Capacity Scaling in Wireless Device-to-Device Caching Networks

Mingyue Ji, Giuseppe Caire, Alexandros Dimakis and Andreas Molisch
Department of Electrical Engineering, University of Southern California, Los Angeles

Introduction

- The bottleneck of current wireless cellular network is the spectral efficiency of the Base Station, which does not scale with the number of users.
- We want to solve this problem by using distributed caching and Device-to-Device (D2D) communication.

Motivation

- There are some redundancies of the requests from users.
- Modern smartphones and tablets have large storage capacity.
- Wireless D2D communication happens in short distance and can achieve very high spectral efficiency.

Network Model

- We consider a squared dense network of area 1, where n nodes are distributed on a grid.
- We consider the delivery of messages from a library of m (function of n) possible messages (files) to the nodes.
- Users make statistically independent requests for a message in the library according to a Zipf distribution with parameter $0 < \gamma_r < 1$.
- Nodes cache the messages at random, and it is assumed that each node can cache at most one message.
- Protocol Transmission model is used and only one-hop transmission is allowed.
- If the users that cannot find the message in the D2D network, then they will be served by the Base Station.

Problem Definition

- Our goal is to find the maximum throughput of D2D network.
- First, we want to find an upper bound of the maximum throughput under the constraint of Protocol Model (channel model) and one-hop transmission.
- Second, we want to find a relatively realistic caching policy and transmission scheme to match the upper bound.
- The throughput can be computed as the following:

$$E[T] = C \cdot E \left[ \text{number of active links} \right]$$

Main Results

- Theorem (achievable bound): Let $m = \Theta \left( \log n \right)$ Users make requests with Zipf distribution with parameter $0 < \gamma_r < 1$ and cache a single message, randomly and independently of their location and of their requests, with a Zipf distribution with parameter $\gamma_c$. Then, the optimal throughput for the clustering scheme under the Protocol Model behaves as:

$$\frac{n}{((\log n) \log \log n) \frac{1}{2-\gamma_r} \gamma_c}$$

which is achieved by using $\gamma_c = 1$.
- Theorem (Upper bound): Assume $m = \Theta \left( \log n \right)$. Users make requests with Zipf distribution with parameter $0 < \gamma_r < 1$ and cache a single message under any caching scheme, the optimal throughput under Protocol Model and one-hop transmission behaves as:

$$E[T] = O \left( \frac{n}{(\log n) \frac{1}{2-\gamma_r}} \right)$$

Remark

- An example of $m = \Theta \left( \log n \right)$. Suppose the typical interest of a person spans K files. Then, the typical interest of next person intersects with that of the first person with K/2 files and the incrementally typical interest of the second person spans K/2 files. Similarly, the incrementally typical interest of the third person spans K/3 files and so on. Eventually, the union of all files which people are interested in is $m = K + K/2 + K/3 + K/4 + \cdots + K/n = \Theta \left( \log n \right)$.
- Our scheme is very practical. We do not need any completed coding scheme for files and only need the rank of files, not distribution.