2011 Infocom, Shanghai

April 12, 2011

Sharing Multiple Messages over Mobile Networks

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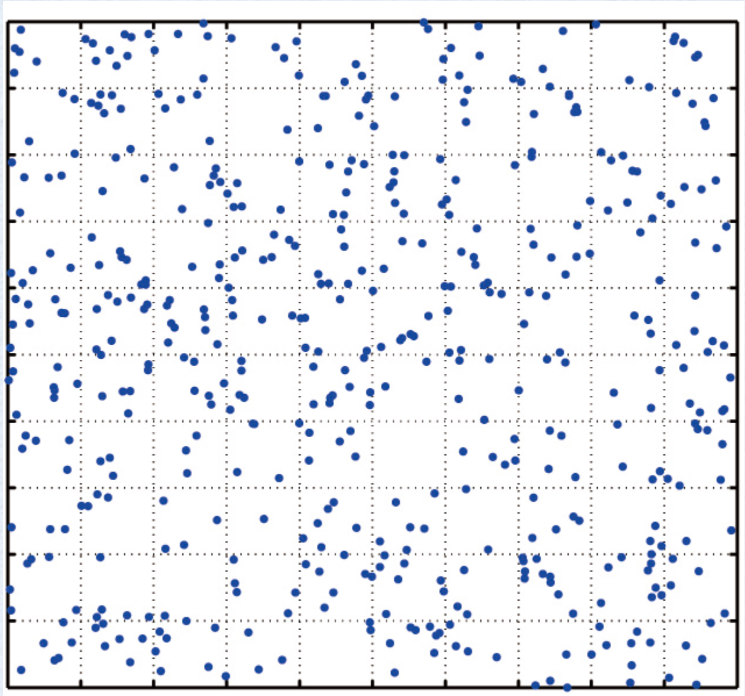
Information Spreading over MANET

- n users over a unit area

- Each user wishes to spread its individual message to all other users



- ***File sharing, distributed computing, scheduling, …***

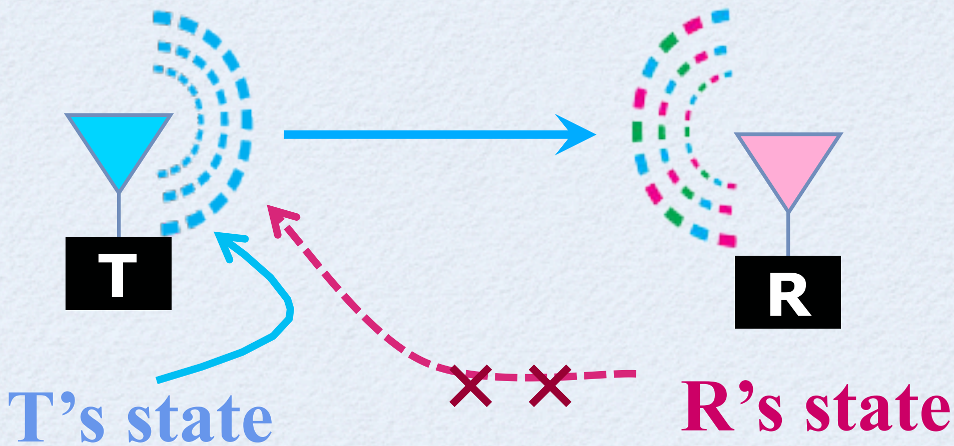
Gossip Algorithms

- **Gossip algorithms** --- ***Rumor-style*** dissemination
  - peer selection → ***random***
  - message selection → ***random***

- **Advantages**
  - decentralized
  - asynchronous

Background

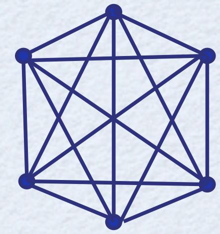
- **One-sided protocol** [Shah'2009]
  - based only on the sender's current state



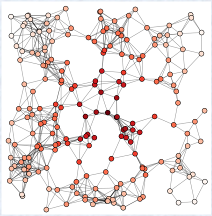
n users: each of them wants to broadcast its message to all other users

Background – spreading time

- **One-sided protocol (push-only)**
  - **FAST** (**within** $polylog(n)$ ratio gap from optimal)



    - graphs with high expansion
    - complete graph: $O(n \log n)$ *v.s.* optimal $\Theta(n)$
  - **SLOW** (**above** $polylog(n)$ ratio gap from optimal)



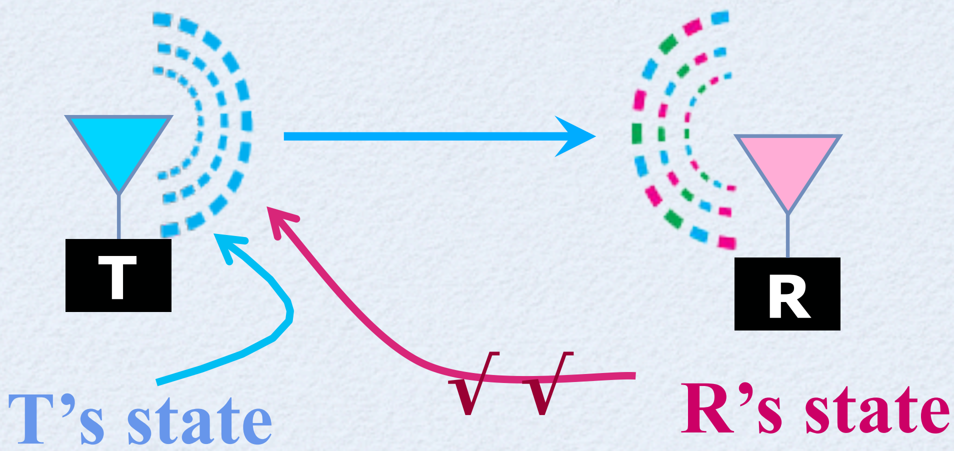
from NetworkX

    - graphs with low expansion
    - geometric graph $\Omega(n^{1.5-\epsilon})$ *v.s.* optimal $\Theta(n)$

---- *we'll show…*

Background

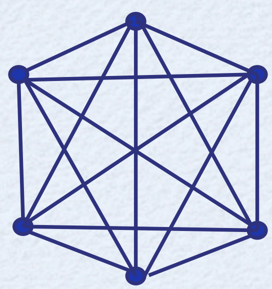
- **Two-sided protocol [SanghaviHajek'2007]**
  - based on both the sender's and the receiver's current state

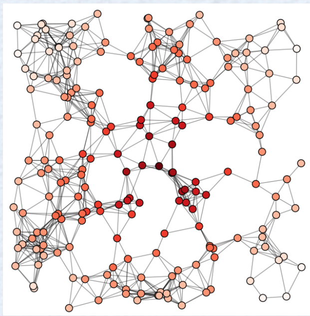


n users: each of them wants to broadcast its message to all other users

Background – spreading time

- **Two-sided protocol**
  - **FAST**: (**order-wise** optimal)
    - complete graph **[SanghaviHajek'2007]**
    - geometric graph (*conjectured*…)



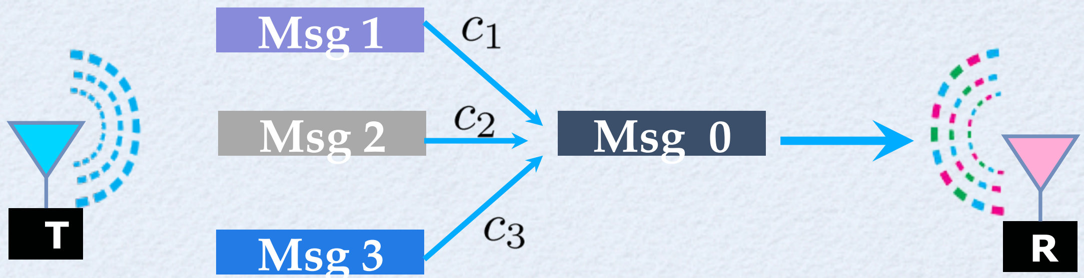


from NetworkX

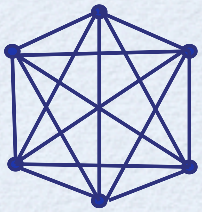
  - **Problem**: two-sided information may **NOT** be obtainable (e.g. privacy/security…)

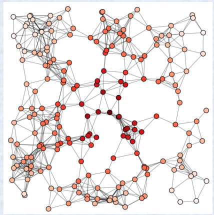
Background – spreading time

- **Variant: *network coding* approach** [DebMedardChoute'2006]
  - one-sided *(but behaves like **two-sided** protocol)*
  - send a random combination of all msgs



  - **FAST**: complete graph, geometric graph…
  - **Problem**: large computation burden





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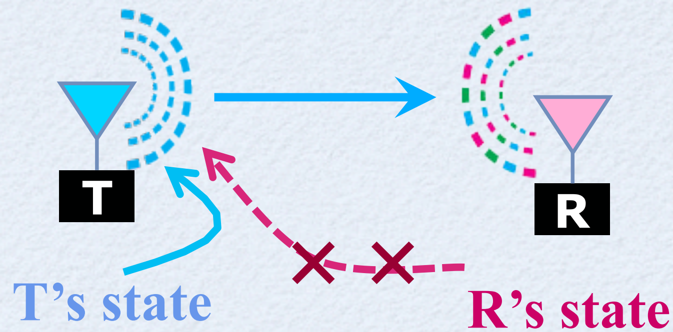
Question

- **How to design a dissemination protocol which is**
  - decentralized
  - asynchronous

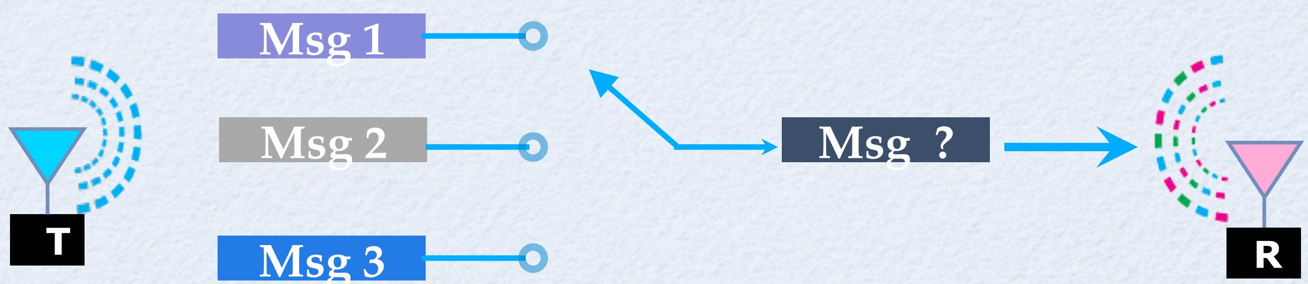


  - **one-sided**
  - **low computation burden (uncoded)**
  - **FAST (for geometric graphs)**

Static Networks

Consider first a SIMPLE protocol…

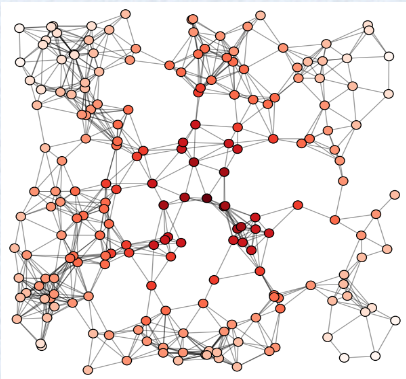
- **RANDOM PUSH**
  - random peer selection
  - random message selection (uncoded)



Static Networks

- **Theorem 1**: Under appropriate initial conditions, using **RANDOM PUSH** in static geometric networks achieves a spreading time $\Omega\left(n^{1.5}\right)$ w.h.p.
  - **Slow**: $\Omega\left(\sqrt{n}\right)$ ratio gap from the lower limit $\Theta\left(n\right)$
  - **Reasons**:
    - **low conductance** / expansion
    - **blindness** of message selection

      -- lots of **wasted** transmissions



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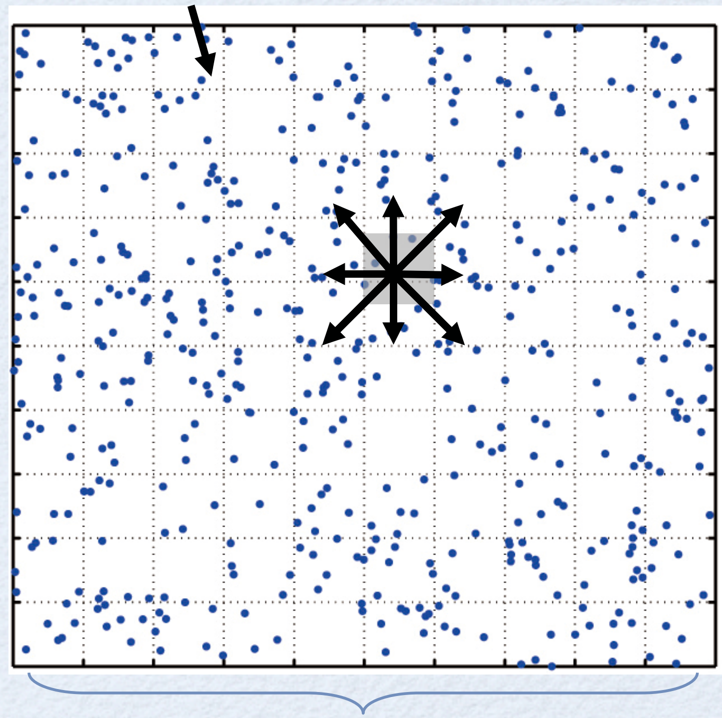
Mobile Networks

- RANDOM PUSH is slow in static networks
- How about mobile networks?

Mobility Pattern

- **Random walk model**
  - A node moves to one of its adjacent subsquares with equal probability.

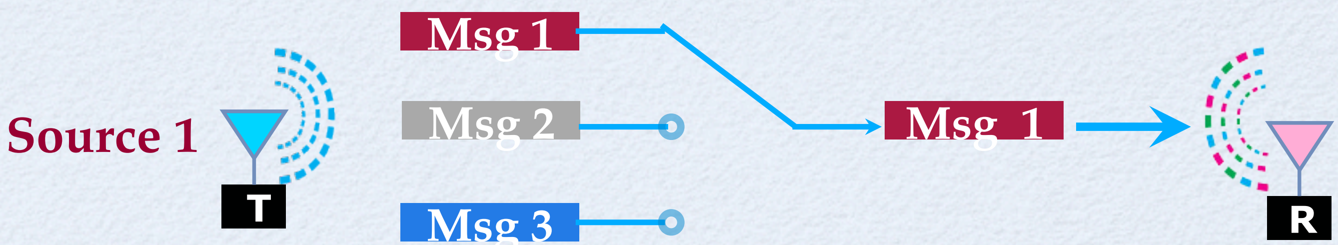


- **Discrete-jump model**
  - At the beginning of each slot: **movement**
  - In the remaining duration: **transmission** (stay *still*)
- **Velocity**: $v(n) = \Omega\left(\sqrt{\log n/n}\right) \ll 1$

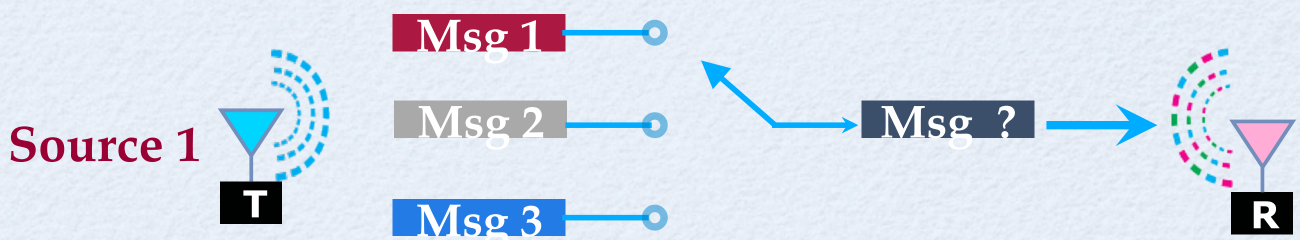
Strategy – mobile networks

MOBILE PUSH

- random neighbor selection
- message selection
  - **odd slot**: priority to **my own** message



  - **even slot:** **random** among all messages I have



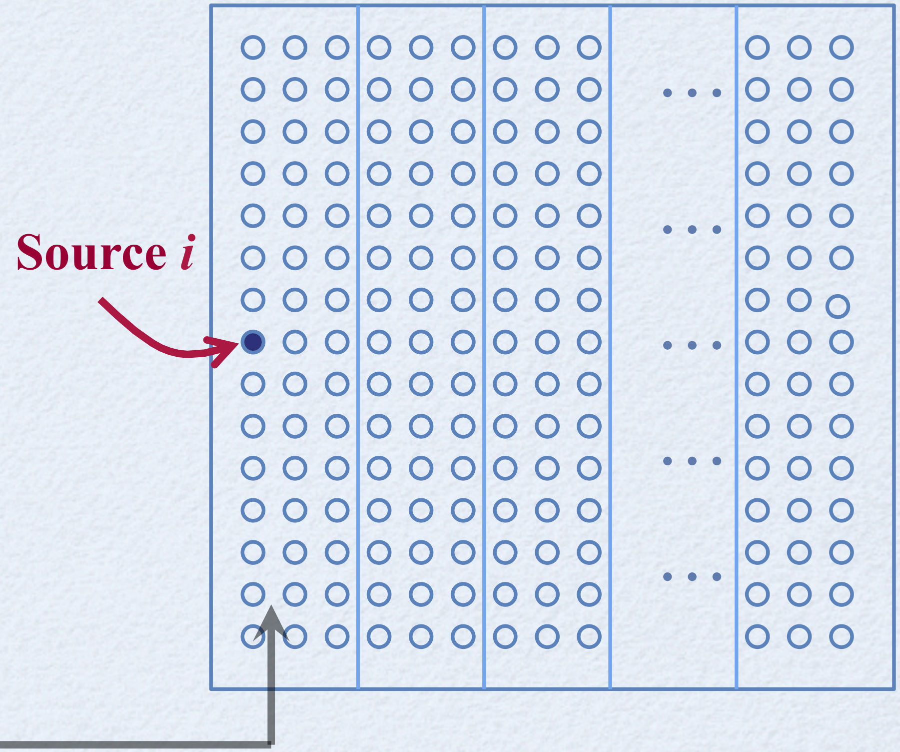
Performance: Mobile Networks

- **Theorem 2**: Using **MOBILE PUSH**, the spreading time in mobile geometric networks is $O\left(n \log^2 n\right)$ w.h.p.
  - **Fast**: logarithmic ratio gap from the lower limit $\Theta\left(n\right)$
  - **Reasons**:
    - **fast mixing:** $t_{mix} \approx \log n / v^2(n) \ll n$
    - **balanced** evolution – simulate a **complete graph**

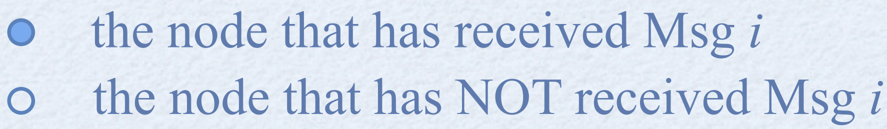
Analysis – static networks

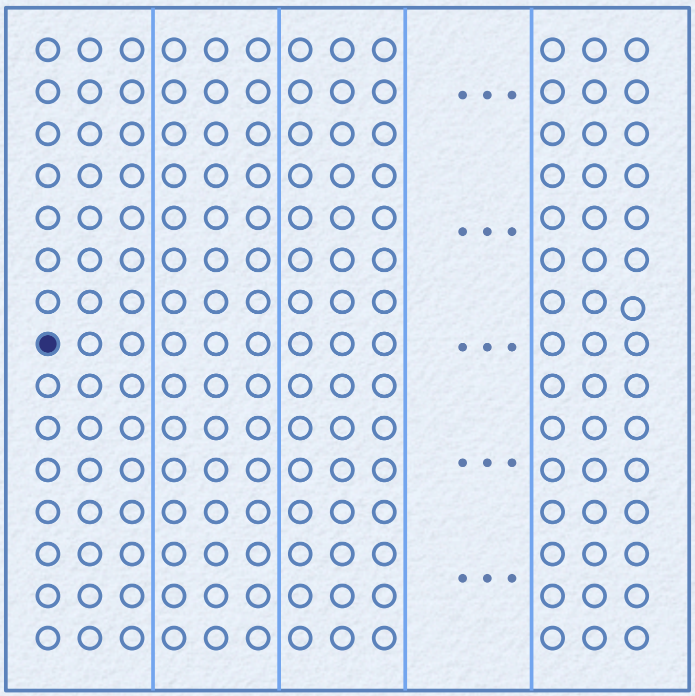
- **Assumptions**
  - Each node contains at least w msgs at time t_0
- Slice the entire area into

$\sqrt{n}/\log^{3/2} n$ **vertical blocks**



Analysis – static networks



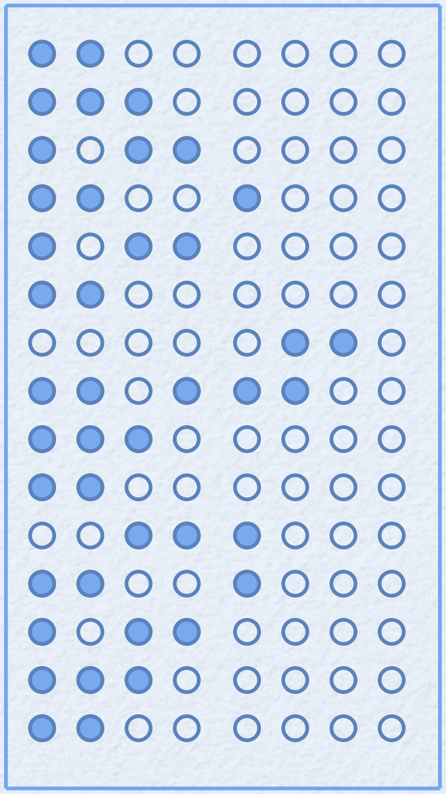


1. Each node contains at least w msgs at time t_0

2. Message spreading experiences resistance due to existing nodes

Analysis – static networks

Each node contains at least w msgs at time t_0



- **Fixed-point equation**
  $\mathbf{E}(N_l(t)) \leq t/w \cdot \mathbf{E}(N_{l-1}(t)) + \mathbf{E}(N_{l+1}(t))$
- It takes $\Omega\left(w^{1-\epsilon}\right)$ slots to cross one block
- roughly $\Theta\left(\sqrt{n}\right)$ blocks in total

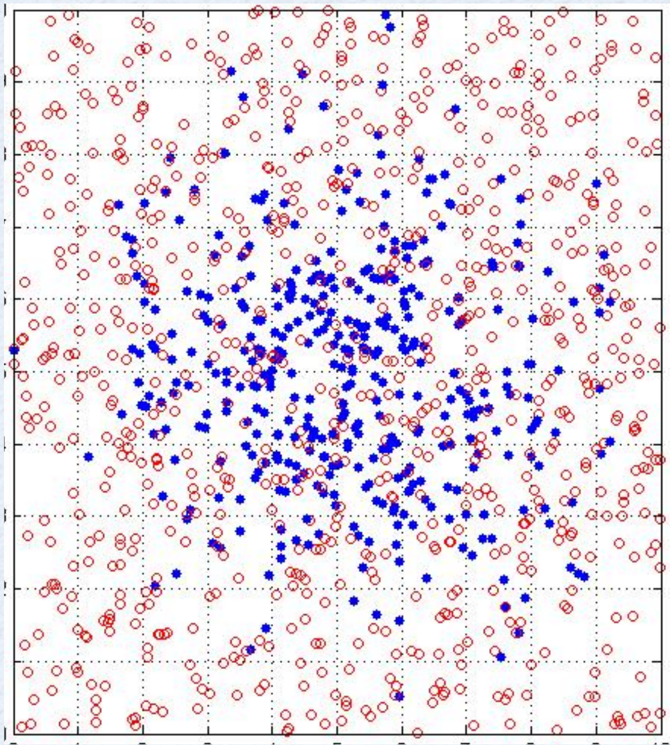
  → spreading time: $\Omega\left(w\sqrt{n}\right)$
- Worse case: $w = \Theta(n)$

  → spreading time: $\Omega\left(n^{1.5}\right)$

Analysis: Phase 1 -- MOBILE PUSH

Phase 1 | Phase 2 | Phase 3

$\underbrace{\hspace{4cm}}_{\log^3 n/v^2(n)}$ **slots**



- **Self-advocating phase**
  - consider only transmissions in odd slots
  - count # **innovative** transmissions
    - calculate return probability for a RW
- **After this phase, each message is contained in $\log n/v^2(n)$ nodes**
- **Summary:** each msg has been **seeded** to a large number of nodes

Analysis: Phase 2 -- MOBILE PUSH

After seeding, spread other people's messages → how long does it take to spread them?

Phase 1 | Phase 2 | Phase 3

$n \log^2 n$ **slots**

*construct a **slower** process*

Spreading Phase | Relaxation Phase | Spreading | Relaxation | … …

$1/v^2(n) \log n$ **slots**

$\log n / v^2(n)$ **slots**

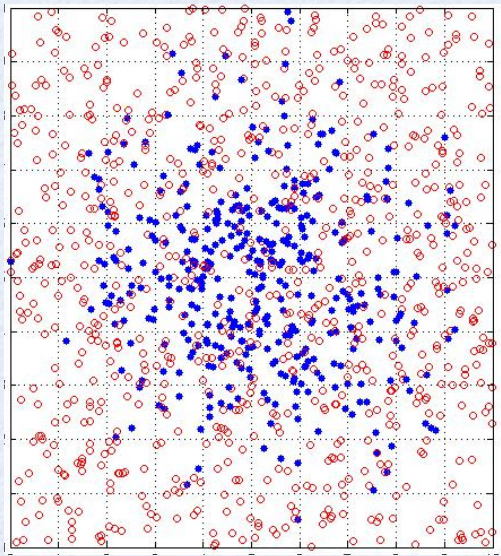
- **Spreading phase:**
  - set message selection probability to $1/n$
- **Relaxation phase:**
  - no transmissions
  - mobility **"uniformizes"** the locations of nodes containing the msg

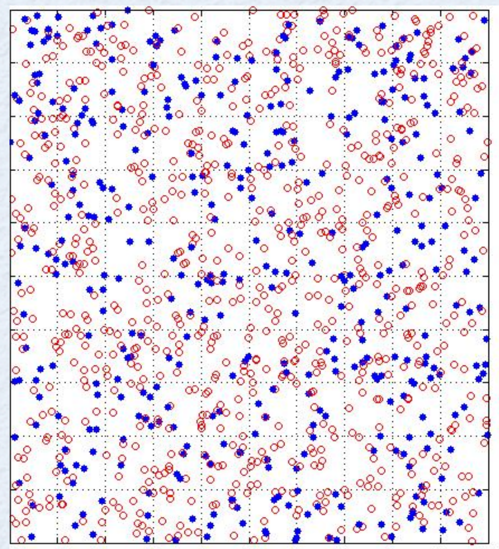
Analysis: Phase 2 -- MOBILE PUSH

Phase 1 | Phase 2 | Phase 3

$n \log^2 n$ **slots**

Spreading Phase | Relaxation Phase | Spreading | Relaxation | … …



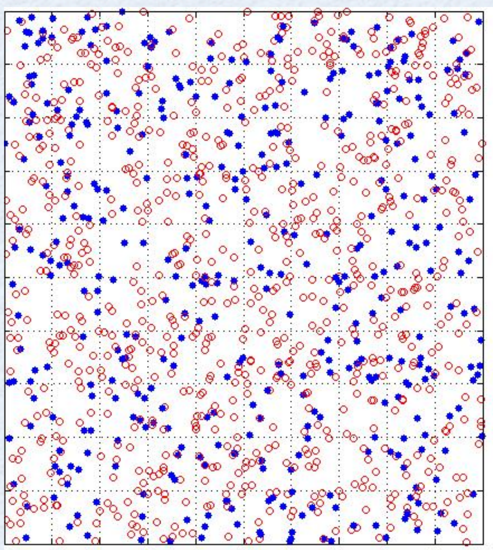


- Evolves like a complete graph across each subphase
- Large expansion property
- By the end of Phase 2, each msg is spread to at least $n/8$ users

Analysis: Phase 3 -- MOBILE PUSH

Phase 1 | Phase 2 | **Phase 3**

$\underbrace{\hspace{6em}}_{n \log^2 n}$ **slots**



- Starting point: $n/8$ (a constant fraction of) users containing the msg
- Evolves like a complete graph for each slot
- Complete spreading within this phase

Concluding Remarks

- Limited velocity is sufficient to achieve **order-optimal** spreading rate

- Mixing allows for ***balanced/uniform*** evolution