

Node Selection Methods for Probabilistic Coverage in People-Centric Sensing

Asaad Ahmed¹, Keiichi Yasumoto¹, Yukiko Yamauchi², and Minoru Ito¹


59th Mobile Computing and Ubiquitous communications Workshop (MBL-59)

¹ Nara Institute of Science and Technology (NAIST), Japan
² Kyushu University, Japan

Motivation Scenario

2

- ❑ **People Centric Sensing (PCS)**
 - ❑ People with mobile devices play a role of mobile sensors and sense data in urban district
- ❑ **Local torrential rain prediction**
 - ❑ Difficult to predict it from satellite photos (sudden, very small area)
 - ❑ WeatherNews company uses PCS to predict 1 hour before occurrence



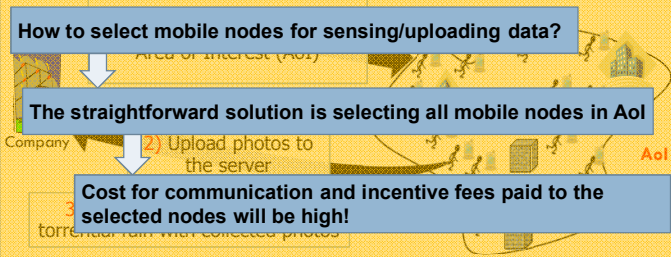
How to select mobile nodes for sensing/uploading data?

The straightforward solution is selecting all mobile nodes in AoI

1) Upload photos to the server

2) Upload photos to the server

3) Cost for communication and incentive fees paid to the selected nodes will be high!



Challenges for PCS

3

- ❑ **Coverage difficulties in PCS**
 - **Mobility** of people is **uncontrollable**
 - **Selecting all** mobile nodes in AoI **induces large costs** in network and server (when # nodes in AoI is large)
 - **Sensing** should be completed **by deadline** (e.g., 1 hour)
- ❑ **Challenges**
 - **Predict** mobile node's future locations
 - **Minimize** overall cost (network, server, incentive fees, etc) by selecting a **minimal set of mobile nodes** that meet the required coverage within specified time constraint

Outline

4

- ❑ **Motivation Scenario**
- ❑ **Related work**
- ❑ **(α, T)-Coverage Problem**
- ❑ **Proposed Algorithms**
- ❑ **Performance Evaluation**
- ❑ **Conclusion**

Related Work

5

- ❑ **SensorPlanet** (<http://www.sensorplanet.org/>)
 - Enables collection of sensor data in large/heterogeneous scale
 - Establishes central repository for sharing the collected data
- ❑ **CarTel** (B. Hull, et al.: CarTel: A Distributed Mobile Sensor Computing System, SenSys'06)
 - Provides urban sensing information such as traffic conditions
 - Based on car-mounted communication platform exploiting open WiFi access points
- ❑ **CitySense** (<http://www.citysense.net/>)
 - Provides a static sensor mesh for urban sensing data
- ❑ **Bubble-sensing** (H. Lu, et. al.: Bubble-Sensing: Binding Sensing Tasks to the Physical World, Journal of Pervasive and Mobile Computing, 2010)
 - Allows mobile users to affix bubble task at area of interest so that they receive sensed data in delay tolerant manner

Related Work (Cont.)

6

- ❑ **Main purpose of existing works**
 - Information collection
- ❑ **Unconsidered issues**
 - Probabilistic nature of coverage in PCS
 - Sensing coverage of a relatively wide area
 - On-demand query with a time deadline
 - Overall cost for network, server, incentive fees, etc

➤ **Our contribution is to provide solutions to the above issues**

Outline

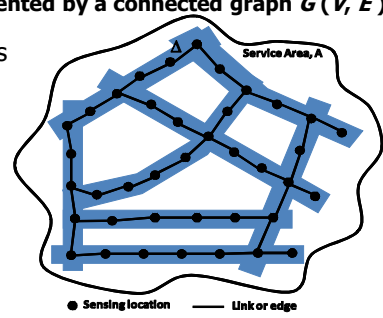
7

- ❑ **Motivation Scenario**
- ❑ **Related work**
- ❑ **(α, T)-Coverage Problem**
- ❑ **Proposed Algorithms**
- ❑ **Performance Evaluation**
- ❑ **Conclusion**

Assumptions – service area

8

- ❑ **A mobile user moves on a road network over service area A**
- ❑ **There are multiple sensing locations on each road with uniform spacing Δ**
- ❑ **Road network is represented by a connected graph $G(V, E)$**
 - V : the set of vertices
 - E : the set of edges



Assumptions – network & node mobility

9

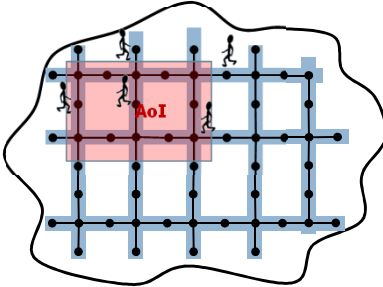
- ❑ There is a server/cloud in the Internet that executes node selection algorithm
- ❑ Each node can communicate with server from any location of service area A via 3G network
- ❑ All nodes move on G according to the same probabilistic model, where moving probability at each sensing location of A is given by matrix P
- ❑ Time progresses discretely and nodes move from one vertex to one of its neighbors in unit of time

(α, T) -coverage definition

10

- ❑ AoI is (α, T) -covered by the set of nodes U

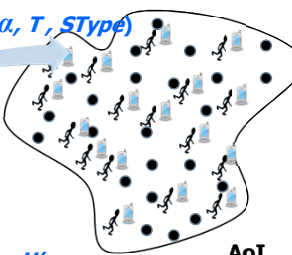
⇔ probability that every sensing location in AoI is visited by some nodes of U in time interval T is equal to/larger than α



Problem Formulation

11

- ❑ **Given**
 - AoI as a set of sensing locations $q(\alpha, T, Stype)$
 - A set of mobile nodes U in AoI
 - A query with
 - A required coverage ratio α
 - A specified interval T
 - Sensing type $Stype$
- ❑ **Objective**
 - Finding a minimal set of mobile nodes U'
- ❑ **Subject to**
 - AoI is (α, T) -covered



Outline

12

- ❑ Motivation Scenario
- ❑ Related work
- ❑ (α, T) -Coverage Problem
- ❑ **Proposed Algorithms**
 - Basic Idea
 - Inter-location based algorithm (ILB) Presented in MBL-55
 - Inter-meeting-time based algorithm (IMTB)
 - Extended algorithm New proposed algorithms
 - Updating mechanism
- ❑ Performance Evaluation
- ❑ Conclusion

Basic Idea

13

❑ **Problem:** How to select a minimal set of mobile nodes to meet the required coverage α within a time interval T

- Compute probability** that each mobile node visits each sensing location in AoI from its initial location
- Select nodes** one by one until sum of probabilities that the selected nodes visit each location is equal to/larger than α

Sum of prob.: 0.375
 u1 visits within $T=2$ at prob. $0.5 \times 0.25 = 0.125$
 u2 visits within $T=2$ at prob. of 0.25

Probability Calculation

14

❑ Probability that a node u visits location x at time t

- Obtained by multiplying probability matrix t times

$$\text{Prob}(u, t, x_0^u, x) = [\text{vector}(x_0^u) \times \mathbf{P}^t]_x$$

Initial location of u N-item vector (0...1...0) N×N matrix representing moving probability between two locs
 N: # locs in A

reducible to the area within distance $T/2$ from AoI

❑ Probability that the set of nodes U visit location x in T

- 1 minus the probability that any nodes **do not** visit x during $1 \leq t \leq T$

$$\text{SetProb}(x, U, T) = 1 - \prod_{u \in U} \prod_{1 \leq t \leq T} (1 - \text{Prob}(u, t, x_0^u, x))$$

Selection Strategy

15

❑ We want to select the minimal set U' satisfying:

- For every location x in AoI, $\text{SetProb}(x, U', T) \geq \alpha$
- Deriving the optimal solution \rightarrow NP-hard

❑ **Heuristic in selecting nodes**

- Random greedy selection: many redundant nodes can be selected
- Better selecting nodes that **are not likely to visit** the same locations

❑ **Proposed selection strategies:**

- Select nodes whose initial mutual distance is **large**
- Select nodes whose first expected meeting time is **late**

Inter-Location Based algorithm (ILB)

16

❑ ILB selects nodes one by one until AoI is (α, T) -covered

- So that the distance between any pair of nodes $\geq d_{th}$ (threshold)

$$d_{th} = \min\left(\frac{T}{\alpha \times d_{max}}, d_{max}\right),$$

$$d_{max} = \max_{u, u' \in U} \{d_{u, u'}\}$$

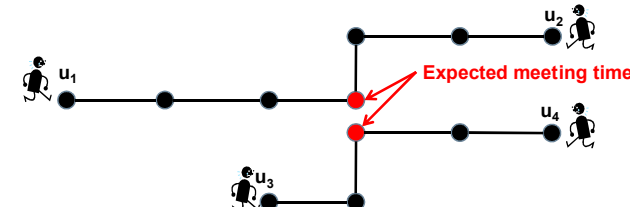
❑ **How to decide d_{th} value**

- Depends on T and α
- Intuitively, it should be larger as T increases and/or α decreases

Inter-Meeting Time Based algorithm (IMTB)

17

- ❑ IMTB selects nodes one by one until AoI is (α, T) -covered
 - So that **expected meeting time** between any pair of nodes $\geq mt_{th}$ (threshold)



$$mt_{th} = \min\left(\frac{T}{\alpha \times mt_{max}}, mt_{max}\right),$$

$$mt_{max} = \max_{u, u' \in U} \{mt_{u, u'} : mt_{u, u'} \neq \infty\}$$

- ❑ **How to decide mt_{th} value**
 - Depends on T and α
 - Intuitively, it should be larger as T increases and/or α decreases

Extended algorithm without Thresholds (EWOT)

18

- ❑ ILB and IMTB consider only nodes inside AoI
- ❑ **To cope with the case that there is insufficient number of nodes inside AoI**
 - We propose extended algorithm called EWOT
 - Take into accounts nodes inside and outside AoI
 - No thresholds are used
 - Selection is based on contribution of a node
- ❑ **Node's contribution**
 - Contribution of a node located outside AoI depends on its shortest distance from its initial location to the AoI
 - The shortest distance must be less than or equal to T
- ❑ **Avoiding the # added node to be very large**
 - We add only nodes if the shortest distance to the AoI is $\leq T/2$

Update Mechanism: ILB-up & IMTB-up

19

- ❑ ILB, IMTB, and EWOT are based on initial locations of nodes and did not consider the latest/current location of nodes during the time period T
- ❑ **To improve the accuracy of the proposed algorithms**
 - We propose an update mechanism for ILB and IMTB algorithms
 - By tracking the location of nodes during time period T
 - Removing useless nodes and adds extra nodes that contribute more coverage
 - Is executed periodically within an *specified updating interval UI*
- ❑ **Value of updating interval, UI**
 - Determined internally
 - Depends on α and T

$$UI = \begin{cases} d_{th} & \text{for ILB} \\ mt_{th} & \text{for IMTB} \end{cases}$$

Outline

20

- ❑ **Motivation Scenario**
- ❑ **Related work**
- ❑ **(α, T) -Coverage Problem**
- ❑ **Proposed Algorithms**
- ❑ **Performance Evaluation**
- ❑ **Conclusion**

Simulation Setting

21

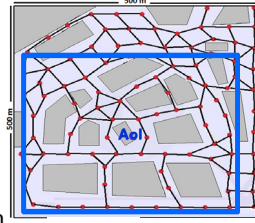
- ❑ **Filed Size:** 500 x 500 m²
- ❑ **# of nodes:** 25-200
- ❑ **Node speed:** 1 meter/second
- ❑ **Area of Interest**
 - **AoI-Size:** 0.01, 0.25, 0.45, 0.5, 0.65, 0.85 of the whole field
- ❑ **Query Deadline T** = 2, 4, 6, ..., 20 [units of time], 1 unit = 50 sec
- ❑ **Required Coverage α** : 0.5

Each experiment was evaluated 5 times and averaged

Evaluation Scenarios

22

- ❑ **Equal Moving Probabilities Scenario**
 - Grid-based map with equal moving probability (i.e., 0.25 for up, down, left, right direction)
- ❑ **Unequal Moving Probabilities Scenario**
 - Grid-based map with unequal moving probability
- ❑ **Realistic Scenario**
 - For city map near Osaka station, Japan, generated a realistic mobility trace with MobiREAL from actually observed pedestrians density on roads
 - Determined probability matrix **P** based on the map and the generated trace

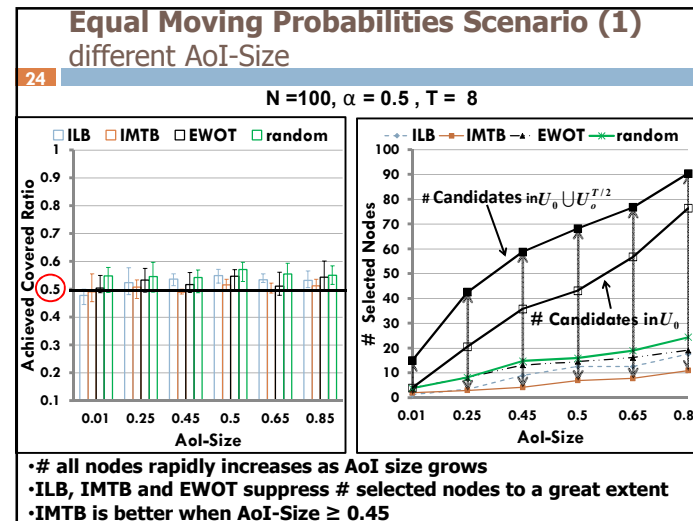


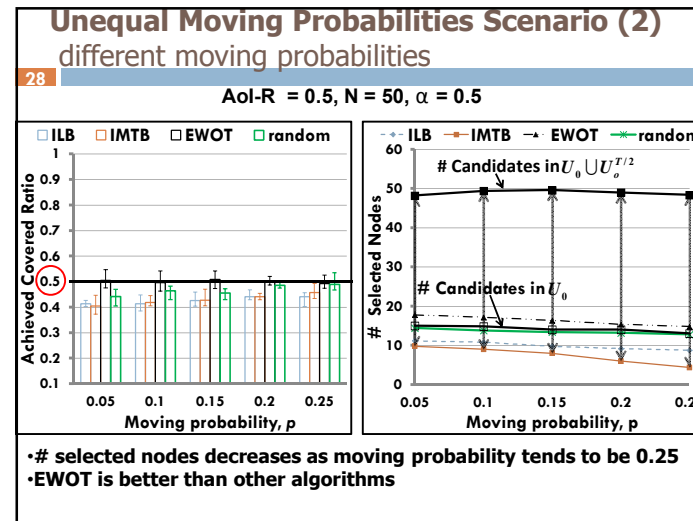
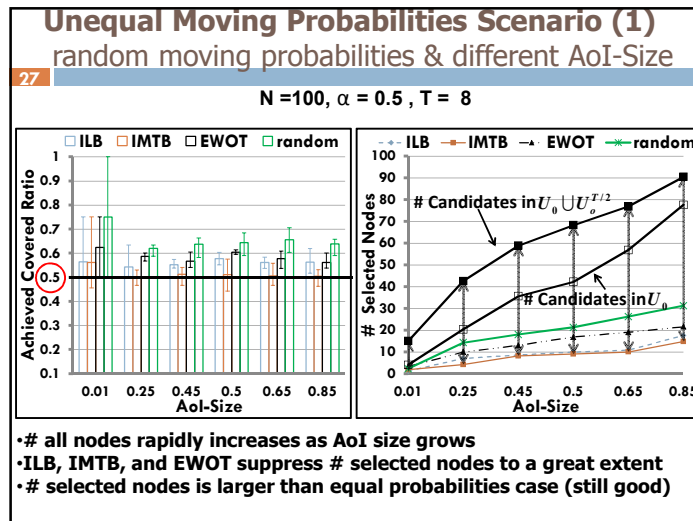
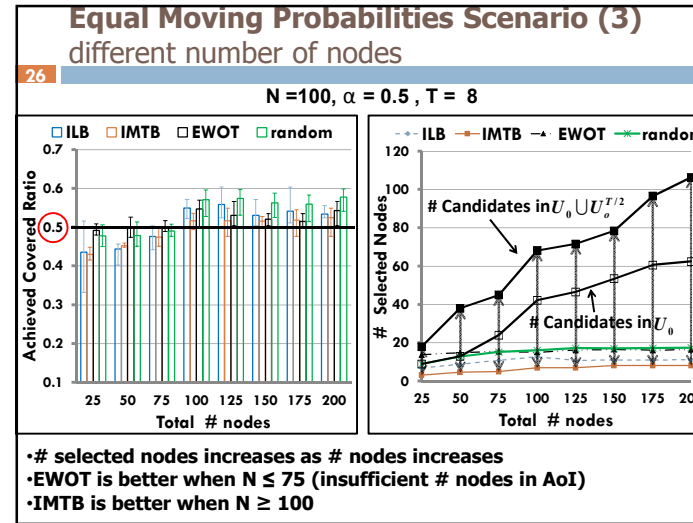
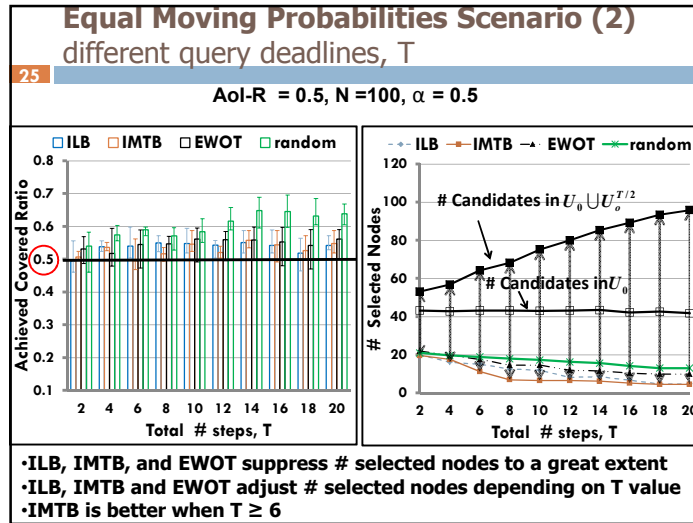
A specific city map near Osaka station in Japan

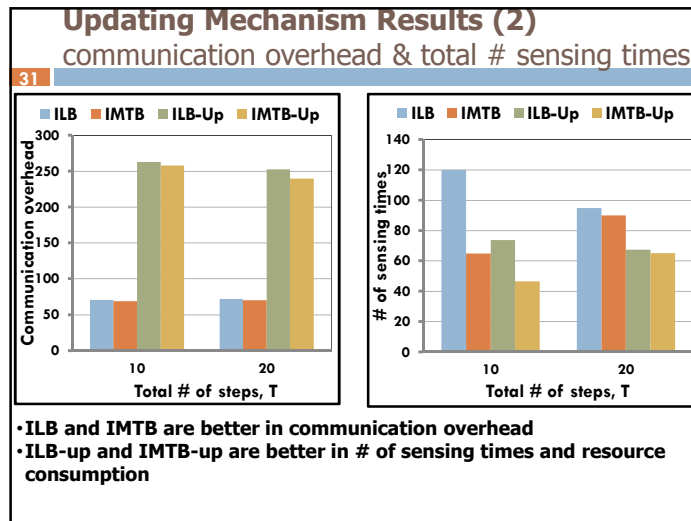
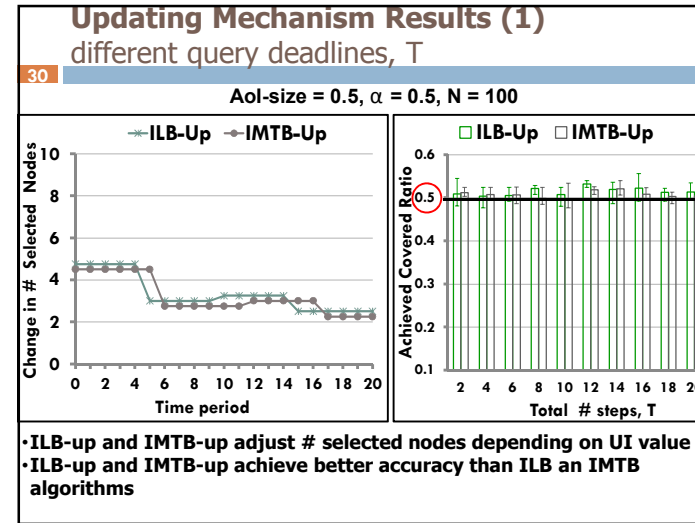
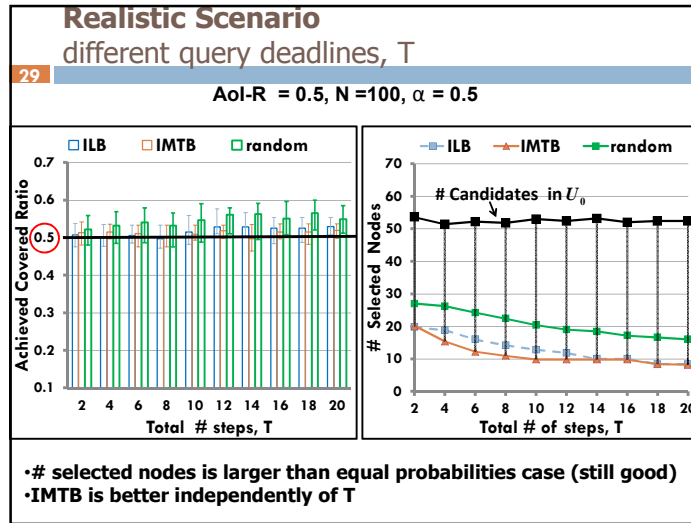
Performance Metrics

23

- ❑ **# selected nodes**
- ❑ **Achieved coverage**
 - The ratio of the number of sensing locations visited by at least one node to the total number of sensing locations in AoI
$$\text{Achieved coverage} = \frac{\text{\# of covered locations}}{\text{Total \# of locations}}$$
- ❑ **Communication overhead**
 - The total # candidate nodes for all updating times during the time period, T
$$\text{ComOverhead} = \sum_{t \in UT} \text{candidates}(t)$$
 - **candidates(t):** # candidates nodes at time t
 - **UT:** the set of updating times
- ❑ **Total # sensing times**
 - The total number of times at which the selected nodes perform a sensing action







- ### Conclusion
- 32
- We formulated (α, T) -coverage problem in PCS
 - We proposed three heuristic algorithms: ILB, IMTB, and EWOT
 - Proposed algorithms achieved (α, T) -coverage with good accuracy for variety of values of α , T , # nodes, Aol size
 - IMTB selects a smaller number of nodes without deteriorating coverage accuracy
 - EWOT achieved (α, T) -coverage with good accuracy when an insufficient number of nodes exists inside Aol
 - We proposed update mechanism to improve the accuracy of the proposed algorithms