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


Liang He

University of Victoria, Canada

Nankai University, China

# Outline

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

# Introduction

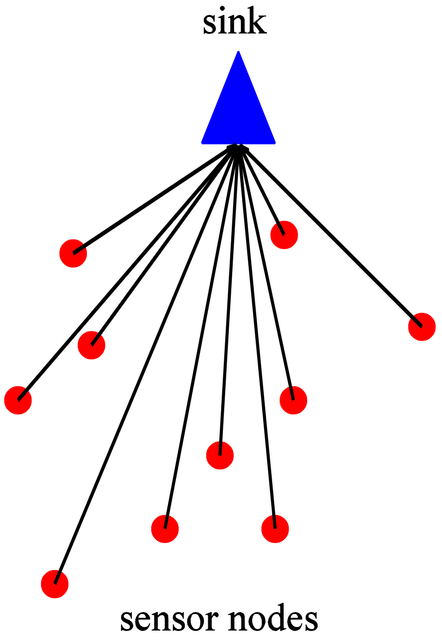
- Data Collection is the main application for wireless sensor networks

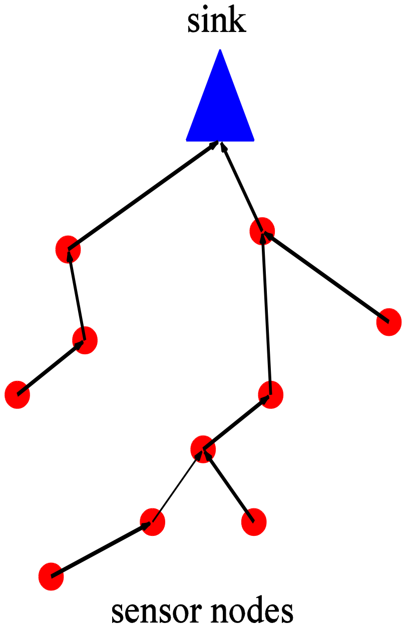
# Introduction

- Traditional Approach for Data Collection

Direct Transmission

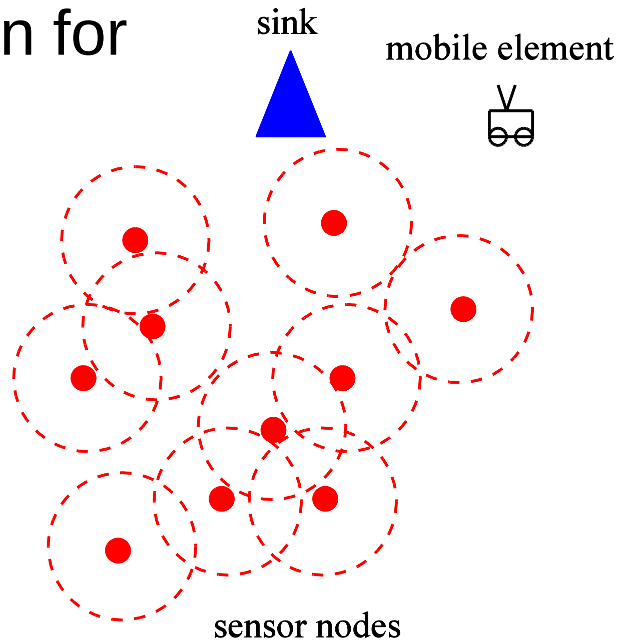



Multihop Forwarding



# 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



# Outline

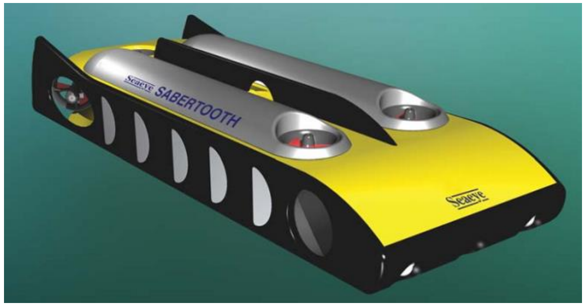
- Introduction
- Potential Applications
- Problem Division
  - Scheme Design for Offline Scenario
  - Modeling Analysis for Online Scenario
- Conclusions

# Potential Applications

- **NEPTUNE Canada**



- **Sabertooth**




# Potential Applications

- **Seatext + Smart Buoy**

# Potential Applications

- **RQ-7A/B Shadow 200**


- **Other Applications**
  - in Gulf oil leak, 2010
  - ...

# Outline

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

# Problem Division

**Mobile Elements**

↓

**Moving speed is limited**

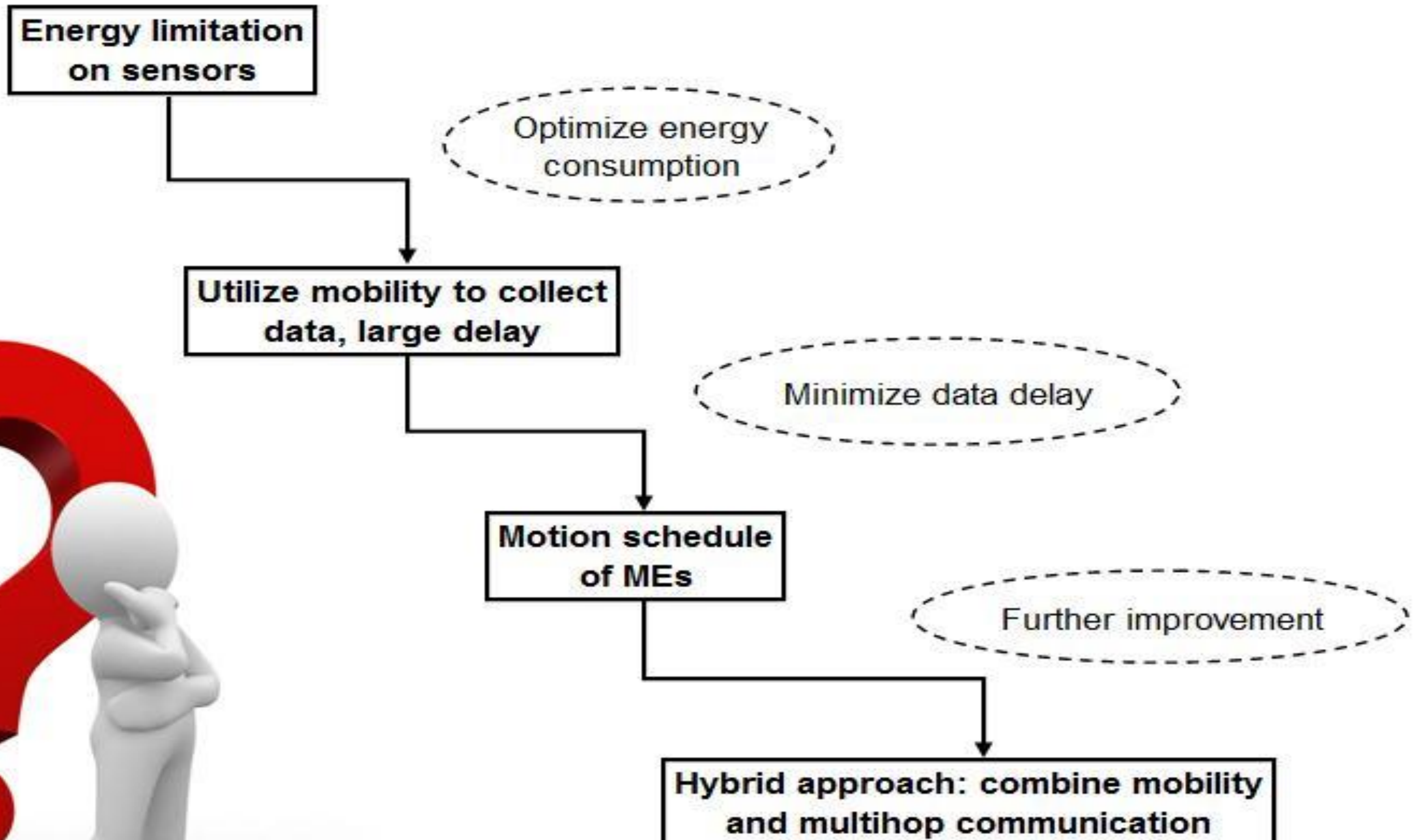
↓

**Larger data collection latency**

↓

**Optimizing the motion of MEs is critical**

# Problem Division




# 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

# Outline

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

# 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

$$\min_{T \in \mathcal{T}} |T| \quad s.t. \quad \forall s_i \in \mathcal{S},\ \exists e \in T,\ |s_i, e| \leq d,$$

- ***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]
  - $S \rightarrow T_{tsp}$

[1] Concorde TSP solver, http://www.tsp.gatech.edu/concorde.html

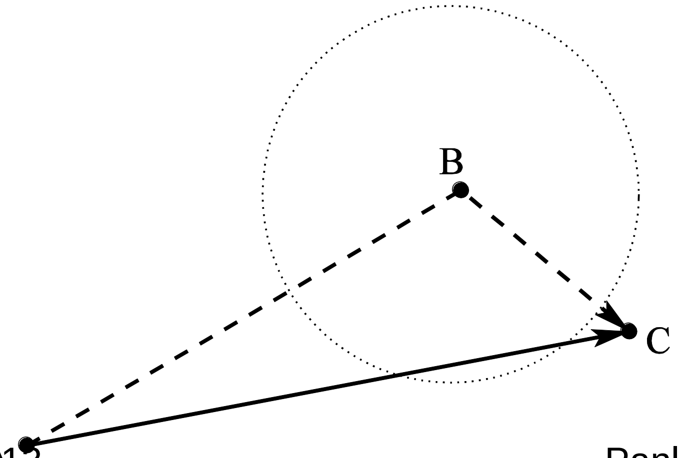
[2] B. Yuan, M. Orlowska, and S. Sadiq, ``On the optimal robot routing problem in wireless sensor networks,'' IEEE Trans. on Know. and Data Eng. 2007.

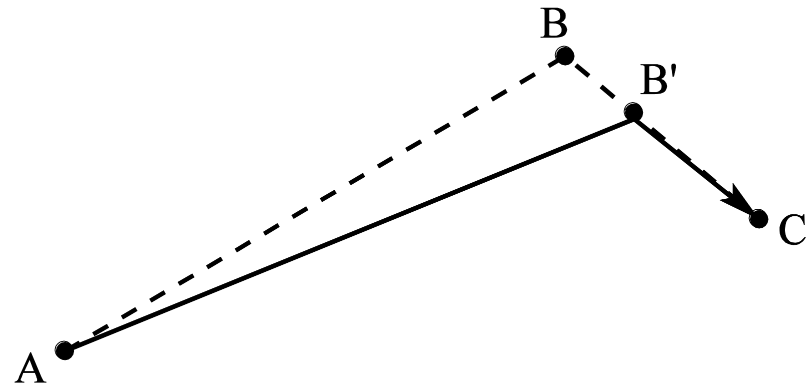
# Scheme Design

- **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

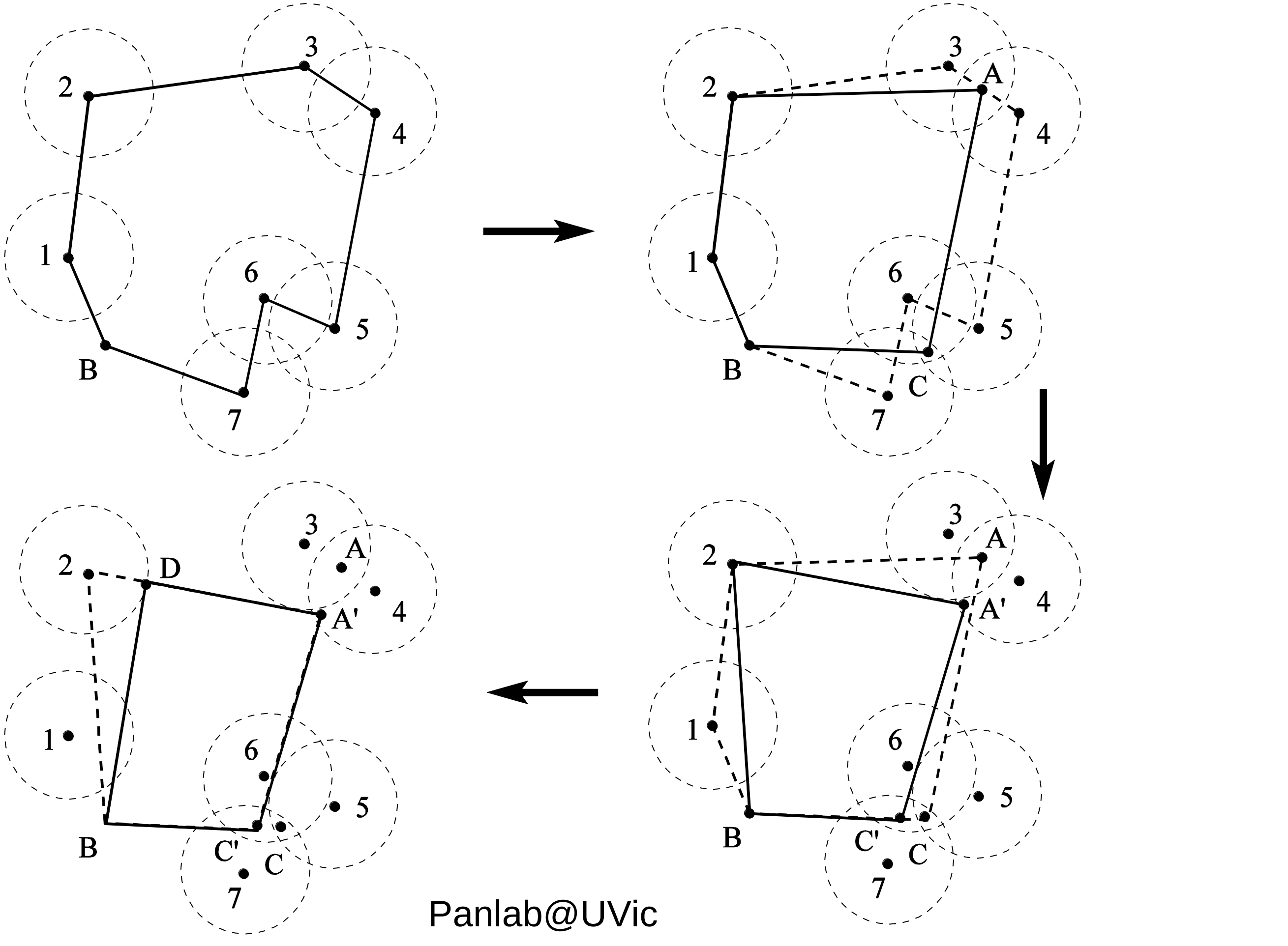
- **Step 3: skip-and-substitute collection sites**
  - skip
  - substitute
    - binary search with control parameter delta
  - in a progressively manner
  - *Tcom* → *Tcss*



# Scheme Design

- CSS Demonstration



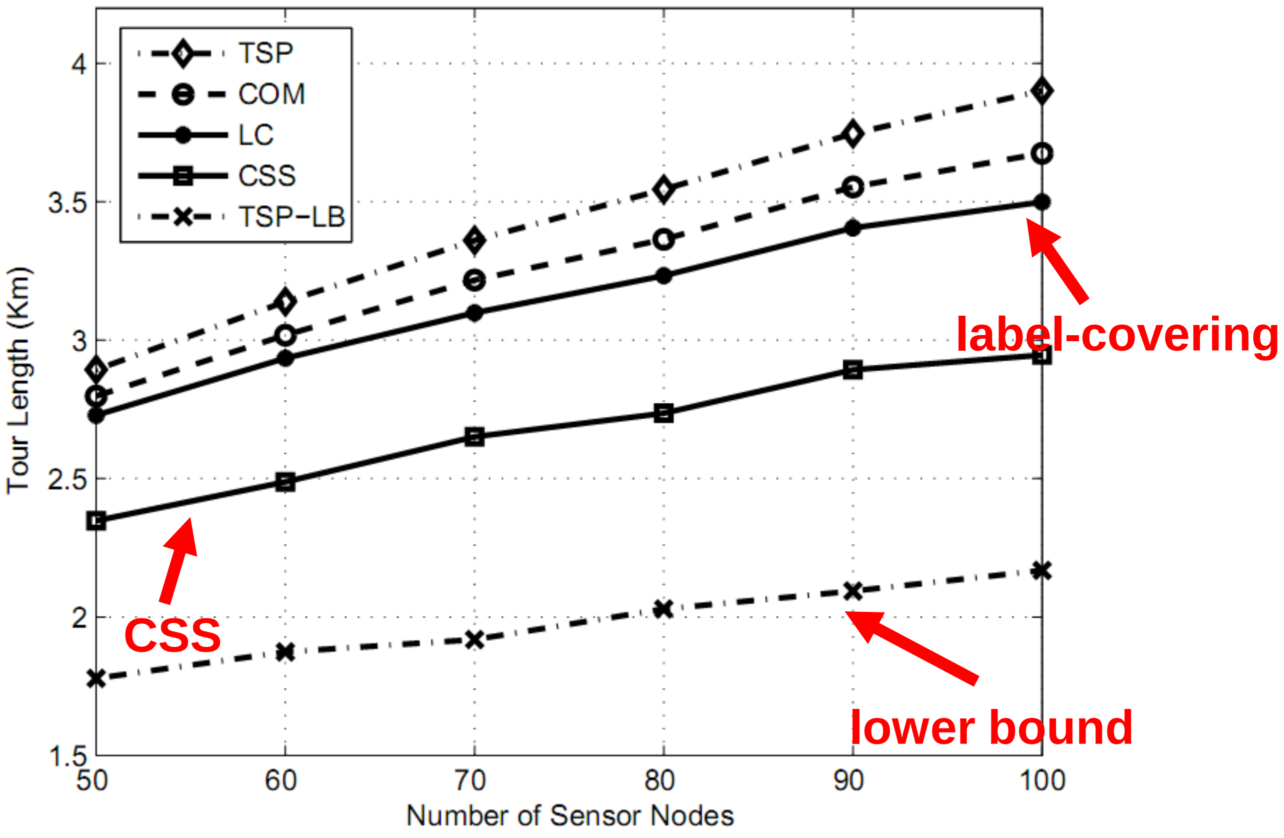
# Scheme Design

- **Correctness**
  - $T_{tsp}$, $T_{com}$, and $T_{css}$ are all *feasible*
- **Optimality**
  - $|T_{css}| <= |T_{com}| <= |T^*| + 2n'd$
  - $|T_{css}| >= L\ sqrt(n''/2)$
    - $n'$ and $n''$ are the number of collection sites in $T_{com}$ and $T_{css}$, respectively
- **Time complexity**
  - $C_{tsp} + O(n^3 logn) + O(n^2 log(1/delta))$

the dominating one

# Scheme Design

- Evaluation



# Scheme Design

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

# Outline

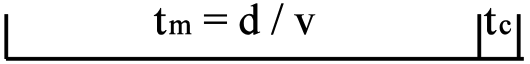
- Introduction
- Potential Applications
- Problem Division
  - Scheme Design for Offline Scenario
  - Modeling Analysis for Online Scenario
- Conclusions

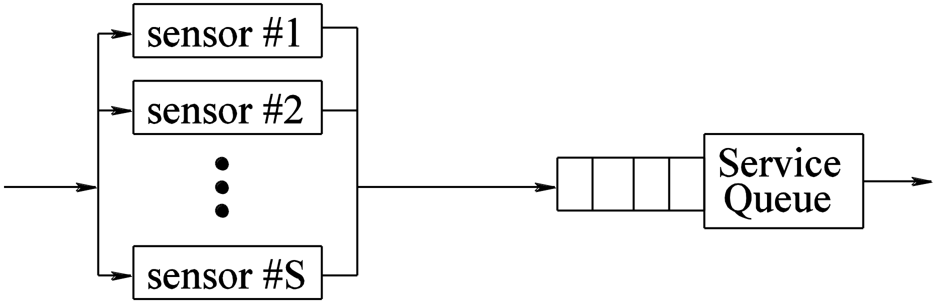
# Modeling Analysis

- 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]

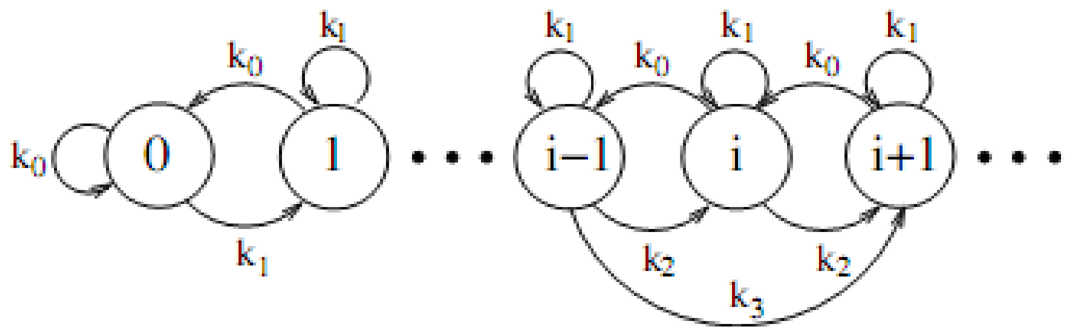



[1] Y. Zhuang, J. Pan, and L. Cai, “Minimizing Energy Consumption with Probabilistic Distance Models in Wireless Sensor Networks”, in Proc. of IEEE INFOCOM, 2010.

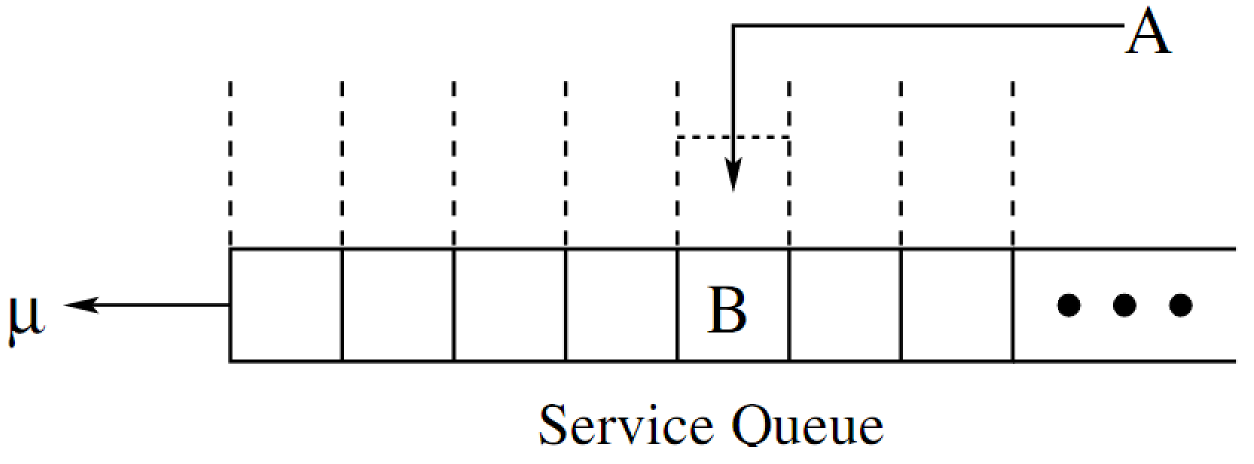
# Modeling Analysis

- 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)

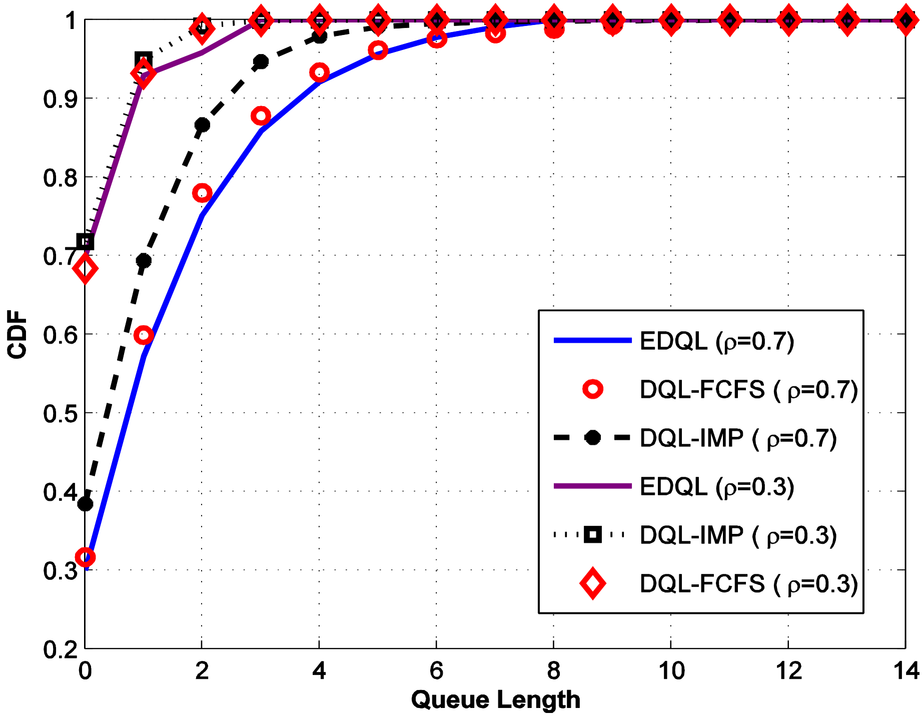



- Combination Probability

$$P(x,n,r,L) = \binom{n}{x} F_D(\frac{r}{L})^x (1 - F_D(\frac{r}{L}))^{n-x}$$

# Modeling Analysis

- Evaluation
  - Probability Distribution of Queue Length



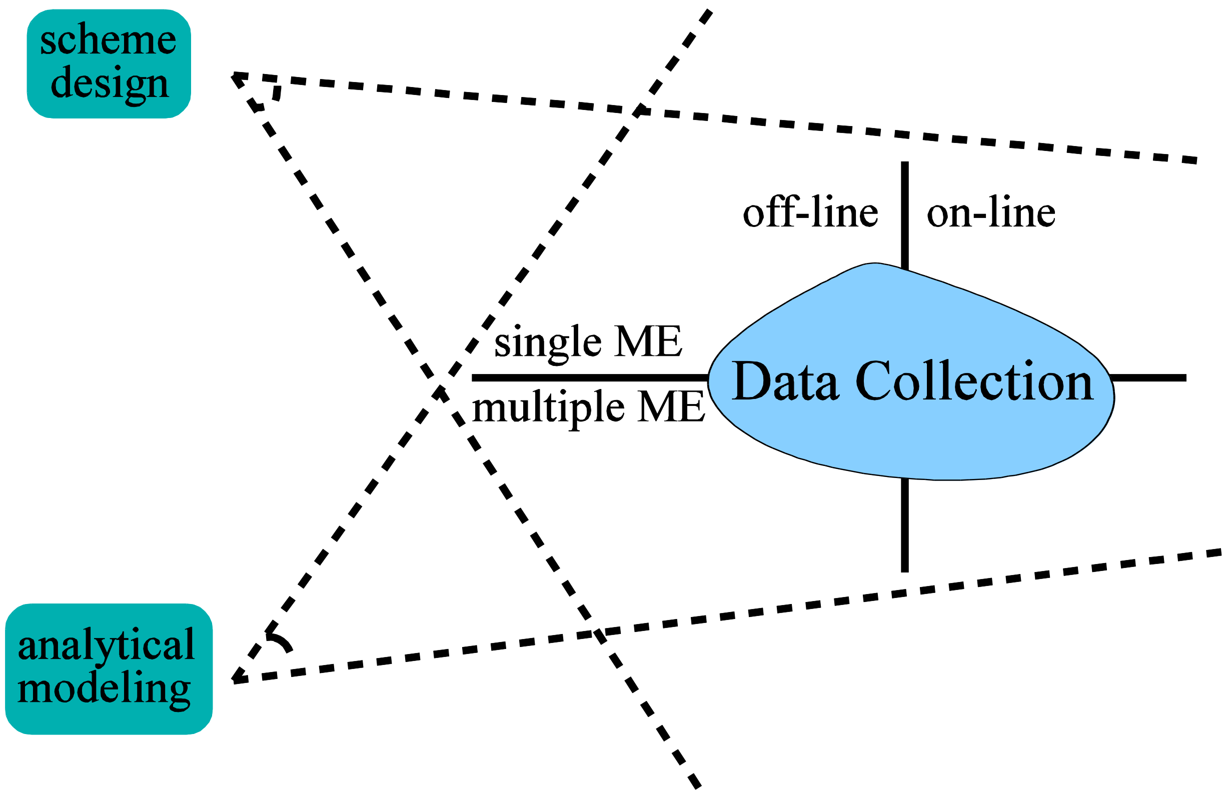
# Modeling Analysis

- Extension
  - single ME → multiple MEs
  - FCFS, FCFSC → NJN, NJNC
  - homogeneous MEs → heterogeneous MEs

# Outline

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

# Conclusions




The problem is far from being solved!

# Thanks!