Consensus-based Decentralized Resource Sharing between Co-located Wireless Sensor Networks

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Outline

• Introduction
• Motivation and contributions
• Problem and proposed solution
• Consensus algorithm
• Experimental setup
• Results
• Conclusions and future work
Introduction

• Internet of Things (IoT)
  – Smart buildings, smart cities

• Co-located WSNs
  – stand-alone entities

• Inter-network communication

• Centralized structure (negotiation manager)¹

• Energy sharing between energy-harvesting WSNs²

• All-to-all communication scheme³

Motivation & Contributions

Motivation:
- Decentralized inter-network communication
- Energy- and time-efficient (not interfering with main WSN task)

Contributions:
- A novel approach for enabling inter-network communication
- A time-limited implementation of the parsimonious consensus algorithm that is induced by changes in the environment
- A theoretical and experimental analysis of consensus algorithm trade-offs
Problem

- Co-located WSNs with energy-hungry sensors
- Event-driven sensing
- Indirect resource transfer

We suppose that co-located WSNs are able and willing to engage in inter-network communication!
Proposed solution

• Focus on consensus-based *intra-network communication*
  – enable decentralized *inter-network communication*

• Each node in the network can initiate the consensus algorithm and determines the estimate of the energy state in its network by only communicating with its neighbors in intra-network communication.

• Reduce the time the radio is occupied
Consensus algorithm

- Energy-efficient, fast
- Not interfere with the main task of WSN (detecting and reporting interesting events)
- If network topology contains a directed spanning tree, the nodes $x_i$ achieve consensus $\|x_i - x_j\| \rightarrow 0$

$$\dot{x}_i = - K \sum_{j \in N_i} (\hat{x}_i - \hat{x}_j) + \omega_i$$

- Consensus (agreement) achieved when all nodes’ states $x_i$ enter $\epsilon$-vicinity
Used topology

- Topology discovery
- Communication slots
- Partitions (avoid collisions)
**Trade-offs**

- **Convergence**
  - Depends on $\tau K$ product
  - Increasing $\tau$, system is more susceptible to noise $\rightarrow$ divergence!
  - For every $K$, there is a $\tau_{\text{max}}$ (boundary of convergence). The larger the $K$, the lower the $\tau_{\text{max}}$.

- **Time-efficiency**
  - For a fixed $K$, the convergence rate increases with decreasing $\tau$.

- **Energy-efficiency**
  - Energy consumed by a node to reach consensus:
    \[ E = P_{T\tau} CT\tau \]

**Challenge:**
Choosing parameters ($\tau$, $K$) to satisfy those three conditions!

\[ \tau \geq \max\{t_{TX}, t_{RX}\} \]
Experimental setup

• A network of 5 TI eZ430-RF2500 nodes
  – MSP430, CC2500

• 2.2 ms for transmitting/receiving a small packet (24 B)
  → hardware-dependent $\tau_{\text{min}}$
\[ P_{Tr} = \frac{1}{T} \left( \sum_{\text{mode}} P_{\text{mode}} \cdot t_{\text{mode}} + \sum_{\text{trans}} P_{\text{trans}} \cdot t_{\text{trans}} \right) \]

Energy consumption

- MCU on; Transceiver on, RX: 21.30 mA
- MCU on; Transceiver on, TX: 25.11 mA
- MCU on; Transceiver off: 3.00 mA
- MCU off; Transceiver off: 0.001 mA

Node operating mode
Results

• Chosen parameters \( K = 1 \); \( \varepsilon = 0.4 \)
• Different \( \tau \) (from \( \tau_{\text{min}} = 2.2 \text{ ms} \) to \( \tau_{\text{max}} = 0.3 \text{ s} \))
• Time to reach consensus \( t_{\text{conv}} = CT\tau \)

\[
ETF = \frac{E_{t_{\text{conv}}}}{(E_{t_{\text{conv}}})_{\text{min}}}
\]

![Graph showing energy consumption and time to reach consensus against \( \tau \)]
Results

States of the nodes for $\tau=0.1\,[s]$

- $x_1$
- $x_2$
- $x_3$
- $x_4$
- $x_5$

Battery state [%] vs. time [s]
Conclusions

- Experimental verification for our topology
- Best performance for $\tau = 0.1$ s (2% duty cycle)
- Convergence time 3.5 s, energy consumption 36 mJ
- Does not jeopardize the WSN performance

Future work
- Time and energy dependence for a range of different initial states and different topologies
- Topology discovery – for mobile networks and node loss problems
Thank you for your attention!

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