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

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Introduction

- 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

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

Communication Scheme

- 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

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

Type	I	II	III
Concurrent transmissions	possible	no	no
Collisions	possible	no	no
Setup of scheme	complex	simple	medium
Passing slots among nodes	not possible	yes	yes

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

Type I

- 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)

Type II

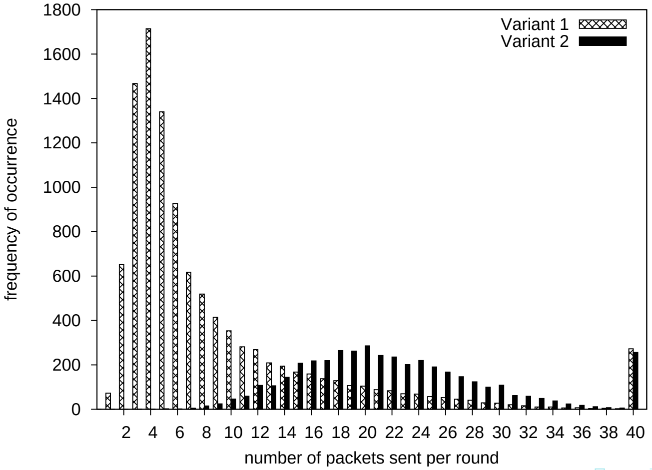
- Simple slot assignment
- No collisions (provided accurate time synchronization)
- Nodes that have forwarded all data hand over slots to parents
- Problem: Bottom-up style leads to more buffer overflow
- Better solutions:
  - A node keeps every other slot handed over by children, all other slots are passed on to parent
  - A node keeps every $d + 1$ th slot (d depth of node)
- Example

Simulation

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

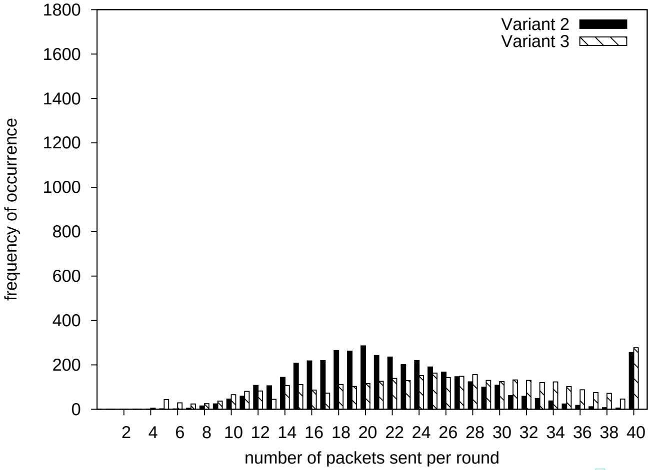
Simulation

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



Type II

- Advantage of 2^{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

TDMA Scheme		# time slots	buffer load (node 1)
Type I	4 slots	1520	210
	5 slots	1900	210
Type II		936	152
Type III	C=30	1110	102
	C=10	930	119

Tpye III

- 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 $L_i + s_i - \lceil L_i / C \rceil$
- Role of C:
  - Buffer requirements rise when C gets smaller
  - but completion time of DTP falls

Conclusion

- 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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