Exploiting Addresses Correlation to Maximize Lifetime of IPv6 Cluster-based WSNs

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Introduction

Related Work

Network Lifetime Optimization

Results

Conclusion and Future works
Introduction

- Wireless sensor networks
- Need of network lifetime improvement
  - Lifetime of several years
Lifetime improvement methods

- Energy harvesting
- Duty cycling
- **Compression / aggregation**
- Energy-efficient networking protocol
- **Clustering**
- Cross layering
- Power management
- Sinks mobility
Compression

- Compression / aggregation
  - Minimizes the number and the size of the packets transmitted
- Packet = control + payload
- Most of studies target payload (data)
Packets in IPv6 context

- 6LoWPAN networks
- IEEE 802.15.4  MTU 127 octets
  - 25 octets MAC Header
  - 21 octets Security (AES)
  - 40 octets IPv6 Header
  - 8 octets  UDP Header
  - 33 octets for data

- We focus on the control header, namely addresses fields
## Control Part Compression

### Header compression

- **Link compression**
  - RFC1144 [1]
  - IP header compression IPHC [2]
  - ROBust header compression ROHC [3]

- **Hop by Hop 6LoWPAN**
  - LoWPAN HC1 (link-local unicast addresses) [4]
  - LoWPAN HC1g (link-local + global intra 6LoWPAN) [5]
  - LoWPAN IPHC (link-local+ global+multicast) [6]

### Kronewitter

- Short addresses assigned to nodes with lowest energy [7]
Motivation

- Is there a **distributed method** than can offer further reduction of the addresses size?
- Can nodes take advantage of the traffic that is not destined to them? *(overhearing)*
Network Model

Diagram of sensor network with different types of sensors and sinks.
Optimize the placement of line-powered nodes to allow battery-powered nodes to:

- Exploit overhearing and correlated addresses
- Reduce the size of the transmitted addresses
Exploiting overhearing

Line-powered sensor

$Y_1$  
$A_{Y_1}$

 Sink

$S_2$  
$A_{S_2}$

Battery-powered sensor
Exploiting overhearing

Line-powered sensor

\[ Y_1 \rightarrow H(A_{Y_1}) \rightarrow \text{Sink} \]

Battery-powered sensor

\[ S_2 \rightarrow A_{S_2} \]
Exploiting overhearing

Line-powered sensor

\[ Y_1 \rightarrow H(A_{Y_1}) \rightarrow \text{Sink} \]

\[ H(A_{S_2} / A_{Y_1}) \leq H(A_{S_2}) \]

Battery-powered sensor

\[ A_{Y_1} \rightarrow \cdots \rightarrow A_{S_2} \]

\[ S_2 \]
Slepian-Wolf coding [8]

- Lossless distributed source coding
- Represents in the most concise way the information produced by a source
- High compression rate in high correlated sources
Exploiting overhearing

Line-powered sensor

\[ Y_1 \]
\[ A_{Y_1} \]

\[ d_H(A_{Y_1}, A_{S_2}) = 1 \]

Sink

\[ S_2 \]
\[ A_{S_2} \]

Battery-powered sensor
Exploiting overhearing

**Line-powered sensor**

\[ B_{Y_1} = A_{Y_1} \]

\[ d_H(A_{Y_1}, A_{S_2}) = 1 \]

**Battery-powered sensor**
Exploiting overhearing

Line-powered sensor

$Y_1 \rightarrow B_{Y_1} = A_{Y_1}$

Battery-powered sensor

$S_2 \rightarrow B_{S_2} = \sigma(A_{Y_1} \oplus A_{S_2}) = (A_{Y_1} \oplus A_{S_2}) \cdot H'$

$d_H(A_{Y_1}, A_{S_2}) = 1$

$[n, k, d]$ binary linear code $C$, $d \geq 2d_H(A_{Y_1}, A_{S_2}) + 1$, $n$ code length, $k$ code dimension, $d$ minimum weight of the code

Compression gain: $n - k$
Example

Line-powered sensor

\[ B_{Y_1} = DD92:8000::1:406 \]

\[ B_{S_2} = \sigma(A_{Y_1} \oplus A_{S_2}) = 7F \] (8 bits)

[128,120,4] code

Battery-powered sensor

\[ d_H(A_{S_1}, A_{S_2}) = 1 \]

\[ A_{S_1} = DD92:8000::1:406 \] (128 bits)

\[ A_{S_2} = DD92:8000::1:407 \] (128 bits)
Compression gain

- If the correlated addresses differ only in one bit
  - 16-bits address and [16,11,4] code → 5 bits
  - 32-bits address and [32,26,4] code → 6 bits
  - 64-bits address and [64,57,4] code → 7 bits
  - 128-bits address and [128,120,4] code → 8 bits
The maximum network lifetime and the optimal placement of line-powered nodes

\[ T = \max_{l \in L} \left[ \min_{i \in S} t^l_i \right] \]

\[ t^l_i = \left( \frac{e^0}{p^l_i} \right), \quad l \in L, \quad i \in S \]
Power consumption

\[ p_i^l = \delta_i \times (g_r \times E_e + g_r \times E_c) + r_{iz}^l \times (E_e + E_{amp} \times d_{iz}^B), \ i \in S, \ j \in N_i^l, \ l \in L \]

Distance bound

\[ d_{\min} = \left( \frac{E_e \times \gamma + E_c}{E_{amp} \times (1 - \gamma)} \right)^{\frac{1}{\beta}} \]
Addresses allocation

\[ d_H (A_{Y_i}, A_{S_j}) = 1 \]
\[ d (S_i, z) \geq d_{\text{min}} \]
\[ d (Y_i, S_j) \leq d (Y_i, z) \]
### Simulations

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery-powered nodes</td>
<td></td>
</tr>
<tr>
<td>Line-powered sensors</td>
<td></td>
</tr>
<tr>
<td>Packet size U</td>
<td>508, 762, 1016 bits</td>
</tr>
<tr>
<td>Address size X</td>
<td>16, 32, 64, 128 bits</td>
</tr>
<tr>
<td>gr</td>
<td>1 packet per hour</td>
</tr>
<tr>
<td>Ec</td>
<td>5, 10, 50 nJ/bit</td>
</tr>
<tr>
<td>Ee</td>
<td>10, 50, 100 nJ/bit</td>
</tr>
<tr>
<td>β</td>
<td>2</td>
</tr>
<tr>
<td>Eamp</td>
<td>100 pJ/bit/m2</td>
</tr>
<tr>
<td>e0</td>
<td>16200 J (AA battery, 3 Ahr, 1.5V)</td>
</tr>
<tr>
<td>Confidence interval</td>
<td>95 %</td>
</tr>
</tbody>
</table>
Network Lifetime gain-1

Ee=50nj/bit, U=508 bits, X=128 bits  
Ec=5nj/bit, U=508 bits, X=128 bits
Network Lifetime gain-2

Ee=50nj/bit, Ec=5nj/bit, U=508 bits

Ee=50nj/bit, Ec=5nj/bit, X=128 bits
Network Lifetime gain-3

400mx400m network
4 clusters
4 Line-powered sensors
40 battery-powered sensors
Packet of 400 bits each hour
128 bits addresses
25 % network lifetime improvement

Ee=50nj/bit, Ec=5nj/bit
Conclusion

- Maximizing network lifetime
  - Propose an optimization problem of the placement of Line-powered nodes
  - Exploiting overhearing and addresses correlation
  - Reducing addresses size by using Slepian-Wolf coding

- Results show 25% lifetime improvement in cluster-based WSN
Future Works

- Evaluation in multi-hop large scale networks
- Addresses allocation scheme to guarantee high correlation in multi-hop networks
Thanks for your attention


