A Distributed and Self-organizing Data Gathering Scheme in Wireless Sensor Networks

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Background
• A data gathering scheme for sensor networks must be
  – energy-efficient
    A sensor node is typically powered by a battery that cannot be easily replaced
  – fully-distributed
    Sensor nodes are often deployed and distributed in an uncontrolled way

Previous work
• Synchronization-based data gathering [2]
  – Fully-distributed, self-organizing, robust, adaptable, scalable, and energy-efficient
  – Sensor information is periodically propagated and aggregated from the edge of a sensor network to the base station
    Concentric circles

Research Target
• Generate a variety of patterns of data gathering
  – Different applications need different types of traveling waves
  – Adopt a pulse-coupled oscillator model

Pulse-coupled oscillator model
• Based on biological mutual synchronization
  – Pacemaker cells, fireflies, and neurons
• Each 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 $A(\phi)$
Two types of synchronization

- Depending on the initial conditions, a set of oscillators reach:
  - Global synchronization
    - They keep the same phases and fire all at once
  - Phase-lock condition
    - Phases are kept constant and different

Variety of traveling waves

- Ring
  - Concentric Circles
  - Radar
  - Assumptions
    - An oscillator ignores all stimuli at the moment of firing
    - An oscillator identifies multiple stimuli received at the same time as one stimulus

Generation of traveling waves

Ring (1)

- A ring of $N$ oscillators
  - An oscillator is stimulated by its two neighboring oscillators
  - Oscillators fire at constant phase-difference $\tau$

Condition for the existence of traveling waves

$$F((N-2)\tau + F(\tau)) + \tau = 1$$
with $F(\phi) = \phi + \Delta(\phi)$

Generation of traveling waves

Ring (2)

- Simulation results
  - $N=10$, $\tau = 0.0964$

Line (1)

- A line of $N$ oscillators
  - An oscillator is stimulated by one or two neighboring oscillators
  - Oscillators fire at constant phase-difference $\tau$, and oscillator $i$ fires after $T$ units of time from a firing of oscillator $N$

Condition for the existence of traveling waves

$$F((N-3)\tau + F(\tau)) + 1 - \tau$$
$$F((N-2)\tau + F(\tau)) = 1 - \tau$$
$$(N-2)\tau + F(\tau) = 1 - T$$

Generation of traveling waves

Line (2)

- Simulation results
  - $N=4$, $T=0.25$, $\tau=0.25$
Generation of traveling waves
Concentric circles (1)

- Concentric circles as in [2]

- Apply the same condition in the case of the line
  - Defining the same initial conditions for oscillators on the same level

Generation of traveling waves
Concentric circles (2)

- Simulation results
  - 25 oscillators, \( T=0.25, \tau=0.25 \)

Generation of traveling waves
Radar (1)

- Radar-like traveling wave
  - Oscillators fire in the order of their level
  - Oscillators fire simultaneously along the front of the “radar beam”

- Assumptions
  - An oscillator receives stimuli only from neighboring oscillators on the same circumference and those in the same radius
  - The center node does not fire, or oscillators on the innermost circle ignore firing of the center node

- We can apply the same condition in the case of the ring for each circumference

Generation of traveling waves
Radar (2)

- Simulation results
  - 60 oscillators
  - \( \tau \) was set at 0.0964, 0.0482, 0.0323 for the inner, middle, and outer circle, respectively

A distributed and self-organizing data gathering scheme

- Assumptions
  - Static and stable sensor network (no addition, removal, or movement of sensor nodes)
  - Communication delay is negligible

- A sensor node has a timer

- Core node: sensor node or a base station that gathers or disseminates information

Initial Settings: Core node

1. Core node determines
   - PRC function \( \Delta(\phi) \)
   - phase-difference \( \tau \)

2. Core node broadcasts a message within its range of radio signals
   - \( \Delta(\phi) \)
   - \( \tau \)
   - type of traveling wave
   - direction of information propagation
   - level value: 0 (diffusion) or \( N \) (fusion)
Sensor nodes: Message reception

- Uninitialized node
  - Adjusts its level and phase in accordance with the type of traveling wave
- Initialized node
  - Examines the message to decide whether it has to be stimulated or not
  - Shifts the timer and periodically emits messages
    * sensor information
    * level value

Conclusion and future work

- Conclusion
  - Investigation of initial conditions that lead to desired phase-lock conditions in the pulse-coupled oscillator model
  - Presentation of a brief sketch of a scenario to apply the pulse-coupled oscillator model to data gathering
- Future work
  - More details taking into account changes in network topology and radio conditions
  - Application scenarios to show the benefit of our scheme

Thank you