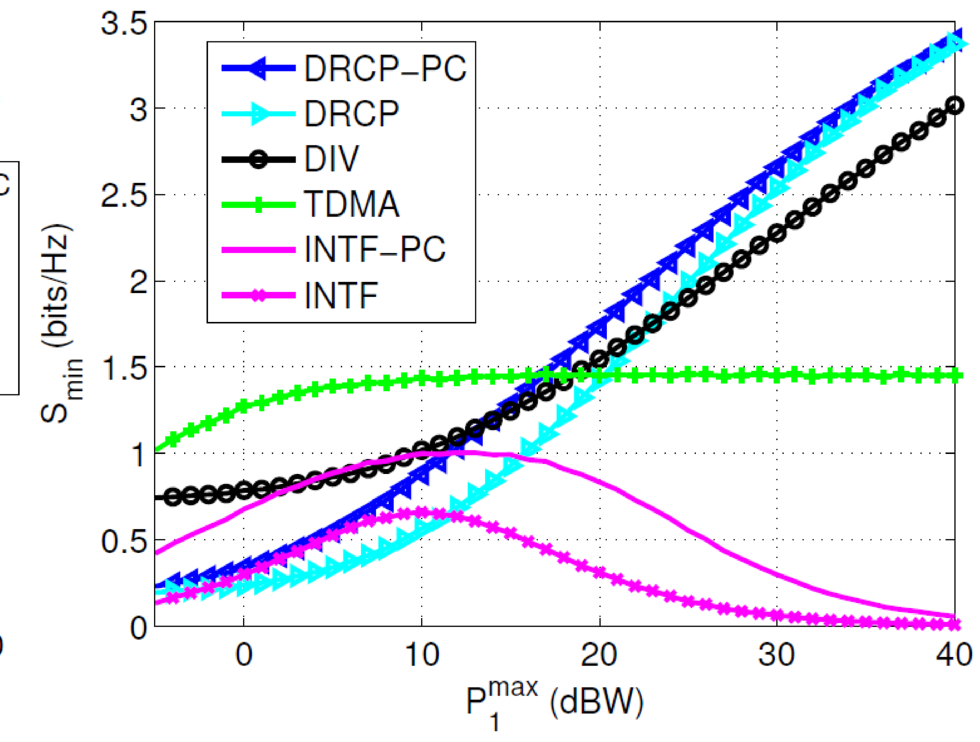
- Low complexity algorithm for minimum DRCP spectral efficiency maximization by reformulating the constraints:

$$(v - 1 - \gamma_{ll}^{\max}) \left(1 + \frac{\gamma_{ll}^{(3)}}{\gamma_{ml}^{\max}+1} + \frac{\gamma_{ll}^{(3)}}{\xi_{ml}^{(m)}} + \frac{\gamma_{ml}^{(3)}}{\xi_{lm}^{(l)}}\right) - \gamma_{ml}^{(3)} = 0$$

$$A_{mn} = \frac{1}{v-1-\gamma_{mm}^{\max}} - \frac{1}{\xi_{mn}^{(m)}}$$

$$P_l^{(3)} = \frac{|h_{ml}|^2 A_{lm} + |h_{mm}|^2 B_{lm}}{|h_{12}|^2 |h_{21}|^2 A_{12} A_{21} - |h_{11}|^2 |h_{22}|^2 B_{12} B_{21}} \qquad B_{mn} = \frac{1}{\gamma_{mn}^{\max}+1} + \frac{1}{\xi_{mn}^{(m)}}$$





Conclusions

- We have proposed a power control mechanism that increases the fairness of DRCP when CSIT is available.
- The optimal solution that maximizes the minimum spectral efficiency for DRCP is to use maximum transmit power in TS1 and TS2, and to use at least one transmit power equal to the maximum power in TS3.
- Using power control allows DRCP to achieve the highest fairness and the largest minimum spectral efficiency for increasing values of transmit power.
- A low complexity algorithm to compute the optimal transmit powers with a uni-dimensional search was also proposed.