A Communication Mechanism using Traveling Wave Phenomena for Wireless Sensor Networks

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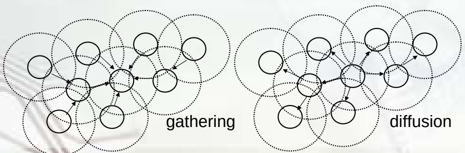
Traveling Waves in Nature

- Synchronous flashing of fireflies

Goal of this Research

- Generate traveling waves inspired by biology for periodic communication in WSN:
  - Information gathering (e.g. temperature data) sensor nodes → base station
  - Information diffusion (e.g. control signals) base station → sensor nodes

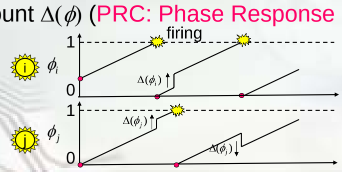


Why use Traveling Waves?

- Synchronization of message emission
  - Efficient sleep scheduling possible
    ➔ Energy efficient operation
- Only local interactions between nodes
  - Scalable with number of nodes
  - Fully distributed operation
  - Robust to topology changes
- However:
  Several iterations necessary for adaptation!

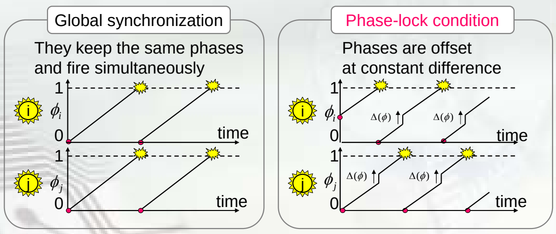
Pulse-Coupled Oscillator Model

- Oscillator i has phase $\phi_i \in [0,1]$
- When the phase reaches 1, the oscillator i fires and the phase jumps back to 0
- Other oscillators coupled with the firing oscillator are stimulated and advance their phase by an amount $\Delta(\phi)$ (PRC: Phase Response Curve)



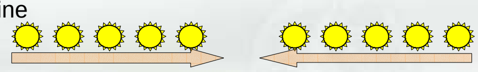
Two Types of Synchronization

- Depending on the initial phase and PRC $\Delta(\phi)$, a set of oscillators reach either:

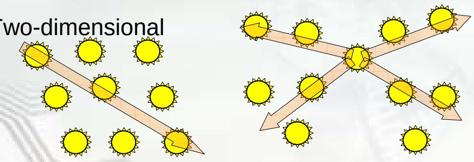


Types of Traveling Wave

- By adjusting parameters and PRC in the PCO model, we can control the traveling wave
  - Line



  - Two-dimensional



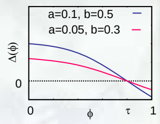
PRC for Generating Traveling Waves

- Conditions of PRC $\Delta(\phi)$ to generate a traveling wave regardless of the initial phases

$$\begin{cases} 0<\Delta(\phi)\le 1-\tau-\phi & (0\le\phi<1-\tau) \\ \Delta(\phi)=0 & (\phi=1-\tau) \\ 1-\tau-\phi\le\Delta(\phi)<0 & (1-\tau<\phi<1) \end{cases}$$

- An example of PRC

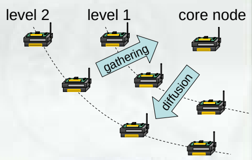
$$\Delta(\phi)=a\sin\frac{\pi}{1-\tau}\phi+b(1-\tau-\phi)$$



a, b: parameters which determine characteristics of PRC
0 < τ < 0.5: diffusion type with phase-difference τ
0.5 < τ < 1: gathering type with phase-difference 1-τ

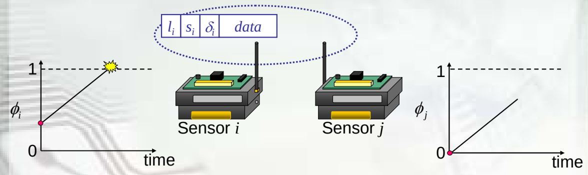
Communication Mechanism

- Core node
  - Sensor node that gathers / diffuses information
- Sensor node *i* has:
  - Timer $\phi_i \in [0,1]$
  - PRC function $\Delta(\phi)$
  - Offset τ
  - Session identifier s_i
  - Level value l_i
    - Number of hops from the core node
  - Direction of propagation δ_i
    - -1:gathering, 1:diffusion



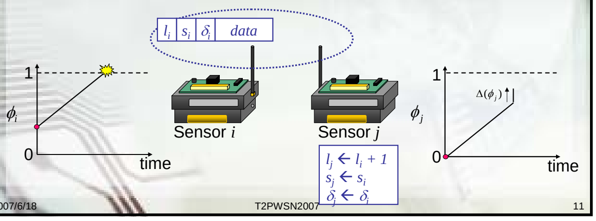
Sensor Node Behavior

- Sensor node *i* broadcasts a message within its radio signal range when timer reaches 1
- A message contains:
  - Level l_i, session id s_i, direction δ_i, sensor data
  - Core node: $l_i \leftarrow 0$, $s_i \leftarrow s_i + 1$ for new session



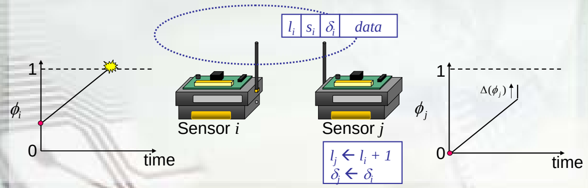
Message Reception (1)

- If session identifier $s_j < s_i$
  - New communication session begins
  - Sensor node *j* sets level l_j, session id s_j, direction δ_j
  - React to stimulation



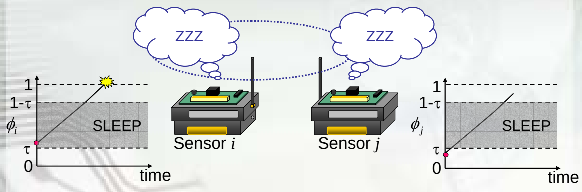
Message Reception (2)

- If session identifier $s_j = s_i$, but level value $l_j > l_i$
  - Sensor node *j* sets level l_j, direction δ_j
  - React to stimulation
- If message comes from upstream node (i.e., $l_j = l_i - \delta_i$)
  - Process received information



Power-saving Mode

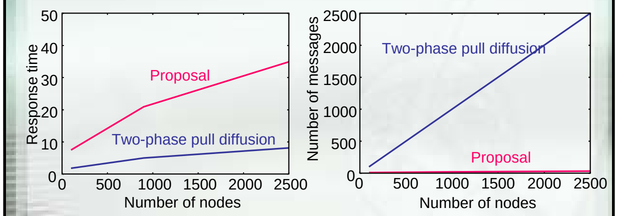
- After traveling wave is generated, sensor node sleeps when $\tau < \phi_i < 1\text{-}\tau$
- Energy consumption is reduced during power-saving mode



Simulation Experiments

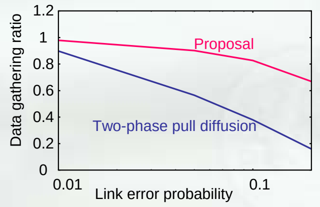
- Simulation settings
  - 100, 900, 2500 nodes are randomly distributed in 10x10, 30x30, 50x50 region
  - Range of radio signal is fixed at 2
  - Offset $\tau = 0.1$
  - A core node gathers information from all nodes
  - Energy consumption model is based on MOTE MICA2
- Evaluation metrics
  - Response time / number of messages
  - Data gathering ratio against packet loss
  - Number of available nodes (lifetime)
- Compared method
  - Two-phase pull diffusion (information gathering)
  - Push diffusion (information diffusion)

Response Time / Number of Messages



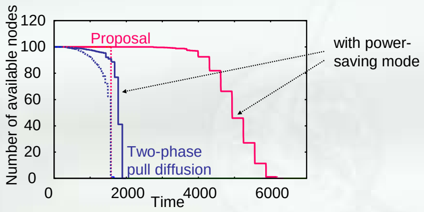
- **Response time:** duration until reception of data from all nodes
- Proposal has larger delay, but less overhead

Data Gathering Ratio vs. Link Error



- **Data gathering ratio:** data reaching core node over all gathered data
- Proposal achieves higher data gathering ratio from multi-path transmission

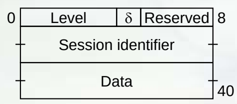
Number of Available Nodes



- Proposal is more energy efficient
- Lifetime of sensor network is extended

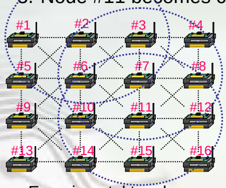
Implementation of the Mechanism

- MOTE MICAz
  - Omni-directional antenna
  - IEEE 802.15.4
- Packet format (40 bits long)



Demonstration Video

- Settings:
  - Cycle time: 3 s, offset τ = 0.3 s
- Scenario:
  1. No core node exists
  2. Node #6 becomes core node for information diffusion
  3. Node #11 becomes core node for information gathering



Experimental topology

Video

Conclusion and Outlook

- Proposal of a bio-inspired communication mechanism for gathering / diffusion in sensor networks
  - Fully distributed and self-organizing
  - Evaluation through simulation and practical implementation
- **Future work**
  - Improvement of the mechanism
  - Additional experiments
    - More nodes, obstructions, interferences, collisions

Thank you