Bespoken: A Protocol for Data Search in Wireless Sensor Networks

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If source knew where the sinks are, we would have an easy routing task.
If source knew where the sinks are, we would have an easy routing task.
Research Area

Problem

Energy-efficient data search in... source
Flooding-based dissemination
...not everyone transmits
sink
Flooding Strategy
Flooding-based dissemination
What have we learned from prior work?
Push-based Strategy

Directed diffusion/ Push-Pull
[Intanagonwiwat et al., 2003; Heidemann et al., 2003]

Efficient if number of sources smaller than number of sinks
Directed diffusion/ Push-Pull
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Pull-based Strategy

Efficient if number of sinks smaller than number of sources
Basis for Random Walk Search Strategies

Observation

Two lines in a bounded rectangle have a 69% chance of intersecting (simulation result of *Rumor Routing, Braginsky, Estrin 2002*)
What have we learned from prior work?

Source Spokes

Sink Spokes
A brief introduction to spoke-building...
...or how to follow direction set by the first two retransmissions without any external geographic reference such as compass or GPS

• Any two successive retransmitting nodes are called **pivot** and **leading relay**
• First pivot and first leading relay define the **direction** (or **axis**) of the spoke
...and for that we need some control frames

\( r \): data range
\( R \): control range

- All nodes are **homogeneous** – same transmission power

- **Spoke generation**: sequence of data hops in a particular direction starting with the source node as node 0.
...and for that we need some control frames

\( r \): data range
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**Spoke generation**: sequence of data hops in a particular direction starting with the source node as node 0.
BeSpoken MAC Protocol

• Important:
  Design of data and control ranges,

• Crescent too small - the spoke stops prematurely

• What if we make the crescent very small?
  Increased crescent area increases maximum deviation from the spoke axis

No nodes in the crescent

Crescent area defining the size of the set of candidate nodes

small?
BeSpoken MAC Protocol

- medium access scheme utilized by the protocol is CSMA/CA based

- Crescent too small - the spoke stops prematurely

- Important: Design of data and control ranges, \( r \) and \( R \)

- Increased crescent area increases maximum deviation from the spoke axis

- What if we make the crescent very small?

Crescent Area defining the size of the set of candidate nodes
BeSpoken MAC Protocol

- medium access scheme utilized by the protocol is CSMA/CA based
  - Crescent too small - the spoke stops prematurely

- Important:
  - Design of data and control ranges $r$ and $R$

- Crescent Area defining the size of the set of candidate nodes

- What if we make the crescent very small?
Data Range Design

- **Connectivity:**
  - Identify data range $r$ which guarantees that the spoke will propagate to the network perimeter

- **Straightness:**
  - We would like the spokes to have relatively little wobble with respect to the spoke axis
Data Range Design

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Data Range Design

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• Straightness:
  – Spokes to have relatively little wobble with respect to the spoke axis
Analytical Model

- $R_n$: network area radius
- $N$: number of source spokes
- $K$: number of sink spokes

Source spokes of length $d = R_n$

Sink spokes of length $d = D_s < d_s$

Replication work

Retrieval work
Analytical Model

$r = r(d)$

Data range for source spokes larger than for sink spokes

Source spokes of length $d = R_n$

Sink spokes of length $d = D_s < d_s$

$N$: number of source spokes

$K$: number of sink spokes

$R_n$: network area radius
**Analytical Model**

- \( p \): data popularity
- \( r = r(R_n) \)
- \( r(d_s) \)
- \( n = \frac{\pi}{N} \)
- \( R_n = \lambda R_n^2 \pi \)
- \( r(\lambda = 1) \)
- \( \alpha \): propagation loss

\( n \): expected number of network nodes distributed as Poisson point process of intensity \( \lambda \)
Total Work

\[ W = NW_{sp}(R_n, \alpha) + 2MW_{sp}(d_s, \alpha) \frac{E(D_s)}{d_s} \]

- Replication work: \( NW_{sp}(R_n, \alpha) \)
- Retrieval work: \( 2MW_{sp}(d_s, \alpha) \frac{E(D_s)}{d_s} \)

\[ W_{sp}(d, \alpha) = \frac{d}{r(d)} W_h = O\left( d^{\frac{7+3(\alpha-1)}{7}} \right) \]

- For \( \alpha = 2 \), the work growth is roughly \( d^{10/7} \)
- For \( \alpha = 3 \) the growth \( d^{13/7} \) is almost quadratic
Optimal number of source spokes $N$

$$N_{opt} = \min_{N} \{ W \} = f(M, \alpha, n)$$

- total number of sink spokes $M = pnk$
- $N_{opt}$ grows with $M$ at a rate defined by $\alpha$
Optimal number of source spokes $N_{opt}$

- Red dashed line: popularity $p=10^{-4}$
- Blue solid line: popularity $p=10^{-5}$
- Black dashed line: popularity $p=10^{-6}$
- Light green dashed line: popularity $p=10^{-7}$

$k = 5$

Network size $n$ vs. optimal number of spokes $N_{opt}$ on a logarithmic scale.
Total Work Bound

\[ W \leq W_{opt} = W_{sp}(R_n, \alpha) \left[ \frac{2}{3} n p \kappa \right]^{G(\alpha)} F(\alpha) \]

\[ G(\alpha), F(\alpha) \] - functions of \( \alpha \)

\[ W = O\left(n^{\frac{5}{7}}\right) \text{ for } \alpha = 2 \]
Comparing BeSpoken Total Work vs. Flooding

- For small $pn$, BeSpoken work growth with $n$ is slower than linear
- Flooding work growth is faster than linear
Total Energy: Observations

• Total work depends on three main factors:
  
  - network size $n$,
  - expected number of sink spokes $p n_k$,
  - propagation exponent $\kappa$

• Growth rate is significantly smaller for small $p$

• Select the smallest possible $\kappa$ (5 is enough)

• *Energy consumption* of BeSpoken is favorable in large networks when data popularity is small
Future Work

• Analyze energy consumption and model robustness under relaxed wobbliness constraints

• Analyze BeSpoken performance under fading channel model (shadow fading)

• BeSpoken allows branching of spokes at a desired angle, at any depth away from the source…

…modify the wheel pattern of data dissemination by adding lateral paths that branch off of spokes
The End