Opportunistic Information Dissemination in Mobile Ad-hoc Networks: The Profit of Global Synchrony

Antonio Fernández Anta[1] Alessia Milani[2] Miguel A. Mosteiro[3]
Shmuel Zaks[4]

[1]Institute IMDEA Networks

[2]LIP6, Université Pierre et Marie Curie - Paris 6

[3]Department of Computer Science, Rutgers University

[4]Department of Computer Science, Technion

DISC 2010

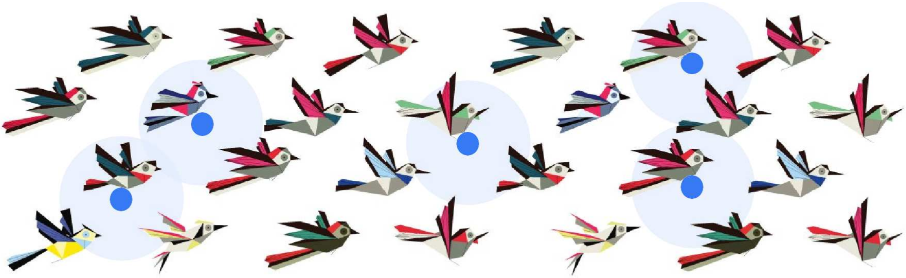
Mobile Ad-hoc Network (MANET)

- 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

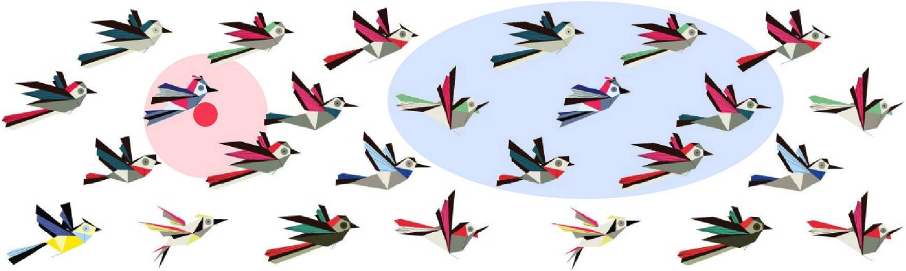
even if a path never exists! (*online route*)

(Loading oportDiss.mov)

e.g. delay/disruption tolerant networks, opportunistic networking, etc.

The Dissemination Problem

Some information held by a given source node x at time t,
must be disseminated to all nodes satisfying a given predicate $\mathcal{P}$.



Notation:

- a node that has received the information is *covered* (may be off)
- a node that holds the information is *informed*

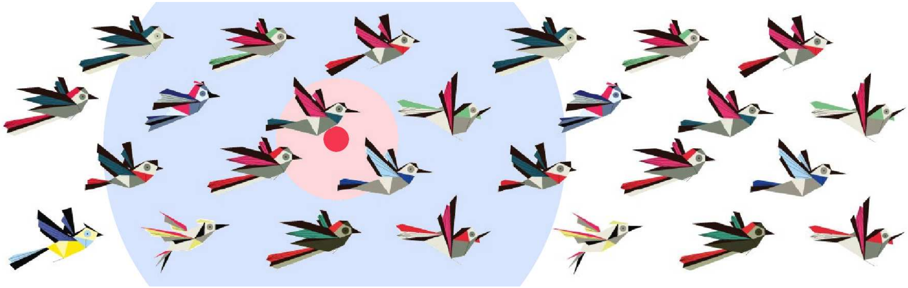
The Dissemination Problem

$\mathcal{P} \Longrightarrow$ Dissemination $\equiv$ Broadcast, Geocast, Multicast, Routing, etc.

In order to prove lower bounds we use Geocast:

$\mathcal{P}(y) =$ true iff, at time t,

y is active and located within distance d of x.



d and t are parameters.

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 $\Longrightarrow$ collisions
    - background noise $\equiv$ collision noise $\Longrightarrow$ no collision detection
    - no simultaneous reception & transmission
    - limited range $r \Longrightarrow$ multihop network

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 $\Longrightarrow$ collisions
    - background noise $\equiv$ collision noise $\Longrightarrow$ no collision detection
    - no simultaneous reception & transmission
    - limited range $r \Longrightarrow$ multihop network

Model

- Adversary:
  - initial position
  - de/activation schedule (many of our lb's don't even use it)
  - movement

Model

- Adversary:
  - initial position
  - de/activation schedule (many of our lb's don't even use it)
  - movement

But, worst-case adversarial topologies
$\Longrightarrow \nexists$ deterministic Broadcast protocol,
even if connectivity is guaranteed! [CPMS'07]
$\Longrightarrow$ adversary must be limited.

Model

- Adversary:
  - initial position
  - de/activation schedule (many of our lb's don't even use it)
  - movement

limited by three parameters:

- a maximum speed $v_{\max} > 0$
- the system must be (α, β)-*connected*, $\alpha, \beta \in \mathbb{Z}^+$

Model

- Adversary:
  - initial position
  - de/activation schedule (many of our lb's don't even use it)
  - movement

limited by three parameters:

- a maximum speed $v_{\max} > 0$
- the system must be (α, β)-*connected*, $\alpha, \beta \in \mathbb{Z}^+$

in words:

- while moving at $\leq v_{\max}$ speed,
- $\leq \alpha$ steps disconnected (w.r.t. progress)
- $\geq \beta$ steps pair-stability (to allow progress)

($\beta \implies$ impossibility results, $\alpha \implies$ time complexity)

Model

- Adversary:
  - initial position
  - de/activation schedule (many of our lb's don't even use it)
  - movement

limited by three parameters:

  - a maximum speed $v_{\max} > 0$
  - the system must be (α, β)-*connected*, $\alpha, \beta \in \mathbb{Z}^+$

Definition

Given a MANET and an instance of Dissemination, the system is (α, β)-*connected* if, $\forall t\ \exists t'$:

- $[t, t+\alpha) \cap [t', t'+\beta) \neq \emptyset$
- $\exists$ nodes x, y: x is informed and y is uncovered at time t':
  x, y are active neighbors during $[t', t'+\beta)$.

Model

(α, β)-connectivity

(Loading alphabeta.mov)

Model

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

We assume that uninformed nodes do not transmit.

Related Work

Dissemination problems studied:

Broadcast, Geocast, k-Selection, Multicast, Gossiping, etc.

But, 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

Dissemination problems studied:

Broadcast, Geocast, k-Selection, Multicast, Gossiping, etc.

But, 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

Dissemination problems studied:

Broadcast, Geocast, k-Selection, Multicast, Gossiping, etc.

But, 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].

Results

- $\forall$ Geocast ... protocol: $\exists$ (α, β)-conn MANET:

  using only arbitrarily slow movements:
  even random $\rightarrow \geq \alpha(n-1)$, $v_{\max} > 0$

  using only activation:
  (equi)periodic $\rightarrow \geq n(n-1)/2$, $v_{\max} \geq 0$

Results

- $\forall$ Geocast ... protocol: $\exists$ (α, β)-conn MANET:

using adversarial activation:

$$\text{oblivious} \begin{cases} \Omega\left(\alpha n + \frac{n^3}{\log n}\right) & v_{\max} \in \Omega\left(\frac{\pi r}{\alpha + n^2 / \log n}\right) \\ \beta \in \Omega\left(\frac{n^2}{\log n}\right) & v_{\max} > 0 \end{cases}$$

even with simultaneous activation and no failures:

$$\text{adaptive} \begin{cases} \Omega(\alpha n + n^2) & v_{\max} \in \Omega\left(\frac{\pi r}{\alpha + n}\right) \\ \beta \geq n - 1 & v_{\max} > 0 \end{cases}$$

- Dissemination protocols:

$$\text{oblivious} \rightarrow \alpha n + O(n^3 \log n), \ \beta \in \Omega(n^2 \log n). \ \text{(Primed-Selection.)}$$

$$\text{quasi-oblivious} \rightarrow \alpha n + n^2, \ \beta \geq n. \ \text{(Round-Robin, piggybacking a counter.)}$$

Lower Bounds

By pigeonhole principle:

Lemma

For any time step t of the execution of a Dissemination protocol, where a subset V' of k informed nodes 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 the interval $[t, t+k-2]$.

By probabilistic method:

Lemma

For any deterministic oblivious protocol that solves Dissemination in a MANET of n nodes, where nodes are activated possibly at different times, and for any subset of k nodes, $k \geq 3$, there exists a node-activation schedule such that, for any time slot t and letting $m = \lfloor k(k-1)/\ln(k(k-1)) \rfloor$, each of the k nodes is activated during the interval $[t-m+1, t]$, and there is one of the k nodes that is not scheduled to transmit uniquely among those k nodes during the interval $[t, t+m-1]$.

Lower Bounds

By pigeonhole principle:

Lemma

For any time step t of the execution of a Dissemination protocol, where a subset V' of k informed nodes 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 the interval $[t, t+k-2]$.

By probabilistic method:

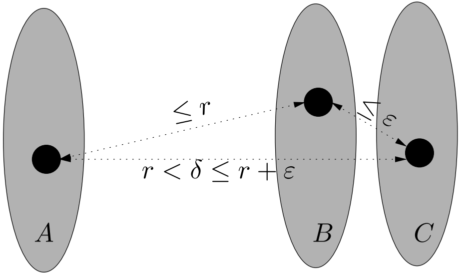
Lemma

For any deterministic oblivious protocol that solves Dissemination in a MANET of n nodes, where nodes are activated possibly at different times, and for any subset of k nodes, $k \geq 3$, there exists a node-activation schedule such that, for any time slot t and letting $m = \lfloor k(k-1)/\ln(k(k-1)) \rfloor$, each of the k nodes is activated during the interval $[t-m+1, t]$, and there is one of the k nodes that is not scheduled to transmit uniquely among those k nodes during the interval $[t, t+m-1]$.

Lower Bounds

Theorem

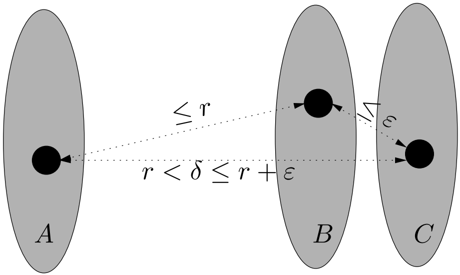
For any $V_{max} > 0$, $d > r$, $\alpha > 0$, *and any deterministic Geocast protocol* Π, *if* $\beta < n - 1$, *there exists an* (α, β)*-connected MANET of* n *nodes such that* Π *does not terminate, even if all nodes are activated simultaneously and do not fail.*



Lower Bounds

Theorem

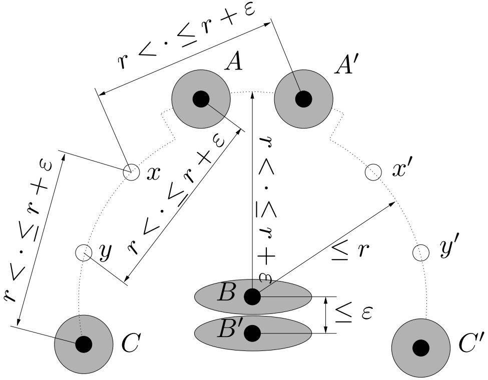
For any $V_{max} > 0$, $d > r$, $n \geq 8$, $\alpha > 0$, and any deterministic oblivious protocol for Geocast Π, if $\beta \leq m = \lfloor (n-1)(n-3)/(4\ln((n-1)(n-3)/4)) \rfloor$, there exists an (α, β)-connected MANET of n nodes such that Π does not terminate.



Lower Bounds

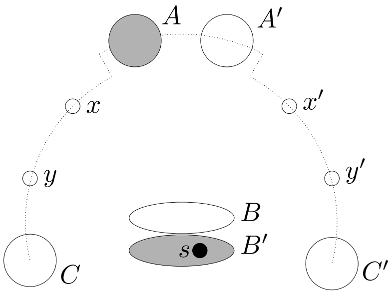
Theorem

For any $v_{max} > \pi r/(3(2\alpha + n - 4))$, $d > r$,
$\forall$ *deterministic Geocast protocol:* $\exists(\alpha, \beta)$*-connected MANET:* $\Omega(\alpha n + n^2)$.

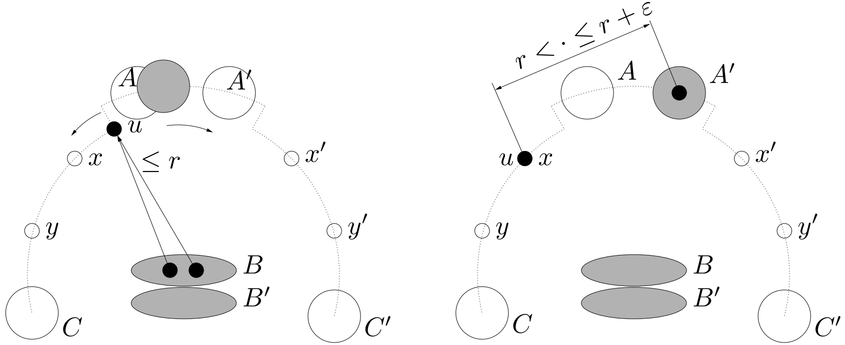


Lower Bounds

Initial configuration

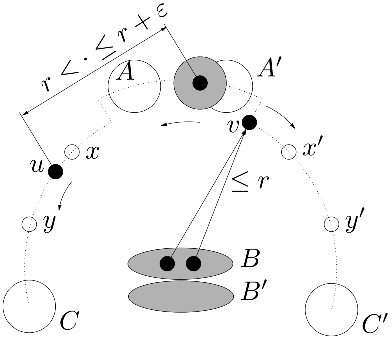


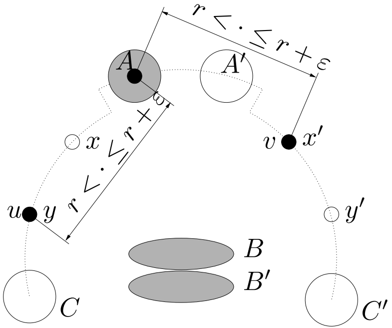
Lower Bounds



(b) End of phase 1 of u

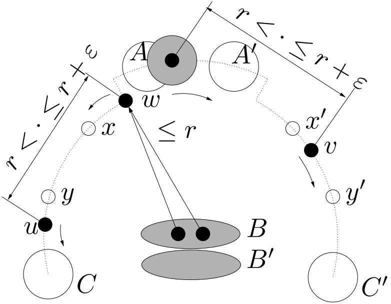
Lower Bounds

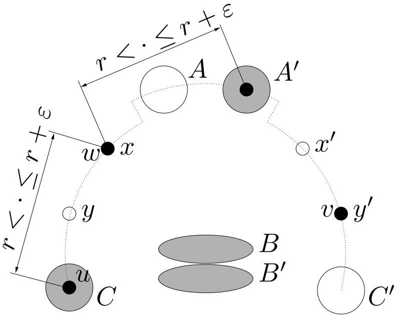




(d) End of phase 2 of u and phase 1 of v

Lower Bounds



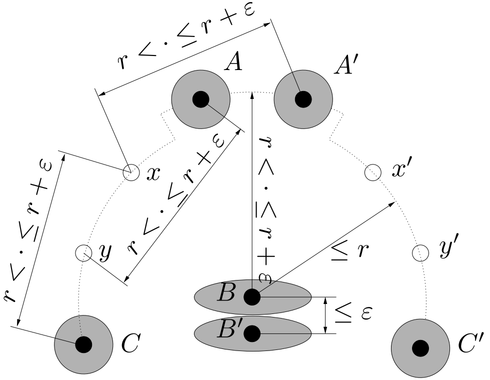


(f) End of phase 3 of u, phase 2 of v, and phase 1 of w

Lower Bounds

Theorem

For any $v_{max} > \pi r/6(\alpha + \lfloor (n/3)(n/3-1)/\ln(n/3(n/3-1))\rfloor - 2)$, $d > r$, $n \geq 9$,
$\forall$ *oblivious deterministic Geocast protocol:* $\exists(\alpha,\beta)$*-connected MANET:*
$\Omega(\alpha n + n^3/\log n)$.



Conclusions

Profit of global synchrony:

- full adaptiveness ($\Omega(\alpha n + n^2)$)
  does not help w.r.t. quasi-obliviousness ($\alpha n + n^2$).
- almost linear separation 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 $\beta \in \Omega(n^2/\log n)$.

Thank you