Online Data Gathering for Maximizing Network Lifetime in Sensor Networks

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Outline

- Introduction
- System Model
- Generic Cost Model of Energy Consumption
- Problem Definition
- Algorithms For Online Data Gathering
- Performance Evaluation
- Conclusion
The main constraint of sensor nodes is their low finite battery energies.

Energy efficiency in the design of routing protocols for sensor networks is of paramount importance.
System Model

- The wireless sensor network can be modeled by a directed graph $M = (N, A)$.
- Edge $<u, v>$ in $A$ exists if node $v$ is within the transmission range of $u$ when $u$ uses its maximum power level to broadcast a message.
- The transmission energy at node $u$ is $d_{u,v}^{\alpha}$ if a unit of message is transferred from $u$ to $v$ directly, where $\alpha$ is a path-loss exponent parameter.
- We take into account the transmission energy consumption only.
Generic Cost Model of Energy Consumption

- The cost $c(v)$ of a relay node $v$ is

$$c(v) = f(l_1, l_2, \ldots, l_t, m_v) d_{c,p(v)}^e + \sum_{i=1}^{t} l_i \cdot r_e + m_v \cdot r_s$$

- $l_1, l_2, \ldots, l_t$: the length of messages that $v$ received from its child nodes $u_1, u_2, \ldots, u_t$
- function $f$: the length of the message transmitted by $v$ to its parent $p(v)$
- $p(v)$: the parent of $v$ in routing tree $T$
- $m_v$: the length of the sensed message by $v$ itself
- $r_e$ and $r_s$: the amount of energy consumption of receiving and sensing a unit of message by a sensor
Problem Definition

- Given a wireless sensor network \( M = (N, A) \) with a sink node.

- Assumption
  - There is an unknown sequence of data gathering queries which arrive one by one. As a query arrive, the response by the system is to build a routing tree rooted at the sink.
  - The length of the message transmitted by each relay node in the routing tree is the sum of the lengths of its children messages and its own sensed message.

- The problem is to maximize the number of queries answered until the first node in the network fails.
To prolong the network lifetime, there are two types of energy optimization metrics
- Minimize the total energy consumption per data gathering query
- Maximize the minimum residual energy among sensors

The authors propose five algorithms for online data gathering problem

These algorithms aim to find the routing tree
Maximize the minimum residual energy among the nodes in the network

Each time a node $v$ is included into the tree, either the network lifetime derived from the current tree is at least as long as that without the inclusion of $v$ to the tree or the amount of reduction of the network lifetime is minimized
Algorithms For Online Data Gathering – (1) MNL

Minimum residual energy among the nodes in the path $P_{v,s}$
Algorithms For Online Data Gathering - (2) MMRE

- Maximize the minimum residual energy among the nodes in the network

- Let $T$ be the tree and $V_T$ be the set of nodes in $T$. The sink node $s$ is included in $T$ and $V_T = \{s\}$ initially. Each time it picks up a node $v \in V - V_T$ if $v$ satisfies
  
  $$re'(v) = \max_{(v', u') \in E} \{re(v') - kd_{v', u'}^\alpha \mid v' \in V - V_T, \ u' \in V_T\}$$

- The algorithm continues until $V - V_T = \emptyset$
Algorithms For Online Data Gathering -
(2) MMRE

\[ V_T \]

\[ V - V_T \]

node's residual energy

s

\[ 15 \]

v_1

\[ 13 \]

v_2

...
Algorithms For Online Data Gathering - (3) SPT

- Minimize the **total transmission energy consumption**
- A directed, energy graph $G(V, E)$ is derived from the sensor network. There is a directed edge $<u, v>$ in $E$ from $u$ to $v$ if the residual energy at $u$ is at least $k_d^{\alpha_{u,v}}$. The weight assigned to the edge is $d^{\alpha_{u,v}}$, which is the energy consumption of transmitting a unit message between the two nodes.
- A single-source shortest path tree rooted at the sink node is constructed.
Algorithms For Online Data Gathering - (3) SPT
Algorithms For Online Data Gathering - (4) BT

- An undirected, energy graph $G(V, E, \omega)$ for the sensor network is defined. A link $(u, v) \in E$ if 1) $u$ and $v$ are within the transmission range of each other 2) the residual energy $re(u)$ and $re(v)$ at $u$ and $v$ are at least $kd_{u,v}^{\alpha}$. The weight assigned to $(u, v)$ is $d_{u,v}^{\alpha}$.

- It constructs a balanced tree [15] in the energy graph $G$ which balances the cost of the minimum spanning tree and the cost of the shortest path tree with $\alpha' = \beta' = 1 + \sqrt{2}$

- It takes the total energy consumption into consideration, but does not take into account the residual energy at each individual node. The nodes near the tree root run out of their batteries quickly.
The idea behind algorithm MDST is similar to the one of algorithm BT, but a different weight function is used. The weight assigned to a link $\langle u, v \rangle \in E$ is $\omega_1(u, v) = d_{u,v}^\alpha (\lambda^\beta(u) - 1)$, where $\beta(u) = \frac{C(u) - re(u)}{C(u)} = 1 - \frac{re(u)}{C(u)}$ is the energy utilization ratio at node $u$ between its consumed energy $C(u) - re(u)$ and its initial capacity $C(u)$, and $\lambda > 1$ is constant. Find a minimum directed spanning tree [6]
Fig. 2. Network lifetime delivered by MNL, MDST, MMRE, SPT, and BT with initial energy $2 \times 10^6$ units and path-loss exponent $\alpha = 2$. 

Performance Evaluation
Performance Evaluation

Network lifetime: MNL > MMRE > MDST > SPT > BT

Fig. 3. Network lifetime delivered by MNL, MMRE, MDST, SPT, and BT with initial energy $2 \times 10^9$ units and path-loss exponent $\alpha = 4$. 
Conclusion

- The experiment results show that algorithm MNL significantly outperforms the other algorithm including MMRE, MDST, SPT, and BT.
- An algorithm taking only the total energy consumption for realizing a data gathering query into consideration, will result in nodes near the tree root running out of their batteries quickly, since those nodes always relay messages for the other nodes.