Vol.2011-MBL-59 No.13
Vol.2011-CDS-2 No.13
2011/9/5

Node Selection Methods for Probabilistic Coverage in People-Centric Sensing

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

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Motivation Scenario

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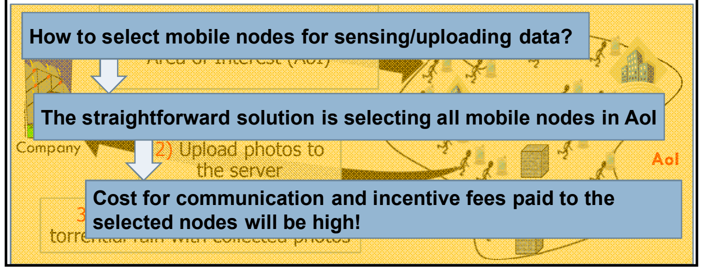
- **People Centric Sensing (PCS)**
  - People with mobile devices play a role of mobile sensors and sense data in urban district

- **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



Challenges for PCS

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- **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

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

Related Work

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- **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.)

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- **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**

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Assumptions – service area

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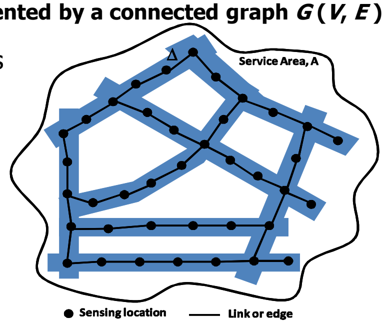
- **A mobile user moves on a road network over service area *A***
- **There are multiple sensing locations on each road with uniform spacing Δ**
- **Road network is represented by a connected graph *G* (*V*, *E*)**

V : the set of vertices

E : the set of edges



Assumptions – network & node mobility

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- ❑ 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

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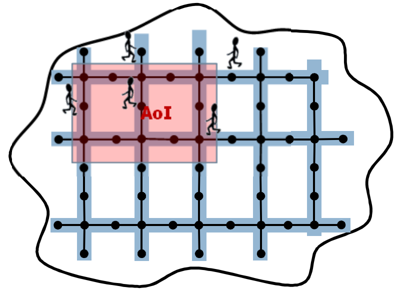
❑ **AoI is (α, T)-covered by the set of nodes U**

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



Problem Formulation

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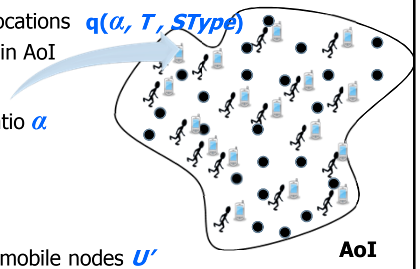
❑**Given**

- AoI as a set of sensing locations q(α, 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

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- ❑ **Motivation Scenario**
- ❑ **Related work**
- ❑ **(α , T)-Coverage Problem**
- ❑ **Proposed Algorithms**
  - ➢Basic Idea
  - ➢Inter-location based algorithm (ILB)
  - ➢Inter-meeting-time based algorithm (IMTB)

    Presented in MBL-55
  - ➢Extended algorithm
  - ➢Updating mechanism

    New proposed algorithms
- ❑ **Performance Evaluation**
- ❑ **Conclusion**

Basic Idea

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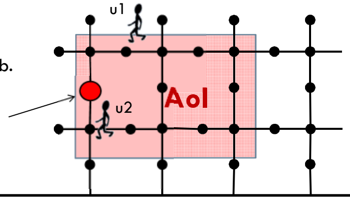
- **Problem: How to select a minimal set of mobile nodes to meet the required coverage α within a time interval T**

(1) **Compute probability** that each mobile node visits each sensing location in AoI from its initial location

(2) **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. 0.5×0.25=0.125
u2 visits within T=2 at prob. of 0.25



Probability Calculation

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- Probability that a node **u** visits location **x** at time **t**
  - Obtained by multiplying probability matrix **t** times

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

reducible to the area within distance T/2 from AoI

Initial location of u

N-item vector (0…1…0) N: # locs in A

N×N matrix representing moving probability between two locs

- 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≤t≤ T**

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

Selection Strategy

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- We want to select the minimal set **U'** satisfying:
  - For every location **x** in AoI, **SetProb(x, U', T) ≥ α**
  - Deriving the optimal solution → 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 fist expected meeting time is **late**

Inter-Location Based algorithm (ILB)

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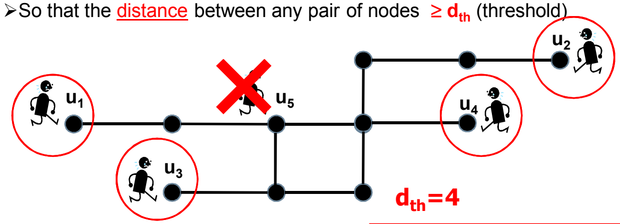
- ILB selects nodes one by one until AoI is (α, T)-covered
  - So that the distance between any pair of nodes ≥ d_{th} (threshold)



$$d_{th} = \min\left(\frac{T}{\alpha \times d_{\max}}, d_{\max}\right),$$
$$d_{\max} = \max_{u,u' \in U}\{d_{u,u'}\}$$

- **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)

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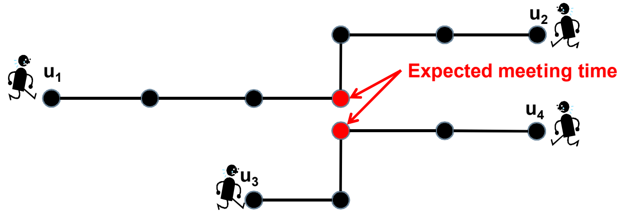
- ❑ IMTB selects nodes one by one until AoI is (α, T)-covered
  - ➢ So that expected meeting time between any pair of nodes $\geq mt_{th}$ (threshold)



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

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

- ❑ **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)

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- ❑ 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

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- ❑ 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

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

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Simulation Setting

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- ❑**Filed Size:** 500 x 500 m^2
- ❑**# 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

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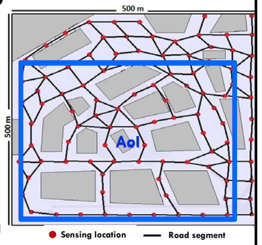
- ❑ **Equal Moving Probabilities Scenario**
  - Grid-based map with equal moving probability (i.e., 0.25 for up, down, left, right direction)
- ❑ **Unequal Moving Probabilities Scenario**
  - Grid-based map with unequal moving probability
- ❑ **Realistic Scenario**
  - For city map near Osaka station, 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

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- ❑ **# 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

$$\text{Achieved coverage} = \frac{\#\,\text{of covered locations}}{\text{Total}\,\#\,\text{of locations}}$$

- ❑ **Communication overhead**
  - The total # candidate nodes for all updating times during the time period, T

$$ComOverhead = \sum_{t \in UT} candidates(t)$$

  - ***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

Equal Moving Probabilities Scenario (1)

different AoI-Size

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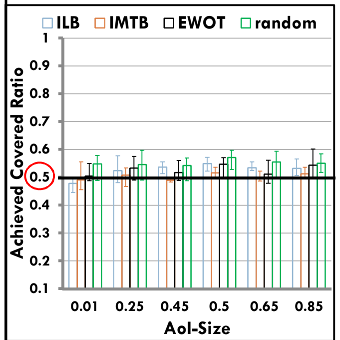
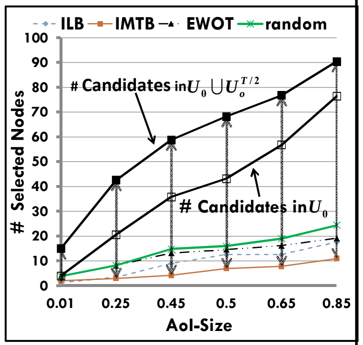
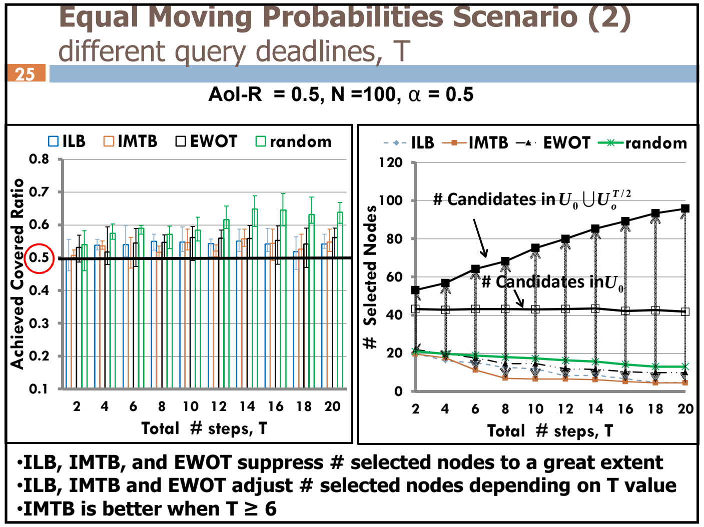
N =100, α = 0.5 , T = 8





- **# all nodes rapidly increases as AoI size grows**
- **ILB, IMTB and EWOT suppress # selected nodes to a great extent**
- **IMTB is better when AoI-Size ≥ 0.45**


Equal Moving Probabilities Scenario (2)
different query deadlines, T
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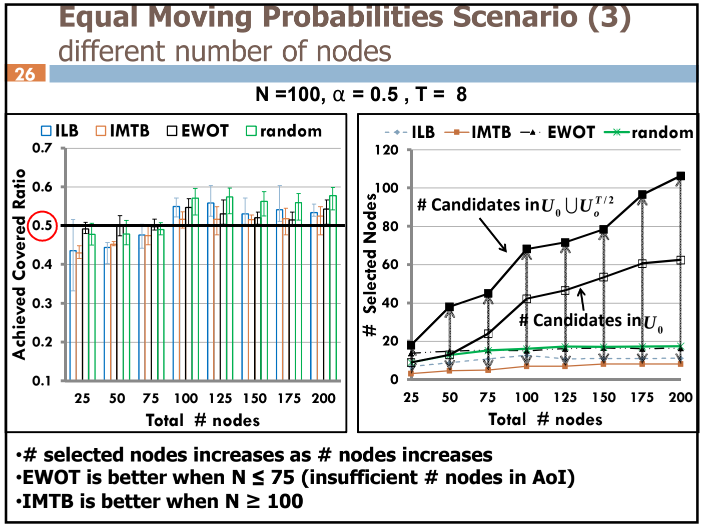
AoI-R = 0.5, N =100, α = 0.5
ILB IMTB EWOT random
Achieved Covered Ratio
Total # steps, T
Selected Nodes
Candidates in $U_0 \cup U_o^{T/2}$
Candidates in U_0
•ILB, IMTB, and EWOT suppress # selected nodes to a great extent
•ILB, IMTB and EWOT adjust # selected nodes depending on T value
•IMTB is better when T ≥ 6


Equal Moving Probabilities Scenario (3)
different number of nodes
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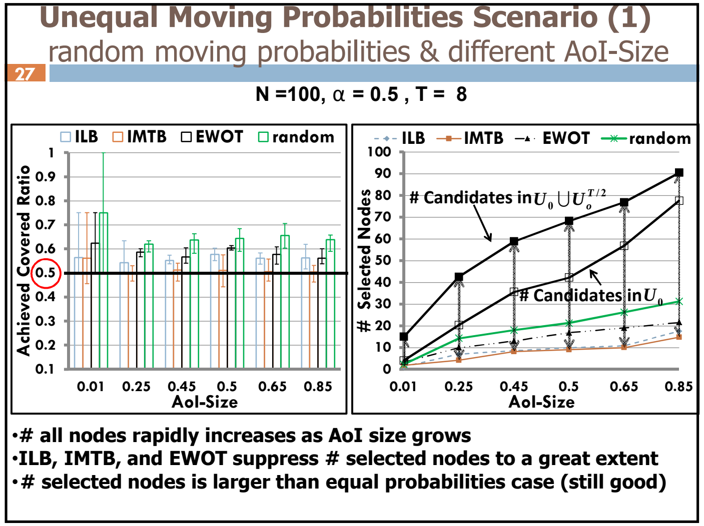
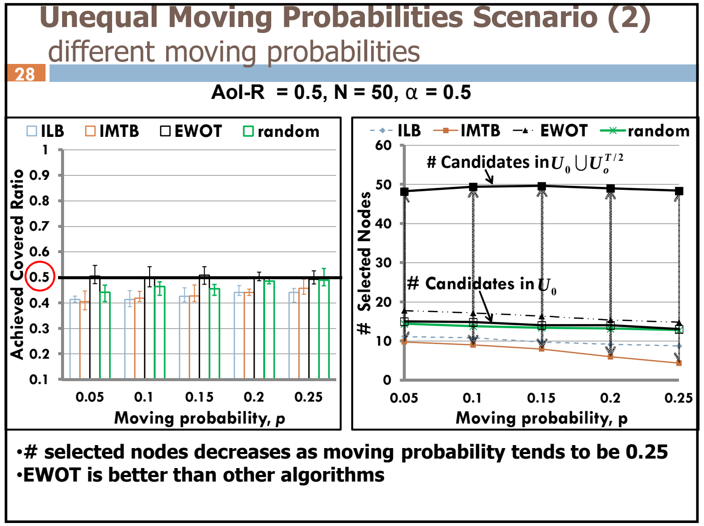
N =100, α = 0.5 , T = 8
ILB IMTB EWOT random
Achieved Covered Ratio
Total # nodes
Selected Nodes
Candidates in $U_0 \cup U_o^{T/2}$
Candidates in U_0
•# selected nodes increases as # nodes increases
•EWOT is better when N ≤ 75 (insufficient # nodes in AoI)
•IMTB is better when N ≥ 100


Unequal Moving Probabilities Scenario (1)
random moving probabilities & different AoI-Size
27
N =100, α = 0.5 , T = 8
ILB IMTB EWOT random
Achieved Covered Ratio
AoI-Size
Selected Nodes
Candidates in $U_0 \cup U_o^{T/2}$
Candidates in U_0
•# all nodes rapidly increases as AoI size grows
•ILB, IMTB, and EWOT suppress # selected nodes to a great extent
•# selected nodes is larger than equal probabilities case (still good)


Unequal Moving Probabilities Scenario (2)
different moving probabilities
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AoI-R = 0.5, N = 50, α = 0.5
ILB IMTB EWOT random
Achieved Covered Ratio
Moving probability, p
Selected Nodes
Candidates in $U_0 \cup U_o^{T/2}$
Candidates in U_0
•# selected nodes decreases as moving probability tends to be 0.25
•EWOT is better than other algorithms

Realistic Scenario
different query deadlines, T

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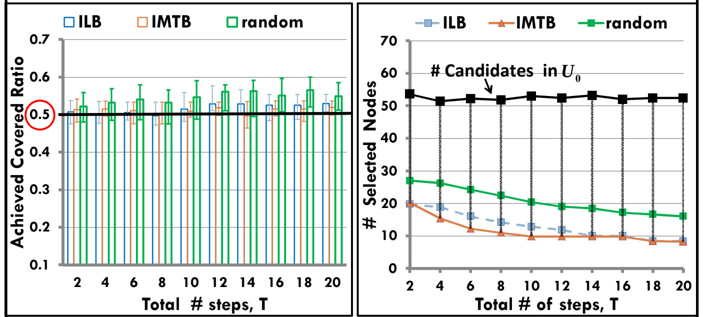
AoI-R = 0.5, N =100, α = 0.5



- # selected nodes is larger than equal probabilities case (still good)
- IMTB is better independently of T

Updating Mechanism Results (1)
different query deadlines, T

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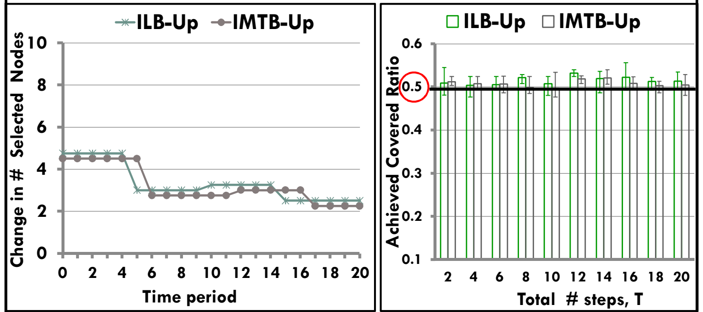
AoI-size = 0.5, α = 0.5, N = 100



- ILB-up and IMTB-up adjust # selected nodes depending on UI value
- ILB-up and IMTB-up achieve better accuracy than ILB an IMTB algorithms

Updating Mechanism Results (2)
communication overhead & total # sensing times

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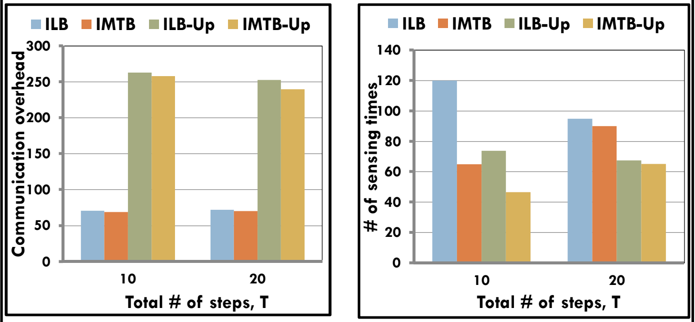

- ILB and IMTB are better in communication overhead
- ILB-up and IMTB-up are better in # of sensing times and resource consumption

Conclusion

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- 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, AoI 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 AoI
- We proposed update mechanism to improve the accuracy of the proposed algorithms