Fast Interference-Aware Scheduling of Multiple Wireless Chargers

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Outline

• Background and contributions
• Model and problem formulation
• Algorithm design
• Performance evaluation
• Conclusion
Background

• Wireless Sensor Network
  – Sensors are powered by small batteries;

• Long-distance charging – Low efficiency

• Ways to improve
  – Increase chargers’ power
  – Use multiple chargers
Background

- Combined energy
  - Combined energy is additive?
Background

- Related work:
  - Calculate the charging energy in advance; complexity grows exponentially with the number of chargers.

- Discovery:
  - Strong and weak areas.

- Diagram:
  - Energy received by sensor vs. distance from charger 1 (m).
  - Comparison between Linear Model and Nonlinear Model.
Contributions

• We apply a new charging model with nonlinear super-position into the FCS problem \(\rightarrow\) NP-complete;

• We propose FastPick algorithm in 1D line \(\rightarrow\) bound (2-\(\epsilon\));

• We propose RoundPick algorithm in 2D network \(\rightarrow\) bound;
Models

• Network model
  – N stationary sensor nodes \( \{ s_1, s_2, \ldots, s_n \} \) and M chargers \( \{ c_1, c_2, \ldots, c_m \} \)

• Charging model
  – frequency component \( \omega_0 \), amplitude \( A_0 \), initial phase \( \varphi_0 \), power attenuation factor \( 2 \)
  – Radio signal received by sensor from charger \( c_i \)
    \[
    a_{i0}(t) = \frac{A_0}{4\pi d_{ij}/\lambda} \cos(\omega_0 t + \varphi_0 - 2\pi \frac{d_{ij}}{\lambda})
    \]
  – Radio signal received by sensor \( s_j \) from charger set \( C \)
    \[
    A_0^j(t) = \sum_{c_i \in C} a_{i0}(t) = \sum_{c_i \in C} \frac{A_0}{4\pi d_{ij}/\lambda} \cos(\omega_0 t + \varphi_0 - 2\pi \frac{d_{ij}}{\lambda})
    \]
Models

• Charging model
  - Power received by sensor $s_j$ from charger set $C$

  $$P_{j|C} = \int [A_0^j(t)]^2 d\omega$$

  $$= P \sum_{c_i \in C} \frac{1}{d_{ij}^2} + P \sum_{c_i \in C} \sum_{c_m \in C, c_m \neq c_i} \frac{1}{d_{ij}d_{mj}} \cos(2\pi \frac{d_{ij} - d_{mj}}{\lambda})$$

  - where $P = \int p_i d\omega$, $p_i = \frac{A_i^2}{2}$
Models

• Harvesting model
  – Threshold of power: $\epsilon$
  – Energy capacity: $E$

\[
e_{j|C,t} = \begin{cases} 
0 & \text{if } P_j|_C < \epsilon \\
0 & \text{if } P_j|_C > \epsilon \text{ and } e'_j > E \\
\alpha t(P_j|_C - \epsilon) & \text{otherwise}
\end{cases}
\]
Problem Formulation

• We use $H_i$ to denote $i_{th}$ charging schedule
  - $H_2 = \{1, 0, 1, 0\}$;
  - $\Delta$ denotes charging duration.

• Problem:
  - Given a set $C$ of chargers with fixed position, a set $S$ of rechargeable sensors, a set $\{d_{ij} \mid 1 \leq i \leq N, 1 \leq j \leq M\}$ of distance between $c_i$ and $s_j$, and an energy capacity $E$ of each sensor, FCS is to find a set of multiple charging schedules $\{H_1, H_2, ..., H_k\}$, to charge each sensor with energy no less than $E$, and $k$ is minimized.
• Rational
  – Assumption: all frequency are the same;
  – Observation: difference of phases between two chargers
• FastPick (Initial phases are adjustable)
  – Choose the sensor with the least energy;
  – Find two chargers that are closest to this sensor;
  – Adjust their initial phases to make most sensors lie in their strong areas;
  – Adjust other chargers’ initial phases to make the strong and weak areas are the same;
  – Reverse the original weak and strong areas.
One-Dimension Line

• Approximation Ratio

  – Lower bound: $T$ (All chargers strengthen each other);
  – FastPick is at most 2 times longer than $T$;
  – $T$ is smaller than OPT;
  – FastPick is $2-\varepsilon$ approximate.
Two-Dimension plane

• Challenges
  – Irregular;
  – Two directions;
  – Cannot coincide.
Two-Dimension Plane

• Partition
  – Every sensor in one slot should be covered by chargers in this slot;
  – There is at least one charger in a slot;
  – The length of slot side should be minimized but no less than $2 \times R$ (R is the charging radius).
• RoundPick
  – Partition the network;
  – In each iteration, algorithm first computes each two chargers strong areas in each slot, then chooses a sensor with the least energy;
  – Add new chargers if more energy would be received;
  – Move slot.

  – We also get a bound of $6-4\epsilon$
Evaluations

• Settings
  
  – Wave length $\lambda = 0.33\text{m}$, threshold of harvesting energy is $15\text{uW}$,
  
  – Distance threshold $6.78\text{m}$, $(0.25 \times \frac{4}{4\pi \times d^2} = 0.015\text{mW})$
  
  – Default number of charger 12, sensor 50, energy capacity 4mJ.
Evaluations
Thank you

Q&A