Analysis of Subcarrier Pairing In a Cellular OFDMA Relay Link

Taneli Riihonen, Risto Wichman,
Jyri Hämäläinen, and Ari Hottinen

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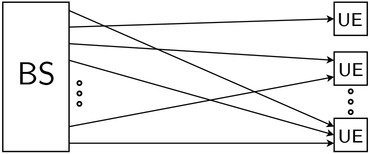
Introduction



- In downlink OFDMA scheduler assigns subcarriers for the UEs.

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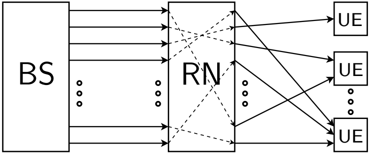

- Two-fold scheduling task in relay-assisted transmission:
  - First conventional scheduling for the second-hop subcarriers.
  - Then the first-hop subcarriers are assigned for transmitting the data to the relay.

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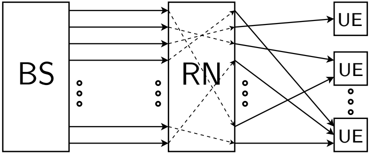
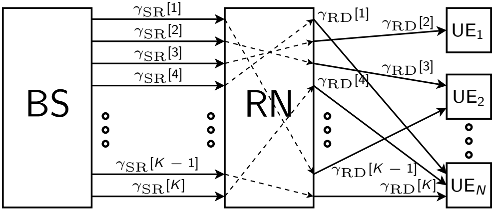


- Two-fold scheduling task in relay-assisted transmission:
  - First conventional scheduling for the second-hop subcarriers.
  - Then the first-hop subcarriers are assigned for transmitting the data to the relay.

How to pair the first-hop subcarriers with the second-hop subcarriers when the second-hop scheduling has already been decided?

System model



- The instantaneous end-to-end SNR with amplify-and-forward:

$$\gamma[k,l] = \frac{\bar{\gamma}_{\mathrm{SR}}[k]\gamma_{\mathrm{RD}}[l]}{\bar{\gamma}_{\mathrm{SR}}[k] + \gamma_{\mathrm{RD}}[l] + 1}.$$

  - Static frequency-selective BS-RN channel: $\gamma_{\mathrm{SR}}[k] = \bar{\gamma}_{\mathrm{SR}}[k]$.
  - Rayleigh-fading RN-UE subcarriers: $\gamma_{\mathrm{RD}}[l] \sim \mathrm{Exp}\left(1/\bar{\gamma}_{\mathrm{RD}}\right)$.
- Round robin scheduling for the RN-UE subcarriers.
- Fixed or adaptive subcarrier permutation in the relay.

Fixed subcarrier pairing

- Any fixed or random subcarrier permutation results in the same average performance. We use $v[k] = k$.
- Transformation of random variables for the exponential PDF.
- Closed-form performance measures by integration over the PDF:
  - Average end-to-end subcarrier SNR:

$$\bar{\gamma}[k] = \bar{\gamma}_{\mathrm{SR}}[k] e^{\frac{\bar{\gamma}_{\mathrm{SR}}[k]+1}{\bar{\gamma}_{\mathrm{RD}}}} E_2\left(\frac{\bar{\gamma}_{\mathrm{SR}}[k]+1}{\bar{\gamma}_{\mathrm{RD}}}\right).$$

  - End-to-end subcarrier capacity:

$$\bar{C}[k] = \frac{1}{2\log_e(2)}\left(e^{\frac{1}{\bar{\gamma}_{\mathrm{RD}}}} E_1\left(\frac{1}{\bar{\gamma}_{\mathrm{RD}}}\right) - e^{\frac{\bar{\gamma}_{\mathrm{SR}}[k]+1}{\bar{\gamma}_{\mathrm{RD}}}} E_1\left(\frac{\bar{\gamma}_{\mathrm{SR}}[k]+1}{\bar{\gamma}_{\mathrm{RD}}}\right)\right).$$

Optimal Subcarrier Pairing

- To maximize sum SNR and sum capacity over all subcarriers, the BS-RN subcarrier having the kth largest SNR is paired with the RN-UE subcarrier having the kth largest SNR.
  - Optimality is proven in references.
- Derivation of performance measures by exploiting results from order statistics.
  - Average end-to-end subcarrier SNR:

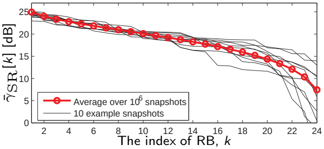
$$\bar{\gamma}^*[k] = \sum_{l=k}^{K} (-1)^{l-k} \binom{K}{k} \binom{K-k}{K-l} \frac{k}{l} \bar{\gamma}_{\mathrm{SR}}[k] e^{\frac{\bar{\gamma}_{\mathrm{SR}}[k]+1}{\bar{\gamma}_{\mathrm{RD}}} l} E_2\left(\frac{\bar{\gamma}_{\mathrm{SR}}[k]+1}{\bar{\gamma}_{\mathrm{RD}}} l\right).$$

  - End-to-end subcarrier capacity:

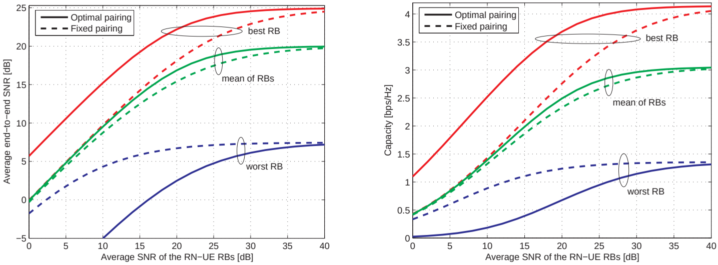
$$\bar{C}^*[k] = \frac{1}{2\log_e(2)} \sum_{l=k}^{K} (-1)^{l-k} \binom{K}{k} \binom{K-k}{K-l} \frac{k}{l} \left[e^{\frac{l}{\bar{\gamma}_{\mathrm{RD}}}} E_1\left(\frac{l}{\bar{\gamma}_{\mathrm{RD}}}\right) - e^{\frac{\bar{\gamma}_{\mathrm{SR}}[k]+1}{\bar{\gamma}_{\mathrm{RD}}} l} E_1\left(\frac{\bar{\gamma}_{\mathrm{SR}}[k]+1}{\bar{\gamma}_{\mathrm{RD}}} l\right) \right].$$

Example system setup

- 3GPP Release 7 OFDMA parameters
  - Pairing on physical resource block (RB) basis instead of subcarrier basis.
  - For 10 MHz system bandwidth, the number of RBs is $K = 24$.
- A WINNER channel model
  - B5f non-line-of-sight rooftop-to-below rooftop channel for the BS-RN link.
  - A relay experiences single static snapshot channel.
  - To generalize evaluation for all different relay locations we apply an average channel for evaluation:

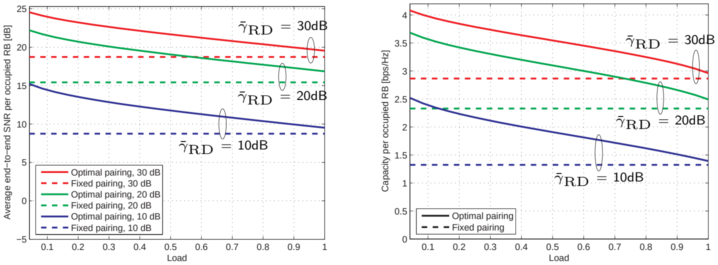


A fully loaded system



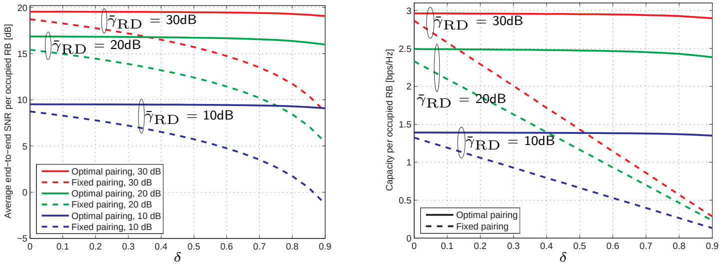
- Performance improvement due to optimal subcarrier pairing is rather small, but in line with literature.
- The UEs that get the worst RBs suffer instantaneously from the optimal pairing, and the UEs that get the best RBs benefit from it.
- However, the UEs are scheduled by round robin scheduler and they are equally probably assigned to the best, the worst or any RB.
  - All UEs benefit from the optimal pairing in the long run.

A partially loaded system



- With fixed subcarrier pairing, the system load does not affect the mean performance an UE would observe.
- With optimal subcarrier pairing, only the best BS-RN RBs are assigned for the users and, thus, the mean performance of occupied RBs increases significantly when the load decreases.

Mitigation of the effect of subcarrier puncturing



- Each BS-RN subcarrier is rendered unusable due to interference or congestion with probability δ.
- With fixed pairing the system is not able to exploit the puncturing information and cannot avoid using punctured BS-RN RBs.
- On the other hand with optimal pairing, the system always uses only the BS-RN RBs that are not punctured.

Conclusion

- An amplify-and-forward relay system with subcarrier pairing for cellular OFDMA downlink.
  - Closed-form expressions for average SNR and capacity.
  - Comparison of fixed and optimal pairing strategies.
- Performance evaluation with example OFDMA parameters.
  - The most promising application is BS coverage area extension.
- Future research topics
  - Joint subcarrier power allocation and pairing.
  - System with unequal average RN-UE SNRs.
  - Analysis of subcarrier pairing when using more sophisticated UE scheduling algorithms.

Thank you!

- Questions?
- Discussion?