Deterministic Communication in the Weak Sensor Model

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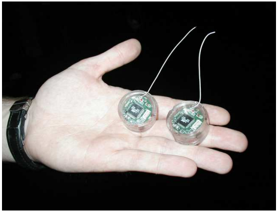
A sensor node

Capabilities

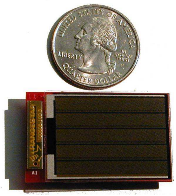
- processing
- sensing
- communication



University of California, Berkeley and Intel Berkeley Research Lab.

Limitations

- range
- memory
- life cycle



PicoBeacon

Berkeley Wireless Research Center

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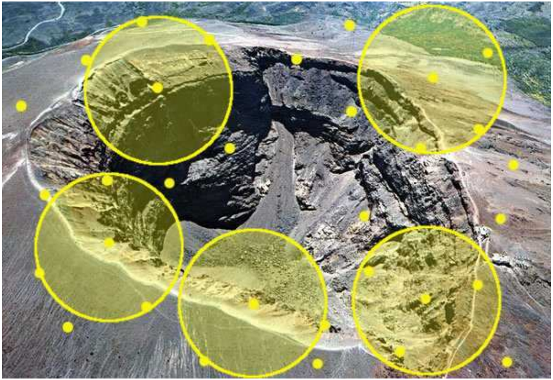

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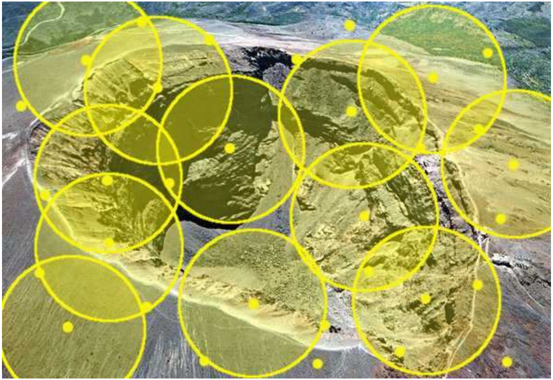

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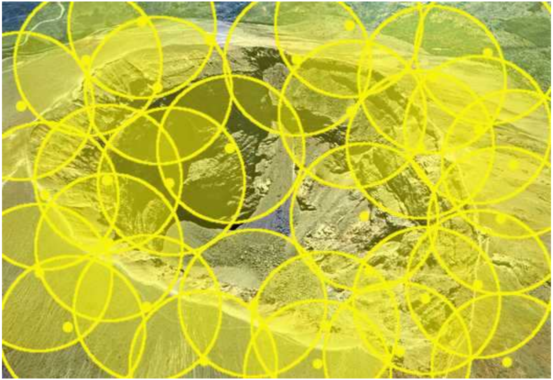

Topology Models

Node Deployment in Sensor Networks

- Hostile or remote environment

  ⇒ deterministic deployment not feasible

  ⇒ *controlled* random deployment.

  ⇒ unknown topology, except for n and max degree $k-1$.

- Uniform Density: Random Geometric Graph, Unit Disk Graph, etc.
- Arbitrary Density: Geometric Graph $\mathcal{G}_{n,r,k}$.

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Node Constraints Models

Sensor Networks

The Weak Sensor Model
[BGI 92, FCFM 05]

- Constant memory size.
- Limited life cycle.
- Short transmission range.
- Low-info channel contention:
  - Radio tx on a shared channel.
  - No collision detection.
  - Non-simultaneous rx and tx.
- Discrete tx power range.
- Local synchronism.
- One channel of communication.
- No position information.
- Unreliability.
- Adversarial wake-up schedule.

$$tx = transmission.$$
$$rx = reception.$$

Why Deterministic Communication?

- Only one channel of communication

  ⇒ must deal with collision of transmissions!

  Popular solution → random protocols.

- BUT scarcest resource is energy and

  random protocols ⇒ redundant transmissions!.

  ⇒ deterministic protocols may help.

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- Sensor Networks application: monitor physical phenomena.

  $\Rightarrow$ protocols must guarantee communication infinitely many times.

- Optimization criteria:

  1) low energy cost.

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- Multi-hop requires precise definition of non-colliding transmissions.
  - *Clear Reception at node x time slot t*:
    Any one node in $N(x)$ transmit and x does not transmit.
  - *Clear Transmission of node x time slot t*:
    Only x transmits in $N^2(x)$.

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- Recurrent generalizations:
  - *Recurring Selection* (single-hop RN, k out of n active)
    Every active node clearly transmits
    infinitely many times.
  - *Recurring Reception* (multi-hop SN, max degree $k-1$)
    Every active node clearly receive from *all* neighbors
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Related Work

- *Message passing*:

  [ABLP'92] Each node receives from all neighbors in $O(k^2 \log^2 n / \log(k \log n))$. $\rightarrow$ synchronous start. $\omega(1)$-degree bipartite-graphs requiring $\Omega(k \log k)$. $\rightarrow$ not embeddable in GG.

- *Broadcast & gossiping*:

  [CGR'00, CGOR'00, CR'03, CGGPR'02] $\rightarrow$ synchronous start, global clock, etc.

- *Selection*

  [Kowalski'05] Static, $\exists O(k \log(n/k))$, +[I'02]: $O(k$ polylog $n)$. $\rightarrow$ synchronous start. Dynamic $O(k^2 \log n)$. $\rightarrow$ nodes turn off upon succ. transmission.

- *Selective families*:

  [I'02] $\exists(k, n)$-selective families of size $O(k$ polylog $n)$.
  [DR'83] (m, k, n)-selectors must be $\Omega(\min\{n, k^2 \log_k n\})$ when $m = k$.
  [DBGV'03] (k, k, n)-selectors must be $\geq (k-1)^2 \log n / (4 \log(k-1) + O(1))$ and $\exists(k, k, n)$-selectors of size $O(k^2 \ln(n/k))$.
  All $\rightarrow$ synchronous start.

Our Results

Study deterministic oblivious (no history) and adaptive protocols for Recurring Selection, Recurring Reception and Recurring Transmission.

- Message complexity oblivious deterministic $\geq k$.
- $O(kn \log n)$-delay message-complexity-optimal: Primed Selection.
- Recurring Selection-lower-bound
  $\Rightarrow$ Recurring Reception and Recurring Transmission lower bounds.
  - $\Omega(k^2 \log n / \log k)$-delay for Recurring Selection.
    (mapping (m, k, n)-selectors $\leftrightarrow$ Recurring Selection)
  - $\Omega(kn)$ for Recurring Selection with *equiperiodic protocols*.
    (memory limitations motivate)
- Choosing appropriately node periods, for $k \leq n^{1/6 \log \log n}$, Primed Selection also delay-optimal for equiperiodic protocols .
- $O(k^2 \log k)$-delay adaptive-protocol, using Primed Selection.
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1 Introduction

2 Oblivious Protocols

3 Adaptive Protocols

Oblivious Protocols

Primed Selection

Theorem

Any oblivious deterministic algorithm for Recurring Selection, single-hop RN, asynch. start, k active nodes $\Rightarrow$ message complexity is $> k$.

PRIMED SELECTION:

For each node i with assigned prime number $p(i)$,

node i transmits with period $p(i)$.

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Equiperiodic Protocols

Memory limitations $\Rightarrow$ periodicity.

Definition

Equiperiodic protocol: set of schedules s.t. in each schedule, every two consecutive transmissions are separated by the same number of time slots.

Theorem

Single-hop RN, asynch. start, k active nodes, any oblivious equiperiodic protocol has delay $\geq kn$.

Using $\log\log n$-factors composite numbers instead of primes...

Theorem

Single-hop RN, asynch. start, $k \leq n^{1/6 \log\log n}$ active nodes, using a compact set of periods, Primed Selection solves Recurring Selection with optimal message complexity k and $O(kn)$ delay, optimal for equiperiodic protocols.

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Adaptive Protocols

Reduced Primed Selection

Primed Selection using $O(k)$ coprime periods yields $O(k^2 \log k)$ delay.
BUT, how do we guarantee every pair of neighbors use different period?

- Further assumptions:
  - Relax memory limitation to $O(k + \log n)$ bits.
  - Double density to be able to half radii of transmission.
- Sketch of protocol:
  - Leave first k primes available.
  - Assign next k primes as before.
  - Nodes use *big* primes to compete for *small* primes using Primed Selection with $r/2$.

Theorem

SN, $k-1$ max. degree, asynch. start, after pre-processing, the delay of Reduced Primed Selection is $O(k^2 \log k)$ and the message complexity is k.

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