Delay/Fault-Tolerant Mobile Sensor Network (DFT-MSN)

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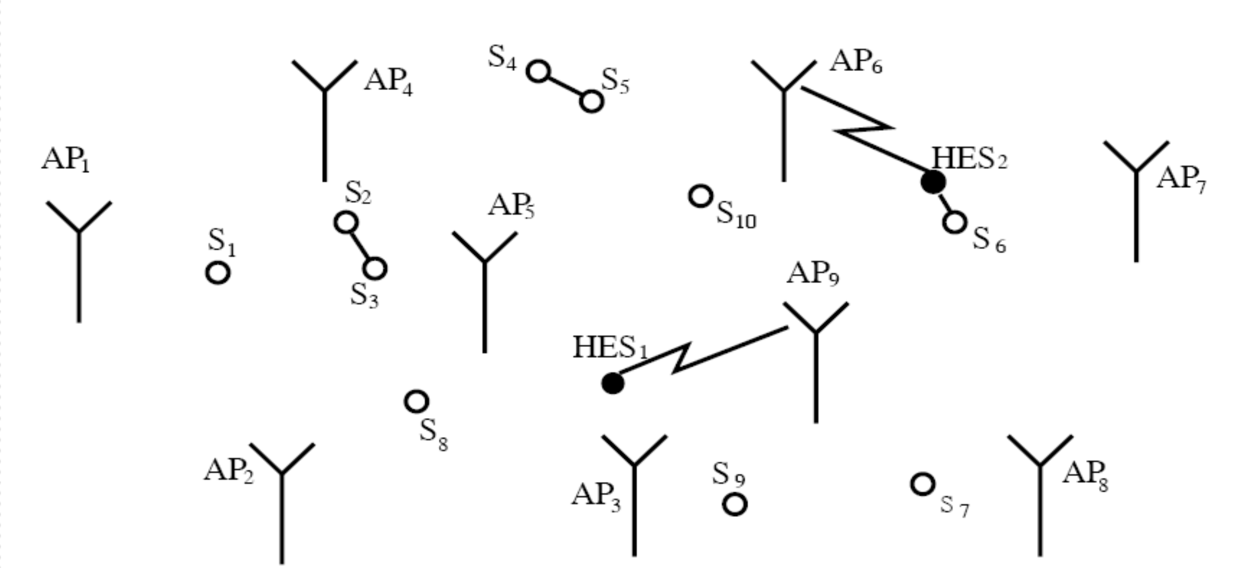
Typical Applications and Unique Characteristics of DFT-MSN

- Applications:
  - Flu virus tracking
  - Air quality monitoring
  - Wild animal monitoring
- Unique characteristics:
  - Nodal mobility
  - Sparse connectivity
  - Delay/fault tolerability
  - Limited buffer
- Mainstream approaches of senor networks may not work effectively.

DFT-MSN: Architecture



An overview of the integrated self-configurable wireless mesh network and delay/fault-tolerant mobile sensor system. S_1-S_{10}: sensors; HES_1-HES_2: high end sensors (sinks); AP_1-AP_9: access points of backbone network. Only S_2 and S_3, S_4 and S_5, and S_6 and HES_2 can communicate with each other at this moment.

Related Work

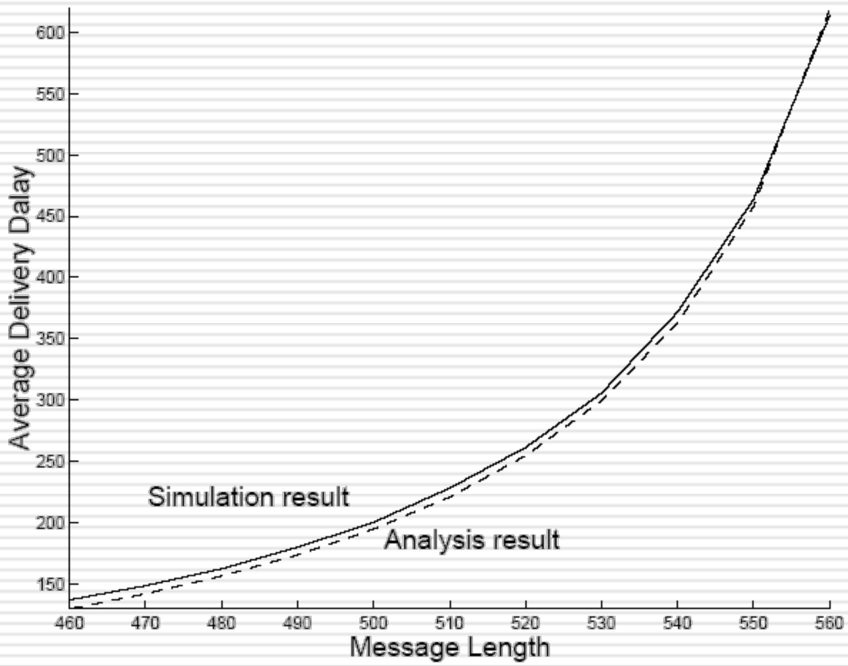
- Delay Tolerant Network (DTN)
  - V. Cerf, S. Burleigh, A. Hooke, L. Torgerson, R. Durst, K. Scott, K. Fall, and H. Weiss, "Delay Tolerant Network Architecture", draft-irtf-dtnrg-arch-02.txt, 2004.
- DTN in Sensor Networks
  - Static sensor nodes and sinks: e.g., Ad hoc Seismic Array, etc.
  - Static sensor nodes and mobile sinks: Data Mule.
  - Mobile sensor nodes and/or sinks: ZebraNet, SWIM, DFT-MSN.

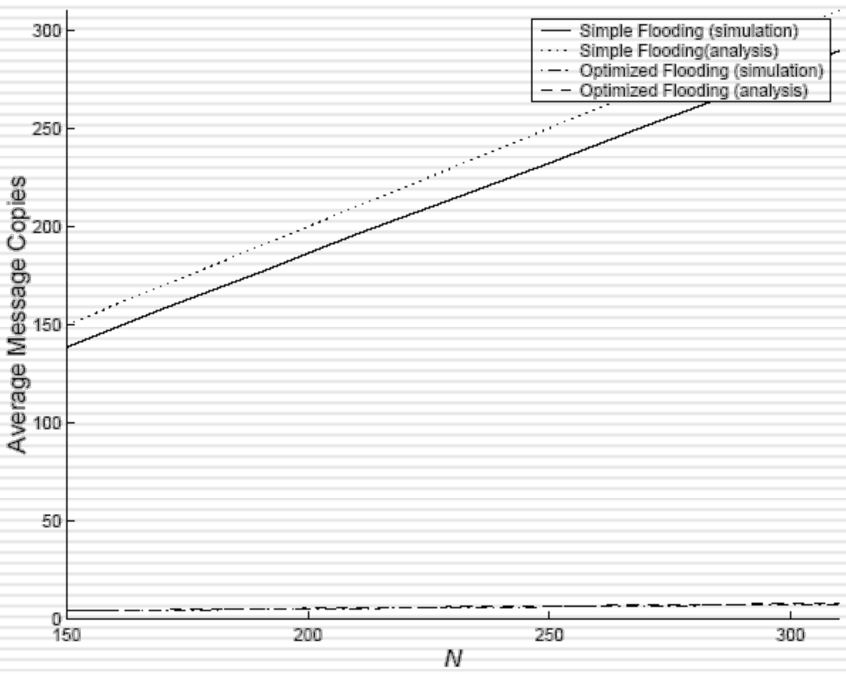
Studies of Two Basic Approaches

- Direct Transmission
  - M/G/1 Queuing Model
  - Assume message generation is Poisson
  - Lemma 1: the service time of the message is Pascal distributed
- Simple Flooding
  - Analyze flooding overhead, delay, and delivery probability
- Optimized Flooding
  - Estimate message delivery probability and terminate flooding
  - To reduce flooding overhead and energy consumption

Studies of Two Basic Approaches

- Analytical models are verified via simulations





An Overview of The Proposed DFT-MSN Data Delivery Scheme

- The proposed *Fault Tolerance-based Adaptive Delivery Scheme (FAD)* is based on two key parameters:
  - The nodal delivery probability:
    - Assisting data transmission.
    - The metrics for when and where to transmit data message
  - The message fault tolerance
    - Assisting queue management.
    - The metrics for which messages to transmit or drop

Nodal Delivery Probability

- The delivery probability indicates the likelihood that a sensor can deliver data messages to the sink. The delivery probability of a sensor *i*, ξ_i, is updated as follows,

$$\xi_i = \begin{cases} (1-\alpha)[\xi_i] + \alpha\xi_k, & Transmission \\ (1-\alpha)[\xi_i], & Timeout, \end{cases}$$

where $[\xi_i]$ is the delivery probability of sensor *i* before it is updated, ξ_k is the delivery probability of node *k* (a neighbor of node *i*), and $0 \leq \alpha \leq 1$ is a constant employed to keep partial memory of historic status.

Message Fault Tolerance

- The fault tolerance of a message is defined to be the probability that at least one copy of the message is delivered to the sink by other sensors in the network.
- Considering a sensor *i* multicasting a data message *j* to *Z* nearby sensors, the message transmitted to sensor ψ_z is associated with a fault tolerance of $\mathcal{F}_{\psi_z}^{j}$,

$$\mathcal{F}_{\psi_z}^{j} = 1 - (1 - [\mathcal{F}_i^{j}])(1 - \xi_i) \prod_{m=1,\ m \neq z}^{Z} (1 - \xi_{\psi_m}),$$

where $[\mathcal{F}_i^{j}]$ is the fault tolerance of message *j* at sensor *i* before multicasting.

The fault tolerance of the copy at sensor *i* is also updated accordingly using similar calculation.

Data Transmission

- Data transmission decision is made based on the nodal delivery probability.
- First step: learns the neighbors' delivery probabilities and available buffer spaces via simple handshaking messages.
- Second step: sends the message to a set of neighbors with higher delivery probabilities, and at the same time, controls the total delivery probability of that message just enough to reach a predefined threshold, in order to reduce unnecessary transmission overhead.

Queue Management

- The queue management scheme is based on the fault tolerance.
- Message with the smallest fault tolerance is always at the top of the queue and transmitted first.
- Message dropping happens in two situations:
  - The queue is full.
  - The fault tolerance of a message is larger than a threshold.

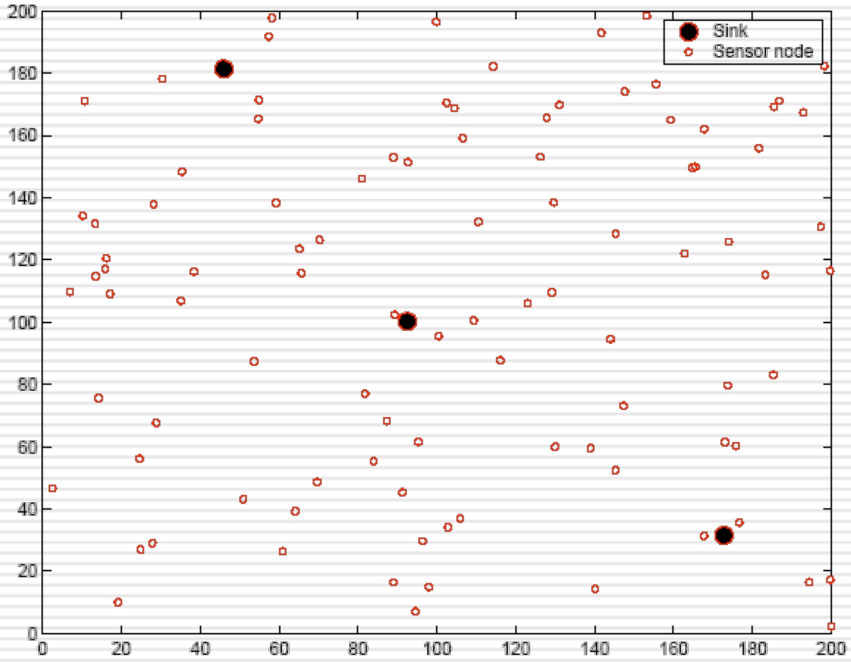
Simulations

- Simulation setup

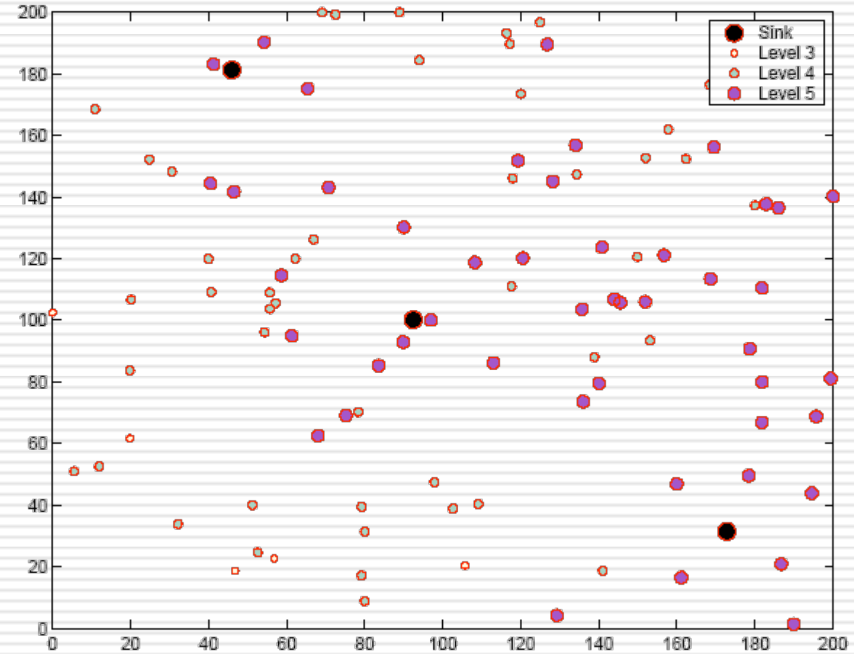
Maximum sensor transmission range	10 m
Number of sensor nodes	100
Number of sink nodes	3
Size of network area	$200 \times 200\ m^2$
Size of a zone	$40 \times 40\ m^2$
Probability to move out of a zone	20%
Probability to move back to home zone	100%
Maximum queue length	200
Message generation rate	$0.01/s$
Message length	50 $bits$
Bandwidth	2500 bps
Nodal moving speed	$0-5m/s$
γ	0.8

Simulations

- Update of delivery probabilities



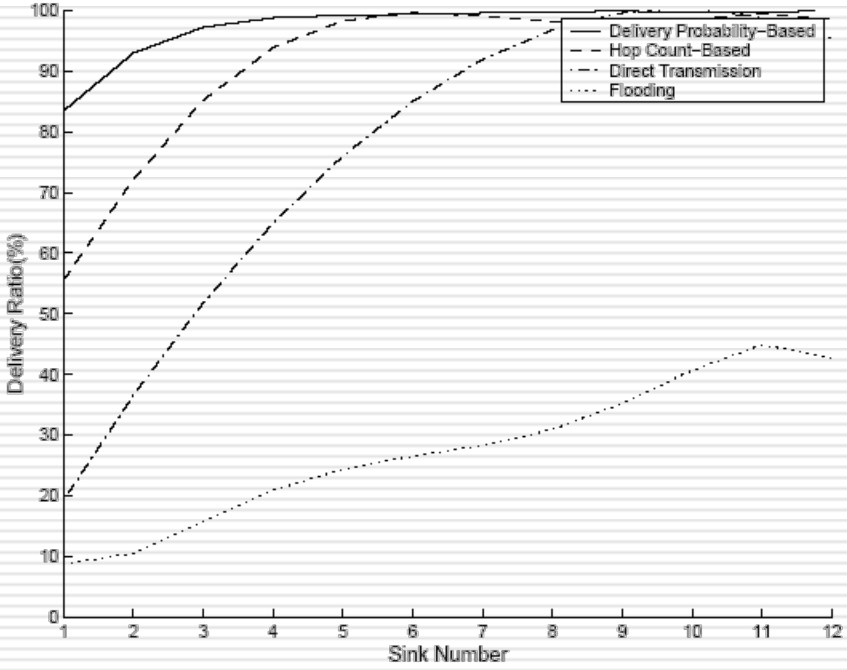
(a) Initial deployment.



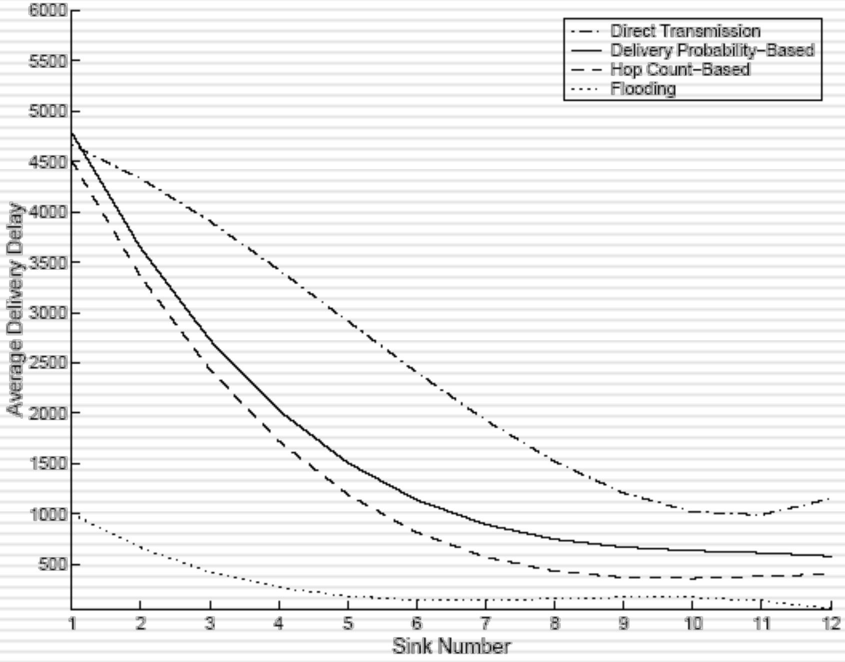
(b) 1000 seconds later.

Simulations

- Impact of number of sink nodes



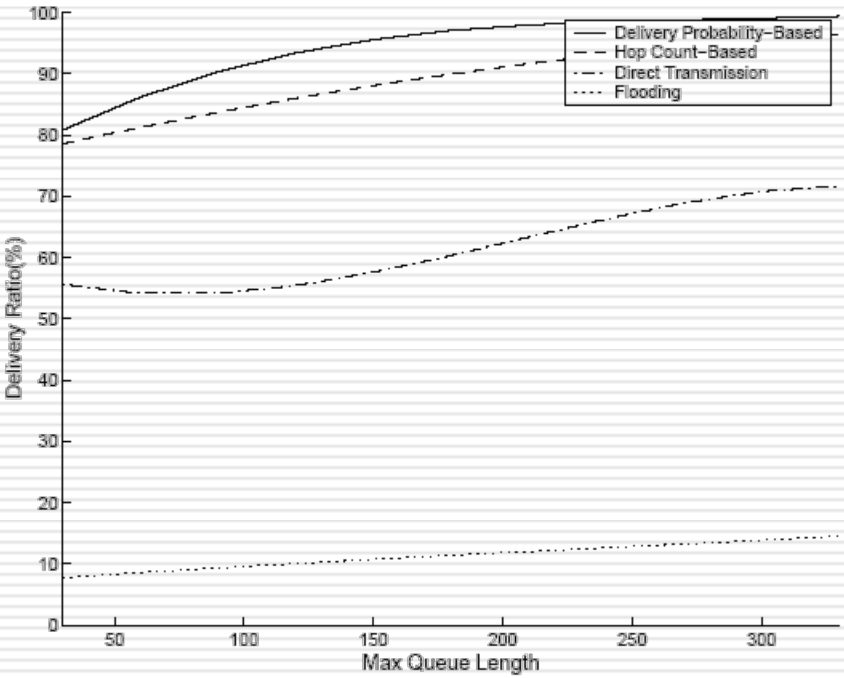
(a) Average delivery ratio.



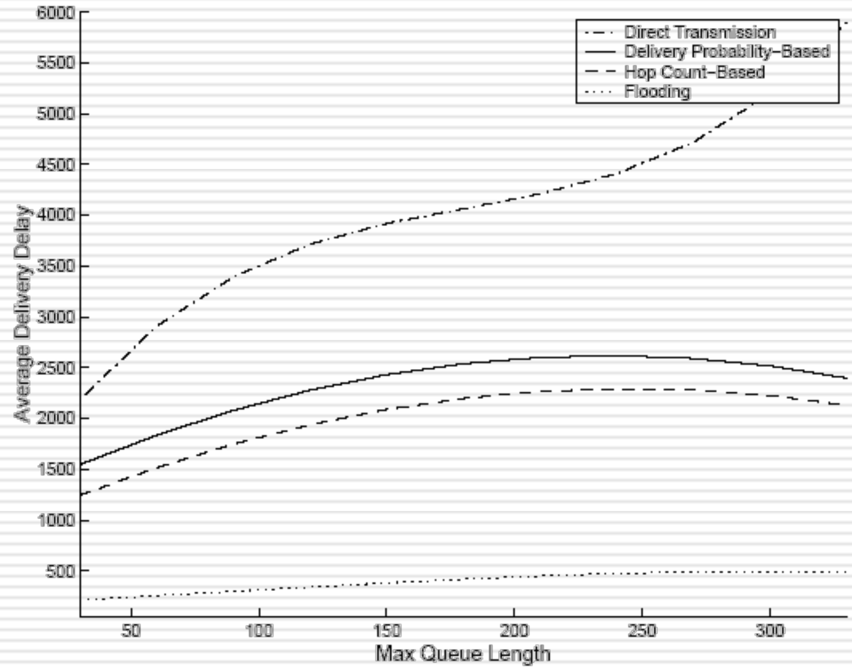
(b) Average delay.

Simulations

- Impact of maximum queue length



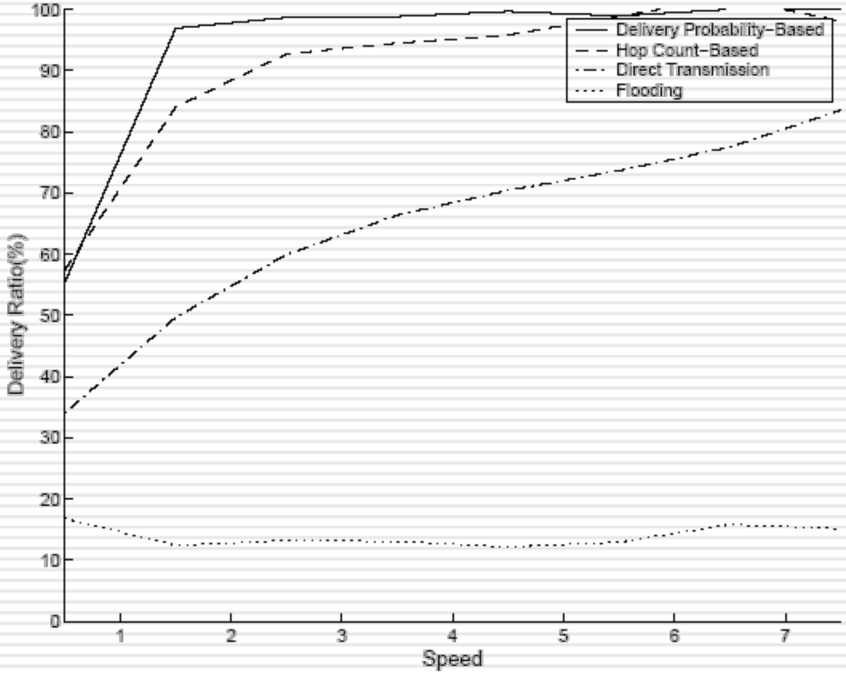
(a) Average delivery ratio.



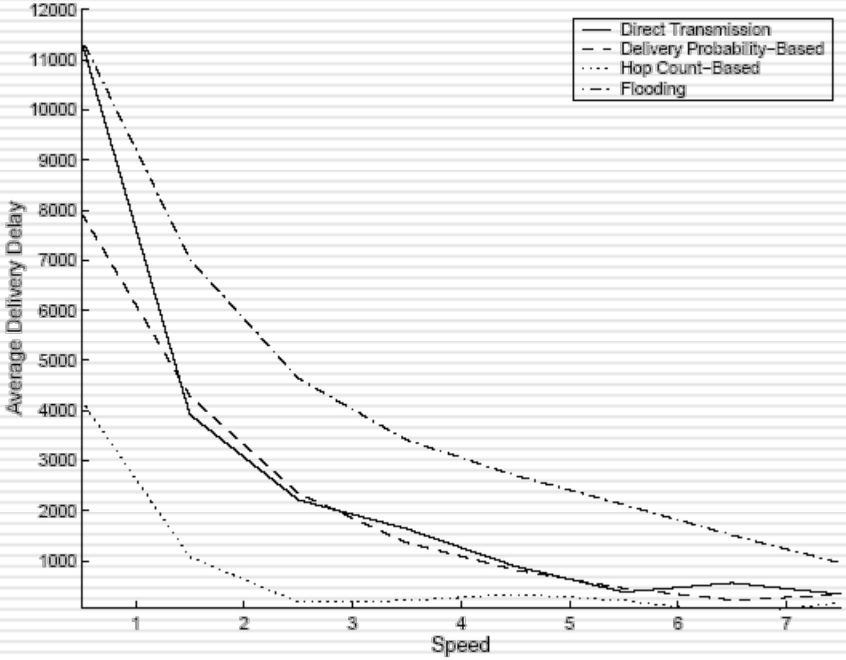
(b) Average delay.

Simulations

- Impact of nodal speed



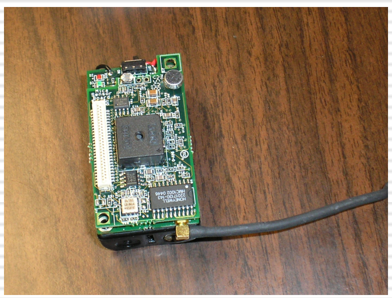
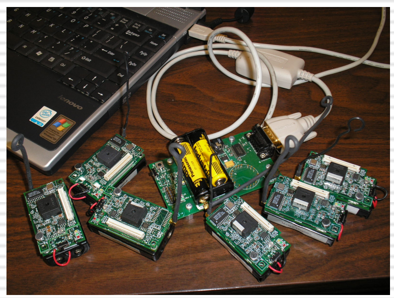
(a) Average delivery ratio.



(b) Average delay.

Follow-up Work

- A generic queuing model for delay tolerant mobile networks
- Prototype and experimental testbed (Percom'06 PerSeNS workshop)

- An alternative approach based on Erasure coding (Percom'06 Ubicare workshop)

Conclusion

- DFT-MSN is proposed for pervasive information gathering
- DFT-MSN has several unique characteristics, such as nodal mobility, sparse connectivity, delay/fault tolerability, and limited buffer
- Studied two basic approaches based on queuing theories
- Proposed an efficient message delivery scheme
- Simulated the proposed data delivery scheme, showing high delivery ratio and low transmission overhead
- In our follow-up work, we have proposed an alternative approach, carried out deep analytic studies, developed a small-scale testbed