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Resource Allocation Techniques in OFDMA-Based Decode-and-Forward Relaying Networks

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Outline

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Motivations

- Multi-hop relaying in cellular network: Enhance coverage; Increase data rate; Ensure cell edge connectivity.

- Efficient resource utilization: Design efficient spectrum/power allocation schemes for OFDMA-based relaying networks.

- Objective: Maximize the total capacity. Users’ data rate requirements (fairness) are also considered.

- Constraint: Limited individual transmission power at each transmitter.
Backgrounds

- Resource allocation in relay-aided cellular network employing OFDMA system:

A Cellular System with Multihop Relaying
System Model

- **Relaying scenarios**
  - The system consists of 1 Base Station (BS), \( L \) Relay Stations (RS), and \( K \) User Equipment (UEs)
  - Two-hop transmission is assumed
  - OFDMA-based downlink transmission
  - Decode-and-forward cooperation strategy
  - Interference is considered as Gaussian noise
System Model

• **System assumptions**
  • In centralized resource allocation, BS knows the entire channel information of BS-UE and RS-UE links.
  • This information needs to be fed back from UEs and RSs using control channels.
  • In distributed resource allocation, each RS knows all the information about the links from itself to the UEs.
  • This can be fed back by the UEs or estimated by uplink transmissions if time division duplex (TDD) is used.
System Model

- Symbols used
  - $h_{l,k}^{(n)}$: the channel gain at subcarrier $n$ from RS $l$ to UE $k$
  - $p_{l,k}^{(n)}$: the power allocated to subcarrier $n$ at RS $l$ to UE $k$
  - $\Omega_{l,k}$: the ordered subcarriers set allocated to UE $k$ at RS $l$
  - $\Omega_{l,k}(j)$: the $j$th element of $\Omega_{l,k}$
  - $R_k$: the total system capacity
Centralized Resource Allocation

• Problem formulation

• Find the optimal subcarrier $\Omega_{l,k}$ and power $p_{l,k}^{(n)}$ allocation schemes to maximize the total capacity

$$\max_{\Omega_{l,k}, p_{l,k}^{(n)}} \sum_{k=1}^{K} R_k$$

• Under the following constraints:

• Subcarrier constraint

$$\Omega_{l,k_1} \cap \Omega_{l,k_2} = \emptyset, \text{ for all } l \text{ and } k_1 \neq k_2$$

$$\bigcup_{k=1}^{K} \Omega_{l,k} = [1, N], \text{ for all } l$$

• Power constraint

$$\sum_{k=1}^{K} \sum_{n \in \Omega_{l,k}} p_{l,k}^{(n)} = P_L, \text{ for all } l$$

$$p_{l,k}^{(n)} \geq 0, \text{ for all } l, k, n$$
Centralized Resource Allocation

• Challenges
  • Due to the combinatorial nature of the subcarrier allocation, the problem is proven to be NP-hard.

• Traditional approach to such problem is to split the problem into two sub-problems
  • Step 1: Allocate subcarrier using greedy methods assuming equal power allocation.
  • Step 2: Adjust power allocation after subcarrier allocation has been done.
  • However, allocate subcarrier by assuming equal power allocation is not applicable for relaying scenarios.

• We propose subcarrier and power co-allocation scheme
Centralized Resource Allocation

• Why co-allocation?
  
  • *Theorem:* In the general situation, for a relaying network where the number of subcarriers \( N \) is much larger than the number of RSs \( L \), and \( L \) is a small integer value, there is approximately only one RS among all \( L \) RSs that
  \[
  h_{s,k}^{(m)} \neq 0.
  \]

• Intuitions behind the theorem
  
  • The theorem says that for each symbol from BS to UE, at the optimal solution, only 1 among all RSs is required to relay for this symbol.
  
  • Even when subcarriers at all RSs are allocated to UEs, for optimal solution, they may not be used because they can be allocated with null power.
  
  • Subcarrier and power co-allocation is necessary.
Centralized Resource Allocation

• Algorithm design
  • Algorithm design is guided by the theorem as well as the following Lemmas.
  
  • **Lemma 1**: when power for all other RSs has been allocated, the optimal power allocation of a RS $l$ is water-filling.

  • **Lemma 2**: $p_{l,k}^{\Omega_{l,k}(j)}$ is not 0 only if $\frac{|h_{l,k}^{(\Omega_{l,k}(j))}|^2}{\mu_k} \geq \frac{|h_{l',k}^{(\Omega_{l',k}(j))}|^2}{\rho_{l'}}$ for all $l', l \neq l$, where $\frac{1}{\mu_k}$ is related to the water level of RS $l$. 
Centralized Resource Allocation

- Algorithm design
  - Intuitively, if a RS has a better channel to user $k$, or it has a higher water-level (either due to it has higher power constraint or it allocates power for less users), it is more likely that it relays data for UE $k$.
  - Our proposed algorithm greedily allocates subcarriers by considering both channel conditions as well as current water-level of each RSs.
Centralized Resource Allocation

• Algorithm Details

• Initialization: greedily map subcarriers to UEs. Decide the initial set of subcarriers that have non-zero power for each RS. Apply water-filling algorithm for these subcarriers.

\[
\text{let } |h_l^{(n)}| = \max_k |h_{l,k}^{(n)}|, \text{ for all } l \in [1, L] \\
\text{sort } |h_l^{(n)}| \text{ in descending order for all } l \in [1, L] \\
\text{let } i_l = N \frac{|h_l^{(n)}|^2}{\sum_{l'}=1} |h_{l'}^{(n)}|^2, \text{ for all } l \\
\text{do water-filling on } |h_l^{(1)}| \text{ to } |h_l^{(i_l)}|, \text{ water level is } \frac{1}{\mu_l} \text{ for all } l
\]
Centralized Resource Allocation

• **Algorithm Details**
  - Iteratively adjust the subcarriers for RSs that have non-zero power. Redo water-filling algorithm for these subcarriers.

  \[
  \text{while } \max\left(\frac{|h_l^{(i_l)}|^2}{\mu_l}\right) - \min\left(\frac{|h_l^{(i_l)}|^2}{\mu_l}\right) > \Delta \\
  i_l^{\text{max}} = i_l^{\text{max}} + 1, \quad i_l^{\text{min}} = i_l^{\text{min}} - 1 \\
  \text{do water-filling for } l^{\text{max}} \text{ and } l^{\text{min}} 	ext{ again}
  \]

  

• Finalization: finalize the matching of subcarriers for each RS. Water-filling is used to determine the power.
Centralized Resource Allocation

• **Proportional Fairness**
  - One more condition for each UE $k$
    \[
    \frac{R_{k}}{c_{K}} - \frac{R_{k}}{c_{k}} = 0
    \]
  - The theorem still holds for subcarrier and power allocation for each UE. I.e., if the subcarriers and total power for a UE $k$ at each RS are determined, the same algorithm can still be applied.
  - Greedy algorithm is proposed
    - Decide the number of subcarriers allocated to the UEs according to their required data rate respectively.
    - Apply previous algorithm for subcarrier and power allocation of each UE.
    - Greedily adjust the subcarrier and power allocation by considering fairness.
Distributed Resource Allocation

- For a distributed system, each RS makes decision on its own.

- Communications among RSs are not required, which reduces the control cost.

- Allocation is assumed to be in rounds. At each round, a RS makes its own decision based on UE feedback of SNR (allocation results of all other RSs if MRC is used).
Distributed Resource Allocation

• Subcarriers are firstly greedily allocated

• From Lemma 1, the best power allocation strategy is water-filling.

• Adjustment is required for user fairness.
Simulation Results

• Parameters
  • Number of RSs
  • Number of UEs
  • Individual transmit power constraint at each RS
  • Fairness weight for each UE

• Assumptions
  • Decode-and-Forward relaying strategy
  • Perfect CSI
  • Frequency selective Rayleigh fading channel
  • 5MHz bandwidth
  • 512 FFT size
  • 300 data subcarriers
Simulation Results

- The total capacity vs. the received SNR (BS-UE & RS-UE links)
  - With 3 UEs and 3 RSs
Simulation Results

- The total capacity & Fairness performances
  - With 3 UEs at SNR=10dB
  - Vary the number of RSs up to 3
Conclusion

- Theorem derived based on maths analysis.
  - Co-allocation of subcarrier and power is necessary.
- Centralized and distributed resource allocation algorithms were proposed and compared by simulations
  - The proposed resource allocation algorithms outperform random allocation scheme.
  - Algorithms with fairness considerations have small loss in system capacity, but achieves significant gain in fairness.
  - Distributed resource allocation algorithms do not perform as good as centralized resource allocation algorithms, but with much less burden to the network.
Thanks for your attention!

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