Opportunistic Information Dissemination in Mobile Ad-hoc Networks:
adaptiveness vs. obliviousness and randomization vs. determinism

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Mobile Ad-hoc Network (MANET)

- Mobile set of nodes (processors with radio)
- No stable communication infrastructure
- Multihop network
Mobile Ad-hoc Network (MANET)

- Mobile set of nodes (processors with radio)
- No stable communication infrastructure
- Multihop network

E.g.
Opportunistic Communication

Thanks to mobility and asynch activation
communication between $x$ and $y$ is feasible
even if a path never exists! (a *chrono-path*)
The Dissemination Problem

Some information held by a given source node $x$ at time $t$, must be disseminated to some set of nodes $S \subset V$.

In order to prove lower bounds we use Geocast.
Model

- **Network:**
  - $n$ mobile nodes deployed in $\mathbb{R}^2$
  - slotted time steps:
    - slot length dominated by communication time
    - same for all nodes

- **Node:**
  - unique ID in $[n]$
  - may start/fail at any time slot
  - radio communication:
    - unique radio channel $\implies$ collisions
    - background noise $\equiv$ collision noise $\implies$ no collision detection
    - no simultaneous reception & transmission
    - limited range $r \implies$ multihop network
Model

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Model

- **Adversary:**
  - initial position and movement
  - de/activation schedule *(many of our lower bounds don’t use it)*

limited by three parameters:
- a maximum speed $v_{\text{max}} > 0$
- the system must be $(\alpha, \beta)$-connected, $\alpha, \beta \in \mathbb{Z}^+$

**Definition ((\(\alpha, \beta\))-connectivity)**

While moving at $\leq v_{\text{max}}$ speed, $\forall$ non-trivial partition $(S, \overline{S})$,

$$\exists \gamma > \alpha \text{ consecutive steps without a } \beta\text{-stable edge} \text{ between } S \text{ and } \overline{S}.$$  

(an edge is $k$-stable at time $t$ if it exists for $k$ consecutive steps $[t, t + k - 1]$)
Model

$(\alpha, \beta)$-connectivity, for the partition defined by the information
Protocols

- **Deterministic:**
  - *oblivious* [K’05,KP’05]: use only node ID and time elapsed since node activation.
  - *quasi-oblivious* [PR’09]: use also the global time.
  - *adaptive*: no restriction.

- **Randomized:**
  - *oblivious* [C’01]: protocol access sequence of random variables at each node, independent of execution and mutually independent.
  - *locally adaptive*: same but rv’s may be mutually dependent. (still independent of the execution)
  - *fair* [C’01]: all nodes transmit with same probability in any given time step. (orthogonal def)
Related Work

Dissemination problems studied:
- Broadcast, Geocast, $k$-Selection, Multicast, Gossiping, etc.

Deterministic solutions rely on strong synchronization or stability:
- deterministic Broadcast in MANET [MCSPS’06].
  (One-dimension, known position.)
- deterministic Multicast in MANET [GS’99, PR’97].
  (Long enough globally stable topology periods.)

Leaving aside channel contention:
- Broadcast in MANET
  - $\Omega(n)$ rounds [PSMCS’04], even if nodes move in a grid.
  - $\Omega(D \log n)$ [BD’97].
  - $\Omega(n \log n)$ in [DP’07]. (linear $D$)
- Geocast in MANET [FM’08].
Related Work

Taking into account contention:

- **Broadcast in Static RNs [KP’05]:**
  adaptiveness helps (randomized and deterministic).

- **Deterministic Dissemination in MANET’s [FMMZ Dist. Comp.’12]:**
  adaptiveness helps, using asynchrony.

- **Randomized Dissemination in MANET’s [FFMMZ LATIN’12]:**
  adaptiveness does not help, even with synchrony, for fair or local adaptive protocols and $\alpha/\beta \in O(1)$.

Lower bounds:

- **Broadcast [ABLP’91]:** $\Omega(\log^2 n)$.
- **Randomized Broadcast [KM’98]:** $\Omega(D \log(n/D))$ exp.
- **Oblivious Randomized Broadcast [KP’05]:** $\Omega(n)$ w.p. $\geq 1/2$.

we improve using mobility...
## Results

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For deterministic algorithms, quasi-obliviousness helps.
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Also, full-adaptiveness does not help w.r.t. quasi-oblivioussness.
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For randomized protocols, local-adaptiveness does not help if $\alpha/\beta \in O(1)$. 
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For oblivious protocols, randomization helps if \( \alpha/\beta \in O(1) \).
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For adaptive protocols, randomization helps if $\alpha/\beta \in O(1)$.
Deterministic Lower Bounds

By pigeonhole principle:

Lemma

For any deterministic Dissemination protocol, for any time step \( t \), and for any subset \( V' \) of \( k \) informed nodes that do not fail during the interval \([t, t + k - 2]\), there exists some node \( v \in V' \) such that \( v \) does not transmit uniquely among the nodes in \( V' \) during such interval.

By probabilistic method:

Lemma

For any deterministic oblivious Dissemination protocol, and for any subset of \( k \) nodes, \( k \geq 3 \), there exists a node-activation schedule such that, for any time step \( t \), each of the \( k \) nodes is activated in \( \left[t - \left\lfloor \frac{k(k-1)}{\ln(k(k-1))} \right\rfloor + 1, t\right] \), and there is one of the \( k \) nodes that is not scheduled to transmit uniquely among those \( k \) nodes in \( \left[t, t + \left\lfloor \frac{k(k-1)}{\ln(k(k-1))} \right\rfloor - 1\right] \).
Deterministic Lower Bounds

Theorem

For any deterministic Geocast protocol $\Pi$, if $\beta < n - 1$,

$\exists (\alpha, \beta)$-connected MANET such that $\Pi$ does not terminate.

Move nodes from $C$ to $B$ to produce collisions. Using lemma claim follows.
Deterministic Lower Bounds

Theorem

For any deterministic oblivious Geocast protocol $\Pi$, if $\beta \leq \left\lfloor \frac{(n-1)(n-3)}{4 \ln((n-1)(n-3)/4)} \right\rfloor$, there exists an $(\alpha, \beta)$-connected MANET such that $\Pi$ does not terminate.

Move nodes from $C$ to $B$ to produce collisions and alternate activations/deactivations. Using lemma claim follows.
Deterministic Lower Bounds

Theorem

For any $v_{max} > \pi r / (3(2\alpha + n - 4))$, and any deterministic Geocast protocol $\Pi$, there exists an $(\alpha, \beta)$-connected MANET such that $\Pi$ takes $\Omega(\alpha n + n^2)$. 

(a) Distances invariant. 

(b) Initial configuration.
Deterministic Lower Bounds

(c) Paths $A \rightsquigarrow C$ and $A \rightsquigarrow A'$.

(d) Paths $A' \rightsquigarrow C'$ and $A' \rightsquigarrow A$. 

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Opportunistic Dissemination in MANETs

Deterministic Lower Bounds

(e) Phase 1 of \( u \) begins.

(f) End of phase 1 of \( u \).

Move nodes between \( B \) and \( B' \) to produce collisions.
Deterministic Lower Bounds

(g) Phase 2 of $u$ and phase 1 of $v$ begin.

(h) End of phase 2 of $u$ and phase 1 of $v$. 

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Opportunistic Dissemination in MANETs
Deterministic Lower Bounds

(i) Phase 3 of $u$, 2 of $v$, and 1 of $w$ (j) End of phase 3 of $u$, 2 of $v$, and 1 of $w$. 

Analysis
Deterministic Lower Bounds

Similarly, but additionally using the adversarial activation schedule,

**Theorem**

For any $0 < \beta < 2 \left( \alpha + \left\lceil \frac{(2n/5)(2n/5-1)}{\ln((2n/5)(2n/5-1))} \right\rceil \right)$,

any $v_{max} > \pi r / \left( 6 \left( \alpha + \left\lceil \frac{(2n/5)(2n/5-1)}{\ln((2n/5)(2n/5-1))} \right\rceil - 2 \right) \right)$,

and any oblivious deterministic Geocast protocol $\Pi$,

$\exists (\alpha, \beta)$-connected MANET such that $\Pi$ takes $\Omega(\alpha n + n^3 / \ln n)$.
Deterministic Upper Bounds

Using known techniques:

- quasi-oblivious:
  Round robin padding global clock to the message $\rightarrow n(\alpha + n)$.

- oblivious:
  Primed selection $\rightarrow n(\alpha + 4n(n - 1) \ln(2n))$. 
Randomized Lower Bounds

Theorem

For any fair randomized Geocast protocol, ∃ (α, β)-connected MANET such that, within $ck \log_4(1/\varepsilon)/(4 \log k)$ steps after $k$ nodes are covered, no new node is covered with probability at least $\varepsilon^c$.

- Place any node $y$ in $B$ forever.
- For each step where $p \geq 4 \log k/k$, place all nodes from $B'$ in $B$. 
Randomized Lower Bounds

Theorem

For any oblivious randomized Geocast protocol, \( \exists (\alpha, \beta) \)-connected MANET such that, within \( ck/(2(1 + \ln k)) \) steps after \( k \) nodes are covered, no new node is covered with probability at least \( (2e^e)^{-c} \).

Probabilities may be different

\[ \rightarrow \text{node } y \text{ to be placed in } B \text{ needs to be chosen more carefully.} \]
Randomized Lower Bounds

Theorem

For any oblivious randomized Geocast protocol, \( \exists (\alpha, \beta) \)-connected MANET such that, within \( ck/(2(1 + \ln k)) \) steps after \( k \) nodes are covered, no new node is covered with probability at least \( (2e^e)^{-c} \).

How node \( y \) is chosen:

- For each sequence of \( \beta \) slots,
  - Define **quiet** and **noisy** slots according to the sum of probabilities.
  - Choose the node with the smallest sum of probabilities over quiet slots.

It works because:

- a) it is unlikely that \( y \) transmits in quiet slot.
- b) it is unlikely that exactly one node transmits in a noisy slot.
**Randomized Lower Bounds**

**Theorem**

For any **oblivious** randomized Geocast protocol, $\exists (\alpha, \beta)$-connected MANET such that, within $ck/(2(1 + \ln k))$ steps after $k$ nodes are covered, no new node is covered with probability at least $(2e^e)^{-c}$.

How node $y$ is chosen:

- For each sequence of $\beta$ slots,
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It works because:

a) it is unlikely that $y$ transmits in quiet slot.

b) it is unlikely that exactly one node transmits in a noisy slot.
Randomized Lower Bounds

Theorem

For any locally adaptive randomized Geocast protocol, \( \exists (\alpha, \beta) \)-connected MANET such that, within \( \frac{k}{(2e\xi \ln(\beta^2k^e/\xi))} \) steps after \( k \) nodes were covered, in expectation no new node is covered.

Protocol is adaptive

\[ \leq r \leq \beta \leq r + \xi \]

\( r < \delta \leq r + \xi \)

\( A \rightarrow B \rightarrow B' \)

→ the adversary doesn’t know the future

→ choose the “most likely” quietest for the next \( \beta \) steps.

(Will have in expectation < 1 transmissions)
Randomized Lower Bounds

Theorem

For any fair randomized Geocast protocol $\Pi$, $\exists (\alpha, \beta)$-connected MANET such that, in order to solve the problem with probability at least $2^{-n/2}$, $\Pi$ takes at least $\alpha n/2 + n^2/(96 \ln(n/2))$. 
Randomized Lower Bounds

Fair protocols

- **Phase 1**: node moves from $A$ to $x$ ($\alpha - 1$ slots)
- **Interlude**: nodes move back and forth between $B$ and $B'$
- **Phase 2**: node moves from $x$ to $C$ ($\alpha - 1$ slots)
Randomized Lower Bounds

Theorem

For any oblivious randomized Geocast protocol $\Pi$, $\exists (\alpha, \beta)$-connected MANET such that, in order to solve the problem with probability at least $2^{-n/2}$, $\Pi$ takes at least $\alpha n/2 + n^2/(48e \ln(n/2))$.

Theorem

For any locally adaptive randomized Geocast protocol $\Pi$, $\exists (\alpha, \beta)$-connected MANET such that, in order to solve the problem, $\Pi$ takes on expectation at least $\alpha n/2 + e^2(e + 1)^2n^2/(2(e - 1)^2 \ln(n/2))$.

Similar proof, choosing $y$ as in $\beta$ lower bounds.
Randomized Upper Bounds

Using known techniques:

- oblivious and fair:
  
  all nodes transmit with probability $\ln n/n$ in each time step,
  
  $\rightarrow O(n(\alpha + (1 + \alpha/\beta)n/\log n))$. 
Conclusions

adaptiveness vs. obliviousness and randomization vs. determinism

Deterministic
- full adaptiveness \( \Omega(\alpha n + n^2) \)
  does not help w.r.t. quasi-obliviousness \( (\alpha n + n^2) \).
- almost linear sep. between oblivious \( \Omega(\alpha n + n^3 / \log n) \)
  and quasi-oblivious protocols \( (\alpha n + n^2) \).
- while \( \beta = n \) is enough for quasi-oblivious,
  oblivious protocols require \( \beta \in \Omega(n^2 / \log n) \).

Randomized
- local adaptiveness \( \Omega \left( \alpha n + \frac{n^2}{\log n} \right) exp \)
  does not help w.r.t. obliviousness \( O \left( \alpha n + \left(1 + \frac{\alpha}{\beta}\right) \frac{n^2}{\log n} \right) whp \).
- linear sep. between oblivious randomized \( O \left( \alpha n + \left(1 + \frac{\alpha}{\beta}\right) \frac{n^2}{\log n} \right) whp \)
  and oblivious deterministic \( \Omega \left( \alpha n + \frac{n^3}{\log n} \right) \).
- log sep. between adaptive randomized \( O \left( \alpha n + \left(1 + \frac{\alpha}{\beta}\right) \frac{n^2}{\log n} \right) whp \)
  and adaptive deterministic \( \Omega \left( \alpha n + n^2 \right) \).
Thank you