Mobility-Assisted Data Collection in Wireless Sensor Networks: Scheme Design and Modeling Analysis

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Outline

• Introduction
• Potential Applications
• Problem Division
  • Scheme Design for Offline Scenario
  • Modeling Analysis for Online Scenario
• Conclusions
Introduction

• Data Collection is the main application for wireless sensor networks
Introduction

• Traditional Approach for Data Collection
Introduction

• Mobility-Assisted Data Collection
  – mobile elements (MEs)
    – mobile sinks, data mules, mobile sensors, …
  – low & balanced energy consumption for sensor nodes
  – suitable for sparse networks
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Potential Applications

• NEPTUNE Canada

• Sabertooth
Potential Applications

- Seatext + Smart Buoy
Potential Applications

• RQ-7A/B Shadow 200

• Other Applications
  – in Gulf oil leak, 2010
  – ...

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Problem Division

Mobile Elements

Moving speed is limited

Larger data collection latency

Optimizing the motion of MEs is critical
Problem Division

- Energy limitation on sensors
  - Optimize energy consumption
    - Utilize mobility to collect data, large delay
      - Minimize data delay
        - Motion schedule of MEs
          - Further improvement
            - Hybrid approach: combine mobility and multihop communication
Problem Division

• Scheme Design for Offline Scenario
  – obtain the nearly-optimal data collection scheme for MEs

• Modeling Analysis for Online Scenario
  – provide performance evaluation of the network
  – guide the scheme design for online scenario
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Scheme Design

• Scenario: start from the easiest
  • single ME
  • constant travel speed
  • unit disk communication model
  • w/o constraints on data rate
  • locations of sensor nodes are available to ME

• Objective
  • reduce data collection latency through obtaining a near-optimal travel path
Scheme Design

\[
\min_{T \in T} |T| \quad \text{s.t.} \quad \forall s_i \in S, \ \exists e \in T, \ |s_i, e| \leq d,
\]

- **Combine-Skip-Substitute scheme**
  - consists of 3 steps
  - optimizes the tour progressively
  - outperforms the best known heuristic so far
Scheme Design

• **Step 1: starts with an optimal TSP tour**
  – Concorde \(^{[1]}\)
    • efficiency verified TSP solver
  – reduces search space of the problem
    • heuristic in nature
    • verified efficiency \(^{[2]}\)
  – \( S \rightarrow T_{tsp} \)

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\(^{[1]}\) Concorde TSP solver, http://www.tsp.gatech.edu/concorde.html

Scheme Design

• Step 2: combines collection sites
  – modified Welzl’s algorithm
    – finds smallest enclosing disk in linear time
    – returns true if radius smaller than comm. range
  – adopts it along $T_{tsp}$, and combine collection jobs with best effort
  – $T_{tsp} \rightarrow T_{com}$
Scheme Design

- **Step 3: skip-and-substitute collection sites**
  - skip
  - substitute
    - binary search with control parameter delta
  - in a progressively manner
  - $T_{com} \rightarrow T_{css}$
Scheme Design

- CSS Demonstration
Scheme Design

• **Correctness**
  - \( T_{tsp} \), \( T_{com} \), and \( T_{css} \) are all feasible

• **Optimality**
  - \(|T_{css}| \leq |T_{com}| \leq |T^*| + 2n'd\)
  - \(|T_{css}| \geq L \sqrt{\frac{n''}{2}}\)
    - \( n' \) and \( n'' \) are the number of collection sites in \( T_{com} \) and \( T_{css} \), respectively

• **Time complexity**
  - \( C_{tsp} + O(n^3 \log n) + O(n^2 \log(1/delta)) \)

\[ \text{the dominating one} \]
Scheme Design

• Evaluation

![Graph showing tour length vs. number of sensor nodes for different schemes: TSP, COM, LC, CSS, and TSP-LB. The CSS scheme is marked with CSS, the lower bound is marked with lower bound, and the label-covering scheme is marked with label-covering.]
Scheme Design

- Extension
  - single ME $\rightarrow$ multiple MEs
  - w/o constraints on data rate $\rightarrow$ with constraints on data rate
  - offline $\rightarrow$ online
    - good or not?
  - constant travel speed $\rightarrow$ variable travel speed
  - unit disk communication model $\rightarrow$ stochastic model
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Modeling Analysis

• Scenario: start from the easiest
  • single ME with constant travel speed
  • sensor nodes initiate data collection requests when their buffer are full
  • ME maintains a service queue for received requests, and serve them with the FCFS discipline

• Objective
  • theoretically analyze the system performance with different service disciplines
Modeling Analysis

• **Queue-based Modeling**
  - **Arrival Rate**
    • exponential inter-arrival time
  - **Service Rate**
    • model service time as travel time
    • distance distribution between two locations \(^1\)

\[
t_m = \frac{d}{v}
\]

Modeling Analysis

• Analytical Results
  – expected values of system measures
  – probability distribution of queue length and response time
  • through an embedded Markov chain
Modeling Analysis

- FCFS with Combination (FCFSC)

\[ P(x, n, r, L) = \binom{n}{x} F_D \left( \frac{r}{L} \right)^x (1 - F_D \left( \frac{r}{L} \right))^{n-x} \]

- Combination Probability
Modeling Analysis

• Evaluation
  – Probability Distribution of Queue Length
Modeling Analysis

• Extension
  – single ME $\rightarrow$ multiple MEs
  – FCFS, FCFSC $\rightarrow$ NJN, NJNC
  – homogeneous MEs $\rightarrow$ heterogeneous MEs
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Conclusions

The problem is far from being solved!
Thanks!