SEEOF: Smart Energy Efficient Objective Function

Adapting RPL Objective Function to enable an IPv6 Meshed Topology Solution for Battery Operated Smart Meters

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Outlines

- Background
- SEEOF - Proposed Algorithm
- Simulations, Graphs and Results
- Conclusion and Future Work
Background

- Internet of Things (IoT)
- Smart Meters
  - Top IoT device among utility companies in the last several years
- Low Power and Lossy Networks (LLN)
- RPL (IPv6 Routing Protocol for LLNs)
  - Pronounced as “RIPPLE”
- Electric Meters + Gas/Water Meters
  - Mains line powered (MLPD)
  - Battery powered (BPD)
Routing
- Key Factor for Meshed network
- Prominent responsibility to make a smart decision in selecting the optimal parent and
- Construct the routes in a single or multi-hop manner
Background

- Parent Selection

- Only ETX: \[ \text{C} \rightarrow \text{A} \]
- Only RE: \[ \text{C} \rightarrow \text{B} \]

WORKS ON SINGLE METRIC ONLY

PROBLEM!!

\[
\text{PathETX} = \sum_{i \in P} \text{linkETX}
\]

5.1 path ETX
6.5 path ETX
Goal

**SEEOF** → In compliance with the standard RPL

→ Consider the consumption limits of BPDs

**AIM** → Balanced and Efficient Energy consumption

→ Improve the Network Lifetime

→ No or low compromise with the quality of service.
Metrics used → Cost Function → Parent Selection → Optimal Energy Efficient Routing
SEEOF: Metrics Used

- **Drain Rate** or slope
  - Used as a **Base Metric** for the proposed algorithm.
  - Based on traffic load condition
  - Avoid over-dissipation, and improves the energy consumption efficiently.

- Does **NOT** consider Remaining Energy.

- **Drain Rate** \( (m) \) = \( \frac{\text{Amount of energy consumed}}{\text{Time}} \)

- \( m = \frac{RE}{S-t} = \frac{RE}{ERLT} \)

- \( \therefore ERLT = \frac{RE}{m} \)
Estimated Remaining Lifetime (ERLT)

- **ERLT** (\(=\text{RE/m}\)) alone is not sufficient
  - Only provides information about parents.
  - No information about parent-child link.

- Necessary to consider **linkETX** along with **ERLT**.
  - Full information
  - Proper parent selection

**Metrics Composition**

- **Additive Combination**
- **Lexical Combination**

\[
\text{ERLT}_A > \text{ERLT}_B, \text{ETX}_A \gg \text{ETX}_B
\]

Parent B suitable
SEEOF: Smart Energy Efficient Objective Function for RPL

**SEEOF Cost Function**

New Cost Function for BPD

\[ \text{Cost} = \frac{\text{ETX}}{\text{ETX}_{TH}} + \frac{\text{MAX}_{LT} - \text{ERLT}}{\text{ERLT}_{TH}} \]

- Minimizable Cost Function
- Better Control over Hysteresis

- **ETX** : link ETX
- **ERLT** : ERLT of parent
- **MAX_{LT}** : Maximum expected lifetime
- **ETX_{TH}** : Threshold in link ETX
- **ERLT_{TH}** : Threshold in ERLT

MLPD : Mains Line Powered Device
BPD : Battery Powered Device
Get Path costs $= \text{Path ETXs}$

Is $P_1$ and $P_2$ different type?

Is $P_1$ MLPD?

Is $P_1 \rightarrow \text{linkETX} > \text{MAX\_LINK\_ETX}$?

Is $P_1 \rightarrow \text{linkETX} > \text{MAX\_LINK\_ETX}$?

Return $P_1$

Return $P_2$

Return $P$ with lower ERLT

Is $P_1 \text{ or } P_2$ Preferred parent?

Return Preferred parent

Get Path costs $= f(\text{ERLT, ETX})$

STOP

$Y$$Y$$Y$$Y$$N$$N$$N$$N$$Y$

Both MLPD

MLPD : Mains Line Powered Device

BPD : Battery Powered Device

Both BPD

Hysteresis

Check Type of Parents

Both are different types

Is $P_2 \rightarrow \text{linkETX} > \text{MAX\_LINK\_ETX}$?

Is $P_1 \text{ MLPD}$?

Is $P_1 \text{ and } P_2 \text{ different type}$?

Return $P_1$ or $P_2$ Preferred parent?

Best parent($P_1, P_2$)

START

Get Parent list of the node

$P = \text{first parent}$

Best $= \text{NULL}$

Is Best $= \text{NULL}$?

Best $= P$

$P = \text{next parent}$

STOP

Both are different types

$Y$$Y$
**SEEOF Implementation to RPL**

- **Two Questions**
  
  A. How to advertise the two metrics?  
  1. ETX (Expected Transmission Count)  
  2. ERLT (Estimated Remaining Life Time)
  
  B. How to know the type of the parents?

- **EWMA Filter on ETX and Drain Rate Calculation**

1. **Advertising ETX Metric**

   ![DIO Control Message Format](Figure: DIO Control Message Format)

   - As in MRHOF the **ETX metric** is carried by the **16-bit RANK field** in the DIO message
SEEOF Implementation to RPL

2. Advertising ERLT Metric

- Measured in terms of time units (hours).
- Advertised using the Node Energy Object (NE Object) in DIO Message.

<table>
<thead>
<tr>
<th>Flags</th>
<th>I</th>
<th>T</th>
<th>E</th>
<th>E_E</th>
<th>Optional TLVs...</th>
</tr>
</thead>
</table>

- 8 bit E_E field
  - Not sufficient to accommodate the entire ERLT.
  - May required higher number of bits.

<table>
<thead>
<tr>
<th>Years</th>
<th>Hours</th>
<th>Bits required</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>43800</td>
<td>At least 15 bits</td>
</tr>
<tr>
<td>10</td>
<td>87600</td>
<td>At least 16 bits</td>
</tr>
<tr>
<td>15</td>
<td>131400</td>
<td>At least 18 bits</td>
</tr>
<tr>
<td>20</td>
<td>175200</td>
<td>At least 18 bits</td>
</tr>
</tbody>
</table>

1 Day = 24 Hours, 1 Month = 30 Days = 720 Hours

- Utilize the Optional TLVs of the existing NE Object to carry full ERLT information.
**SEEOF Implementation to RPL**

- **Node energy object Re-defined**

<table>
<thead>
<tr>
<th>Flags</th>
<th>1</th>
<th>T</th>
<th>E</th>
<th>E_E (Months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hours</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

  **Type** 0-1, **Length** 0xff

  - **MLPDs**
    - `'T'` → 0
    - `'E_E', 'Days', 'Hours' = 0xff`
  - **BPDs**
    - `'T'` → 1
    - `'E_E', 'Days', 'Hours' = ERLT`

- **Max value of ERLT that can be advertised is up to 21 years.**

- **Advantages** of using Node Energy Object.
  - No new metric Object has to be defined.
  - `'T'` flag → gives information about the type of the parent (MLPD or BPD) necessary for optimal and energy efficient parent selection in SEEEOF

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**Example Table**

<table>
<thead>
<tr>
<th>Type</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>0xff</td>
</tr>
</tbody>
</table>
SEEOF: Summary

Drain Rate → Residual Energy

Residual Energy + Estimated Remaining LifeTime → ERLT

ERLT + Link ETX → Additive combination

Additive combination + Lexical combination → Smart Cost Function

Smart Cost Function

\[ C = f(\text{pathETX}) \]

\[ C = f(\text{linkETX}, \text{ERLT}) \]

Parent Selection
Simulation

- The performance evaluated using Cooja Simulator with ContikiOS.

- Compared with MRHOF using ETX metric
  - better suited in terms of energy consumption, PDR and latency

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol</td>
<td>RPL</td>
</tr>
<tr>
<td>Device Model</td>
<td>TMote Sky (MSP430 + CC2420)</td>
</tr>
<tr>
<td>Number of Nodes</td>
<td>18</td>
</tr>
<tr>
<td>Radio Medium</td>
<td>UDGM-Distance Loss</td>
</tr>
<tr>
<td>Battery Capacity</td>
<td>3.65AH, 1.6V</td>
</tr>
<tr>
<td>RX Success Ratio</td>
<td>40%, 60%, 80%, 100%</td>
</tr>
<tr>
<td>Simulation Time</td>
<td>60 Hours</td>
</tr>
</tbody>
</table>

Simulation Time: 60 Hours
Simulation Topology

- Sink (Node 1)
- MLPD (Even)
- BPD (Odd)
- 18 nodes
- All cases involved
  - MLPD Parents
  - BPD Parents
  - Hybrid Parents

Result Evaluation: only for the BPDs at the end of the simulation time
Graphs (Network Behavior)

- **Total energy consumed** by the BPDs in the network

![Network Energy Consumption](image)

- Total Energy consumption lower in proposed Algorithm [SEEOF]
Graphs (Network Lifetime)

- Minimum lifetime among all the BPDs in a network

Network Lifetime higher in proposed Algorithm [SEEOF]
Graphs (End to End PDR)

- \( PDR = \frac{\text{Total packets received}}{\text{total packets sent}} \); MAINTAINED

<table>
<thead>
<tr>
<th>Packet Reception Ratio</th>
<th>MRHOF</th>
<th>SEEOP</th>
</tr>
</thead>
<tbody>
<tr>
<td>40%</td>
<td>0.999990741</td>
<td>0.999990741</td>
</tr>
<tr>
<td>60%</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>80%</td>
<td>0.99981483</td>
<td>0.99990742</td>
</tr>
<tr>
<td>100%</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
BPD Router Behavior

- (60% Reception ratio)

Higher Energy Consumption

Node 5 & 9 are BPD Routers

Lower Lifetime
BPD Router Behavior (Nodes 5 and 9)

Large Gap

Much Balanced

RE vs Time

ERLT vs Time

Time (mins)

Time (mins)

(hours)

(mJ)
Conclusion

- New parent selection algorithm (SEEOF) developed
  - Enabling gas/water meters work in parallel with meshed network containing electric meters.
    - New Cost function for BPDs
      - Link quality
      - Node energy in terms of lifetime
  - Implemented to RPL
    - Metric ERLT advertised using existing NE object.

- Performance evaluation in ContikiOS with Cooja.

- Simulation results show
  - Energy consumption is balanced more efficiently (Fair Distribution).
  - Improvement in the network lifetime (upto 27%).
Future Work

- Implementation on the test-bed
- Scalability in terms of more number of BPD hops
Thank You...

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