Cooperative Mobile Internet Access with Opportunistic Scheduling

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Agenda

- Introduction
  - Motivation
  - System setting
- Cooperative Internet access
  - Optimization
- Evaluation results
- Conclusion

Introduction

- Advances in technology of mobile devices
  - Smartphones and tablets
  - Video streaming
  - Video chats
  - Surfing the Internet

- Ubiquitous and resilient Internet access
  - Accessing the Internet from everywhere

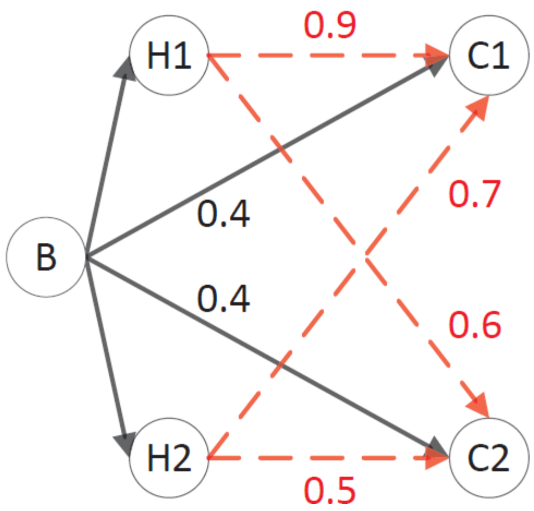
Introduction

- Challenges in resilient and ubiquitous Internet access
  - Cellular data traffic growth
  - Changes in the channel quality
  - Low cellular channel quality
    - Might not be sufficient to meet the user's demand

- Solution: cooperative downloading
  - Using idle user resources to provide Internet access to other users, or improve their data rates

Motivation

- Example
  - Bandwidth:10 Mb/s
  - Utility: total download rate



- No cooperation
  - C1: 4 Mb/s
  - C2: 4 Mb/s
- Cooperation
  - C1: 13 Mb/s
  - C2: 9 Mb/s

- Resilient communication in addition to increased download rate

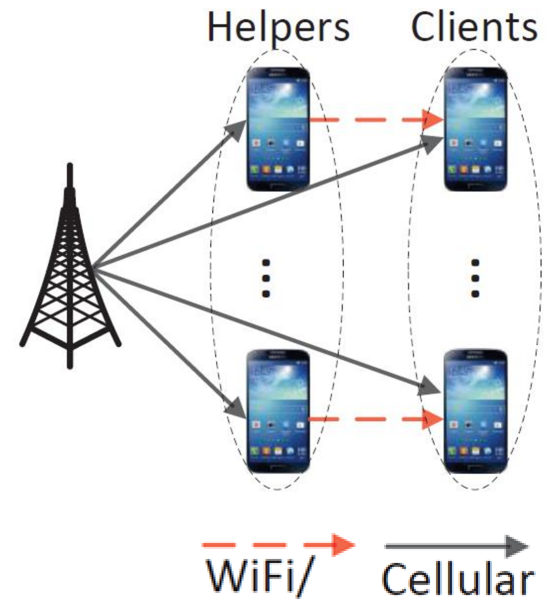
Challenges to Address

- How to motivate the helpers to participate?
  - 4G/LTE cost
  - Transmission drains the battery

- How to assign the helpers to the clients?
  - In order to maximize the utility
  - Fair assignment

- What is the optimal download rate?
  - The relation of the download rate and satisfaction is not linear
  - Transmission drains the battery

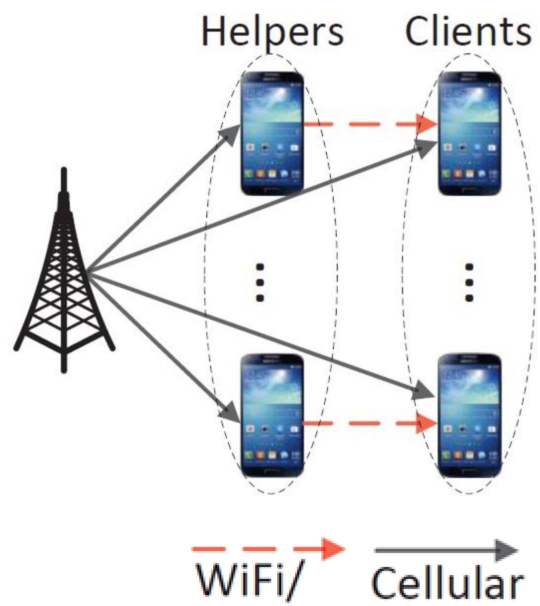
Setting



- A set of helpers
  - Access to the Internet through a BS
- A set of clients
  - Download from BS using 4G/LTE
  - Download from helpers using WiFi

- Each helper can serve only one client at a time
- During each time slot the channel conditions are fixed

Setting



- Transmission consumes energy
  - Energy consumption of the nodes are different
  - Cellular connections use more energy than WiFi connections
- Unreliable links
  - Delivery rate changes over time
  - Using random linear network coding to eliminate feedback messages

Network Coding

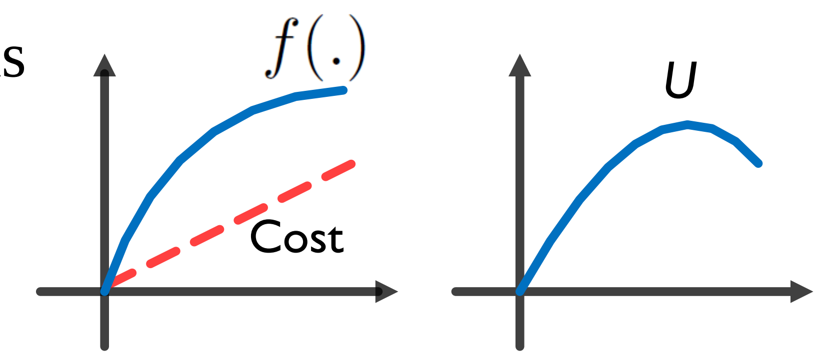
- Random linear network coding
  - Coding: linear combinations of the packets

$$
\begin{cases}
q_1 = \alpha_{1,1}p_1 + \alpha_{1,2}p_2 + \alpha_{1,3}p_3 \\
q_2 = \alpha_{2,1}p_1 + \alpha_{2,2}p_2 + \alpha_{2,3}p_3 \\
\vdots \\
q_{\mathrm{n}} = \alpha_{n,1}p_1 + \alpha_{n,2}p_2 + \alpha_{n,3}p_3
\end{cases}
$$

  - Decoding: Gaussian elimination
- Applications of network coding
  - Reliable transmissions
  - Throughput/capacity enhancement
    - Distributed storage systems/ Content distribution/ Layered multicast

Problem Statement

- Incentive mechanism
  - Motivating the helper to participate
  - Clients pay helpers based on the data transmission rate
- Utility function
  - $U(i,t) = f(x_{ji}^t p_{ji}^t + x_i^t p_i^t) - e(i,t) - x_{ji}^t z$
- $f(.)$: strict concave
  - Law of diminishing returns



- Objective: maximizing the aggregated utility of the clients

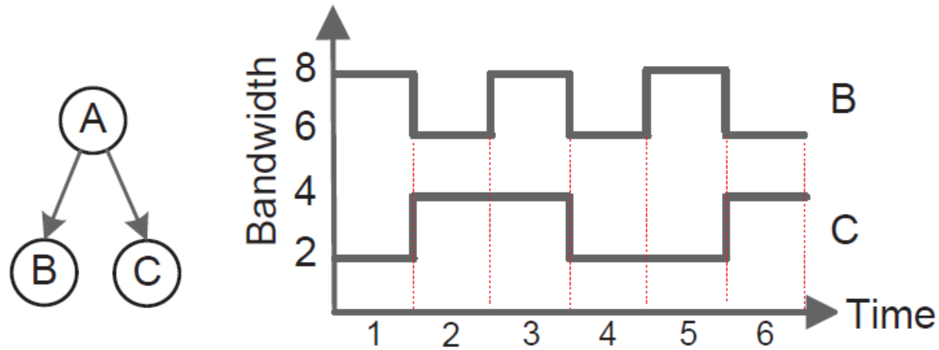
Cooperation Scheme

- *Case 1*: without energy consumption and the credit payments

- Providing fairness
  - Without fairness, the solution is straightforward
    - Maximal bipartite matching
  - Clients with good WiFi channel conditions keep the channels

- Opportunistic scheduling

Opportunistic scheduling

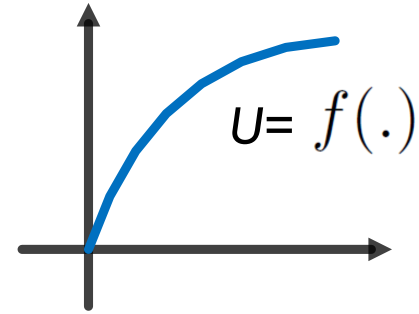


- Without fairness: *A* always transmits to *B*
- Sharing each time slot between *B* and *C*
  - *B*: $(8/2 + 6/2) \cdot 3 = 21$ Mb
  - *C*: $(4/2 + 2/2) \cdot 3 = 9$ Mb
- Assigning time slots 1, 3, and 5 to node *B*
  - *B*:24 Mb
  - *C*:10 Mb

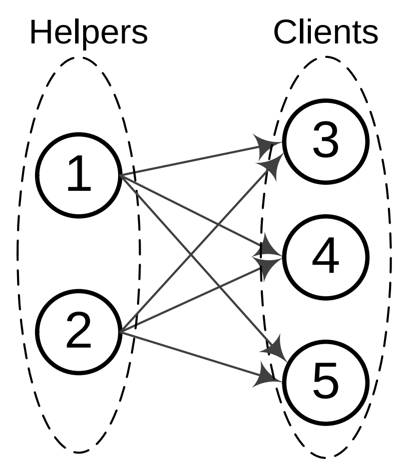
Fairness

- Original objective: maximizing $\sum_{i=1}^{n} U(i,t)$
- *Idea*: instead of maximizing the total utility, we maximize $\sum_{i=1}^{n} \alpha_i^t U(i,t)$
  - α_i^t : parameters that control the fairness
  - Give the client with the low received utility the chance to use the helpers
  - For each time slot, the relatively best clients get assistance

Algorithm

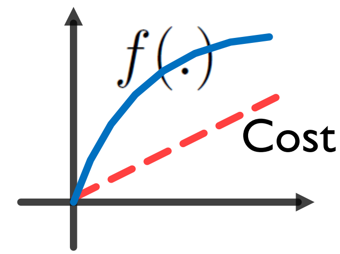


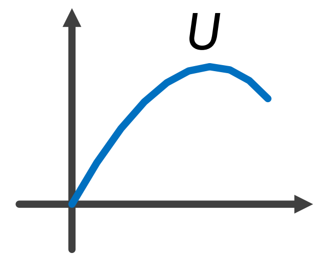
- Calculate the utility of client *i* when it uses only the cellular connection
- Calculate the increase in client *i*'s utility in the case of using helper *j* and cellular connection
- Multiply the enhancement by $\alpha_i^t = 1/\sum_{t'=1}^{t-1} G(i,t)$ and assign it to link from helper *j* to client *i*
- Run the Hungarian algorithm to find the maximum weighted bipartite matching of helpers-clients



Cooperation Scheme

- *Case 2*: considering energy consumption and the credit payments





- Utility function:

$$U(i,t) = f(y_i^t) - x_i^t p_i^t e_i^c - \sum_{j \in H} [x_{ji}^t p_{ji}^t e_i^w + z x_{ji}^t]$$

- First phase: linear programming

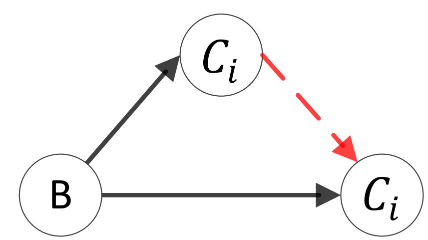
$$\max U(i,t) = f(y_i^t) - x_i^t p_i^t e_i^c - x_{ji}^t p_{ji}^t e_i^w - z x_{ji}^t$$

$$s.t\ x_{ji}^t \le p_j^t b_j^t / p_{ji}^t$$

$$x_{ji}^t \le b_{ji}^t$$

$$x_i^t \le b_i^t$$

$$y_i^t \le x_i^t p_i^t + x_{ji}^t p_{ji}^t$$

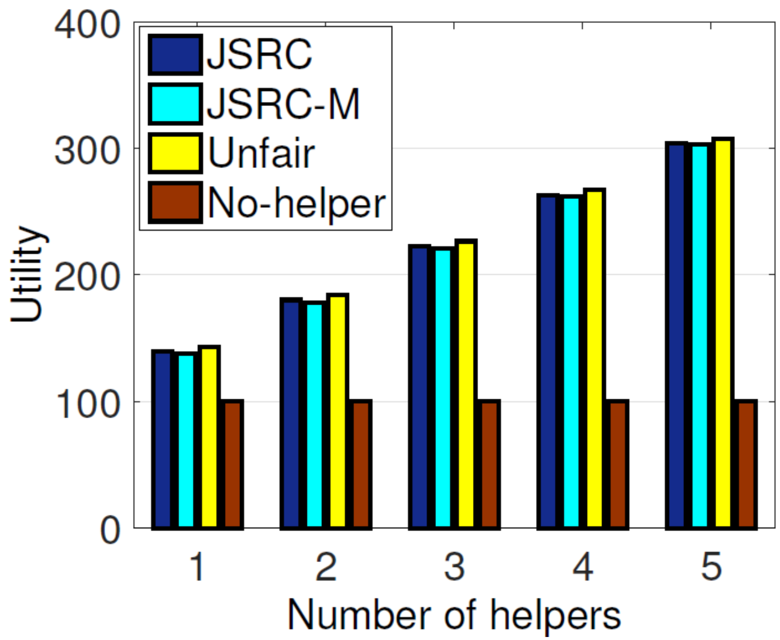


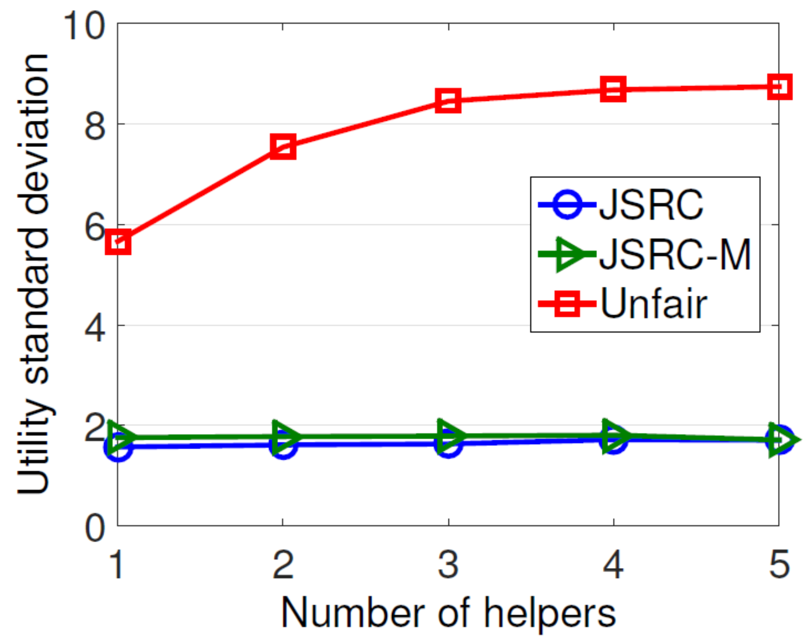
Evaluations

- Simulator in Matlab environment
- Comparison
  - Proposed fair scheduling
  - No-helper
  - Unfair scheduling
  - Modified fair scheduling
- 200 runs
- $f(y_i) = \log(y_i + 1)$

Evaluations

- Delivery rate $\in [0.5, 1]$
- Clients: 10
- Time slots: 50





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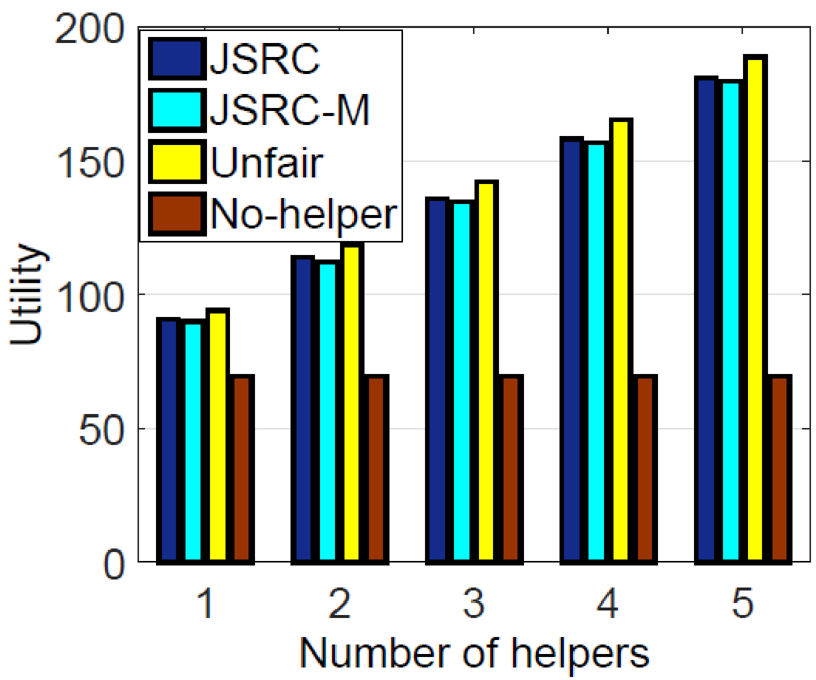

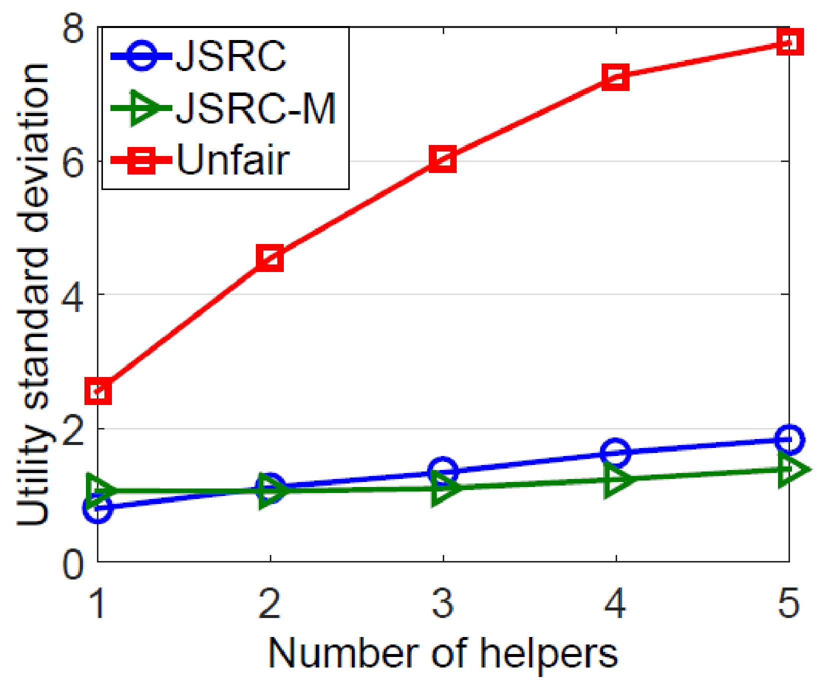

Conclusion

- Providing ubiquitous Internet access
- Cooperation among nodes
- Incentive mechanism to motivate helpers
- Considering the energy consumption
- Fairness
- Opportunistic scheduling
- Two-phases mechanism
  - Optimization
  - Maximum matching

Thank you!

Questions?