Link Scheduling In Cooperative Communication With SINR-Based Interference

Chenxi Qiu and Haiying Shen

Dept. of Electrical and Computer Engineering
Clemson University, SC, USA
Outline

- Introduction
- Model
- Methodology
- Performance Evaluation
- Conclusion
Introduction

• Link scheduling
  – Problem: due to broadcast nature of wireless communication, links may interfere with each other.
  – One strategy: schedule the interfered links in different time slots.
  – So the question is: in which time slots links should be active to prevent links from interfering with each other.
Introduction

- Cooperative communication (CC)
  - Physical interference model: a signal can be successfully received if its SINR is higher than a threshold.
  - CC: receiver can combine signals from multiple senders using CC techniques (e.g., Maximum Ratio Combining) to increase SINR.
Introduction

• Example
  - $v_4$ has received and stored the messages from $v_5$, then $v_4$ and $v_5$ are able to send the message together to their destination $v_3$.

• Our goal
  - Schedule links in different time slots in CC to prevent interference
  - Inform all the receivers using the minimum number of time slots or maximize the number of receivers informed (links scheduled) in time slot
Related work

• Graph-based model
  – [Sharma, Mobicom 2006]: k-hop interference model, proved NP hard.
  – [Hand, Percom 2015]: RTOB, efficient use of radio channels based mobile slotted Aloha.
  – [Murakami, Percom 2015]: multiple APs working on the same channel concurrently transmit frames to avoid interference.

• SINR-based model
  – [Chafekar, Infocom 2008]: algorithm with $O(g(D))$ approximation ratio.
  – [Brar, Mobicom 2006] [Goussevskaia, Infocom 2009]: algorithm with $O(1)$ approximation ratio.
The System Model

- A set of nodes $V$, a set of links $L \subseteq V \times V$, a set of requests $f_1, \ldots, f_N$, where each $f_i$ can be represented by a receiver $r_i$ and a set of links $I_i$ directed to $r_i$.

- The length of each link $l_{s,r}$ is defined as the Euclidean distance between the link’s sender $s$ and receiver $r$. And the signal power is

$$P(l_{s,r}) = P \cdot d(l_{s,r})^{-\alpha}$$

- SINR:

$$\text{SINR}_{r_i} \triangleq \frac{\sum_{l_{s,r_i} \in I_i} d(l_{s,r_i})^{-\alpha}}{\sum_{l_{s,r} \in I \setminus I_i} d_{s,r_i}^{-\alpha}}$$

- $r_i$ can correctly decode the message (or be informed) iff $\text{SINR} > \gamma_{th}$
Cooperative Link Scheduling (CLS) problem

The objective is: *to find a feasible schedule that takes the minimum number of time slots.*

**Instance:** Instance: A finite set of nodes in a geometric plane \( V \), a set of requests \( F = \{f_1, ..., f_N\} \), and decoding threshold \( \gamma_{th} \) and time constraint \( T \).

Question: Existence of a schedule s.t. 1) No interfered links are scheduled in the same time slot and 2) Each receiver is informed by time slot \( T \).
Problem Formulation

One-shot Cooperative Link Scheduling (OCLS) problem

The objective is: \textit{to find a feasible schedule that the number of receivers is maximized in one time slot.}

\textbf{Instance}: A finite set of nodes in a geometric plane \(V\), a set of requests \(F = \{f_1, \ldots, f_N\}\), decoding threshold \(\gamma_{th}\), also includes a constant \(M\).

\textbf{Question}: Existence of a schedule \(s.t.\) at least \(M\) receivers can be informed.
Approximation Algorithms

Definition:

**(Length diversity)** Length diversity of a set of links L, denoted by \( g(L) \), indicates the number of magnitudes of link distances of L. We define the link length set of L by

\[
G(L) \triangleq \{ h | \exists l, l' \in L : \lfloor \log(d(l)/d(l')) \rfloor = h \}
\]

and define the link length diversity (LLD) by \( g(L) = |G(L)| \).

In reality, \( g(L) \) is usually a small constant [1].

Approximation Algorithms

The link length diversity (LLD) based algorithm for link scheduling problem (CLS) (LLD-CLS)

Step 1: build $g(K)$ disjoint link classes $L_1, \ldots, L_{g(K)}$ from $L$, s.t.

$$L_k = \{l \in L | 2^{h_k} \cdot \sigma \leq d(l) < 2^{h_k+1} \cdot \sigma\}$$

Where $\sigma$ is the length of the shortest link in $L$.

Step 2: when scheduling $L_{k'}$, the whole region is partitioned into a set of squares $A^k = \{A^k_{a,b}\}$, where $(a,b)$ represents the location of the square in the grid.
Approximation Algorithms

The LLD based algorithm for CLS (LLD-CLS)

**Step 3:** all the squares in $A^k$ are colored regularly with 4 colors. Links whose receivers belong to different cells of the same color are scheduled simultaneously.

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Theorem 1: The approximation ratio of LLD-CLS is $O(g(K))$. 
Approximation Algorithms

The LLD based algorithm for one-shot cooperative link scheduling problem (OCLS) (LLD-OCLS)

**Step 1:** build $g(K)$ disjoint link classes $L_1, \ldots, L_{g(K)}$ from $L$ base on the length of links.

**Step 2:** partition the whole region into a set of squares when scheduling $L_k$.

**Step 3:** color the squares with four colors and pick the link in one color $j$ and put it in a link set $I(k, j)$.

**Step 4:** select $I(k, j)$ that has the largest throughput as the final solution.

**Theorem 2:** The approximation ratio of LLD-OCLS is $O(g(K))$. 
Approximation Algorithms

CC-Greedy

Consider a special case, in which the desired link set of each receiver is upper bounded by a constant $\Omega$.

**Basic idea:** in each iteration, select the links with strong enough signal power, and then remove the links that may interfere with the selected links.

Theorem 3: all the selected receivers can be successfully informed.

Theorem 4: The approximation ratio of the greedy algorithm is $O(1)$. 
Approximation Algorithms

CC-Greedy

Details:
In each iteration:

Step 1: the algorithm greedily selects the uninformed receiver with the shortest key link in K, and activates all the links with length shorter than a threshold (line 3-4).

Step 2: the algorithm deletes the links that may conflict with the selected links to guarantee the selected links are successfully informed (line 5-6).

Algorithm 3: Pseudo code for the greedy algorithm.

```
input : L = {I_1, ..., I_N}
output: I_{ocls}
1 I_{ocls} ← φ;
2 while L ≠ I_{ocls} do
3     Pick up the receiver r_i with the shortest link in L;
4     Add the link set I_i = {l ∈ I_i | d(l) < ξ · d(κ(r_i))} to I_{ocls};
5     Remove I_i \ I_i from L;
6     Remove all the links l_{s,r}, s.t. d_{s,r} < c · d(κ(r_i)) from L;
7     Remove any link set I_j, s.t. RI_{ocls}(r_j, I_j) > 1/2;
8 return I_{ocls};
```
Performance Evaluation

• **Settings**
  – all nodes were distributed uniformly at random on a plane field of size 100X100.
  – the number of senders is set by 200.
  – the number of receivers from 10 to 100 with 10 increase in each step.
  – the path loss exponent was varied from 2.5 to 6 with 0.5 increase in each step

• **Metrics**
  – (1) maximum delay: the number of time slots used to inform all receivers;
  – (2) throughput: the number of receivers informed in a single time slot.
Performance Evaluation

• Comparison

− ApproxDiversity [2]: partitions the link set into disjoint link classes and schedules the links in each class separately.


− ApproxLogN [3]: always picks up the shortest link and excludes links conflicted with the picked links in each iteration.


Main difference: ApproxLogN and ApproxDiversity do not allow CC in transmission.
Performance Evaluation

Different number of receivers

Maximum delay

LLD-CLS < ApproxDiversity

Throughput

LLD-OCLS > ApproxDiversity
Performance Evaluation

Different path loss exponent

Maximum delay
LLD-CLS < ApproxDiversity

Throughput
LLD-OCLS > ApproxDiversity
Performance Evaluation

Compare the throughput of CC-Greed, ApproxLogN, LLD-OCLS, and ApproxDiversity. The number of receivers from 40 to 400, and $\alpha$ is set by 3.

CC-Greed > LLD-OCLS
> ApproxLogN > ApproxDiversity
Conclusion

• Our contributions
  – Formulate two new problems: CLS and OCLS.
  – propose algorithms LLD-CLS and LLD-OCLS for CLS and OCLS with $g(K)$ ratio.
  – propose a decentralized algorithm for OCLS with $O(1)$ approximation ratio.

• Future work
  – Take into account probabilistic fading models for this problem.
Thank you!

Questions & Comments?

Haiying Shen

shenh@clemson.edu

Associate Professor

Pervasive Communication Laboratory

Clemson University