# Frog Call-Inspired Self-Organizing Anti-Phase Synchronization for Wireless Sensor Networks

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## Background

- Self-organized network control which obtained the idea from the biology of the nature
  - Feeding behavior of ants (routing)
  - Process of pattern generating of the body surface (clustering)
  - Synchronization in luminescence of firefly (scheduling)



- Important characteristic of self-organized systems
  - Robustness against various perturbations
  - Scalability to the number of the network components

Self-organized control is suitable for sensor network

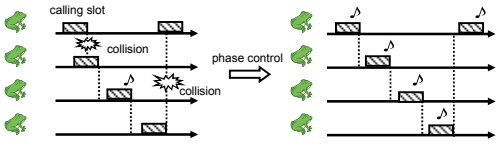
## Alternative calling behavior of Japanese tree frog

Japanese tree frog *(Hyla japonica)*

(This sound was recorded and offered by Mr. Ikkyu Aihara.)

## Anti-phase synchronization in calling behavior

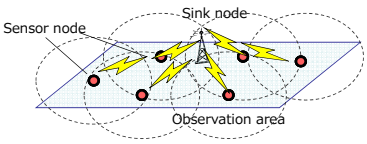
- Main reasons for the calling behavior is to attract females
- Avoiding of the collision with the voice of other males by shifting the timing of calling
- Anti-phase synchronization is achieved by only local interaction in self-organized fashion




Self-organized anti-phase synchronization is applicable to transmission control of sensor networks

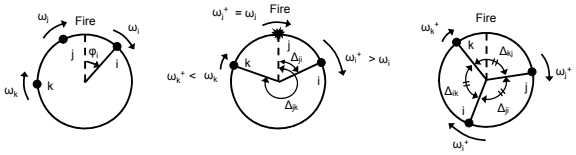
## Application to sensor network

- Each sensor nodes measures data and sends it to a sink node by wireless communications
- It is very important to avoid packet collision
- Performance improvement is expectable by anti-phase synchronization
  - Data collection ratio
  - Delay
  - Energy consumption of battery
  - etc




## Modeling with pulse-coupled oscillator

- Phase of oscillator : $\phi_i \in [0, 2\pi]$
- Firing frequency: $\omega_i = \frac{d\phi_i}{dt}$
- Phase difference: $\Delta_{ji} = \phi_j - \phi_i$




All nodes give a stimulus of positive/negative mutually, and adjust firing frequency

$$\omega_j^+ = \omega_j + g(\Delta_{ji})$$

$g(\,)$ : phase shift function defines repulsive force

## Proposed phase control mechanism

Conditions for stable state of anti-phase synchronization in *n* nodes

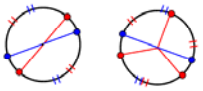
$$\Delta_{12} = \Delta_{23} = \cdots = \Delta_{n1}$$

$$\sum_{k \in N} g(\Delta_{1k}) = \sum_{k \in N} g(\Delta_{2k}) = \cdots = \sum_{k \in N} g(\Delta_{nk}) = 0$$

Aihara's model :

$$g(\Delta) = \alpha \sin(\Delta)$$

Synchronization cannot be achieved in 4 or more oscillators



**Proposed phase shift function**

$$\delta(\Delta) = \min\{\Delta, 2\pi - \Delta\}$$

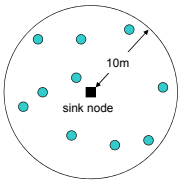
$$g(\Delta) = \alpha \sin(\Delta) \exp(-\delta(\Delta))$$

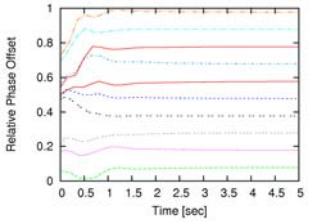
Stimulus needs to be weighted depending on the phase distance between the coupled oscillators

## Evaluation by simulation

**Simulation model**

- Radius of monitoring region: 10m
- MAC layer: CSMA/CA
- Sensing: every 0.16s
- Channel speed: 50kbps
- Packet size: 400bit



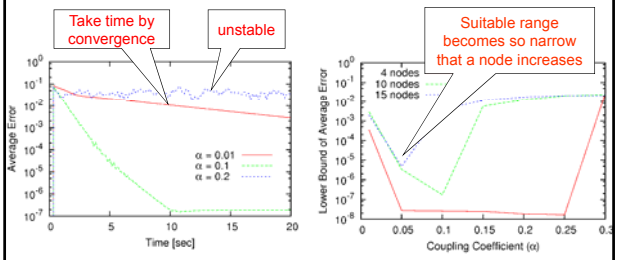




Phase transition in 10 nodes

Resulted in anti-phase synchronous state about 1 second (7times of interaction)

## Setting of coupling coefficient

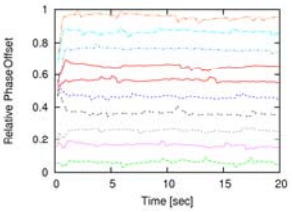
$\alpha$ determines the intensity of stimulus between oscillators



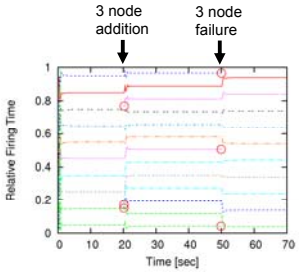

Transition of average error with 10 nodes

## Evaluation of robustness

Packet loss probability: 1%

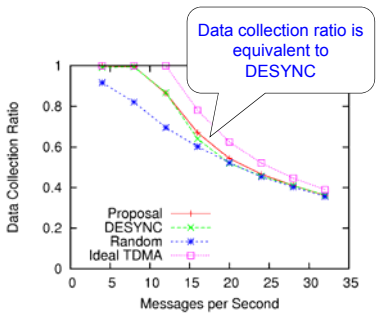



Robust against packet loss




Robust against topology change

## Comparison of data collection ratio




- DESYNC
  - Distributed type phase control
  - Timing is set to the midpoint of adjacent nodes
- Ideal TDMA
  - Centralized control
- Random

## Conclusion

- We applied an anti-phase synchronization in calling behavior of Japanese tree frog to the transmission timing control of a sensor network
  - Robustness over packet loss or change of topology
  - Performance equivalent to DESYNC which is a distributed type technique
- Future work
  - Stability of anti-phase synchronization by analysis
  - Extension to multi-hop in order to apply large scale network
  - Application of a behavior called *satellite* observed in frogs or crickets