Cloud-Based Cell Associations

Aly El Gamal

Department of Electrical and Computer Engineering
Purdue University

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Cloud Communication

Global Knowledge / Control available at Central nodes
Cloud-Based Interference Management

Enabling centralized approaches:

1. Learning the network / channel state information
2. Transmission schedules
3. Cell association decisions

Application in Multi-RAT Environments
Linear Interference Networks

\[ M_1 \rightarrow \text{Tx}1 \rightarrow \text{Rx}1 \rightarrow \hat{M}_1 \]

\[ M_2 \rightarrow \text{Tx}2 \rightarrow \text{Rx}2 \rightarrow \hat{M}_2 \]

\[ M_3 \rightarrow \text{Tx}3 \rightarrow \text{Rx}3 \rightarrow \hat{M}_3 \]

Generic Time Varying Channel
Linear Interference Networks

$M_1$  BS1  MT1  $M_1$

$M_2$  BS2  MT2  $M_2$

$M_3$  BS3  MT3  $M_3$

**BS:** Base Station

**MT:** Mobile Terminal

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Cloud-Based Cell Associations

Each Mobile Terminal can be associated with $N$ Base Stations
Degrees of Freedom (DoF)

\[ \text{DoF} = \lim_{{\text{SNR} \to \infty}} \frac{\text{sum capacity}}{\log \text{SNR}} \]

- **Objective:** Determine Per User DoF as a function of \( N \).

\[ \text{PUDoF}(N) = \lim_{{K \to \infty}} \frac{\text{DoF}(K, N)}{K} \]

What is the optimal cell association?
What we know

For Uplink:

$$\text{PUDoF}(N) = 1, \forall N \geq 2$$

For Downlink:

$$\text{PUDoF}(N) = \frac{2N}{2N + 1}$$
Uplink: Achieving Full DoF

Associating each MT with two BSs connected to it

Interference-free Degrees of Freedom
Downlink: Exploiting Global Topology Knowledge

Achieving $\frac{4}{5}$ Per User DoF

$$\text{PUDoF}(N) = \frac{2N}{2N+1}$$
Average Uplink-Downlink DoF

Downlink Associations

\[ N = 3 \]

Uplink Associations

\[ PUDoF = \frac{1 + \frac{4}{5}}{2} = \frac{9}{10} \]
Average Uplink-Downlink DoF

\[ \text{PUDoF}(N) = \frac{4N-3}{4N-2} \]
Further Questions

1. General network topologies
2. When to simplify into optimizing for uplink / downlink only
3. Constrain average number of cell associations
Next: Transmit Cooperation with no CSIT

We know that flexible cell association is useful ¹

We do not know whether cooperative transmission is useful

No CSIT: Linear Interference Networks

Theorem

Transmitter cooperation with no CSIT does not increase the asymptotic per user DoF in linear interference networks

\[ \text{PUDoF}(N > 1) = \text{PUDoF}(1) = \frac{2}{3} \]
Converse Proof

- Channel is time varying with joint pdf
- Once message is transmitted, it appears at all connected receivers
- Coordinated Multi-Point transmission cannot be used to cancel interference
Next Tasks

- Can transmitter cooperation help in any network topology
- Characterize DoF for general network topologies
- Extend to other backhaul constraints
Coordinated Learning of Network Topology

• Earlier work for the broadcast problem\(^2\)

• Cloud communication can enable some of these ideas

Coordinated Learning of Network Topology

Lemma

For any $x_1, \cdots, x_s \leq n$, there exists a prime $p \leq s \log n$ such that,

$$x_i \neq x_j \mod p, \forall i, j \in \{1, \cdots, s\}$$

$s$ : Connectivity parameter

$n$ : total number of users
Coordinated Learning of Network Topology

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For any \( x_1, \cdots, x_s \leq n \), there exists a prime \( p \leq s \log n \) such that, \( x_i \neq x_j \mod p, \forall i, j \in \{1, \cdots, s\} \)

1. Let \( p_1, \cdots, p_m \) be the prime numbers in \( \{1, \cdots, s \log n\} \)
2. \( m \) phases of transmission
3. in \( i^{th} \) phase, \( x_j \) transmits in slot \( x_j \mod p_i \)
Coordinated Learning of Network Topology

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\( O(s^2 \log^2 n) \) Communication rounds
Converse?

- Mimic Probabilistic method for broadcast channel?
- Slight variation of Group Testing?
Conclusions

Cloud-Based Wireless Networks:

- Enabling centralized approaches
- New questions and conclusions
- Value of flexible cell association
- Coordinated transmission / reception
- Different learning strategies
- Benefit with no CSIT / Ad-hoc networks?