MobiSensing: Exploiting Human Mobility for Multi-Application Mobile Data Sensing with Low User Intervention*

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Outline

- Introduction
- System Design
- Performance Evaluation
- Conclusion

Introduction

- Explosive growth of mobile devices
  - Smart phones, tablets, and wearable devices
  - Around 2 billion smart phone users now

- Rich sensing & computing capability on those mobile devices
  - GHz level CPUs
  - Various sensors: GPS/Microphone/Accelerometer

Introduction

- Inspires mobile device based sensing systems
  - Exploit otherwise underutilized resources
  - Does not need dedicated infrastructure
  - A bunch of existing endeavors
    - Bus arrival time prediction (MobiSys'12)
    - Red light advisory (MobiSys'11)
    - Remote sensing (MobiSys'10)
    - Road status sensing and mobitoring (SenSys'08)
    - etc.

Introduction

- Mobile devices holders are not dedicated
  - Do not want to move or operate purposely for sensing
  - Want to be interrupted as few as possible
  - A major barrier for such distributed sensing systems

- The passive mode appears to be more attractive
  - Collect data without explicit user interruption
  - Can exploit more resources

Introduction

- How to realize passive data sensing effectively?
  - Accurate mobility prediction
    - Understand where mobile devices are going
  - Efficient task assignment
    - Send the task to the device that is most likely to finish it
  - Reduce explicit user participation as much as possible
    - Enhance the accuracy of the above two steps "silently"

Introduction

- MobiSensing is proposed in this direction
  - Exploit the heterogeneous semi-markov model for mobility modeling
  - Mobility model based task assignment
    - A task is always assigned to devices that are most likely to complete them
  - Exploit mobile device's intermittent connection to server for
    - Mobility model refinement
    - Task assignment and data collection

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System Design : Mobility Modeling

- Treat device mobility as transition between landmarks
  - $\mathcal{L} = \{L_1, L_2, L_3, \dots, L_m\}$: landmark space consisting of m landmarks

- Using semi-markov process (SMP) to model those transitions
  - X_n: the status (i.e., which landmark) after the n-th transition
  - T_n: the time when the node changes to X_n
  - Kernel:

$$Q_{ij}(t) = P[\mathrm{X}_{n+1} = L_j, \mathrm{T}_{n+1} - T_n \leq t | \mathrm{X}_n = L_i]$$

  - It means the probability of transiting to L_j after staying at L_i for less than t time slots

System Design : Mobility Modeling

- How to obtain $Q_{ij}(t)$?

$$Q_{ij}(t) = P\left[\mathrm{X}_{n+1} = L_j, \mathrm{T}_{n+1} - T_n \le t \middle| \mathrm{X}_n = L_i\right]$$
$$= P\left[\mathrm{X}_{n+1} = L_j \middle| \mathrm{X}_n = L_i\right] * P[\mathrm{T}_{n+1} - T_n \le t | \mathrm{X}_{n+1} = L_j, \mathrm{X}_n = L_i]$$
$$= p_{ij} U_{ij}(t)$$

- p_{ij}: the probability of transiting to L_j after staying at L_i

$$p_{ij} = V_{ij} / V_i$$

  - V_{ij}: the number of transits from L_i to L_j
  - V_i: the number of transits leaving L_i

System Design : Mobility Modeling

- How to obtain $Q_{ij}(t)$?

$$
\begin{aligned}
Q_{ij}(t) &= P\left[\mathrm{X}_{n+1} = L_j, \mathrm{T}_{n+1} - T_n \le t \middle| \mathrm{X}_n = L_i\right] \\
&= P\left[\mathrm{X}_{n+1} = L_j \middle| \mathrm{X}_n = L_i\right] * P[\mathrm{T}_{n+1} - T_n \le t | \mathrm{X}_{n+1} = L_j, \mathrm{X}_n = L_i] \\
&= p_{ij} U_{ij}(t)
\end{aligned}
$$

- $U_{ij}(t)$: the probability that the sojourn time at L_i is no more than t on the condition that the node transits to L_j after staying at L_i

$$U_{ij}(t) = V_{ij}(t)/V_{ij}$$

  - $V_{ij}(t)$: the number of transits from L_i to L_j with the sojourn time at L_i less than t
  - V_{ij}: the number of transits from L_i to L_j

System Design : Mobility Modeling

- Usage of $Q_{ij}(t)$
  - Deduce $\Phi_{ij}(t)$: the probability of at status L_j after t time slots if the node is at status L_i at time 0.
  - Refer to the paper for the detail of getting $\Phi_{ij}(t)$

- Usage of $\Phi_{ij}(t)$
  - If a node is at L_i now, it has a probability of $\Phi_{ij}(t)$ to be at L_j after t time slots
  - Use it to determine what tasks can be assigned to the node

System Design : Sensing Task

- A sensing task is a tuple with four elements

$$\{DataType, Location, Date, TimeSlot\}$$

  - The $DataType$ must be supported by mobile devices
  - The $Location$ refers to landmarks
  - Time is slotted
  - A job that spanning a longer period of time is divided into consecutive sensing tasks

System Design : Task Assignment

- Mobility prediction based task assignment
  - Predict future mobility

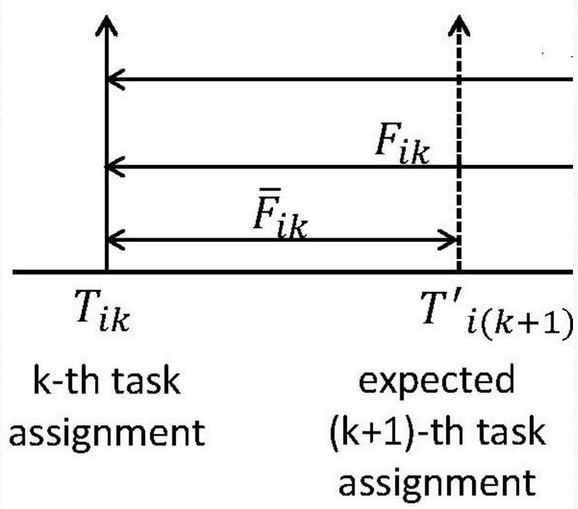
- How long we need to look into the future?
  - User mobility has uncertainty
  - The longer we look, the low prediction accuracy we have
  - The prediction for the next hour is more accurate that for 1 day later

System Design : Task Assignment

- How long we need to look into the future?
  - Exploit user's intermittent connection to the network (WiFi or LTE)
  - Conduct a task assignment at each connection
  - Only need to predict the mobility between this connection and the next connection
    - Between T_{ik} and $T_{i(k+1)}$, where T_{ik} denotes the k-th connection to the server
    - Can refine the accuracy of mobility prediction
    - Can reduce the overhead, as we only need to consider sensing tasks in this period of time

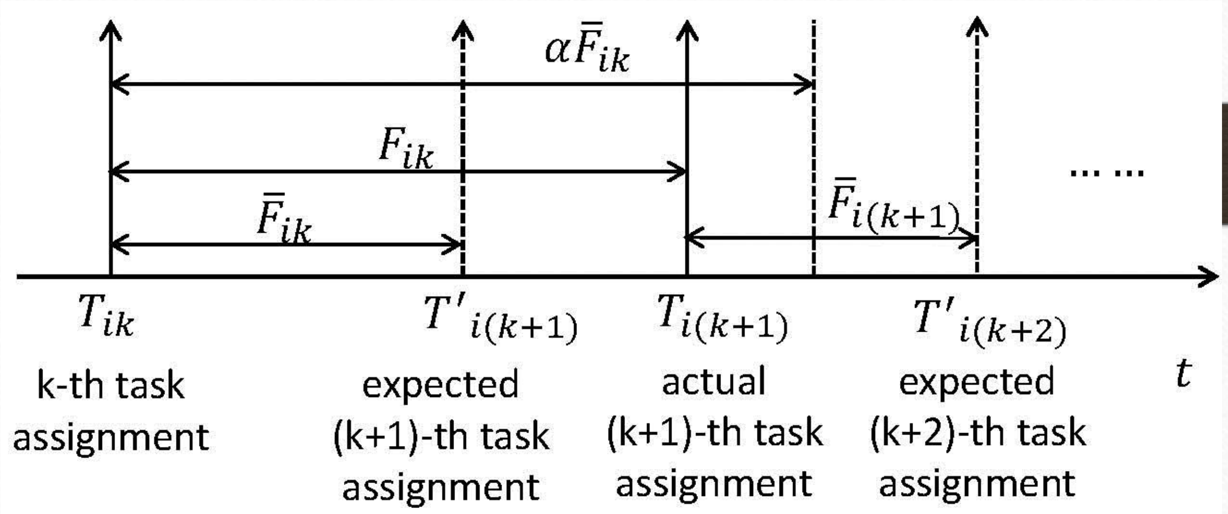
System Design : Task Assignment

- When is the next connection?
  - It is unknown as we do not require user participation
    - To reduce user interruption
  - Predict it with historical data
    - Using the average interval between two task assignments
    - $\bar{F}_{ik}$ in the figure



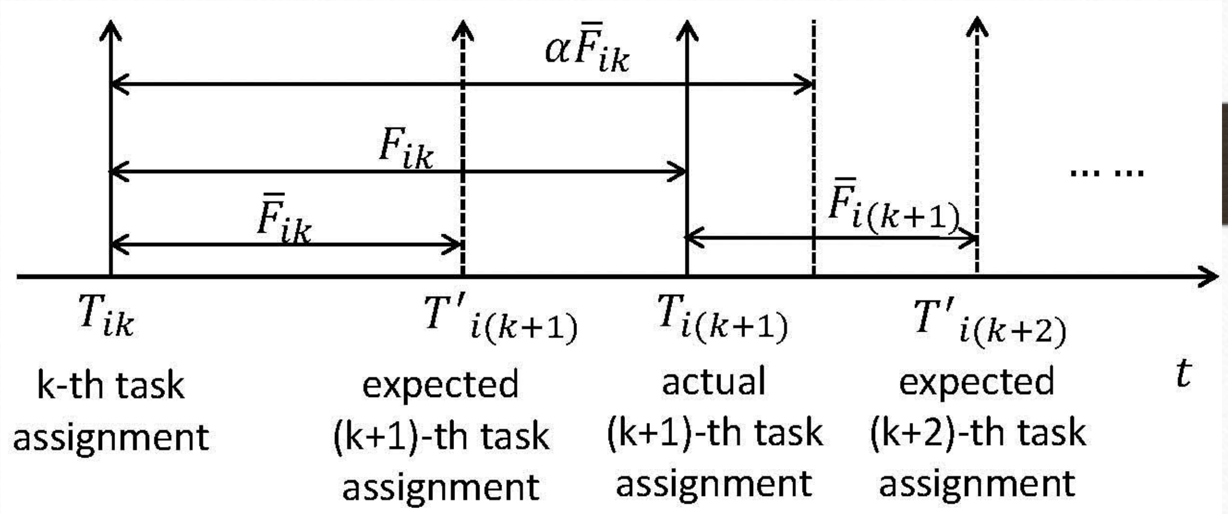
System Design : Task Assignment

- Incorrectly predicted next task assignment may miss tasks
  - When actual next task assignment happens after the predicted one, i.e., $T_{i(k+1)}$ is after $T'_{i(k+1)}$
  - As we only consider tasks between T_{ik} and $T'_{i(k+1)}$, tasks between $T'_{i(k+1)}$ and $T_{i(k+1)}$ will not be assigned to any node



System Design : Task Assignment

- Solve the problem with a redundancy factor α
  - Consider tasks in the period of $\alpha\bar{F}_{ik}$
  - Can effectively reducing the chance of missing tasks
  - Duplicate period of time is fine as it only indicates a little more overhead



System Design : Task Assignment

- Summary of task assignment
  - When a node connects to the server, determine the period of future time slots to consider, i.e., $\alpha\bar{F}_{ik}$
  - Calculate the node's probability of appearing at each landmark, i.e., $\Phi_{ij}(t)$ at time slots $1,2,3,\ldots,\alpha\bar{F}_{ik}$ for landmarks L_j, $\mathrm{j} = 1,2,3,\ldots,\mathrm{m}$,
  - Tasks corresponding to $\Phi_{ij}(t)$ that is larger than a threshold is assigned to the node

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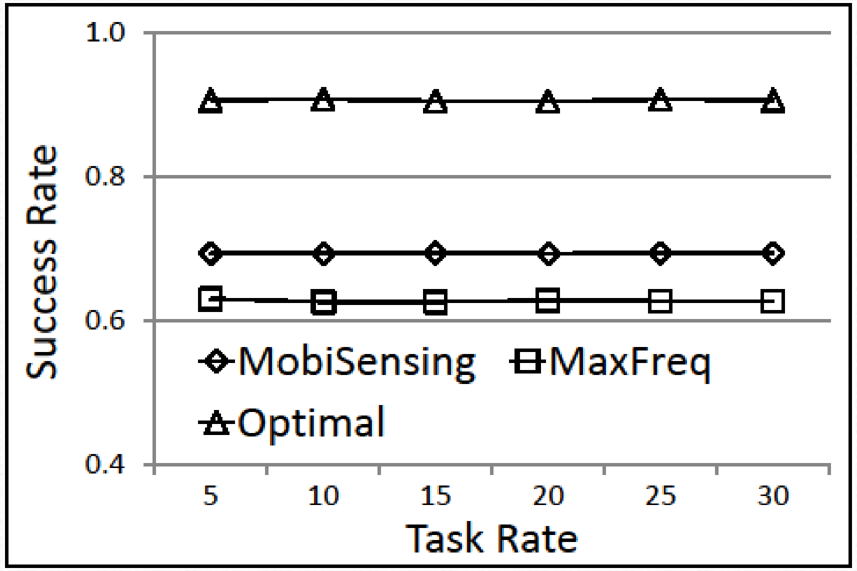
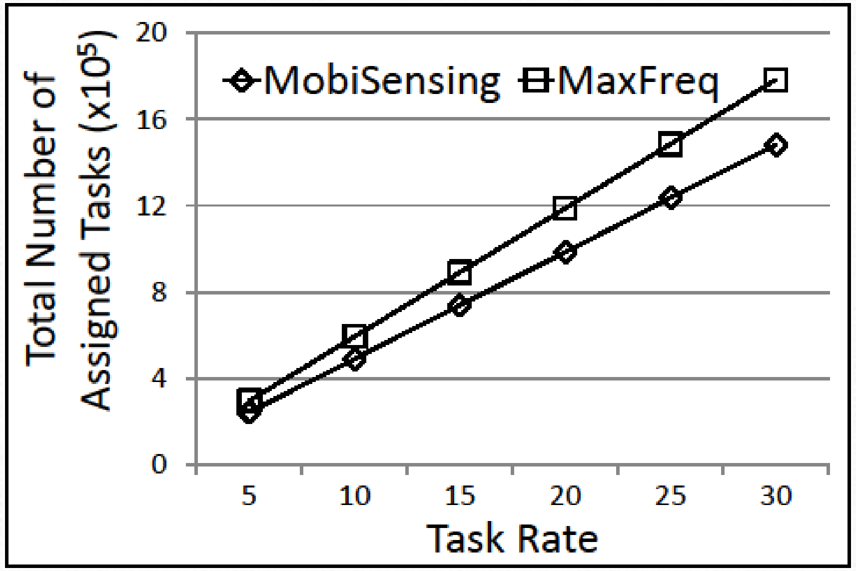
Evaluation

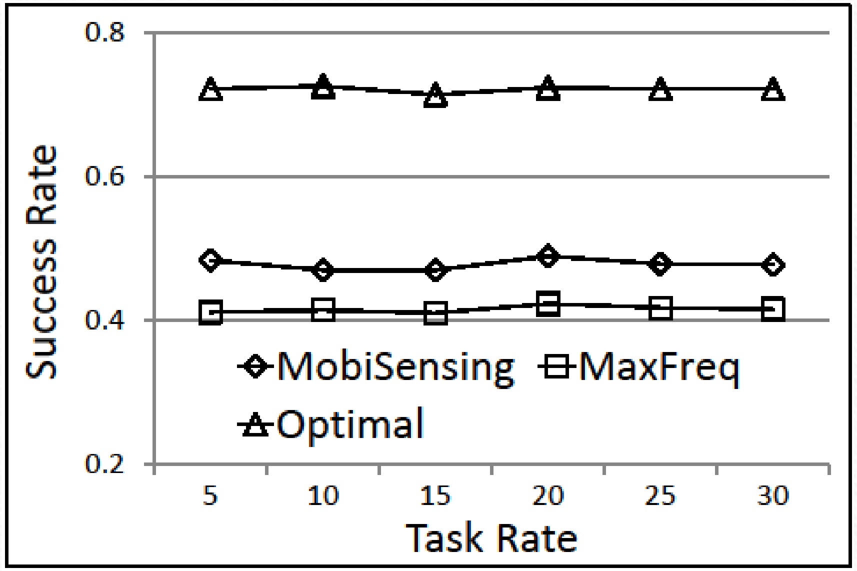
- Traces
  - MIT Reality: encountering of mobile devices on a campus
  - DieselNet: encountering of buses in a community
- Metrics
  - Success rate: percentage of successfully completed sensing tasks
  - Overhead: total # of assigned tasks
- Methods
  - Optimal: assign a copy of a task to every node
  - MaxFreq: assign a task to nodes most frequently visit the target landmark

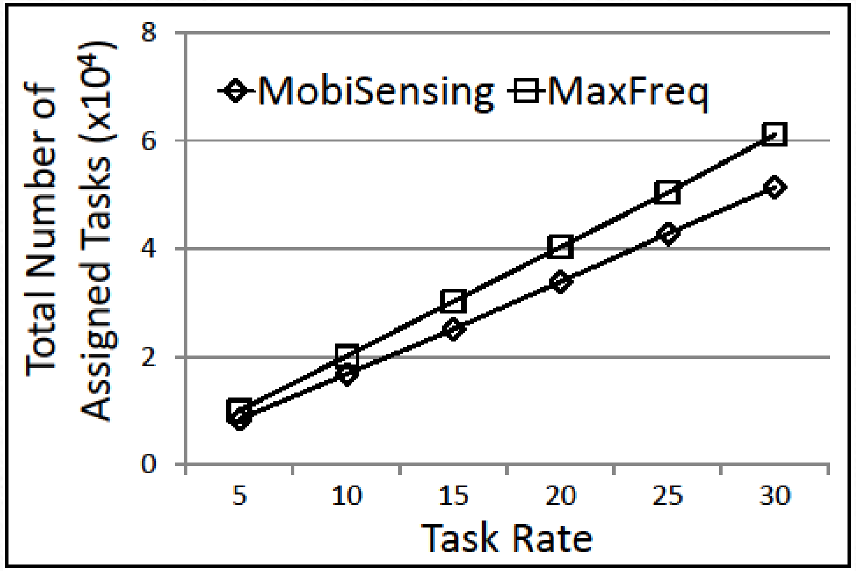
Evaluation : MIT Reality Trace





Evaluation : DieselNet





- MobiSensing leads to a high success rate and low overhead compared to MaxFreq

Conclusion

- The popularity of mobile devices leads to rich sensing capability
- Ideally to exploit such capability passively with a low interruption to users
- Solution:
  - Assign tasks to mobile devices during their intermittent connection to the network
  - Modeling user mobility with semi-markov process for efficient task assignment
- Future work:
  - Privacy protection: not all users are willing to share their locations
  - Social properties: mobility patterns reflected in social structures

Thank you!

Questions & Comments?