


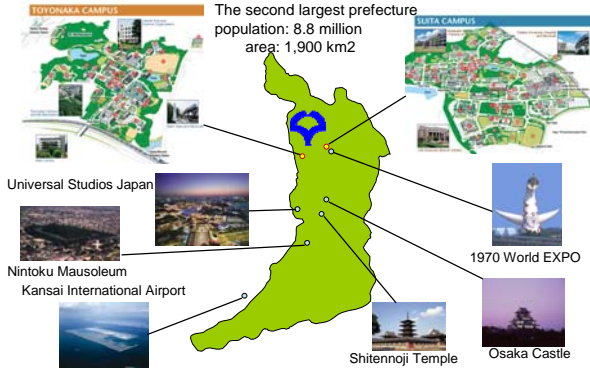
Research Works on Sensor Networking Technologies



Naoki Wakamiya
Osaka University, Japan
wakamiya@ist.osaka-u.ac.jp

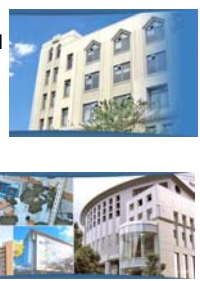
Osaka University

The second largest prefecture
population: 8.8 million
area: 1,900 km²




Osaka University

- established in 1931 as the sixth imperial university
- has
 - 12 faculties/schools
 - 14 graduate schools + 1 law school
 - 5 research institutes
 - 15 joint-use facilities
 - 2 nationwide joint-use facilities
 - 3 university libraries
 - 2 hospitals GRADUATE
- 4,500 staff and 20,000 students
 - undergraduate 12,000
 - + graduate 8,000



Bio-inspired Network Technologies


 "New Information Technologies for Building a Networked Symbiosis Environment" in The 21st Century Center of Excellence Program (COE) of the Ministry of Education, Culture, Sports, Science and Technology of Japan.


New Network Paradigm

- Networks constituting of end nodes
 - Overlay networks
 - Ad-hoc networks
 - Sensor networks
- We need technologies (protocol, algorithm, mechanism)
 - scalable to the size of a network
 - robust to failures of nodes and links
 - adaptive to changes in network conditions
 - fully distributed and self-organizing





Getting Inspiration from Biology

Swarm Intelligence

- The emergent collective intelligence of groups of simple agent.
 - Ant trail (foraging behavior of ants)
 - Cemetery organization and brood sorting
 - Colonial closure
 - Division of labor and task allocation
 - Pattern forming
 - Synchronization in flashing fireflies
- A group exhibits an intelligent and organized behavior without any centralized control, but with local and mutual interactions among individuals (**stigmergy**)
- The behavior is adaptive to changes in environments
- A group keep working even if a part fails




Bio-inspired Networking

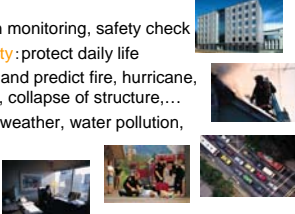
- **Overlay Network Symbiosis**
symbiosis of different cells, organisms, groups, and species 
- **Waveform Synchronized Data Gathering**
synchronized flashes in a group of fireflies 
- **Reaction-Diffusion based Control Scheme for Sensor Networks**
pattern formation on the surface of the body of an emperor angelfish 
- **Scalable Ant-based Routing Scheme**
foraging behavior of ants 

Waveform Synchronized Data Gathering in a Sensor Network

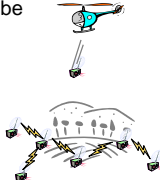
synchronized flashes in a group of fireflies

Sensor Network

- **Sensor node:**
 - Sensor: Temperature, Humidity, Acceleration,...
 - Processor: limited computational capability
 - Memory: limited capacity
 - Wireless Transceiver: 802.11, IrDA, bluetooth,...
 - Battery: sometimes with power supply

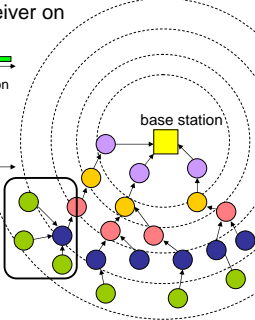
MOTE2
Crossbow Technology, Inc.
- **Application:**
 - **Health and Welfare:** vital sign monitoring, safety check
 - **Crime Prevention and Security:** protect daily life
 - **Disaster Prevention:** monitor and predict fire, hurricane, earthquake, floods, landslide, collapse of structure,...
 - **Environment:** surveillance of weather, water pollution, air pollution,...
 - Others: Plants, factory, farm, transportation, distribution

Requirements

- **Sensor nodes**
 - are many (hundreds to thousands)
 - are deployed in an uncontrolled and unorganized way
 - are added, removed, and moved
 - halt due to depletion of the battery or failure
- Therefore, a control mechanism must be
 - fully-distributed and self-organizing
 - adaptive to changes
 - robust to failures of nodes
 - scalable to the size of a network
 - energy-efficient

Energy-Efficient Periodic Data Gathering

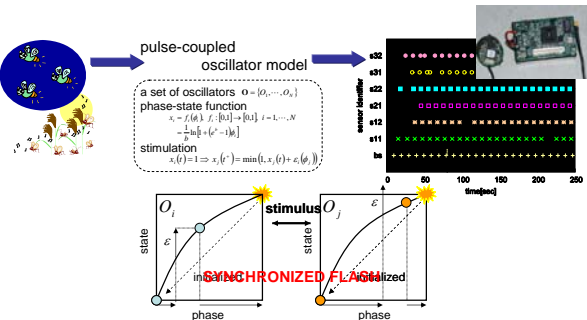
- Turning off unused components contributes very much
 - asynchronous emission
a blue node must keep a receiver on
 - synchronous emission
a blue node can sleep



• **Sensor nodes on the same circumference must be SYNCHRONIZED**

Bio-Inspired Synchronized Data Gathering

- A group of fireflies flash in synchrony
- **Fully-distributed and self-organizing**

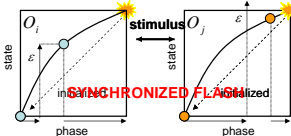
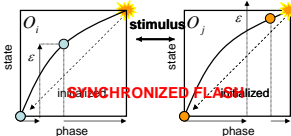
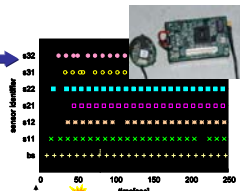


pulse-coupled oscillator model

a set of oscillators $\theta = \{\theta_1, \dots, \theta_N\}$
 phase-state function $x_i = f(\theta_i)$, $f(\theta) = [f_1(\theta), \dots, f_N(\theta)]$, $i = 1, \dots, N$
 $f_i(\theta) = \frac{1}{2\pi} \ln |e^{i(\theta_i - \theta_i)}|$
 stimulation $x_i(t) = 1 \Rightarrow x_i(t^+) = \min(1, x_i(t) + \epsilon_i(t))$

state θ_i phase θ_i stimulus θ_j state θ_j phase θ_j

in SYNCHRONIZED FLASH

Characteristics of Synchronized Data Gathering

It can collect sensor information from a large number of randomly distributed sensors at regular intervals in an energy-efficient way

Sensor information propagates from the edge to the center in a synchronized manner

Data Gathering in a Building

- Unstable and unreliable radio communication
- Components
 - monitoring PC: collects sensor information, a sink
 - parent node: with power supply, wired connection to monitoring PC
 - child node: with battery, wireless connection

Unstable and Unreliable Radio

- Find a stable path to a parent node
 - introduction of a cost function
 - RSSI and the ratio of successful reception

$$\text{cost} = \text{round} \left(\left(S + \left(1 - \frac{R - R_{\min}}{R_{\max} - R_{\min}} \right) \right) \times 10 \right) + C_p$$

- Avoid collisions of wireless communication
 - among child nodes with the same next-hop node
 - regulate timing of packet emission by RSSI
 - among parent nodes with overlapping radio ranges
- Eliminate unidirectional links
 - detection by received packets

Basic Behavior

monitoring PC

- a child node chooses a node with the lowest cost as the next-hop node and gets synchronized
- a child node who cannot communicate with a parent node chooses a neighboring child node as a next-hop node and gets synchronized
- each child node emits a packet slightly earlier than packet emission of its next-hop node
- a parent node emits beacon packets at regular intervals specified by the monitoring PC

Distribution of Packet Emission

- Synchronized emission causes severe collisions
- Regulate timing of packet emission based on RSSI

received radio signal strength R_i , R_j , R_k

parent node

child node i

child node j

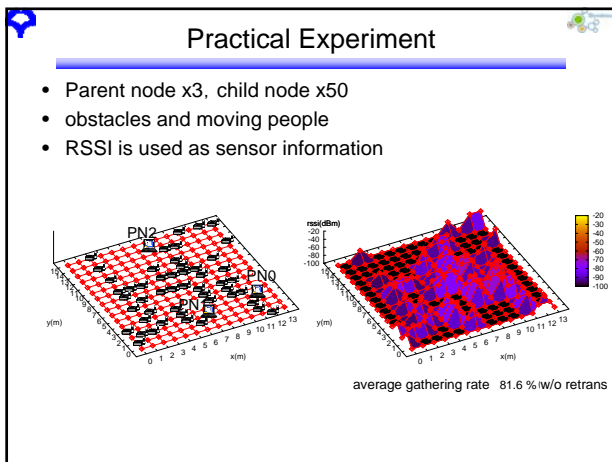
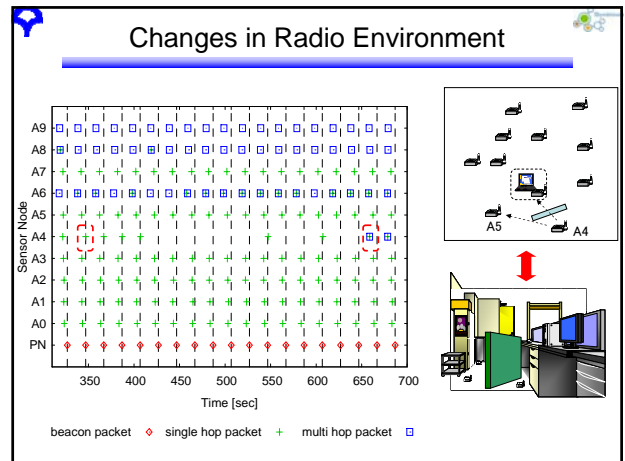
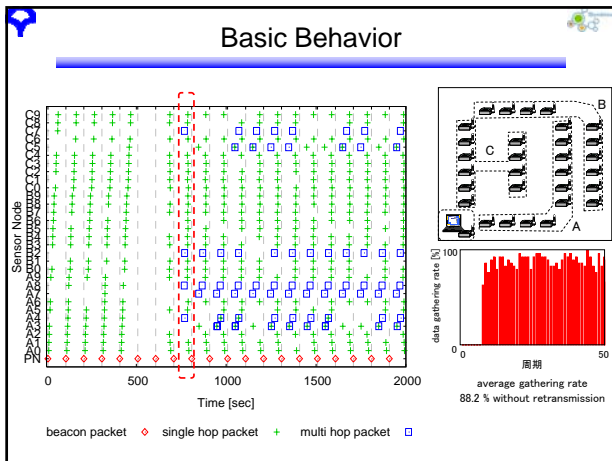
child node k

beacon packet

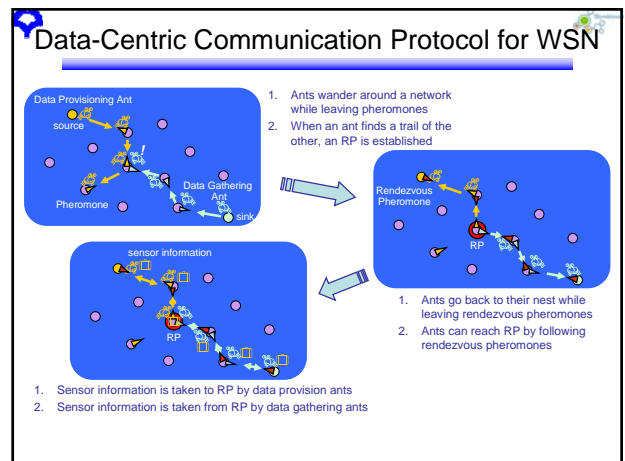
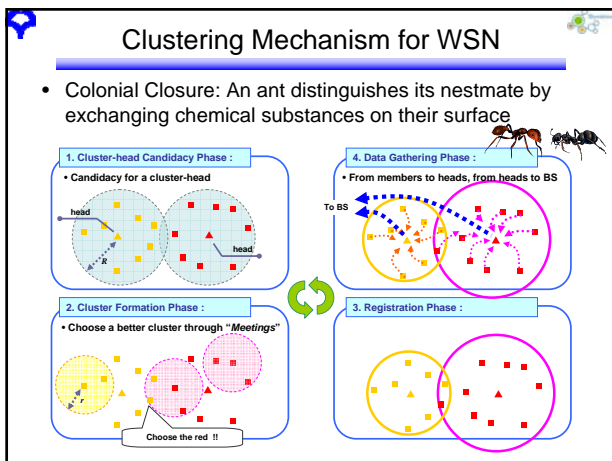
ϵ , δ_i , δ_j , δ_k

Prototype System

- Sensor node
 - Oki Electric Industry
 - MAC protocol
 - IEEE 802.15.4
 - transmission range 5 m
 - max 100 m
 - AAA battery x3
- Experiments
 - basic behavior
 - addition, removal, movement of child nodes
 - changes in communication environment
 - overlapping radio ranges among parent nodes
 - practical test

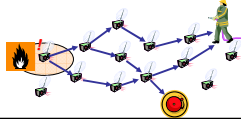


Other Research Topics



Sensor Network Technologies for Safe and Secure Life

- Prolong the lifetime of a sensor network
- Certain detection of emergency and fast and reliable transmission of urgent information
- A combination of
 - normal operation preparing for emergency
 - emergent operation for fast and reliable communication
 is needed taking into account heterogeneity in sensor information and sensor nodes



For Safety of Children

- (1) Reliable data gathering from hundreds of children
- (2) Secure data communication to protect personal information
- (3) Data mining for fast detection of emergency and tracking a misbehaving child

