TDMA-Schemes for Tree-Routing in Data Intensive Wireless Sensor Networks

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Sensor networks are increasingly used in applications where sensors periodically measure data with high frequency.

**Problem**

How to reliably transport high volumes of data through unreliable multi-hop networks.

- Difficulties derive from:
  - wireless communication
  - tight resources
  - malfunction of sensors

- Focus of this work: energy and memory efficiency
Motivation

Premises

- Stationary sensor network
- Sensing and forwarding phase
  - Sensing phase: Data is stored in persistent storage
  - Forwarding phase: Stored data is forwarded
- Nodes have fixed amount of buffer space
- Forwarding via routing tree

Data transmission problem (DTP)

Transport all data packets via a routing tree efficiently to sink

- Contribution of this work:
  An energy efficient solution of DTP based on TDMA
Idea: Exploit tree structure
Goal: No idle listening and low control packet overhead

Approach
- Nodes can only send packets to parents, which respond with an acknowledgment
- Nodes cannot proactively send packets to children
- Remedy against buffer overflow: Parents advise children to suspend sending if buffer is full (with acknowledgment)
- Realization with a TDMA protocol

Advantage: Nodes only listen when child is about to send packet
# TDMA-Schemes

## Approach

**Type I:** More than one node per slot  
**Type II:** Exactly one node per slot  
**Type III:** More slots than nodes

<table>
<thead>
<tr>
<th>Type</th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concurrent transmissions</td>
<td>possible</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Collisions</td>
<td>possible</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Setup of scheme</td>
<td>complex</td>
<td>simple</td>
<td>medium</td>
</tr>
<tr>
<td>Passing slots among nodes</td>
<td>not possible</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

**Question**

Which scheme is most suitable for DTP?
Goals

- Increase the sampling rate of sensors
  - Minimize total completion time and
  - Minimize buffer usage for packets in transit
- Algorithms must
  - handle different loads at different nodes
  - account for communication errors
Classical TDMA, Example

Minimum number of time slots for DTP for unlimited buffer:

$$\max_{x \text{ child of } S} s \sum_{i \in T_x} L_i$$

Problems:
- Hard to set up with small $s$
- Not completely free of collisions
- Once node has forwarded all packets, its slot is no longer used
- No straightforward way to reassign a slot
- Buffer requirements (children have more slots)
Simple slot assignment

No collisions (provided accurate time synchronization)

Nodes that have forwarded all data hand over slots to parents

Problem: Bottom-up style leads to more buffer overflow

Better solutions:
- A node keeps every other slot handed over by children, all other slots are passed on to parent
- A node keeps every $d + 1$ th slot ($d$ depth of node)

Example
40 nodes
500 packets stored per node
Length of time slot 100 ms
Length of round 4 s
Buffer limit 1,000 packets
Simulation

Variant 1: All forwarded slots remain with parent
Variant 2: Every second forwarded slot remains with parent
Simulation

Variant 2: Every second forwarded slot remains with parent
Variant 3: A node keeps every $d + 1$ th forwarded slot
Advantage of 2\textsuperscript{nd} alternative:
- If a node keeps a slot, all nodes on path to sink have already received an additional slot
- Total completion time is reduced
- Simple to implement
- Scheme does not consider individual loads and buffer sizes
Type III

- Principle: Number of assigned slots depends on slots of children and buffer load
  
  \[ s_i = \lceil L_i/C \rceil + \sum_{j \in Ch(i)} s_j \]

- Example

- Comparison

<table>
<thead>
<tr>
<th>TDMA Scheme</th>
<th># time slots</th>
<th>buffer load (node 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 slots</td>
<td>1520</td>
<td>210</td>
</tr>
<tr>
<td>5 slots</td>
<td>1900</td>
<td>210</td>
</tr>
<tr>
<td>Type II</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>936</td>
<td>152</td>
</tr>
<tr>
<td>Type III</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C=30</td>
<td>1110</td>
<td>102</td>
</tr>
<tr>
<td>C=10</td>
<td>930</td>
<td>119</td>
</tr>
</tbody>
</table>
Slot assignment based on depth first search

Performance:
- DTP needs at most $C$ rounds, provided no buffer overflow and no packet loss
- A round consists of $\sum_{i \in T^*} d(i) \lceil L_i/C \rceil$ slots
- Maximal buffer load of node $i$ is $L_i + s_i - \lfloor L_i/C \rfloor$

Role of $C$:
- Buffer requirements rise when $C$ gets smaller
- but completion time of DTP falls
Work on TDMA-schemes for DTP in data-intensive WSNs
Simple schemes that use slots exclusively are superior to classical schemes
Schemes of type II/III are faster and require less buffer
Type III schemes observe sizes of available buffer space
Current work: Simulation and field test of schemes II and III
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