An Energy-Renewal Approach With Wireless Power Transfer

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Outline

- Introduction
- Problem description
- Optimal traveling path
- Numerical Results

Introduction 1 / 3

- Employing a mobile vehicle carrying a power-charging station to periodically visit each sensor node and charge it wirelessly.

- Device

- This **mobile wireless charging vehicle** (WCV) can either be manned by a human or be entirely autonomous.
- **Wireless Power Transfer**

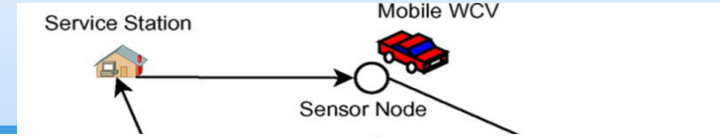
Introduction 2 / 3

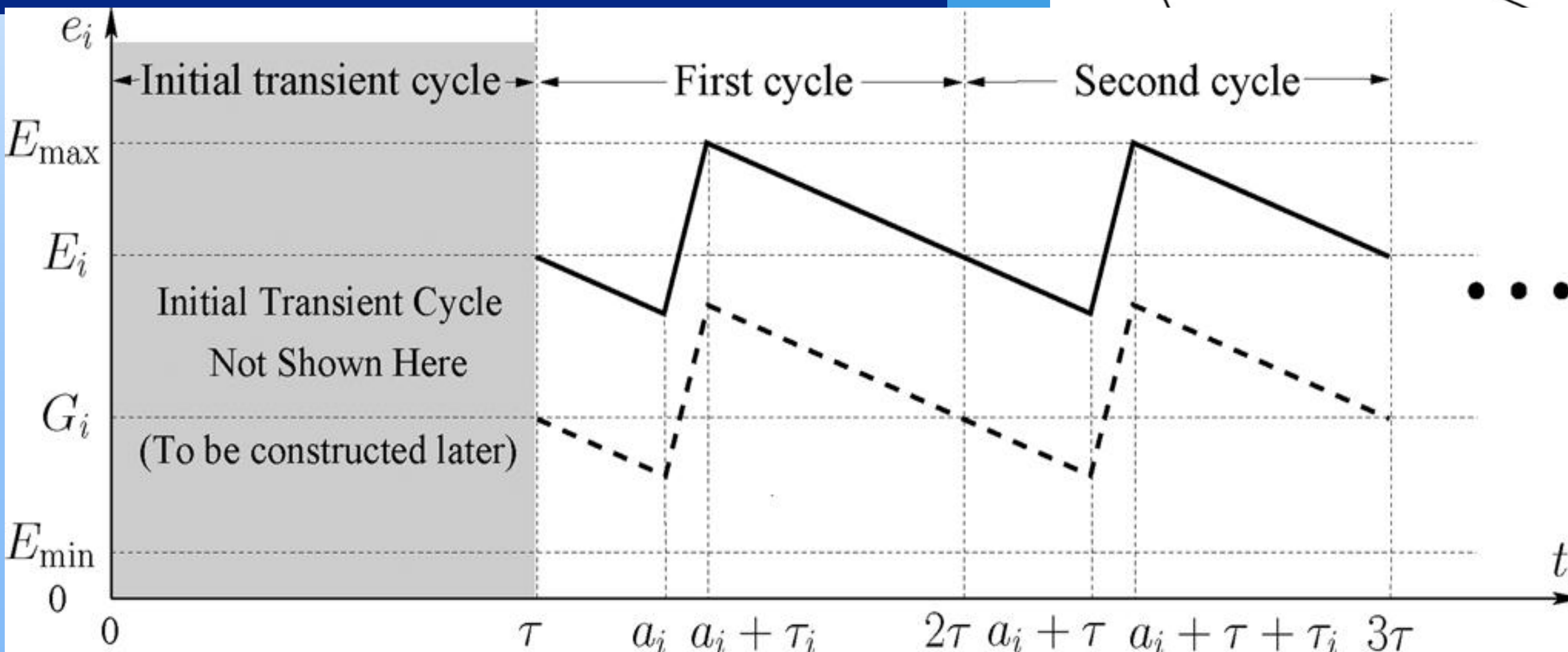
- **Renewable energy cycle**

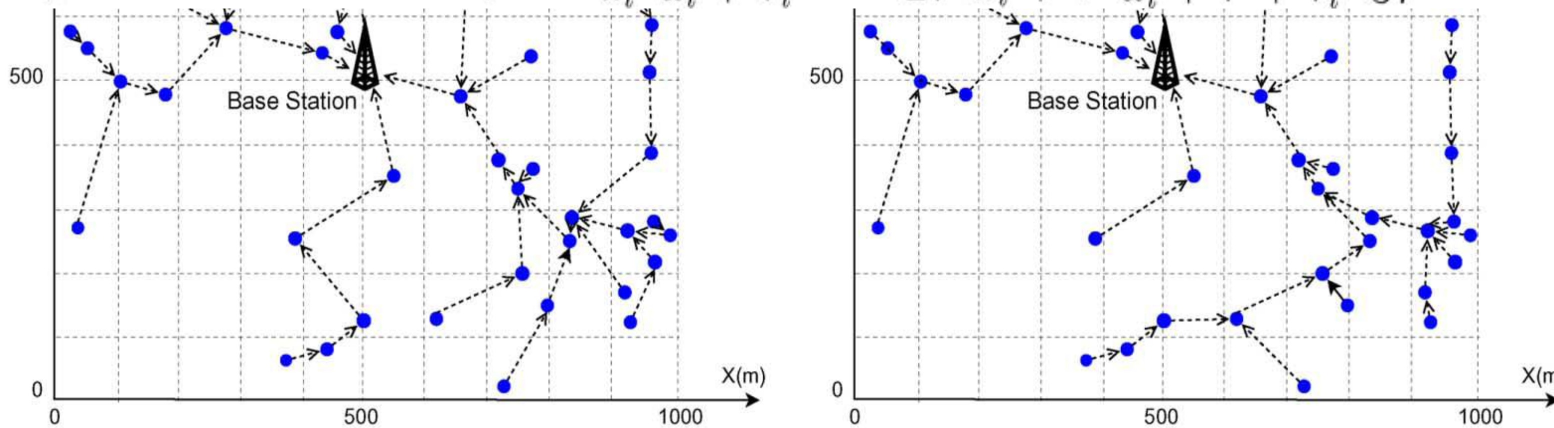
- Remaining energy level in a sensor node's battery exhibits some periodicity over a time cycle.
- Formulate an optimization problem for joint flow routing and charging schedule for each sensor node.

(Objective of maximizing the ratio of the WCV's vacation time)

Introduction 3 / 3







(a) (b)

Problem description

- Parameter 1/2
  - sensor nodes N
  - battery capacity of E_{max} , E_{min}
  - sensor node i generates sensing data with a rate of R_i (in bits/second)
  - f_{ij} the flow rate from sensor node i to sensor node j (b/s)
  - f_{iB} the flow rate from sensor node i to the base station B (b/s)

Problem description

- Flow balance constraint at each sensor node :

$$\sum_{k\in\mathcal{N}}^{k\neq i} f_{ki} + R_i = \sum_{j\in\mathcal{N}}^{j\neq i} f_{ij} + f_{iB} (i \in \mathcal{N}). \qquad (1)$$

- Energy consumption model :

$$p_i = \rho \sum_{k\in\mathcal{N}}^{k\neq i} f_{ki} + \sum_{j\in\mathcal{N}}^{j\neq i} C_{ij} f_{ij} + C_{iB} f_{iB} (i \in \mathcal{N}) \qquad (2)$$

reception transmission

- ρ is the rate of energy consumption for **receiving** a unit of data rate
- Cij (or Ci*B*) is the rate of energy consumption for **transmitting** a unit of data rate from node to node (or the base station B)

Problem description

- Parameter 2/2
- **V** is traveling speed of the WCV(m/s)
- **U** the energy transfer rate of the WCV
- Charge the sensor node i , spend a time of τ
- After the WCV visits all the sensor nodes, it will return to its service station, call this resting period vacation time, denoted as τ_{vac}

Problem description

- $P = (\pi 0, \pi 1, \ldots \pi N, \pi 0)$ the path traversed by the WCV

- The cycle time τ can be written as

$$\tau = \tau p + \tau \text{vac} + \sum_{i \epsilon \mathbf{N}} \tau \text{i}$$

– Denote Dp the distance of path P, $\tau p = Dp \,/\, V$

Optimal traveling path

- **OPT-R**

$$\max \ \eta_{\text{vac}}$$

$$\eta_{\text{vac}} = \frac{\tau_{\text{vac}}}{\tau}$$

$$\text{s.t.} \quad \sum_{j \in \mathcal{N}}^{j \neq i} f_{ij} + f_{iB} - \sum_{k \in \mathcal{N}}^{k \neq i} f_{ki} = R_i (i \in \mathcal{N}$$

Flow conservation constraint

$$\rho \cdot \sum_{k \in \mathcal{N}}^{k \neq i} f_{ki} + \sum_{j \in \mathcal{N}}^{j \neq i} C_{ij} f_{ij} + C_{iB} f_{iB} - U \eta_i = 0 \qquad (i \in \mathcal{N}) \qquad (20)$$

Energy constraint

$$\eta_{\text{vac}} \leq 1 - \sum_{k \in \mathcal{N}} \eta_k - \frac{U \cdot \tau_{\text{TSP}}}{E_{\max} - E_{\min}} \cdot \eta_i \cdot (1 - \eta_i) \qquad (i \in \mathcal{N}) \quad (21)$$

$$f_{ij}, f_{iB} \geq 0, 0 \leq \eta_i, \eta_{\text{vac}} \leq 1 \qquad (i, j \in \mathcal{N}, i \neq j).$$

Optimal traveling path

Construction of a Near-Optimal Solution

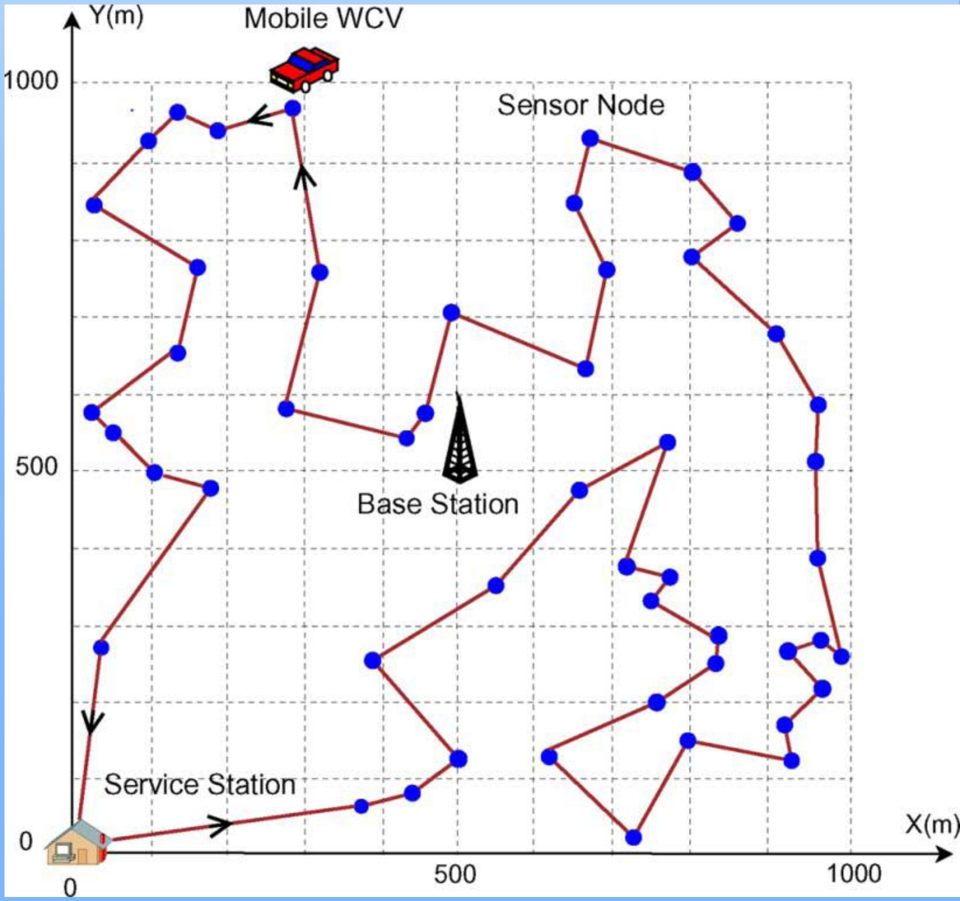
1. Given a target performance gap ϵ.
2. Let $m = \left\lceil \sqrt{\frac{U \tau_{\text{TSP}}}{4\epsilon(E_{\max} - E_{\min})}} \right\rceil$.
3. Solve Problem OPT-L with m segments by CPLEX, and obtain its solution $\hat{\psi} = (\hat{f}_{ij}, \hat{f}_{iB}, \hat{\eta}_i$, Problem$_{ik}$, $\hat{\lambda}_{ik}, \hat{\zeta}_i)$.
4. Construct a feasible solution $\psi = (f_{ij}, f_{iB}, \eta_i, \eta_{\text{vac}})$ for Problem OPT-R by letting $f_{ij} = \hat{f}_{ij}$, $f_{iB} = \hat{f}_{iB}$, $\eta_i = \hat{\eta}_i$ and $\eta_{\text{vac}} = \min_{i \in \mathcal{N}} \{1 - \sum_{k \in \mathcal{N}} \hat{\eta}_k - \frac{U \tau_{\text{TSP}}}{E_{\max} - E_{\min}} \cdot \hat{\eta}_i \cdot (1 - \hat{\eta}_i)\}$.
5. Obtain a near-optimal solution $(f_{ij}, f_{iB}, \tau, \tau_i, \tau_{\text{vac}}, p_i)$ to Problem OPT by Algorithm 1.

Numerical Results

- Simulation Settings
  - Consider a randomly generated WSN consisting of 50 nodes
  - Sensor nodes over a square area of 1 km × 1 km
  - The traveling speed of the WCV is V= 5 m/s
  - Let $Emax$= 10.8 KJ , $Emin$= 5.4 KJ
  - U= 5W

Numerical Results

- In this optimal cycle,
  D_{TSP}=5821 m and
  τ_{TSP} =1164.2 sec
- target ϵ = 0.01, m= 4
- τ=17.34 hour
- τ_{ac}= 1164.2 sec
- η_{vac}= 77.51%



Numerical Results

Renewable cycle