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

Vana Jeličić, Domagoj Tolić, and Vedran Bilas

University of Zagreb, Faculty of Electrical Engineering and Computing, Croatia

vana.jelicic@fer.hr

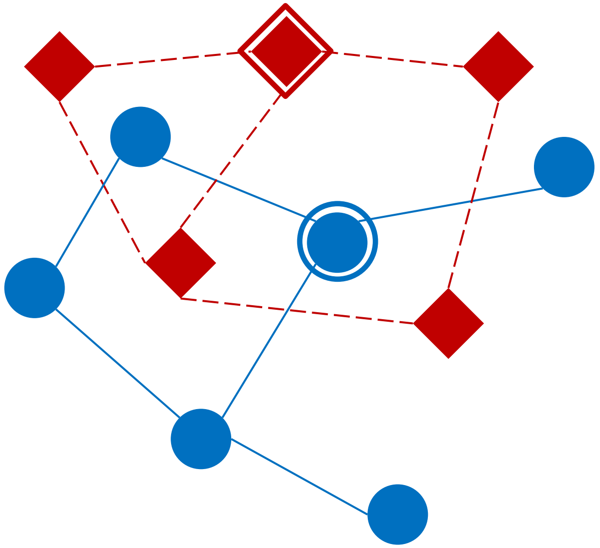
IEEE ISSNIP, 21-24.4.2014., Singapore

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 WSNs[2]
- All-to-all communication scheme[3]

1) De Poorter *et al.*: "A negotiation-based networking methodology to enable cooperation across heterogeneous co-located networks", *Ad Hoc Networks,* 2012.
2) Jiang *et al.*: "Opportunistic energy trading between co-located energy-harvesting wireless sensor networks", *1st Int'l Workshop on Energy Neutral Sensing Systems (ENSSys)*, 2013.
3) Landsiedel *et al.*: "Chaos: Versatile and efficient all-to-all data sharing and in-network processing at scale", *11th ACM Conf. on Embedded Networked Sensor Systems (SenSys),* 2013.

Motivation & Contributions

MOTIVATION:

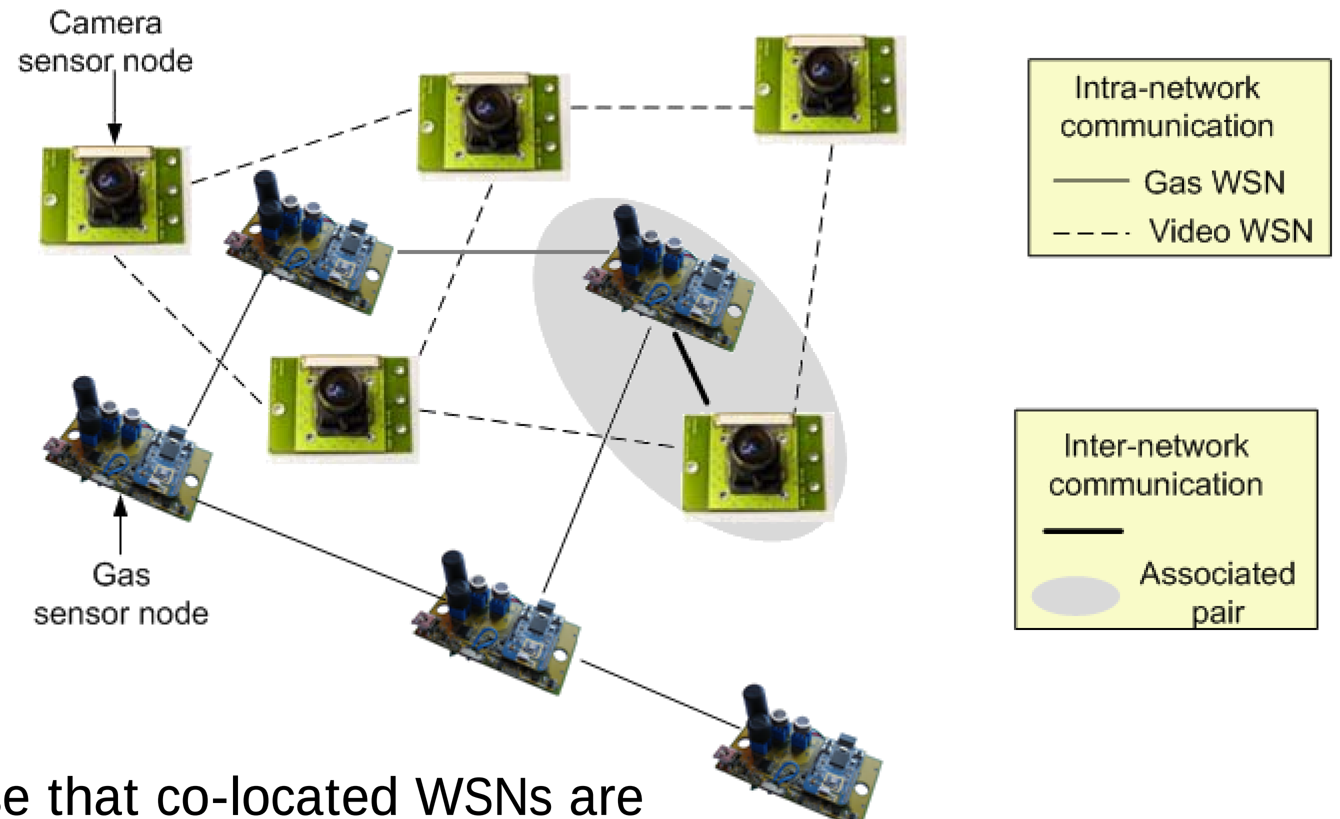
- Decentralized inter-network communication
- Energy- and time-efficient (not interfering with main WSN task)

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

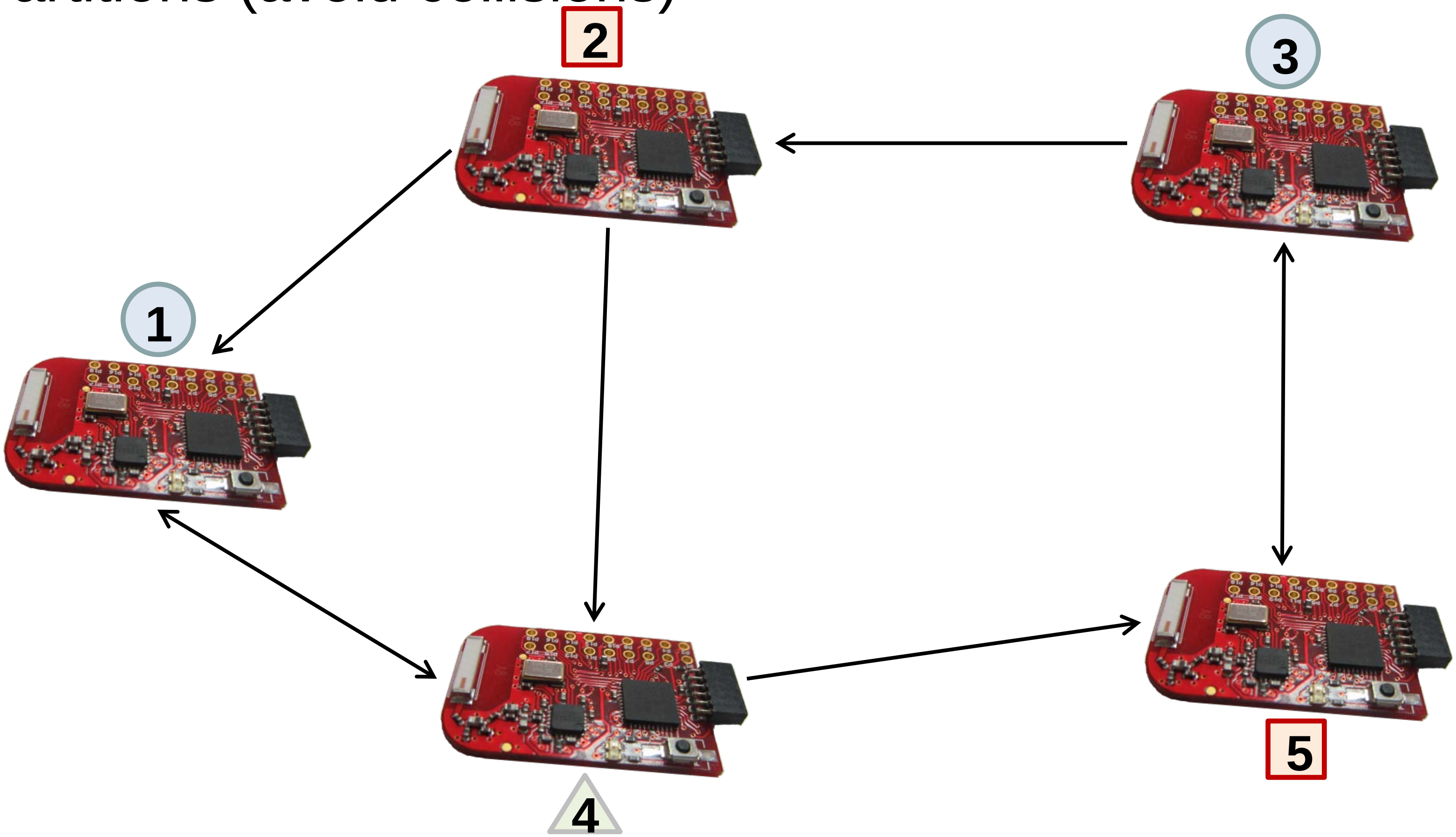
- Energy-efficient, fast
- Not interfere with the main task of WSN (detecting and reporting interesting events)
- If network topology contains a directed spanning tree, the nodes x_i achieve consensus $\left\| x_i - x_j \right\| \to 0$

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

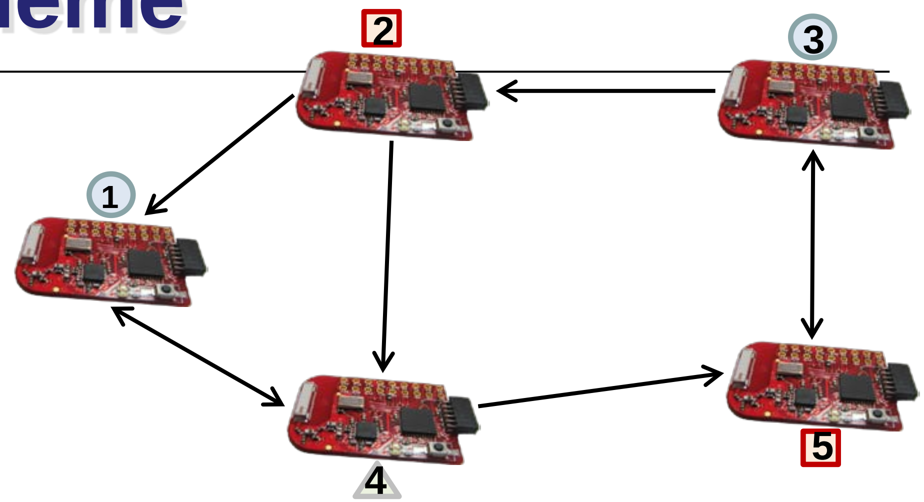
- Consensus (agreement) achieved when all nodes' states x_i enter ε-vicinity

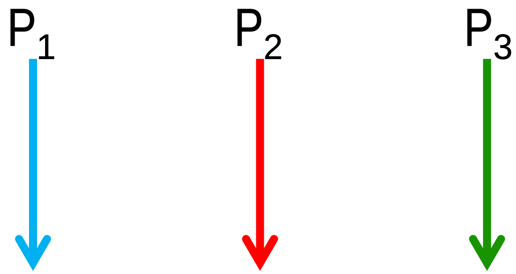
Used topology

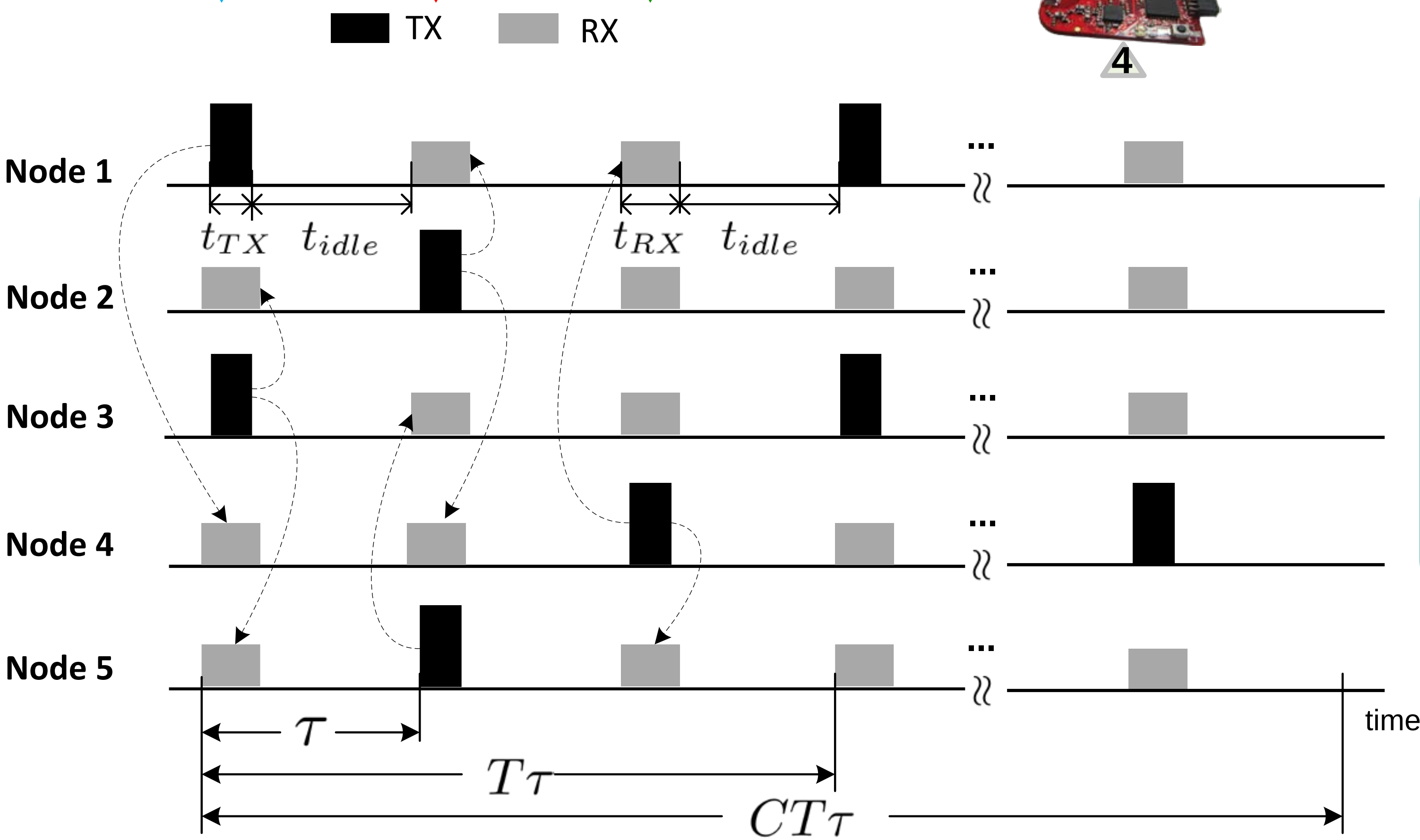
- Topology discovery
- Communication slots
- Partitions (avoid collisions)



Communication scheme







τ Inter-partition time interval

T Number of partitions

C Number of communication cycles

Trade-offs

- Convergence
  - Depends on τK product
  - Increasing τ, system is more susceptible to noise → divergence!
  - For every *K*, there is a $\tau_{\max}$ (boundary of convergence). The larger the *K*, the lower the $\tau_{\max}$.
- Time-efficiency
  - For a fixed *K*, the convergence rate increases with decreasing τ.
- Energy-efficiency
  - Energy consumed by a node to reach consensus:

$$E = P_{T\tau} C T \tau$$

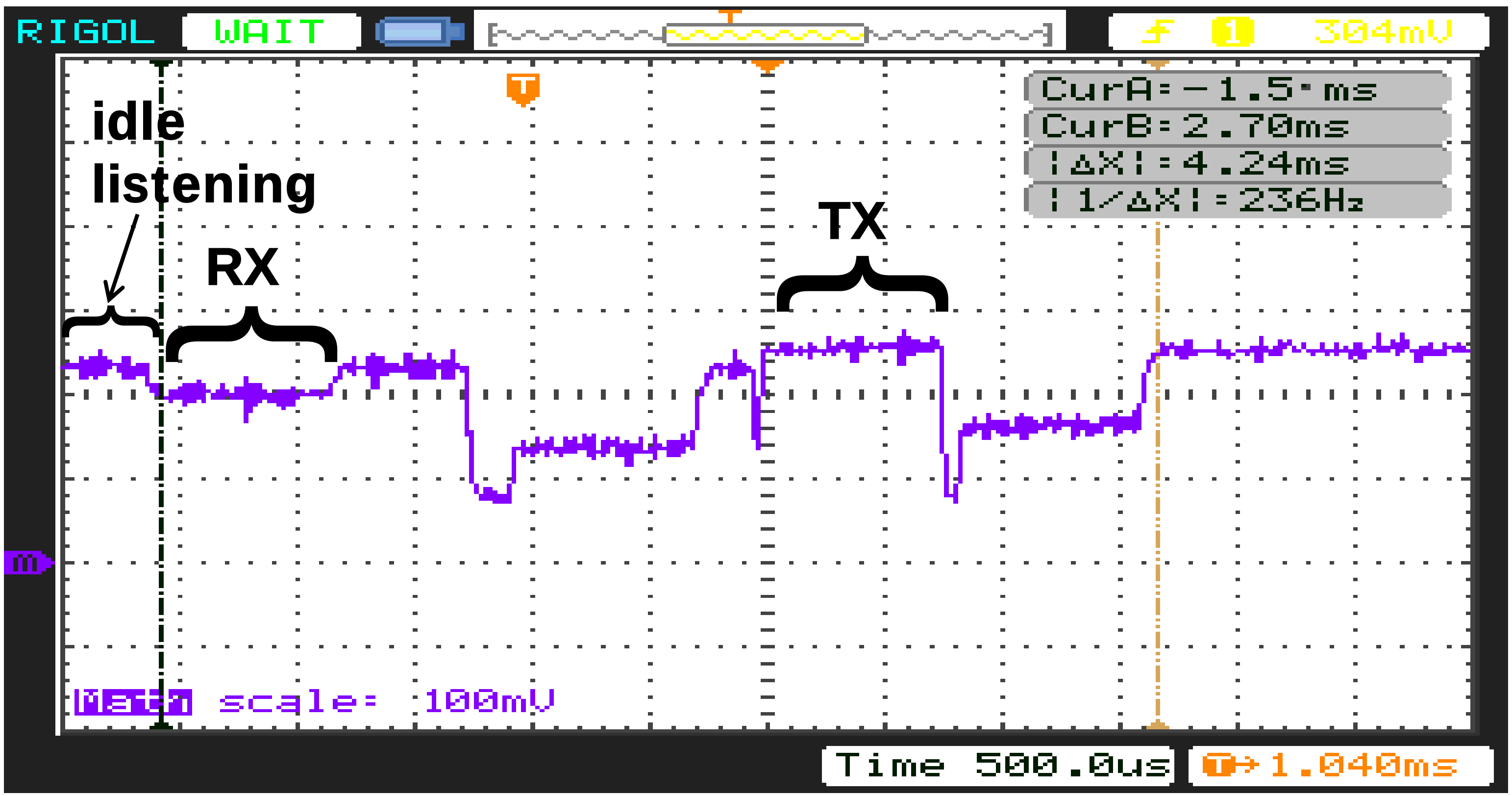
Challenge:
Choosing parameters (τ, *K*) to satisfy those three conditions!

$$\tau \geq \max\{t_{TX}, t_{RX}\}$$

Experimental setup

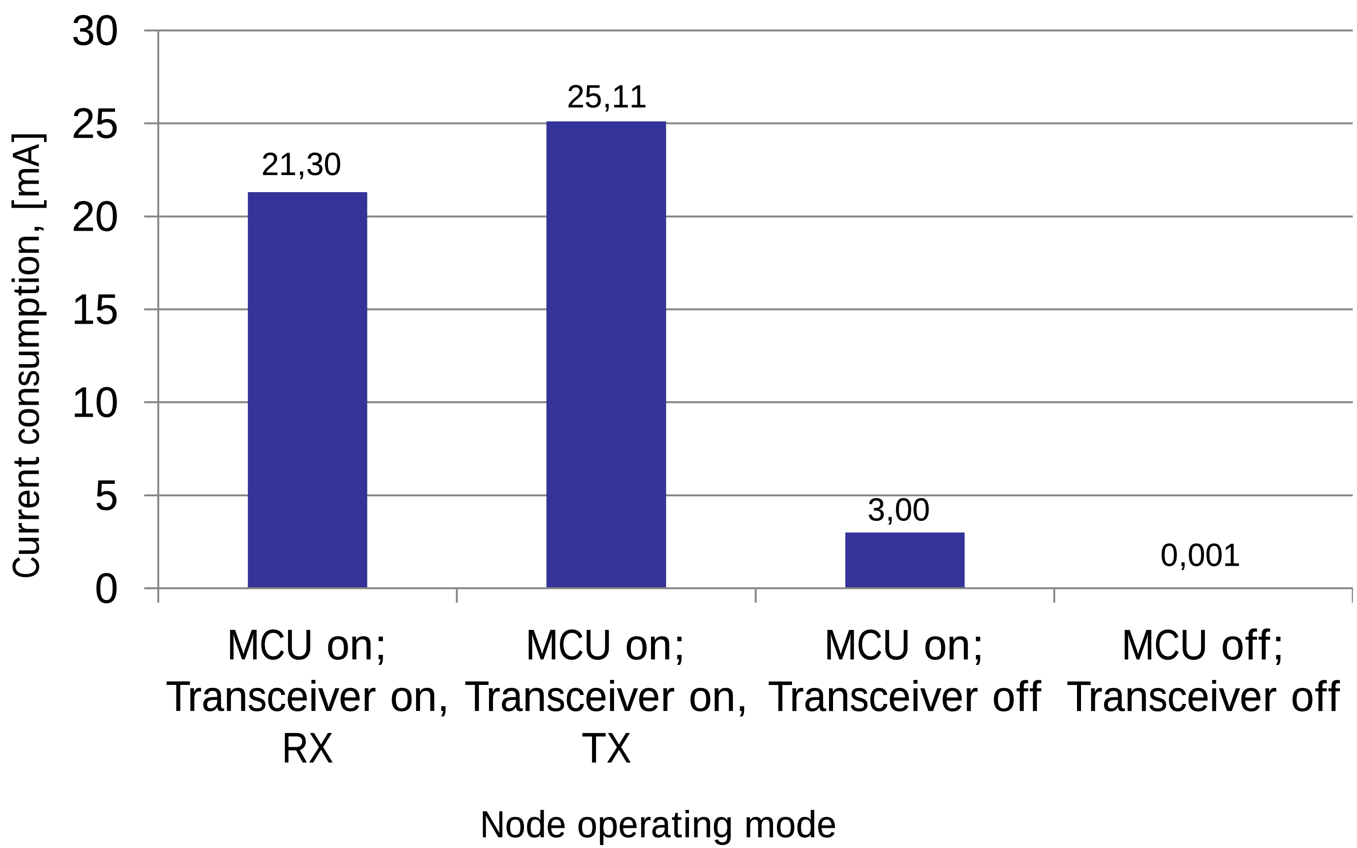
- A network of 5 TI eZ430-RF2500 nodes
  - MSP430, CC2500
- 2.2 ms for transmitting/receiving a small packet (24 B)

  → hardware-dependent $\tau_{\min}$



Energy consumption

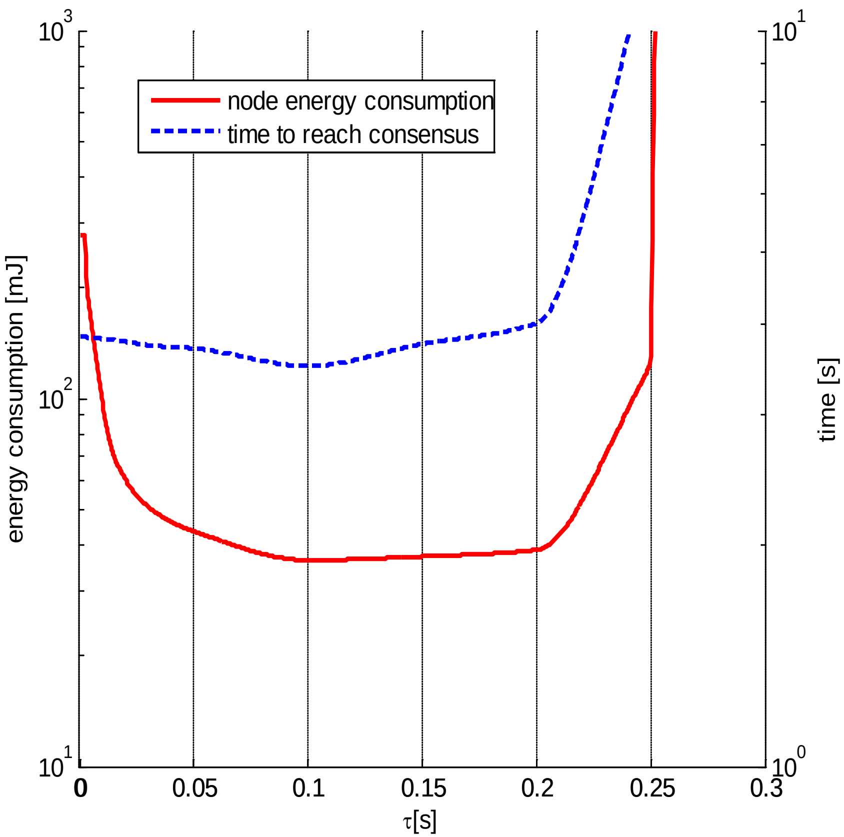
$$P_{T\tau} = \frac{1}{T\tau}\left(\sum_{mode} P_{mode} \cdot t_{mode} + \sum_{trans} P_{trans} \cdot t_{trans}\right)$$

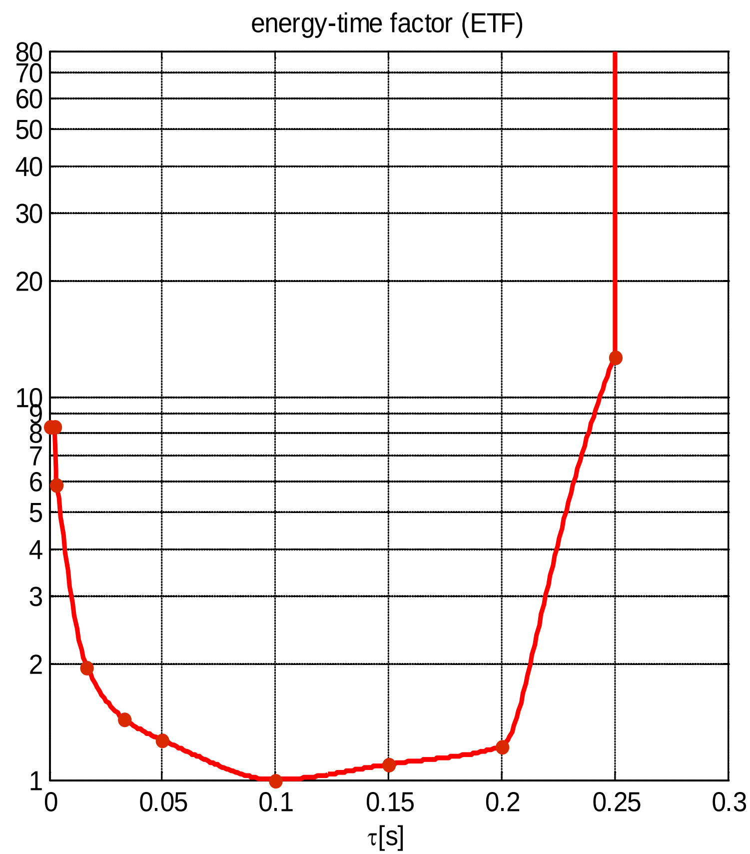


Results

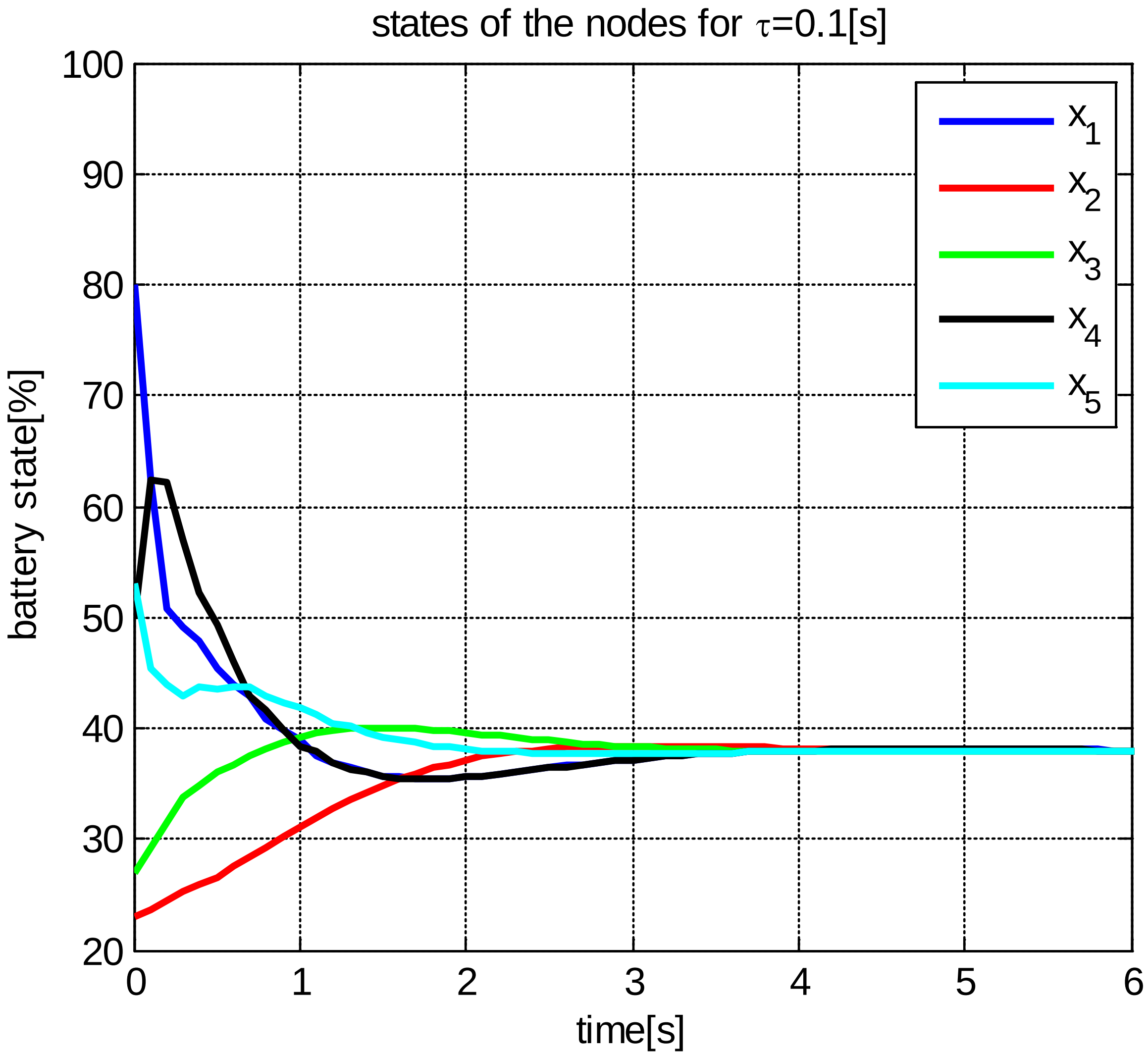
- Chosen parameters $K = 1$; $\varepsilon = 0.4$
- Different τ (from $\tau_{\min} = 2.2$ ms to $\tau_{\max} = 0.3$ s)
- Time to reach consensus $t_{conv} = CT\tau$

$$ETF = \frac{Et_{conv}}{\left(Et_{conv}\right)_{\min}}$$





Results



states of the nodes for τ=0.1[s]
battery state[%]
time[s]
100
90
80
70
60
50
40
30
20
0
1
2
3
4
5
6
x1
x2
x3
x4
x5

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!

Contact: **vana.jelicic@fer.hr**

www.unizg.fer.hr/across

ACROSS

Centre of Research Excellence
for Advanced Cooperative Systems