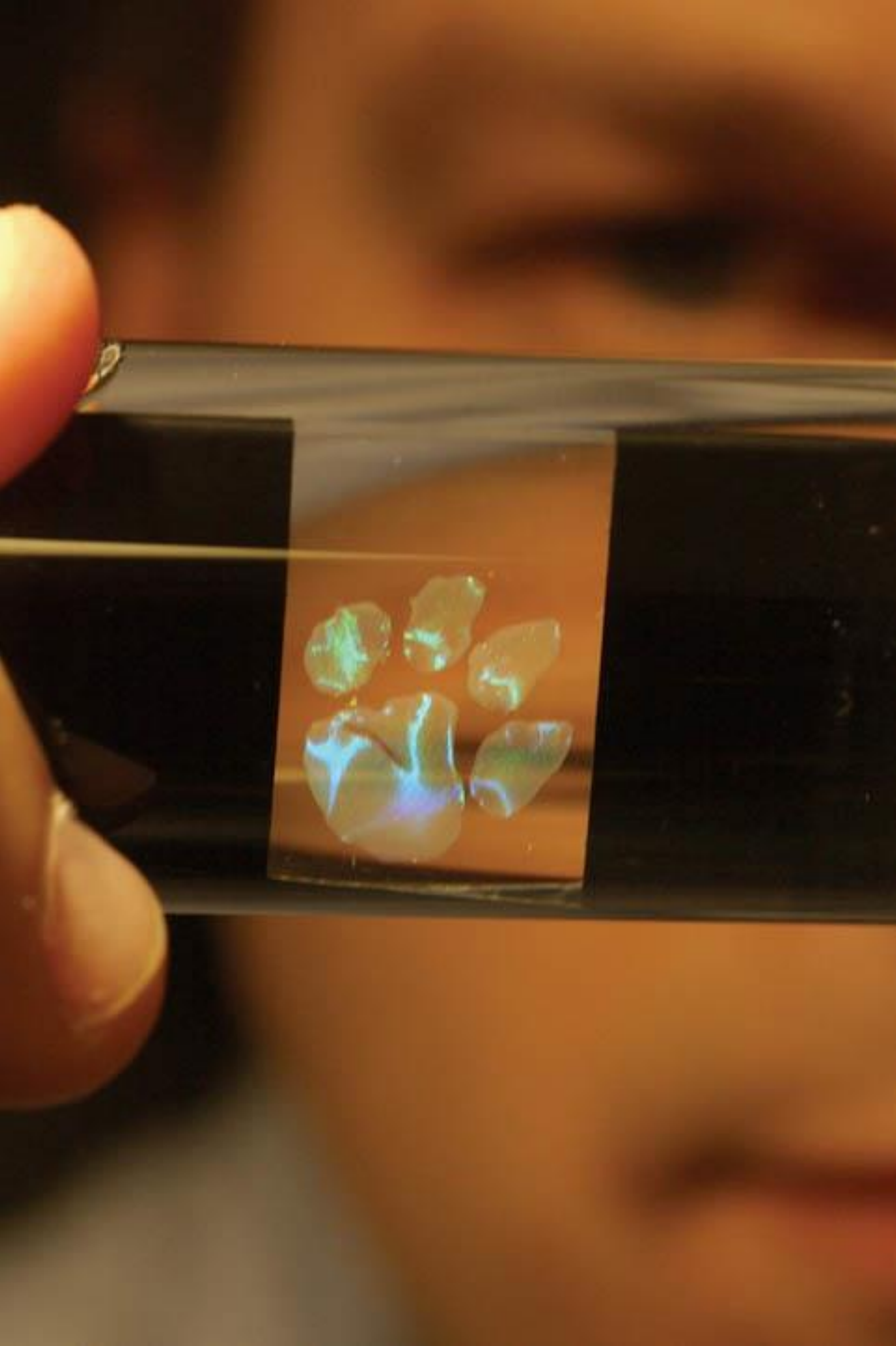

Link Scheduling In Cooperative Communication With SINR-Based Interference

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Outline

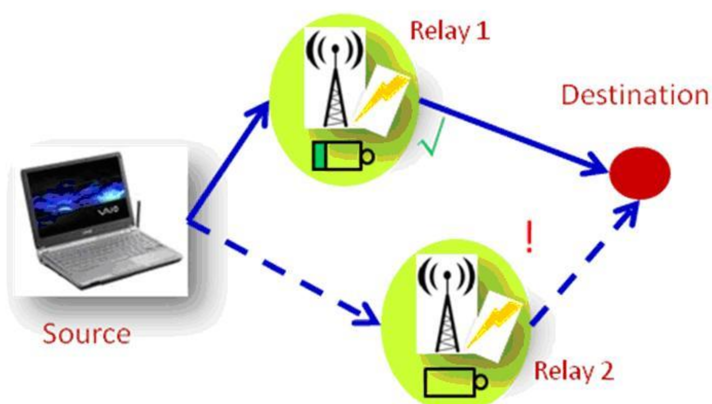
- Introduction
- Model
- Methdology
- Performance Evaluation
- Conclusion

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.

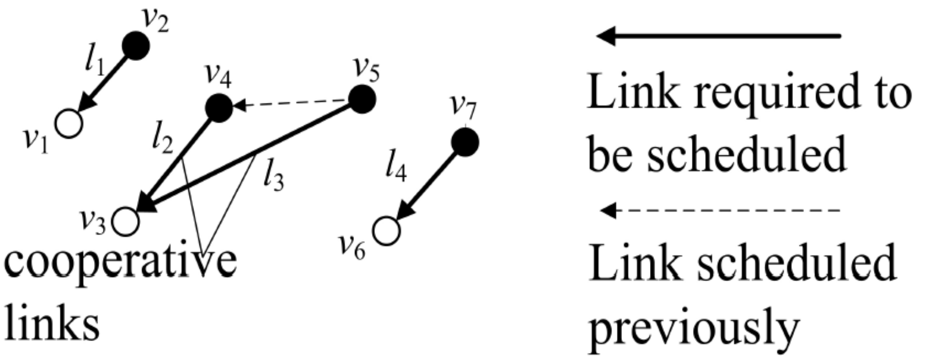
Introduction

- 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
  - [Goussevskaia, Mobihoc 2007]: geometric SINR model, proved NP-hard.
  - [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

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

- SINR:

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

- r_i can correctly decode the message (or be informed) iff SINR > γ_{th}

Problem Formulation

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 $F = \{f_1, \ldots, f_N\}$, and decoding threshold γ_{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: *to find a feasible schedule that the number of receivers is maximized in one time slot*.

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

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].

[1] O. Goussevskaia, Y. A. Oswald, and R. Wattenhofer, “Complexity in geometric SINR,” in Proc. of Mobihoc, 2007.

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, ..., $L_{g(K)}$ from L, s.t.

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

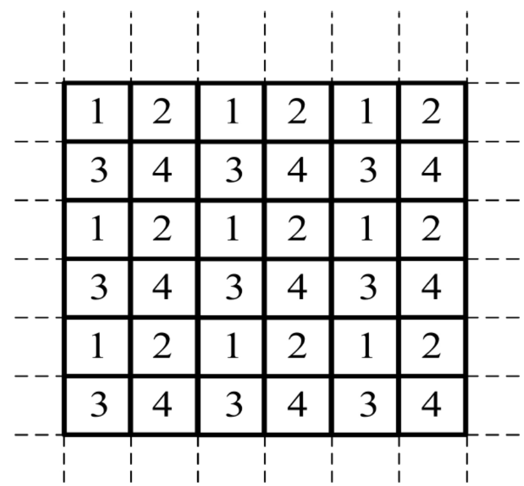
Where σ is the length of the shortest link in L.

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



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 $\mathrm{I}(k, j)$.

Step 4: select $\mathrm{I}(k, j)$ 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 Ω.

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.

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input : $L = \{I_1, ..., I_N\}$
output: $\mathcal{I}_{\text{ocls}}$
1 $\mathcal{I}_{\text{ocls}} \leftarrow \phi$;
2 **while** $L \neq \mathcal{I}_{\text{ocls}}$ **do**
3   Pick up the receiver r_i with the shortest link in L;
4   Add the link set $\mathcal{I}_i = \{l \in I_i | d(l) < \xi \cdot d(\kappa(r_i))\}$ to $\mathcal{I}_{\text{ocls}}$;
5   Remove $I_i \backslash \mathcal{I}_i$ from L;
6   Remove all the links $l_{s,r}$, *s.t.* $d_{s,r} < c \cdot d(\kappa(r_i))$ from L;
7   Remove any link set I_j, *s.t.* $RI_{\mathcal{I}_{\text{ocls}}}(r_j, I_j) > 1/2$;
8 **return** $\mathcal{I}_{\text{ocls}}$;

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.

  [2] O. Goussevskaia, Y. A. Oswald, and R. Wattenhofer, "Complexity in geometric SINR," in Proc. of Mobihoc, 2007.

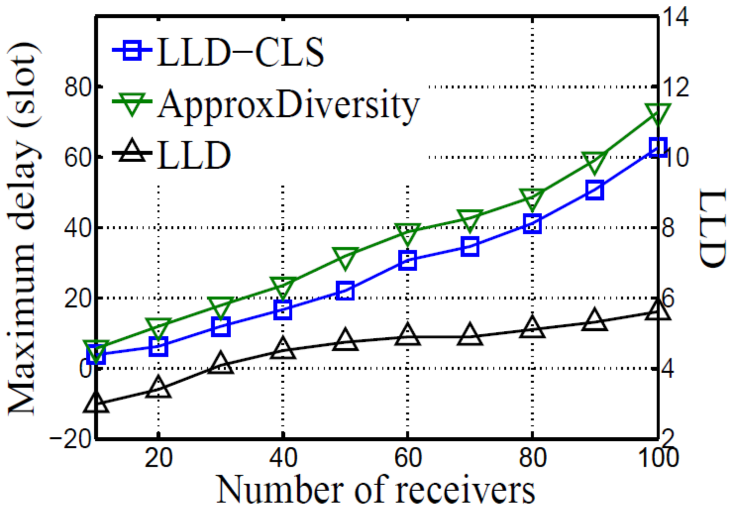
  - ApproxLogN [3]: always picks up the shortest link and excludes links conflicted with the picked links in each iteration.

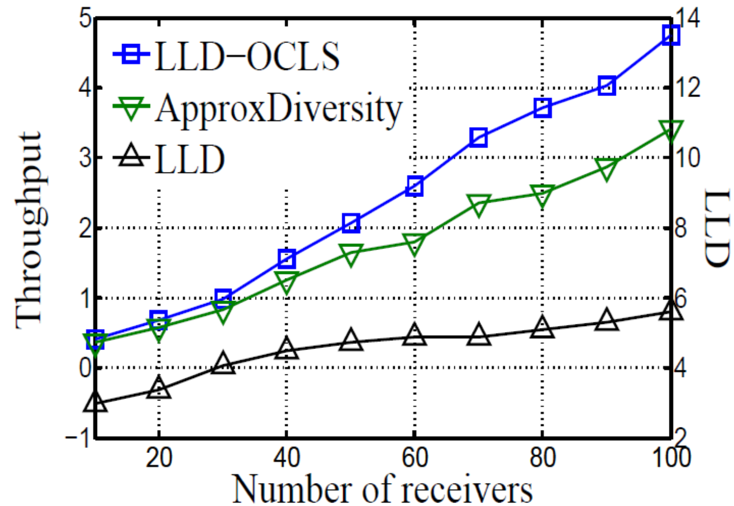
  [3] O. Goussevskaia, R. Wattenhofer, M. M. H. orsson, and E. Welzl., "Capacity of arbitrary wireless networks.," in Proc. of Infocom, 2009.

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

Performance Evaluation

Different number of receivers





Maximum delay

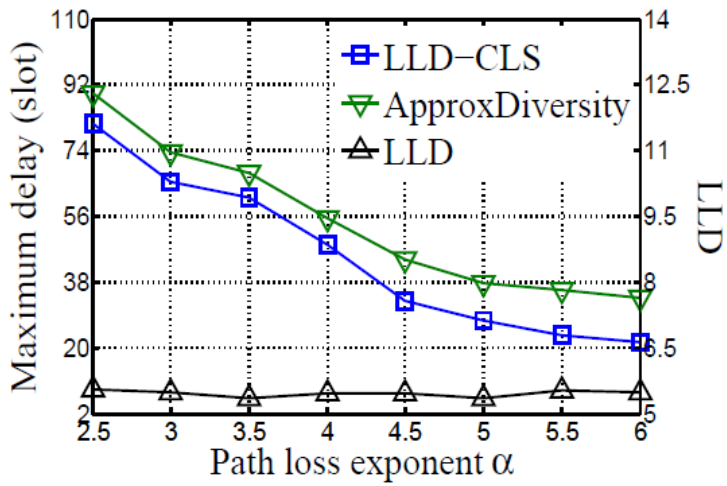
Throughput

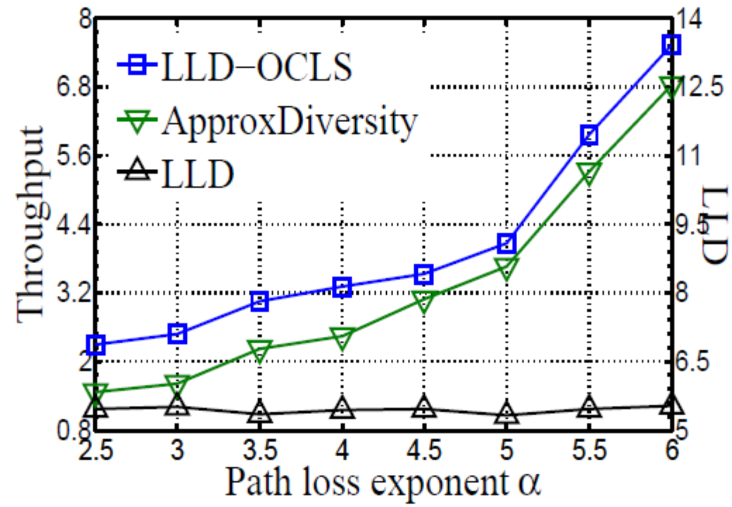
LLD-CLS < ApproxDiversity

LLD-OCLS > ApproxDiversity

Performance Evaluation

Different path loss exponent





Maximum delay

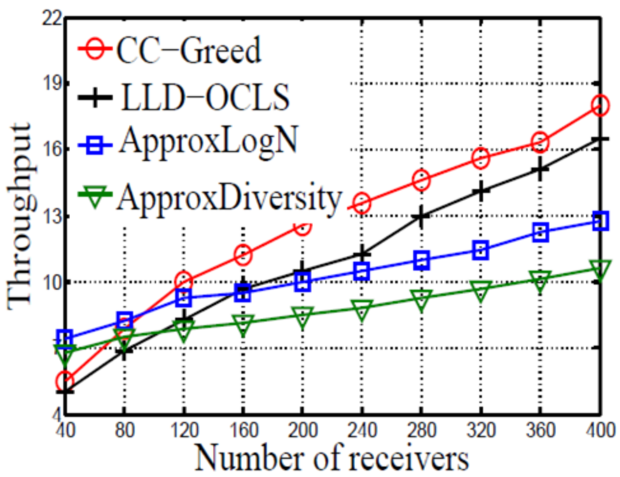
LLD-CLS < ApproxDiversity

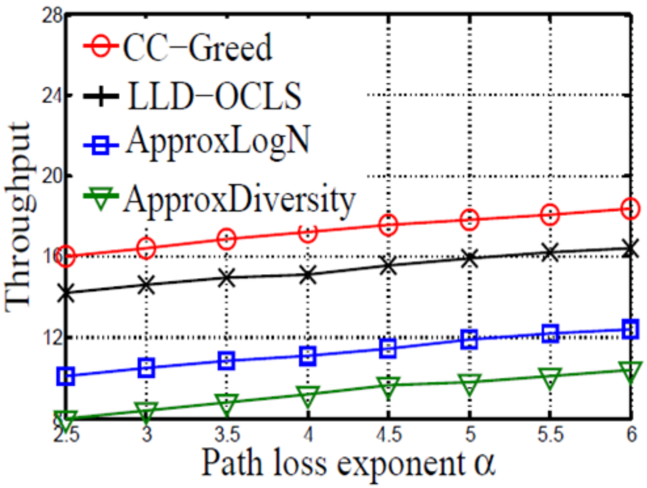
Throughput

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 α 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?

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