On the Ability of Mobile Sensor Networks to Diffuse Information

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Introduction

We examine the ability of networks formed by mobile sensor nodes to diffuse information in the case when communication is only possible during opportunistic encounter events.

Communication model

- Every mobile node is a sensor and continuously acquires information about the world.
- Communication is only possible during opportunistic encounter events.
  - When two nodes are in sufficient proximity.
  - No other global communication infrastructure is available.
- When two nodes communicate, they exchange all they know.

How the actual patterns of encounters affect the ability of the network to diffuse information?

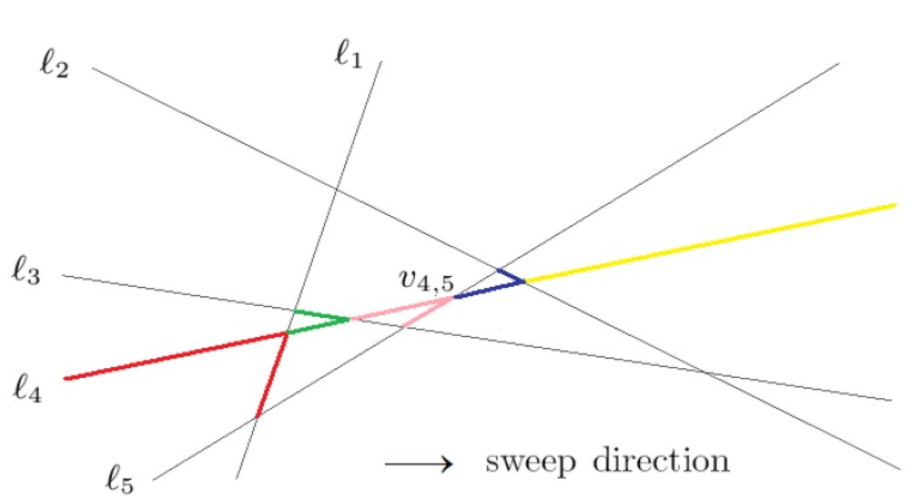
- We study a simple/uniform case: each pair of nodes meet exactly once.
- Compare encounter patterns from different networks.

Network settings

- Combinatorial setting: arbitrary contact patterns between n nodes.
  - $\binom{n}{2}!$ temporal permutations of all pairwise communications.
- Geometric setting: the encounter patterns are constrained by physical motions of the mobile nodes.
  - We analyze the case for planar linear motions, which can be realized by sweeping a line arrangement.
- Realistic setting: encounter patterns from GPS traces of real vehicles.

Measurement

- We lump all the information collected by a node between two successive encounters with other nodes into an information packet.
- In theoretical setting there are n^2 information packets and we hope for at most n^3 information packet deliveries. If S is the total number of successful deliveries, we look at S/n^3 as the capacity of the network to diffuse information.



- Geometric interpretation: how many (vertex, line) pairs are reachable by a path monotone in the sweeping direction?

Key results

- Asymptotically (as $n \to \infty$), in the random combinatorial network setting, the capacity tends to 1, and the variance is low.
- In the random geometric case, however, there is a hard asymptotic upper bound $\kappa < 1$ on the capacity.
- In the realistic scenario performance is close to the geometric setting. For a fixed time period, the capacity is asymptotically bounded by a constant $\kappa < 1$, while κ may increase as we lengthen the time period.

Theoretical Underpinnings

Combinatorial setting

- The expected network capacity is $1\text{-}O(\log^2 n/n)$, the variance is $O(\log^2 n/n)$.
  - Compare to gossiping communication protocols.
- 2/3 of information can be delivered within 1 hop.

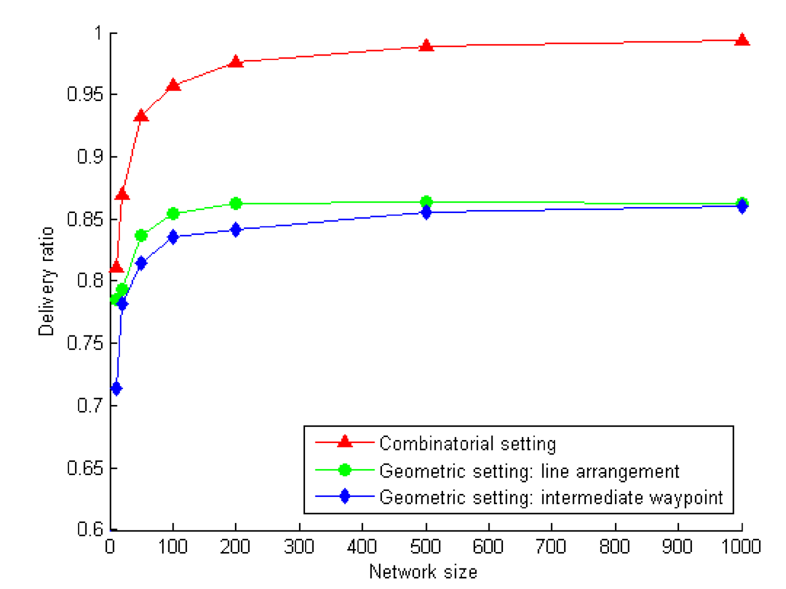
Geometric setting

- The expected network capacity is bounded above by some constant $\kappa < 1$.
  - A convex region gets some non-vanishing fraction of the arrangement vertices and avoids a non-vanishing fraction of the lines.
- Hop counts of length 2 suffice.

The encounter patterns arising out of physical motions in a geometric space are not ideal for information diffusion.

Experimental Results

The network capacity and hop counts can be computed by dynamic programming.



Combinatorial and Geometric settings.

hops	$(v_{i,j}, \ell_k)$ pairs	percentage
0	999000	0.2%
1	332334000	66.5%
2	152602789	30.6%
3	7433886	1.5%
4	1700798	0.3%
5—18	1148477	0.2%
total	496218950	99.3%

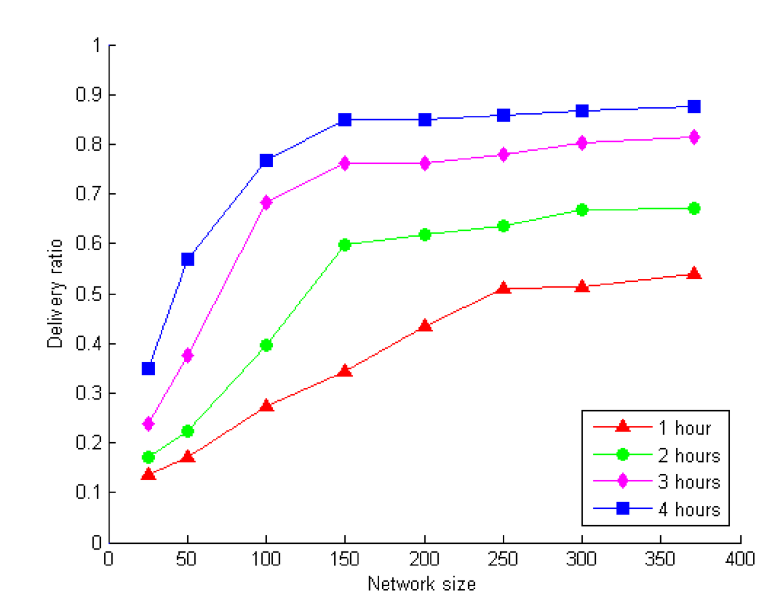
(a) Combinatorial setting.

hops	$(v_{i,j}, \ell_k)$ pairs	percentage
0	999000	0.2%
1	332334000	66.5%
2	97406815	19.5%
total	430739815	86.2%

(b) Geometric setting: line arrangement.

hops	$(v_{i,j}, \ell_k)$ pairs	percentage
0	995588	0.2%
1	297394821	59.7%
2	128701240	25.9%
3—5	832418	0.2%
total	427924067	86.0%

(c) Geometric setting: intermediate waypoint.

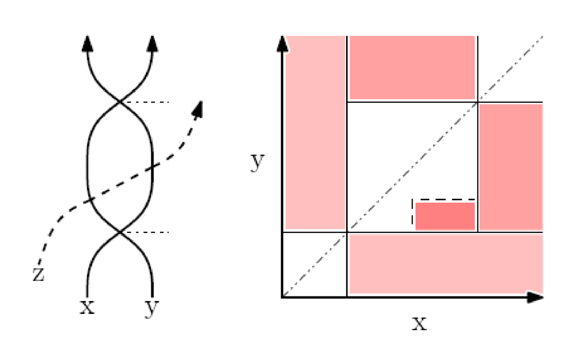


Realistic setting: GPS coordinates of taxis collected in the San Francisco Bay Area.

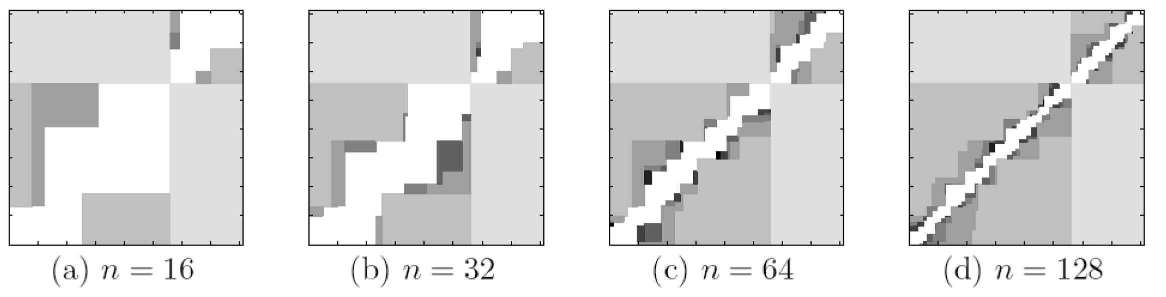
hops	$(v_{i,j}, \ell_k)$ pairs	percentage
0	478502	0.5%
1	15432785	17.4%
2	49797990	56.1%
3	9510208	10.7%
4	1746776	2.0%
5—12	804878	0.9%
total	77771139	87.6%

(d) Realistic setting (371 taxis in 4 hours).

Network Visualizations

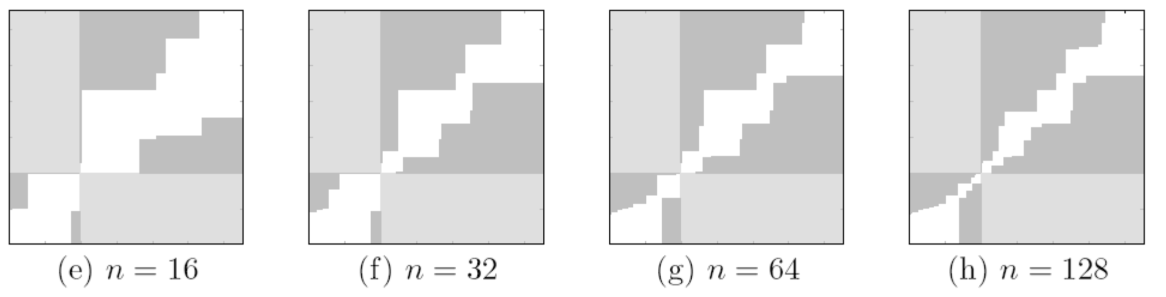


A network of 3 mobile agents and the visualization of the connectivity between agent x and y.



(a) $n = 16$ (b) $n = 32$ (c) $n = 64$ (d) $n = 128$

combinatorial networks



(e) $n = 16$ (f) $n = 32$ (g) $n = 64$ (h) $n = 128$

geometric networks