Interactive Communication for Resource Allocation

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Outline

1. Introduction
2. Problem Model
3. Analysis
4. Results
5. Conclusions
Motivation

- Which user to assign the subcarrier to
- Which modulation and coding scheme to employ

M. I. Salman etc. "IETE Technical Review"
Adaptive Modulation and Coding

- Overheads
  - Reference Signals
  - Channel Quality Indicators
  - Control Decisions

- Occupy the OFDMA resource blocks
- Approximately 1/4 to 1/3 of all downlink transmission in LTE
Introduction

Background

Rateless Codes

- Almost achieve channel capacity
- Without requiring of channel information at the transmitter side
- Allow variable block length

BS: wishes to maximize the system throughput
Only needs to learn the arg-max

http://www.telematica.polito.it/oldsite/sas-ipl/
Background

Interactive Communication

- Interaction for Lossy Source Reproduction (Kaspi 1985)
- Interaction for function computation (Ishwar & Ma 2011)
  - Benefit can be arbitrarily large
  - Infinite rounds interaction may help

\[ \mathcal{R}_t = \{ \mathbf{R} | \exists \mathbf{U}^t, \ s.t. \forall i = 1, \ldots, t \]

\[ R_i \geq I(X; U_i | Y, U^{i-1}), \ U_i - (X, U^{i-1}) - Y, \ i \text{ odd} \]

\[ R_i \geq I(Y; U_i | Y, U^{i-1}), \ U_i - (Y, U^{i-1}) - X, \ i \text{ even} \]

\[ H(f(X, Y) | Y, U^t) = 0 \]
Main Contribution

Achievable Interactive Communication Scheme for Resource Allocation

- Determine the arg-max (use rateless codes for data transmission)
- Solve by dynamic programming
- Show huge savings
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Problem Model

\[ U_t(\lambda_t = 3dB) \]

**Notations**

- \( X_i \in X_t = \{ a_t, \ldots, b_t \} \)
- \( U_t \) Broadcasting message at round \( t \)
- \( V_t^i \) Replied message from MS \( i \) at round \( t \)

**Achievable Interaction Scheme**

1. BS broadcasts a threshold \( \lambda_t \) at round \( t \)
2. MS \( i \) replies a 1 if \( X_i \geq \lambda_t \) and 0 otherwise
3. Stops when BS knows arg-max reliably
Some Assumptions

- BS knows the initial distribution of $X$
- BS knows the initial number of MSs
- MSs are not allowed to communicate with each other
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Non-increasing Support set of $X$

If some users reply 1

$$a_{t+1} = \lambda_t$$
$$b_{t+1} = b_t$$
$$F_{t+1}(x) = \frac{F_t(x) - F_t(\lambda_t)}{F_t(b_t) - F_t(\lambda_t)}$$

(2)

If no user replies 1

$$a_{t+1} = a_t$$
$$b_{t+1} = \lambda_t$$
$$F_{t+1}(x) = \frac{F_t(x) - F_t(a_t)}{F_t(\lambda_t) - F_t(a_t)}$$

(3)
Analysis

Aggregate rate

\[ R_t(\lambda) = H(\lambda|\lambda_1, \cdots, \lambda_{t-1}) + N_t + (F_t(\lambda))^{N_t} R^*(N_t, a_t, \lambda) \]
\[ + \sum_{i=1}^{N_t} (1 - F_t(\lambda))^i F_t(\lambda)^{N_t-i} \frac{N_t!}{i!(N_t-i)!} R^*(i, \lambda, b_t) \]  

Policy Iteration

\[ \lambda_t^* = \arg \min_{\lambda} R_t(\lambda) \]
Analysis

- Efficiently Encode the Threshold
  \[ H(\lambda_t|\lambda_1, \ldots, \lambda_{t-1}) \quad (6) \]

- Why \( H(N_t|N_{t-1}) \) works?
  - \( \lambda_t \) and \( N_t \) determines \( \lambda^*_t \)
  - \( \lambda_{t-1}, N_{t-1} \) and \( N_t \) determines \( \lambda_t \)
  \[
  \lambda_t = \begin{cases} 
  \{\lambda_{t-1}^*, b_{t-1}\} & \text{if } N_t < N_{t-1} \\
  \{a_{t-1}, \lambda_{t-1}^*\} & \text{if } N_t = N_{t-1} \text{ and } \lambda_{t-1}^* > x_i \\
  \{\lambda_{t-1}^*, b_{t-1}\} & \text{if } N_t = N_{t-1} \text{ and } \lambda_{t-1}^* \leq x_i
  \end{cases}
  \quad (7)
  \]

- Two other strategies
  - Non-conditioning Encode the Threshold: \( H(\lambda_t) \)
  - Encode the Number of Users: \( H(N_t|N_{t-1}) \)
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Results

- $\mathcal{X} = \{1, \ldots, 16\}$
Some Extensions

Interaction with Distortion

\[ \mathbb{E}[\max\{X_1, \ldots, X_{N_t}\} - X_i] \leq D \] (8)

Bits Cost Vs. Time Cost

\[ C = \mu R + (1 - \mu) T \] (9)
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Conclusions

Contribution & Future Work

Review of Contribution

• Achievable Interactive Communication Scheme for Resource Allocation
• Solve by Dynamic Programming

Future Work

• Consider Scalar Quantization than the 1-bit Message
• Fundamental Limits (Rate-distortion Curve)
• Resource Allocation in MIMO system
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