Capacity Improvement through Buffer-Aided Successive Opportunistic Relaying

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Contents

2

- Introduction-Motivation
  - Cooperative relaying
  - Buffer-aided relaying
  - Opportunistic relaying
  - Successive relaying
- System model
- Buffer-aided successive opportunistic relaying
  - Contributions
  - Relay-pair selection algorithm
- Numerical results
  - Outage probability
  - Average capacity
  - Average delay
- Conclusions
- Future directions

Introduction-Motivation

3

- The development of spectral efficient protocols is an important research area
  - The goal of providing data at Gbps levels requires the efficient use of spectral, temporal and spatial resources
- Multi-hop communications is another field which has attracted the attention of the academia and the industry
  - Cooperative relaying employs intermediate nodes to relay the information towards the destination

Cooperative relaying

4

- Cooperative relaying is a major element of next generation wireless networks
- Relaying increases the diversity gain by offering alternative and independent transmission paths [Laneman et al., 2004]
- Enhancing the relays with buffering capabilities increases the degrees of freedom in the network
  - Improved diversity as relays which have packets in their buffers can be scheduled to transmit to the destination
- Opportunistic relay selection improves the usage of network resources by selecting one best relay among multiple relay nodes [Bletsas et al., 2006]
  - The best relay is selected based on the end-to-end channel quality without sacrificing the outage performance
- Successive relaying [Ding et al., 2012] allows the source and the relay to transmit simultaneously
  - Full-duplex operation but with inter-relay interference (IRI)

Opportunistic relaying

5

- Opportunistic relay selection is based on the max-min criterion and its variations [Bletsas et al., 2006], [Michalopoulos et al., 2008], [Krikidis et al., 2009]
  - In these works the source and the relay transmitted in orthogonal time-slot, thus reducing the end-to-end rate by one-half
  - In opportunistic relay transmission only one relay is activated after a selection process

Successive relaying

6

- Successive relaying is coupled with relay selection to combine the advantages of these techniques
  - In successive relaying we have two overlapping transmissions
  - In [Nomikos et al., 2012/1] the IRI was canceled at the relays for cases of strong interference
  - In [Nomikos et al., 2012/2] relays with multiple interfaces are employed and out-of-band transmissions are possible

Buffer-aided relaying

7

- The addition of buffering at the relays has been suggested as a way to further improve the diversity of the network
- Buffering decouples the receiving relay at the previous time slot to be the transmitting relay at the next slot
  - In [Ikhlef et al., 2012/1] max-max relay selection (MMRS) was proposed in which the relay with the best source-relay (*SR*) link is selected for reception and the relay with the best relay-destination (*RD*) link is selected for transmission
  - Also, in [Ikhlef et al., 2012/1] hybrid relay selection (HRS) is presented which combines the max-min with max-max relay strategies when buffers are almost full to avoid diversity losses
  - In [Krikidis et al., 2012] max-link selection was proposed where the best link among the *SR* and *RD* is selected in each time-slot
- In [Ikhlef et al., 2012/2] MMRS is coupled with successive relaying leading to the space full-duplex MMRS (SFD-MMRS)
  - No IRI is considered as relays are isolated

System model

8

- A simple cooperative network consisting of one source S , one destination D and a cluster C with K decode-and-forward (DF)
- Rayleigh block fading
- Half-duplex buffer-aided relays
- IRI arises between the selected relay-pair
- Global CSI is available

Buffer-aided successive opportunistic relaying

9

- In this work a buffer-aided successive opportunistic relaying (BA-SOR) scheme is proposed
- Buffering at the relays is combined with opportunistic and successive relaying
  - Opportunistic relaying and buffering increase the chances of improved diversity
  - Successive relaying aims to leverage the half-duplex loss of relaying
  - IRI is introduced in the network requiring efficient mitigation techniques

Contributions

10

- The selection of the relay-pair that achieves the best end-to-end capacity
- IRI is considered and can be treated either through interference cancellation (IC) or through interference avoidance (IA)
  - If the inter-relay link is strong, the receiving relay can decode the interfering signal → IC is performed
  - Otherwise, IA is achieved through the selection of the relay-pair with the minimum IRI

Relay-pair selection algorithm

11

- Due to the concurrent transmissions, relay selection does not depend solely on the quality of the SR and RD links
- IRI is the defining factor in this relay selection policy
- IC is feasible if the inter-relay channel capacity is above the rate threshold r_o

$$r_{R_t R_r} \triangleq \log_2 \left(1 + \frac{g_{R_t R_r} P_{R_t}}{g_{S R_r} P_S + n} \right) \geq r_o$$

where g_{ij} denotes the channel power between nodes i, j , P_i is the transmission power of node i and n is the AWGN

- $K(K-1)$ relay pairs are examined depending on the end-to-end rate they can achieve
- The complexity of the proposed relay selection policy is equal to $O(K^2)$

Relay-pair selection algorithm

12

- First, the candidate relay for transmission t is examined
- Then, the IC feasibility check is performed with the other $K-1$ relays
- The *best* pair is selected according to

$$\max_{t \in \mathcal{T}} \left\{ \min \left[\max_{i \in \mathcal{C} - \{t\}} \left(\frac{g_{SR_i}}{g_{R_t R_i} (1 - \mathbb{I}(R_t R_i)) + \mathbb{I}(R_t R_i)} \right), g_{R_t D} \right] \right\}$$

where $\mathbb{I}(R_t R_i)$ is an indicating factor which is:

- 1, if IC is feasible
- 0, if it is not

Numerical results

13

- Comparisons with **successive** and **non successive** relay selection schemes
- The successive category includes:
  - the SFD-MMRS of [Ikhlef et al., 2012/2] which is considered as the upper bound to our work due to the absence of both IRI and constraints due to full or empty buffers
- The non-successive category includes:
  - the HRS of [Ikhlef et al., 2012/1]
  - the max-link of [Krikidis et al., 2012]
- The capacity threshold is $r_0=2\text{bps/Hz}$
- The results are obtained in terms of:
  - outage probability
  - average end-to-end capacity
  - average delay

Outage probability

14

- max-link has the best performance as diversity is equal to $2K$ (high SNR)
- HRS achieves a diversity order equal to K (high SNR)
- SFD-MMRS (Selection Bound) requires two links not to be in outage to achieve successive transmissions, thus leading to increased outage probability
- BA-SOR reduces the gap with the Selection Bound for increasing buffer size L

Average capacity

15

- Clear advantage of the full-duplex schemes which employ two simultaneous transmissions during the whole time-slot
- For high transmit SNR, the capacity of the successive schemes is almost twice the capacity of the half-duplex schemes
- Increased L does not offer big gains in capacity indicating that this metric depends mostly on the number of relays

Average capacity

16

- As the numbers of relays increase $\rightarrow$ the average capacity increases
- Performance gap increases with each relay addition

Average delay

17

- The half-duplex schemes experience increased delay
- Due to successive transmissions packets tend to stay less in the buffers
- As relay number increases some packets tend to stay longer in the buffer as the probability to select each relay decreases

Conclusions

18

- In the proposed BA-SOR scheme in each timeslot, a relay-pair is selected and thus activated for transmission and reception
  - Diversity is increased via opportunistic relay-pair selection
  - The half-duplex loss of relaying is leveraged through successive transmissions
  - The outage probability for small buffer sizes is worst than the half-duplex schemes
  - IRI is introduced in the network
- Two possible interference mitigation techniques
  - Interference cancellation at the receiving relay
  - Interference avoidance when cancellation is not feasible
- Numerical results indicate that BA-SOR leverages the disadvantages of half-duplex relaying in terms of average capacity and average delay at the cost of increased outage probability

Future directions

19

- Future directions include:
  - The combination of BA-SOR with a more robust half-duplex scheme in order to merge the best of both techniques
  - The investigation of additional important network parameters such as power consumption
  - More efficient ways of interference mitigation and exploitation can be examined based on network coding aiming to increase the diversity of the network
  - The development of distributed coordination aiming to reduce the CSI overhead

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