Mobile Charger Coverage Problem for Specific Heterogeneous Wireless Sensor Networks

Abdalaziz Sawwan (Presenter) and Jie Wu.

Department of Computer and Information Sciences,

Temple University.

Outline

- Introduction
- Previous Work
- The Optimal Solution of the Problem
- Approximation Solutions of the Problem
- Simulation
- Future Work

Outline

- Introduction
- Previous Work
- The Optimal Solution of the Problem
- Approximation Solutions of the Problem
- Simulation
- Future Work

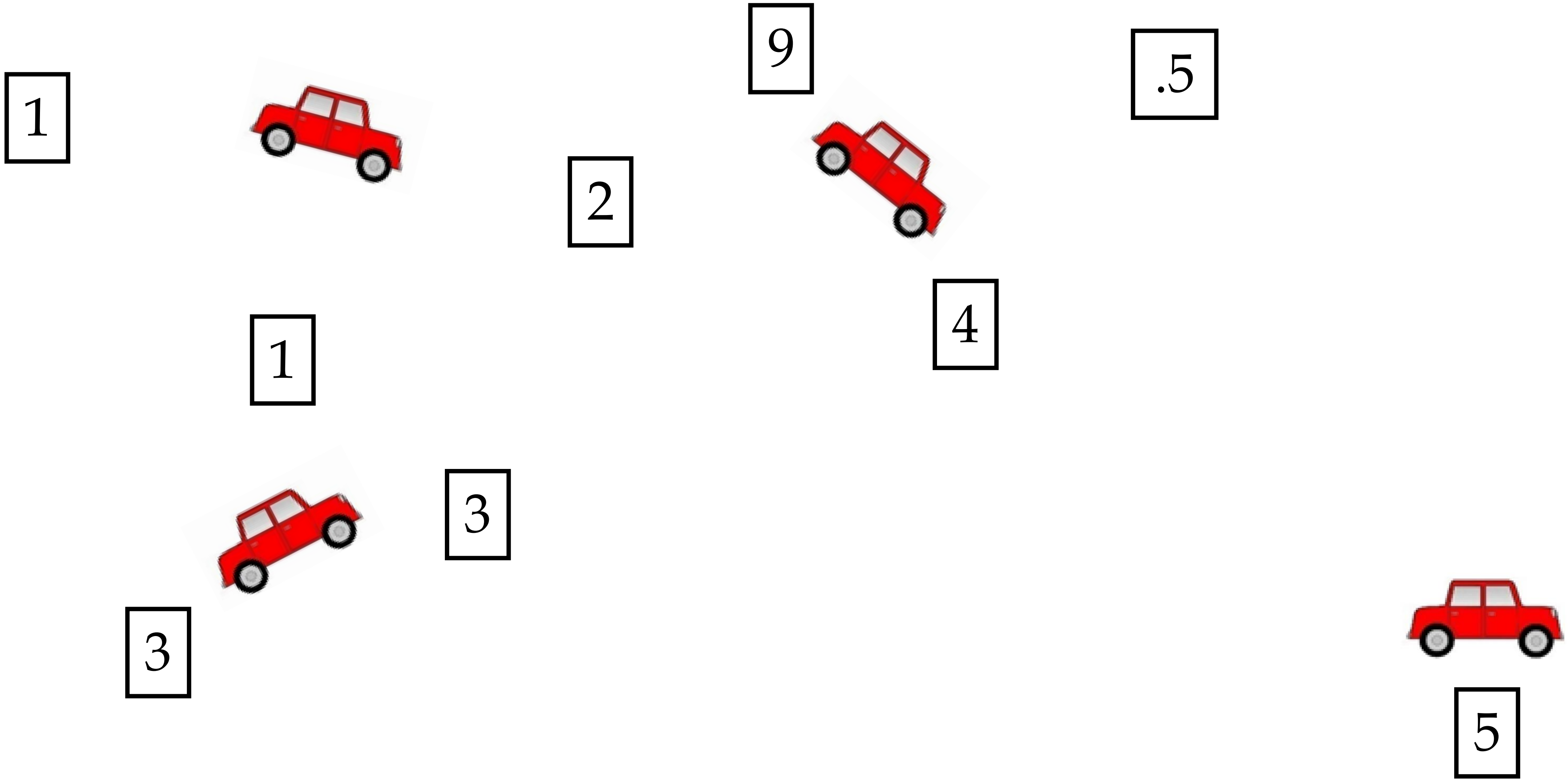
Introduction

- We consider a simple Wireless Sensor network (WSN), which is a space that has sensors distributed on it, each sensor has to be visited by a Mobile Charger (MC) to recharge its battery.
- The battery capacities of the sensors are different.
- Recent breakthroughs in rechargeable batteries, provide several applications of mobile vehicles in the field of wireless networks.

Introduction

- We assume the MCs have a maximum certain speed, with infinite power.
- We consider instantaneous charging once the sensor is visited by the MC.
- The problem of minimizing the number of those MCs in Wireless Sensor Networks (WSNs) is the **Mobile Charger Coverage Problem**

Introduction



Outline

- Introduction
- Previous Work
- The Optimal Solution of the Problem
- Approximation Solutions of the Problem
- Simulation
- Future Work

Previous Work

- Wu et al. have come up with an optimal solution for the homogeneous mobile charger coverage problem for both the 1-D ring and 1-D line distributions of sensors.

- They showed that the solution for a line distribution has at most one MC more than the number of MCs in the solution of the same distribution on a ring.

R. Beigel, J.Wu, and H. Zheng. "On optimal scheduling of multiple mobile chargers in wireless sensor networks." In Proceedings of the first international workshop on mobile sensing, computing and communication (MSCC '14), 1–6, 2014.

Previous Work

- Their optimal solution to solve the homogeneous line problem is done by simply scheduling k MCs to cover non-overlapping fixed intervals of length 0.5 so that all of the sensors are covered.

- Assuming that the maximum speed of the MCs to be one unit distance per unit, and the frequencies of the sensors to be 1.

R. Beigel, J.Wu, and H. Zheng. "On optimal scheduling of multiple mobile chargers in wireless sensor networks." In Proceedings of the first international workshop on mobile sensing, computing and communication (MSCC '14), 1–6, 2014.

Previous Work

- On the top of that, they started the investigation of the heterogeneous problem by proposing an approximation algorithm with a factor of 2 that solves the problem for a line distribution of sensors with any frequencies.

Algorithm 2 Greedy Algorithm for the Heterogeneous WSNs

Input: Locations $\{x_1, ..., x_n\}$ and frequencies $\{f_1, ..., f_n\}$ of uncovered sensors $\{s_1, ..., s_n\}$;

1: **if** $n = 0$ **then return**;

2: Generate a car that goes back and forth as far as possible at a full speed to cover sensors at $\{x_1, ..., x_{i-1}\}$;

3: Recursively call Algorithm 2 for $\{s_i, ..., s_n\}$;

R. Beigel, J.Wu, and H. Zheng. "On optimal scheduling of multiple mobile chargers in wireless sensor networks." In Proceedings of the first international workshop on mobile sensing, computing and communication (MSCC '14), 1–6, 2014.

Previous Work

- From there, we tackle the problem of the heterogeneous case with sensors of frequencies of 1’s and 2’s to investigate the boundaries between the tractable and intractable variation of the problem.

Outline

- Introduction
- Previous Work
- The Optimal Solution of the Problem
- Approximation Solutions of the Problem
- Simulation
- Future Work

The Optimal Solution of the Problem

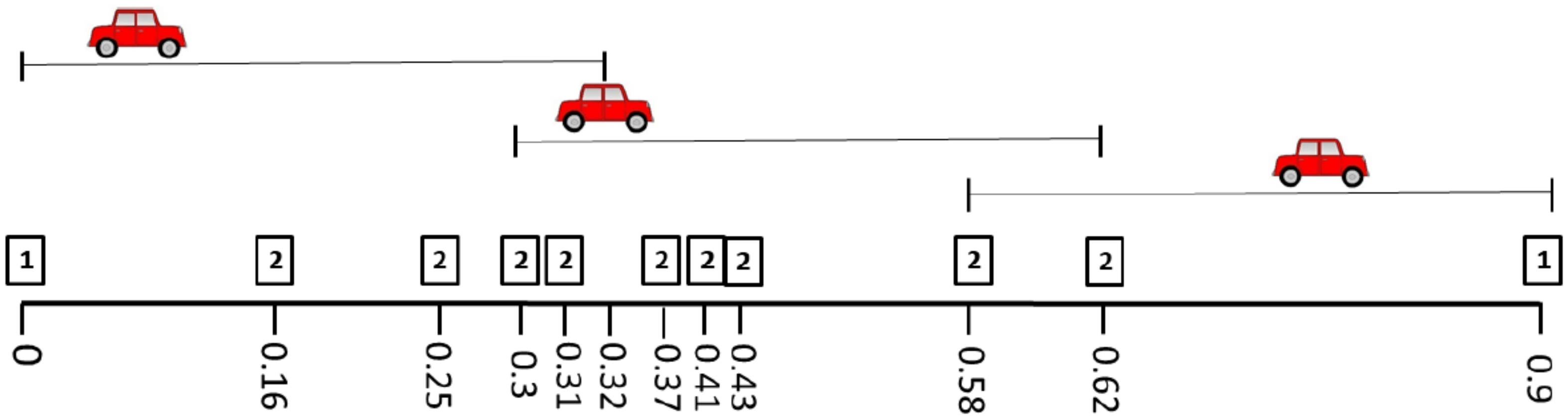


Fig. 1: Toy example for the problem showing an optimal MC-solution.

The Optimal Solution of the Problem

- We reduce the search space for the MC solution into one that has at least one optimal solution by imposing some restrictions for the possible solution. We will call our target optimal solution $\mathcal{O}$.

Property 1: The optimal solution $\mathcal{O}$ has the leftmost uncovered sensor completely supplied by exactly one MC.

Property 2: No sensor is supplied by more than two MCs in the optimal solution $\mathcal{O}$.

Property 3: An MC's starting point is always more than 0.25 away from the starting point of the previous MC in $\mathcal{O}$.

The Optimal Solution of the Problem

- We generate the MCs one by one determining the start point of the currently-generated MC and the end point of it.
- Determining the start point is straightforward: Start from the leftmost sensor that has not been covered so far.
- Determining the end points is the hard part.

The Optimal Solution of the Problem

Algorithm 1 Endpoint selection for MC

Input: Sensor locations $\{x_1, x_2, \ldots, x_n\}$ and frequencies $\{f_1, f_2, \ldots, f_n\}$, $f_k \in \{1, 2\}$.
The length l of the previous MC's coverage area // $l = 0$ if there is none.

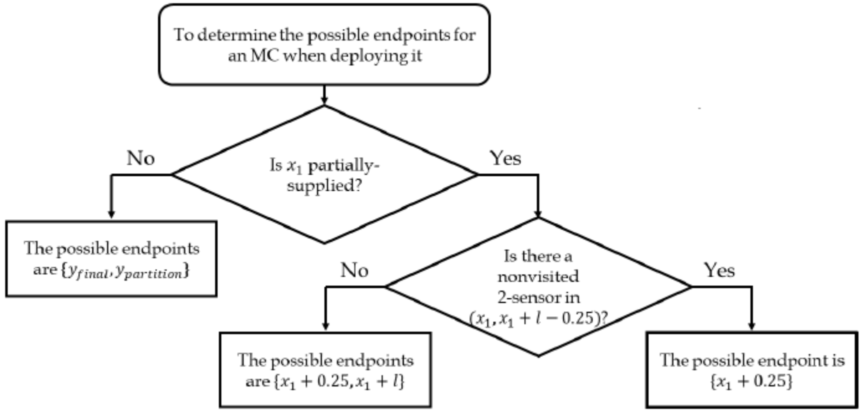
Output: The set of possible endpoints for the MC.

Depending on criterion $\mathcal{C}$, Assign $Possible\_Endpoints$ to be:

Case 1: $\{y_{\text{final}}, y_{\text{partition}}\}$.

Case 2: $\{x_1 + 0.25\}$.

Case 3: $\{x_1 + 0.25, x_1 + l\}$.



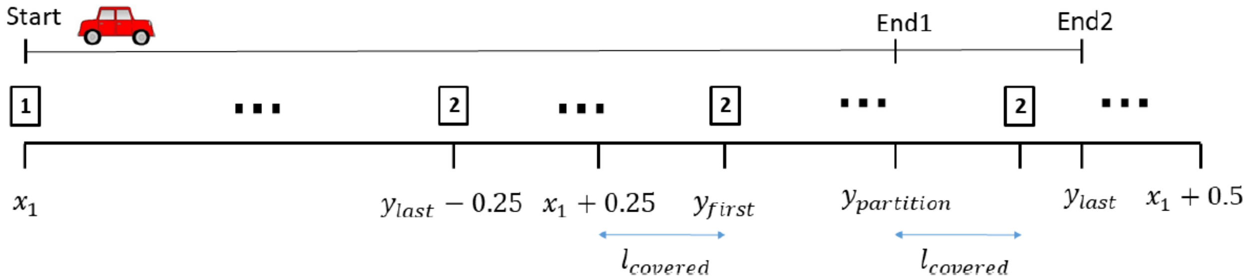


Fig. 2: Deploying an MC with no previously 'visited' sensors.

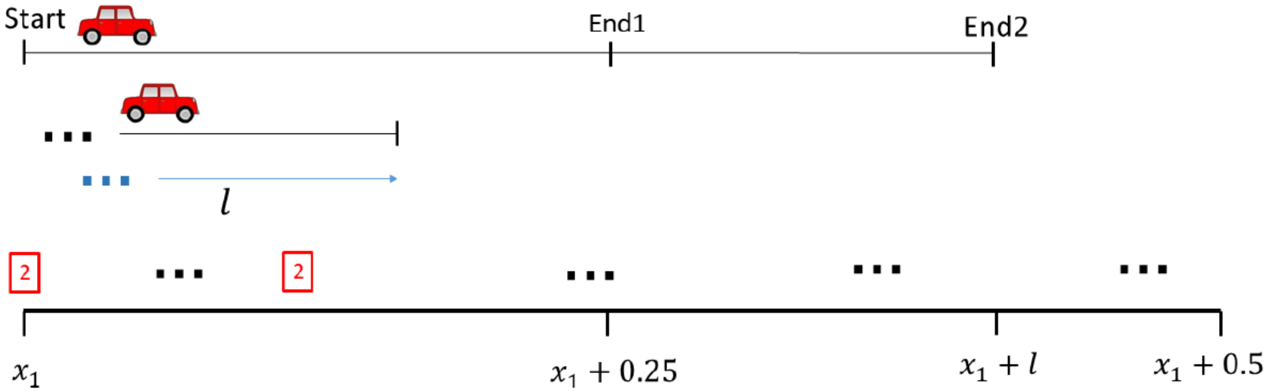


Fig. 3: Deploying an MC with previously visited sensors.

The Optimal Solution of the Problem

Algorithm 2 Search space for the optimal solution $\mathcal{O}$

Input: Sensor locations $\{x_1, x_2, \ldots, x_n\}$ and frequencies $\{f_1, f_2, \ldots, f_n\}$, $f_k \in \{1, 2\}$.
Output: The set of possible MC-solutions including $\mathcal{O}$.
Initialization: All sensors are unvisited.
$S = \{\}$ //The search space of the MC-solutions.
$l = 0$ //The last deployed MC's coverage area.
Optimal($x_1, x_2, \ldots, x_n, l, S$):
1: **if** all sensors are completely supplied **then**
$S = S \cup \{$Last generated MC-solution$\}$.
return
2: Call Algorithm 1 to determine $Possible\_Endpoints$.
3: **for** each k in $Possible\_Endpoints$ **do**
4: Generate an MC that covers $[x_1, k]$, add it to the current MC-solution, and let $l = k - x_1$.
5: Eliminate all sensors in $[x_1, x_1 + 0.25]$ and 1-sensors in $[x_1 + 0.25, k]$.
6: Annotate the 2-sensors in $(x_1 + 0.25, k]$ as 'visited'.
7: Call **Optimal**($x_1, x_2, \ldots, x_n, l, S$) where x_1 is the leftmost sensor.

Theorem 1. *The MC-solution in S, which is produced by Algorithm 2, with the least number of MCs is the optimal solution $\mathcal{O}$ and has a time complexity of $O(d \times 16^L)$.*

Outline

- Introduction
- Previous Work
- The Optimal Solution of the Problem
- Approximation Solutions of the Problem
- Simulation
- Future Work

Approximation Solutions of the Problem

- 1) Greedy 1.5-approximation solution.
- 2) Enhancement of the greedy 1.5-approximation solution.
- 3) The general greedy 2-approximation solution.

Approximation Solutions of the Problem

- 1) Greedy 1.5-approximation solution.
- 2) Enhancement of the greedy 1.5-approximation solution.

Algorithm 3 Greedy 1.5-approximation solution

Input: Sensor locations $\{x_1, x_2, \ldots, x_n\}$ and frequencies $\{f_1, f_2, \ldots, f_n\}$, $f_k \in \{1, 2\}$.
Output: A 1.5-approximation MC-solution.
Initialization: $i = 0$ //The MCs' indexes.
1: **While** there is a non-zero leftmost sensor x **do**
2: $i = i + 1$.
3: **if** there is a leftmost 2-sensor x' in $[x, x + 0.25]$ **then**
Generate MC_i that covers $[x, x' + 0.25]$.
4: **else**
Generate MC_i that covers $[x, x + 0.5]$.
5: Eliminate the sensors in $[x, x + 0.25]$.
6: Subtract 1 from visited sensors in $(x + 0.25, x + 0.5]$.
7: for every MC_{2i}, generate an additional MC that covers the same area MC_{2i} covers.

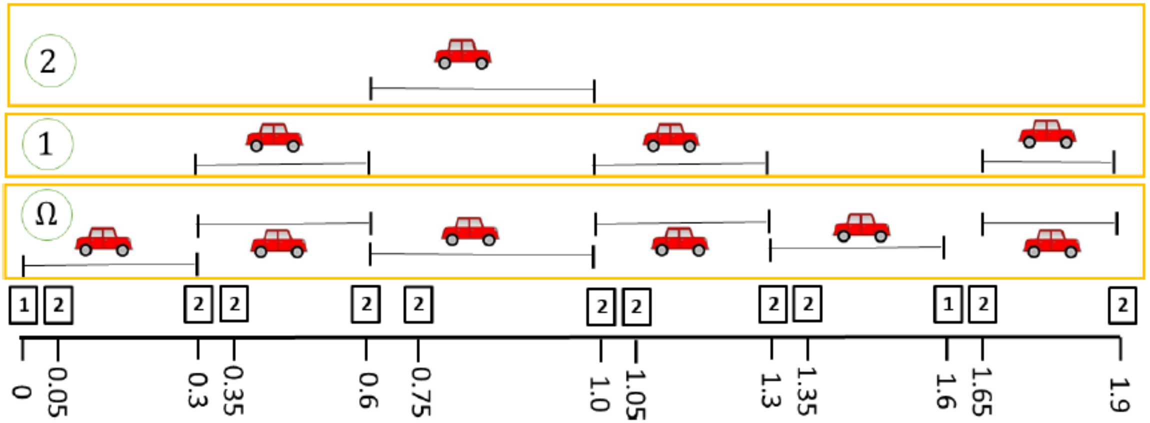


Fig. 5: The lower bound of the optimal, the 1.5-approximation algorithm, and the enhanced 1.5-approximation algorithm.

Approximation Solutions of the Problem

- 3) The general greedy 2-approximation solution.

Algorithm 4 General greedy solution

Input: Uncovored sensor locations $\{x_1, x_2, \ldots, x_n\}$ and frequencies $\{f_1, f_2, \ldots, f_n\}$, $f_k \in \mathbb{R}$.
Output: A 2-approximation MC-solution.
1: **if** $n = 0$ **then return**.
2: Generate an MC that goes back and forth as far as possible at a full speed to cover sensors at $\{x_1, \ldots x_{i-1}\}$.
3: Recursively call Algorithm 4 for $\{x_i, \ldots x_n\}$.

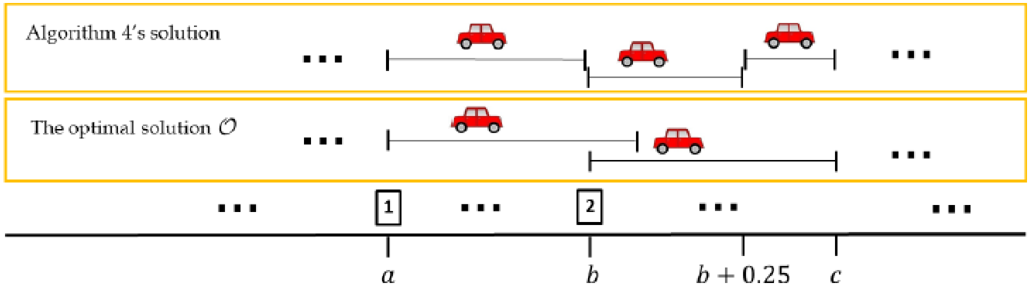


Fig. 6: The optimal solution $\mathcal{O}$ and Algorithm 4's approximation solution.

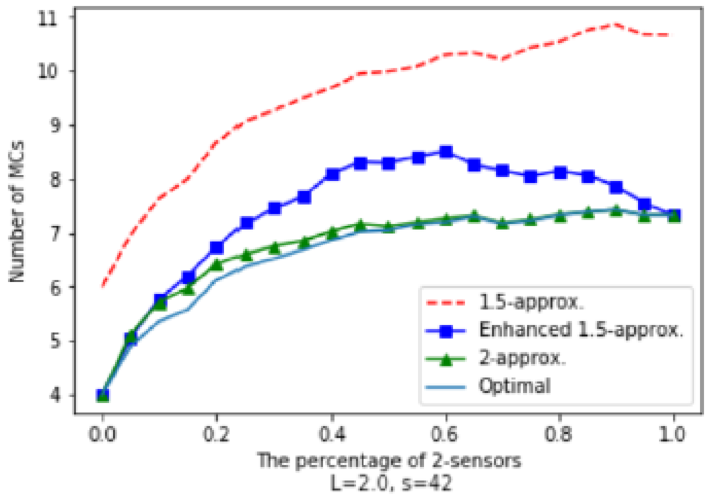
Outline

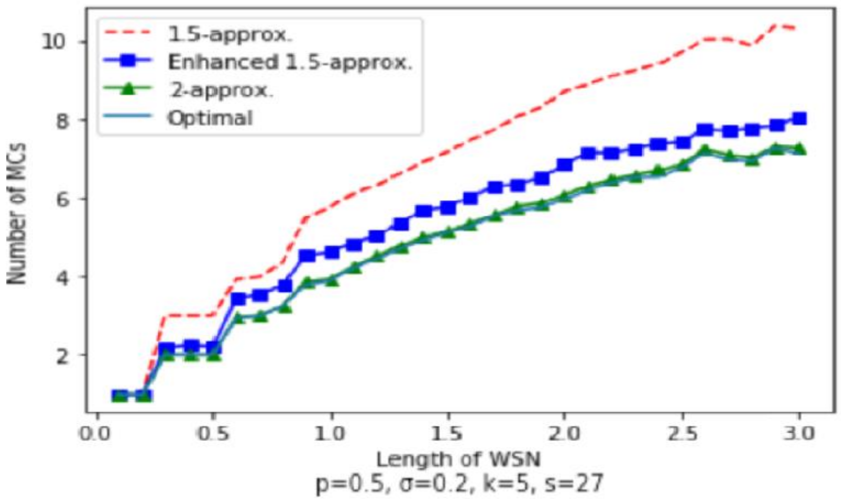
- Introduction
- Previous Work
- The Optimal Solution of the Problem
- Approximation Solutions of the Problem
- Simulation
- Future Work

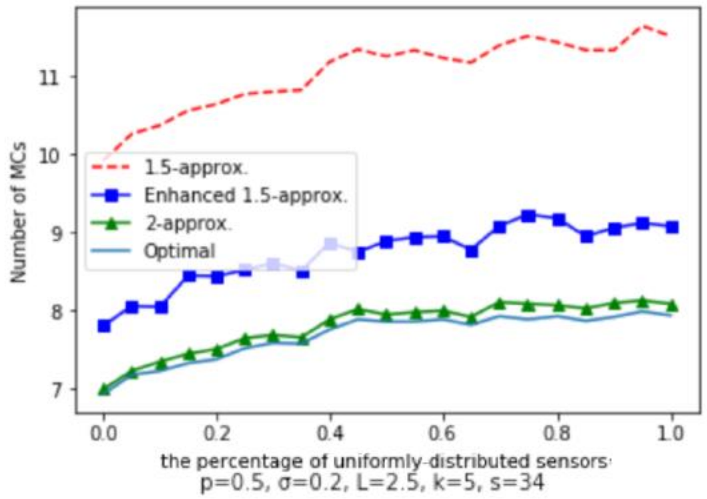
Simulation

- We consider multiple variations of the distribution of sensors:
- 1) Uniform distribution
- 2) Cluster distribution
- 3) Mixed distribution

Simulation


Number of MCs
1.5-approx.
Enhanced 1.5-approx.
2-approx.
Optimal
The percentage of 2-sensors
L=2.0, s=42


Number of MCs
1.5-approx.
Enhanced 1.5-approx.
2-approx.
Optimal
Length of WSN
p=0.5, σ=0.2, k=5, s=27


Number of MCs
1.5-approx.
Enhanced 1.5-approx.
2-approx.
Optimal
the percentage of uniformly-distributed sensors
p=0.5, σ=0.2, L=2.5, k=5, s=34

Outline

- Introduction
- Previous Work
- The Optimal Solution of the Problem
- Approximation Solutions of the Problem
- Simulation
- Future Work

Future Work

- Considering the optimization of the trajectories of the minimized number of MCs in term of power consumed.
- Studying different line WSNs of different frequency ranges, prove the NP-hardness of this problem, and come up with better approximations.

Conclusion

- We obtain the optimal solution for this problem by exhausting all of the possible solutions with specific properties, and conjecture the NP-hardness of it.
- We propose a novel 1.5-approximation algorithm, an enhancement of this approximation, and an analytical expansion for a previously proposed general 2-approximation algorithm.
- We verify the performance of the algorithms by the simulation.

Q&A

Abdalaziz Sawwan (Presenter) and Jie Wu.
Department of Computer and Information Sciences,
Temple University.