Dynamic Mobile Charger Scheduling in Heterogeneous Wireless Sensor Networks

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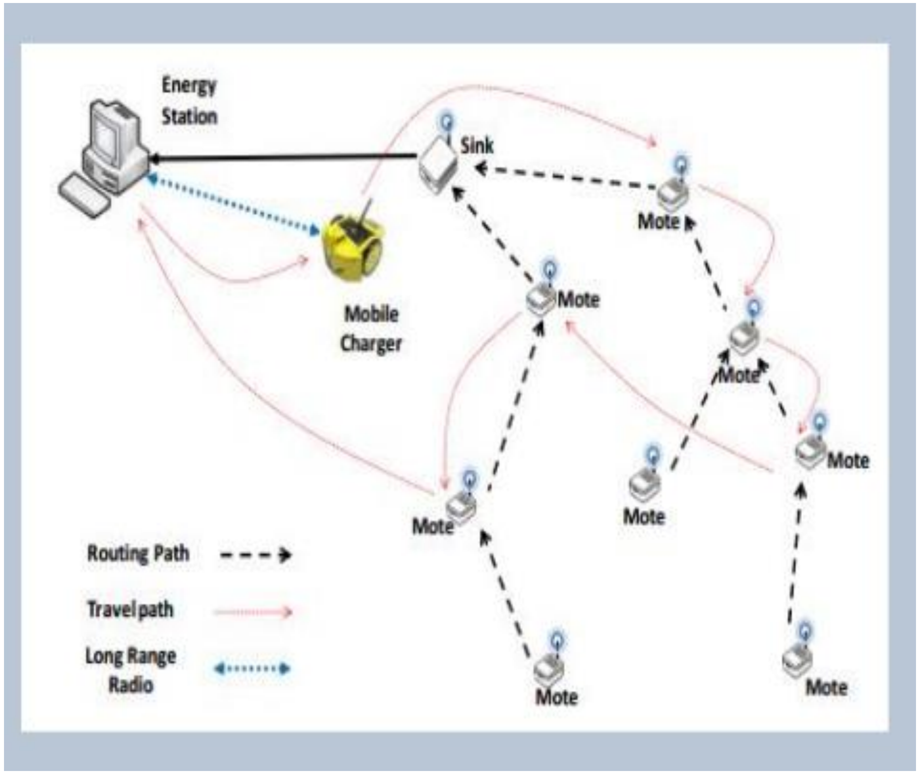
Problem Description

- Network Model
  - Sensor set: V, mutual distance matrix: D
  - battery capacity: E_{max}, energy consumption rate: $r_i(t)$
- Charger Model
  - single mobile charger
  - zero charging time
- Optimization Goal
  - **Coverage Ratio B_C**
  - **Energy Storage B_E**



Problem Formulation

$$
\begin{aligned}
\max_{\mathbf{x}^k, c_k} \quad & B_C + \beta B_E \\
= \quad & \textstyle\sum_{k=1}^{W} (|\mathbf{e}^k|_0 + \beta|\mathbf{e}^k|_1)/N \\
s.t. \quad & e_i^0 = E_{max}, i = 1, 2, \ldots N \\
& e_i^k = max(0, e_i^{k-1} - \mathbf{x}^{k-1T} \cdot D \cdot \mathbf{x}^k r_i^k) + x_i^k c_k, \\
& i = 1, 2, \ldots., N, k = 1, 2, \ldots, W, \\
& 0 \leq e_i^k \leq E_{max}, i = 1, 2, \ldots., N, k = 1, 2, \ldots, W, \\
& \mathbf{1}_N^T \mathbf{x}^k = 1, k = 1, 2, \ldots, W \\
& x_i^k \in \{0, 1\}, i = 1, 2, \ldots., N, k = 1, 2, \ldots, W, \\
& 0 \leq c_k \leq E_{max}, k = 1, 2, \ldots, W.
\end{aligned}
$$

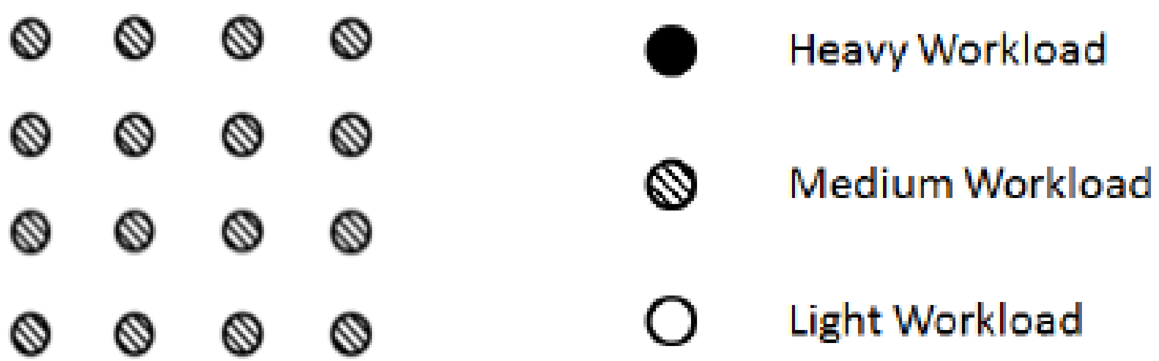
- Maximizing a convex function, discrete constraints
- NP complete
  - proved by reducing the Traveling Salesman Problem (TSP) to it

Related Work

- Zhang, Sheng, Jie Wu, and Sanglu Lu. "Collaborative mobile charging for sensor networks." *Mobile Adhoc and Sensor Systems (MASS), 2012 IEEE 9th International Conference on*. IEEE, 2012.
- He, Liang, et al. "Esync: An energy synchronized charging protocol for rechargeable wireless sensor networks." *Proceedings of the 15th ACM international symposium on Mobile ad hoc networking and computing*. ACM, 2014.
- Xie, Liguang, et al. "On traveling path and related problems for a mobile station in a rechargeable sensor network." *Proceedings of the fourteenth ACM international symposium on Mobile ad hoc networking and computing*. ACM, 2013.

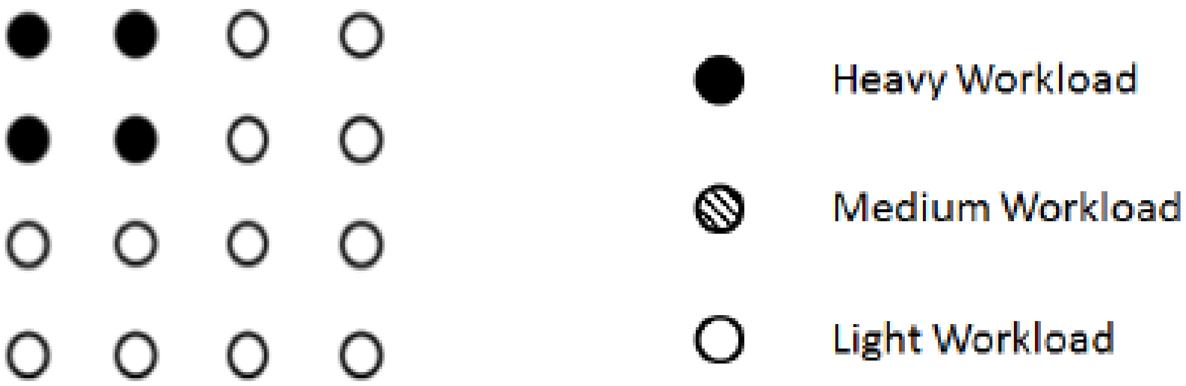
Challenge

- Shortest Route (TSP) Scheduler
  - charges along shortest route
  - Fail to consider about node urgency



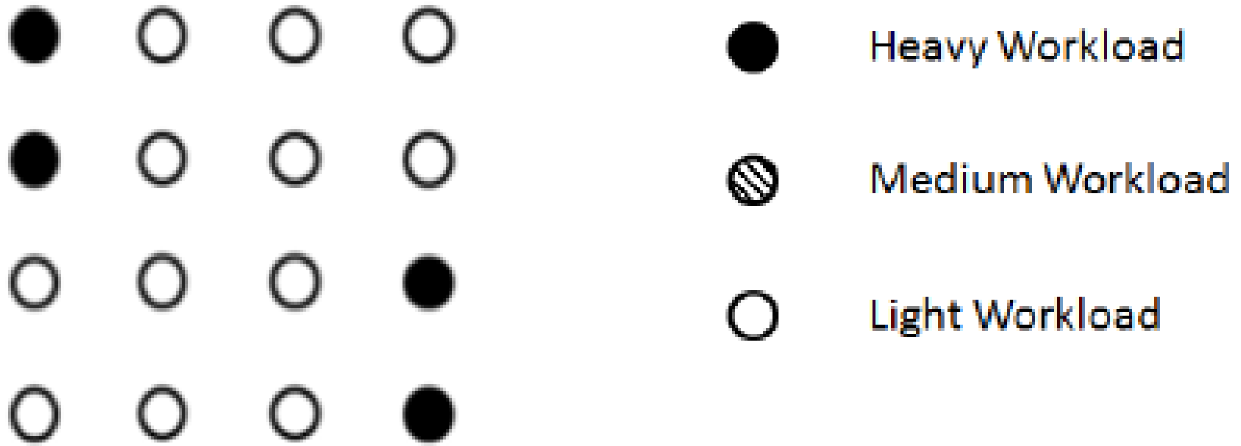
Challenge

- Earliest Deadline First (EDF) Scheduler
  - charges most urgent node
  - Fail to consider about traveling cost



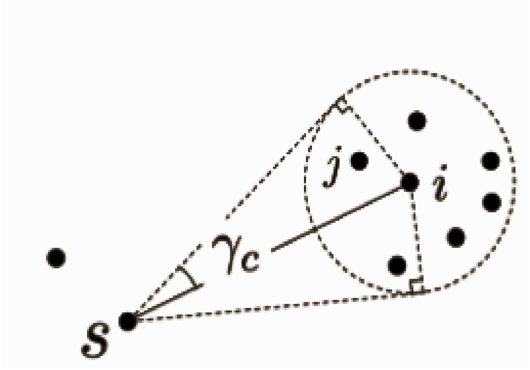
Challenge

Both traveling cost and node urgency are essential

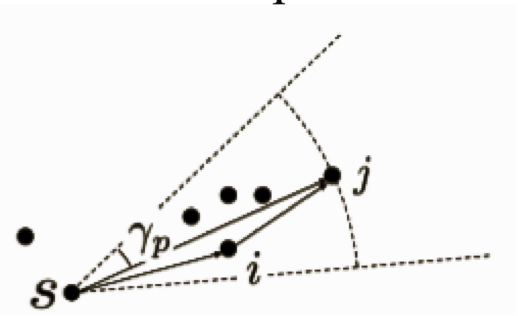


Spatial Dependent Model

- Cluster Dependency:
  - When charging i, traveling costs for nearby nodes are reduced.



- Path Dependency:
  - When traveling to i, nodes near the path are recharged without much detour



Spatial Dependent Task (SDT) Scheduler

- Idea:
  - Searches for the most urgent node cluster
  - charges nearby nodes along the path

- Solution Overview
  1. Search the cluster to recharge
  2. Construct the directed acyclic travel graph
  3. Searches for the route to travel using critical path algorithm

Spatial Dependent Task (SDT) Scheduler

- Cluster Priority:

$$P^{c}_{v_i}(k) = \overbrace{\frac{\sum_{v_j \in cluster(v_i)} w(j) * (E_{max} - e_j^k)}{\sum_{v_j \in cluster(v_i)} w(j)}}^{\text{Weighted sum of urgency}} / \overbrace{d_{si}^{\alpha}}^{\text{Distance}}$$

- Path Priority:

$$P^{p}_{\mathbf{l}}(k) = \sum_{v_j \in \mathbf{l}} \big(\overbrace{E_{max} - e_j^k}^{\text{Extra gain}} - \overbrace{d_{v^*_{j-1}, v^*_j} |\mathbf{r}^k|_1}^{\text{detour cost}} \big)$$

Spatial Dependent Task (SDT) Scheduler (cont'd)

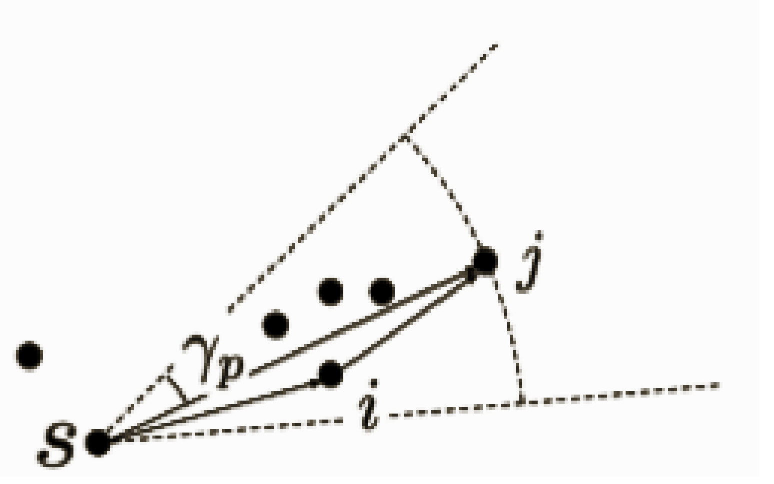
Traveling graph definition

Given the distance j

Directed Edge $\overline{si}$ exists if:

$\angle jsi < \gamma_p$

$d_{si} < d_{ij}$



Evaluation

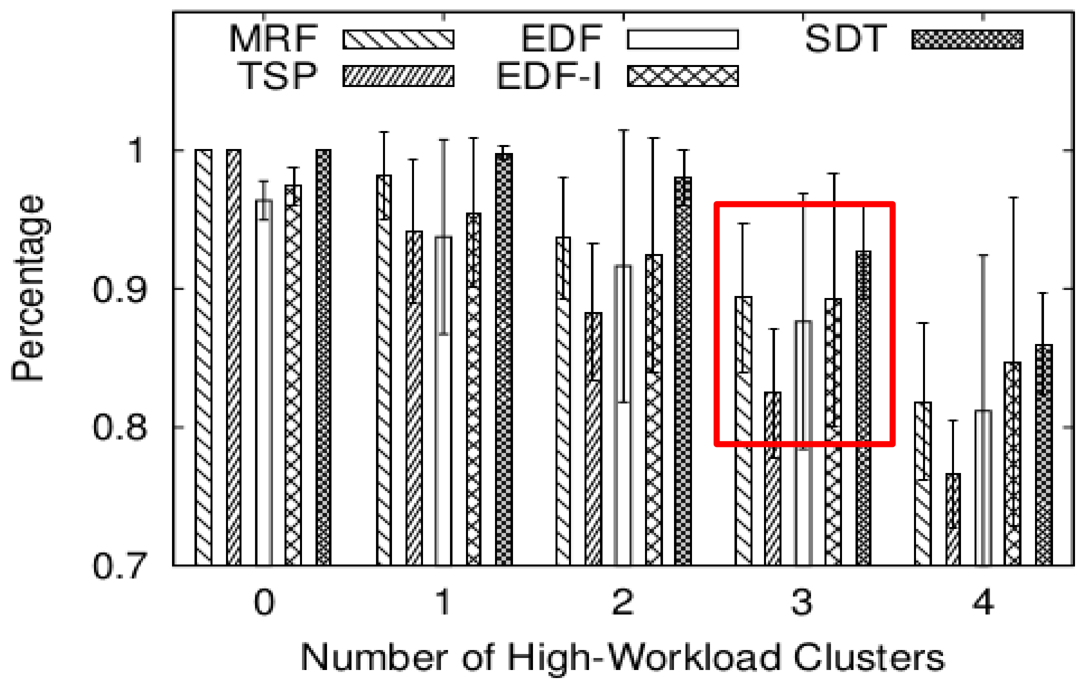
- Baseline algorithms
  - Shortest Route (TSP) scheduler
  - Earliest Deadline First (EDF) scheduler
  - Maximum Response Ratio First (MRF) scheduler
  - EDF with node insertion (EDF-I)

- Simulation set-up
  - energy consumption rate modeling real traces
  - 225 nodes in square area
  - different sizes and workloads

Evaluation

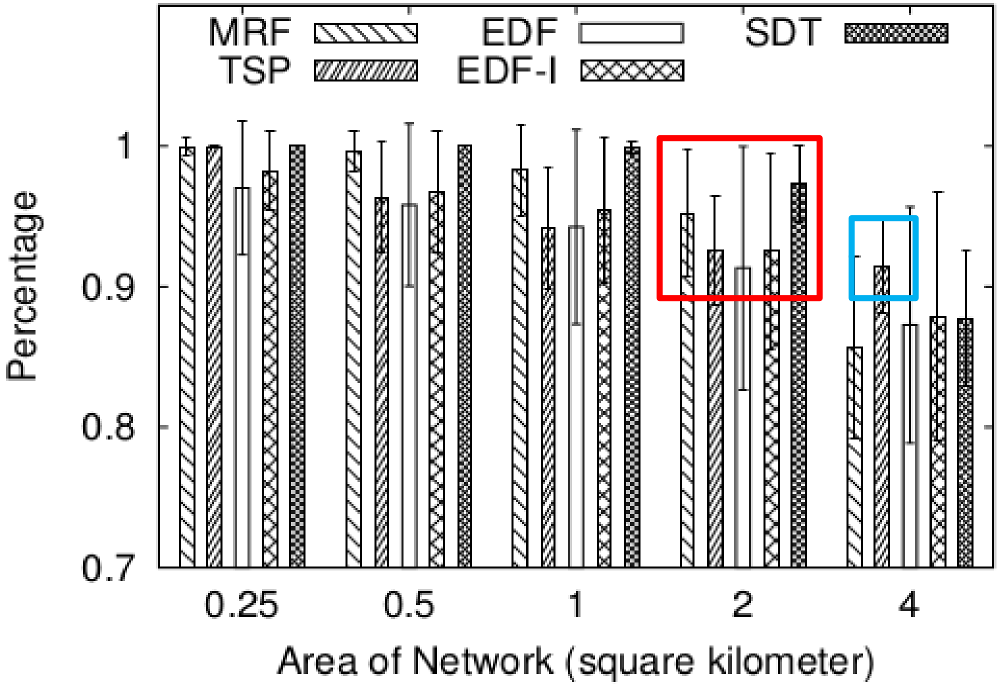
Influence of work loads

- SDT performs well when energy consumption rates
  - 3 clusters, SDT10% better than TSP, 5% better than EDF



Evaluation

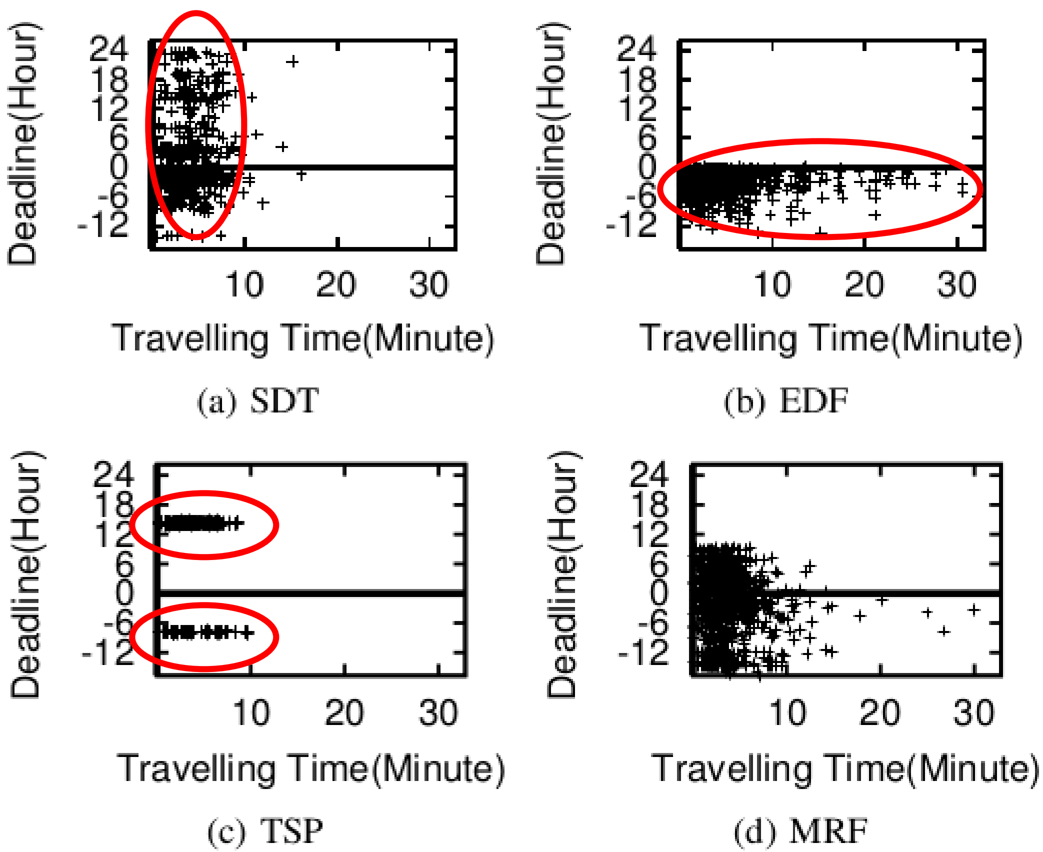
- SDT degrades gracefully. 5% better than EDF
- TSP performs well when network area ⇧ 4% better than others



Evaluation (cont'd)

Trade-off between traveling time and urgency

SDT scheduler spends most of the time charging urgent nodes



Conclusion

- Problem Definition
  - Models and optimization goal
- Challenge
  - NP-Complete
  - Consider both Spatial and temporal constraints
- SDT Scheduler
  - Select cluster
  - Search best path
- Evaluation
  - SDT scheduler Achieves better performance
  - TSP works well in large networks

Future Work

Design algorithms with performance bounds

Questions?