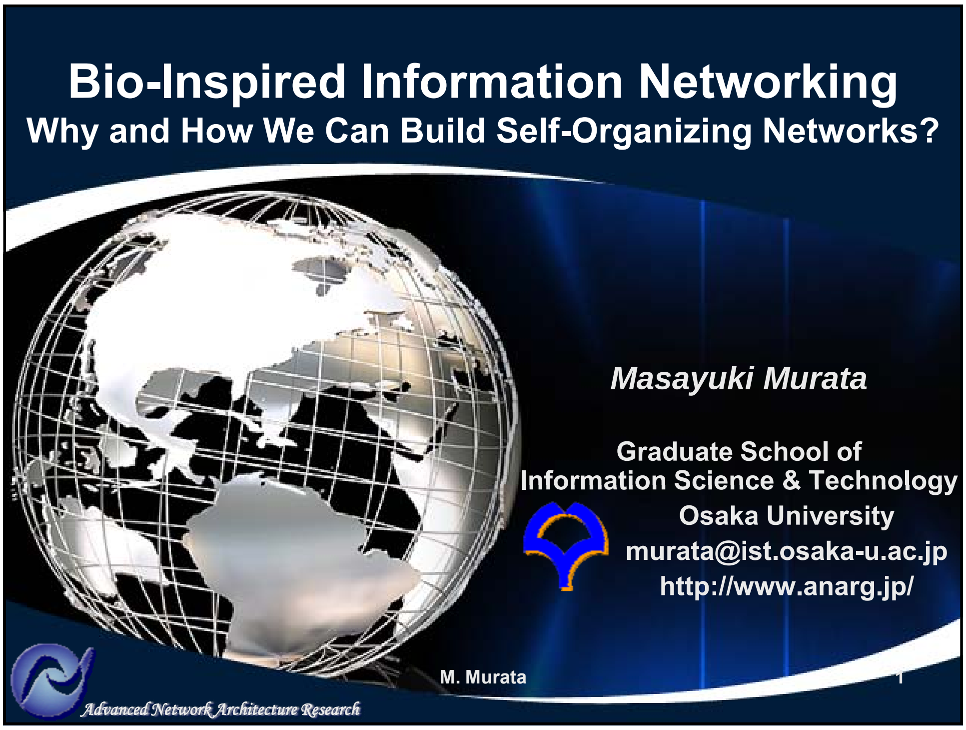

Bio-Inspired Information Networking

Why and How We Can Build Self-Organizing Networks?

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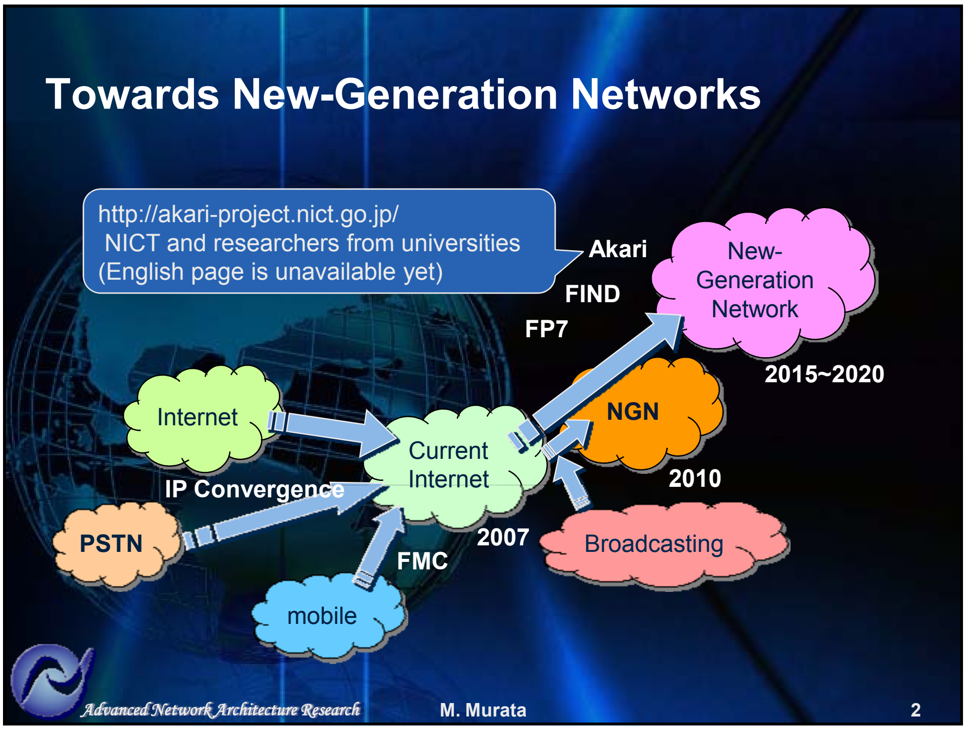


Towards New-Generation Networks

http://akari-project.nict.go.jp/
NICT and researchers from universities
(English page is unavailable yet)

Akari
FIND
FP7

New-Generation Network
2015~2020

Internet

IP Convergence

PSTN

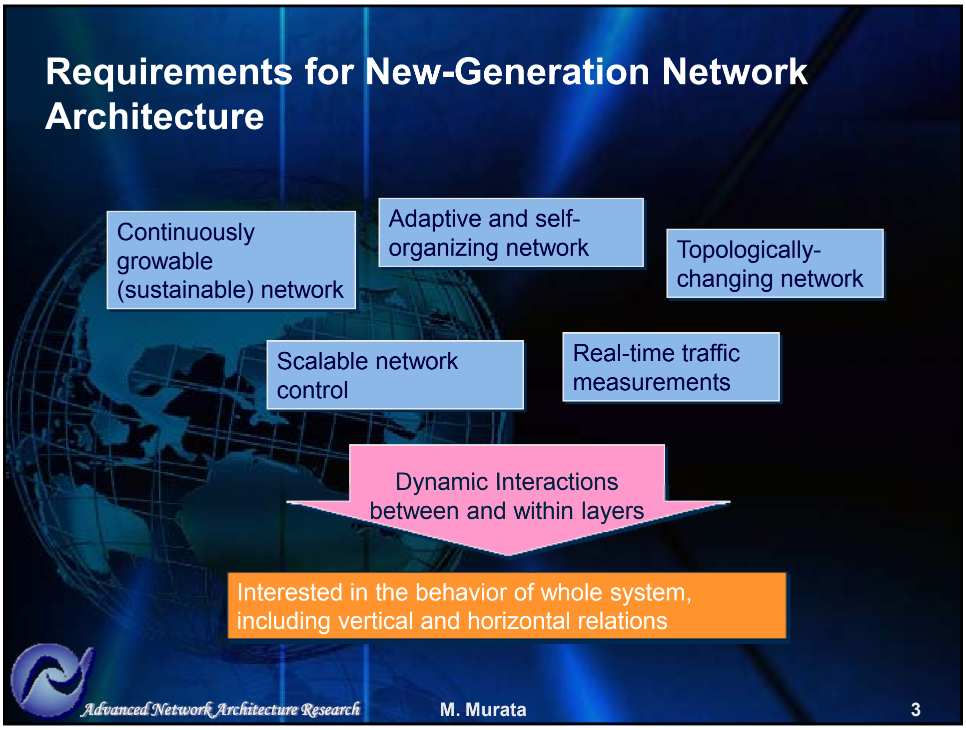
Current Internet
2007

FMC

mobile

NGN
2010

Broadcasting



Requirements for New-Generation Network Architecture

Continuously growable (sustainable) network

Adaptive and self-organizing network

Topologically-changing network

Scalable network control

Real-time traffic measurements

Dynamic Interactions between and within layers

Interested in the behavior of whole system, including vertical and horizontal relations

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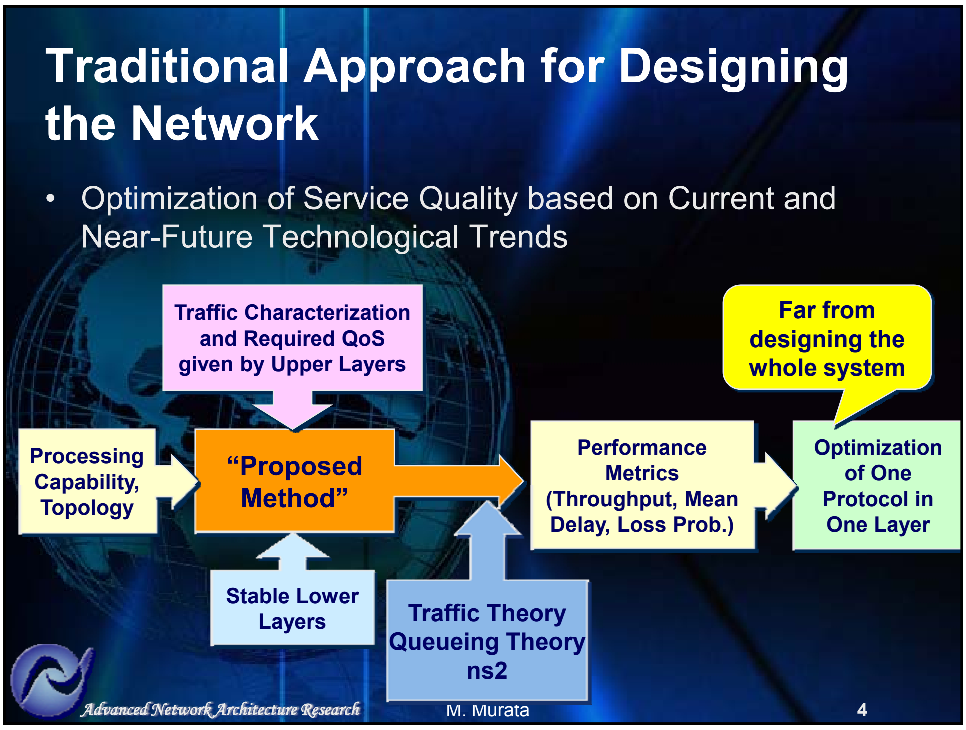


Traditional Approach for Designing the Network

- Optimization of Service Quality based on Current and Near-Future Technological Trends

Traffic Characterization and Required QoS given by Upper Layers

Far from designing the whole system

Processing Capability, Topology

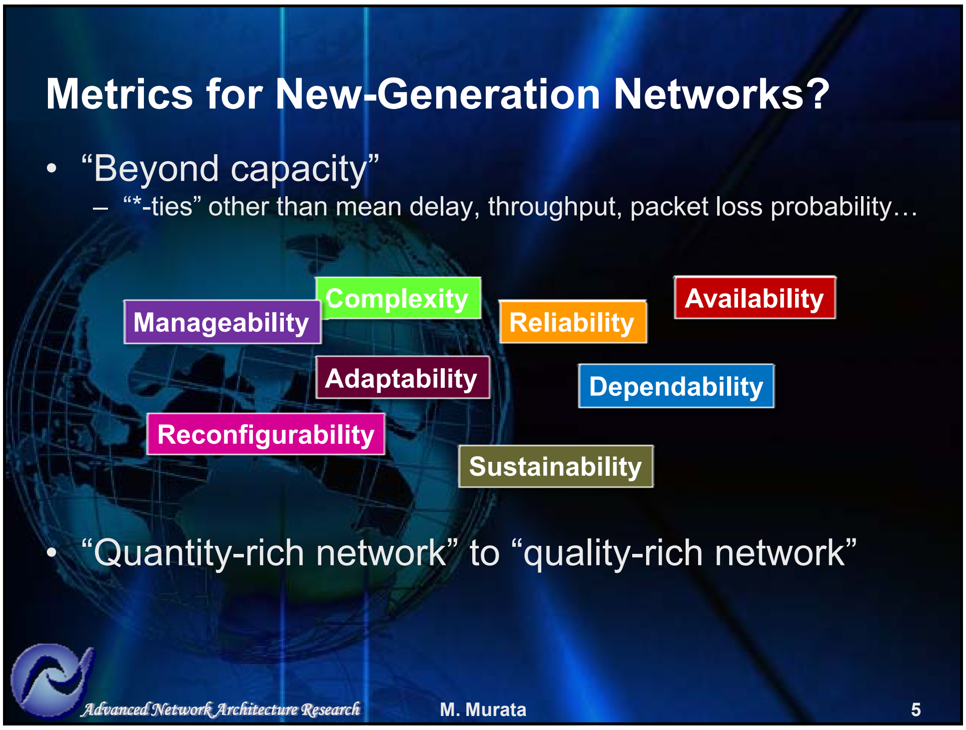
“Proposed Method”

Performance Metrics (Throughput, Mean Delay, Loss Prob.)

Optimization of One Protocol in One Layer

Stable Lower Layers

Traffic Theory Queueing Theory ns2



Metrics for New-Generation Networks?

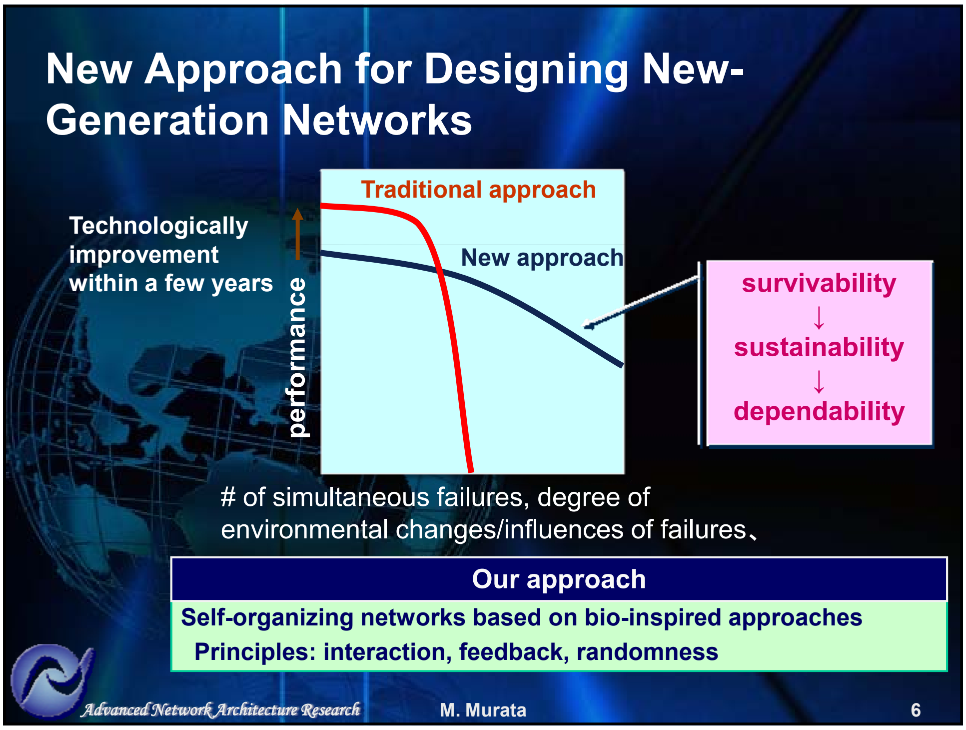
- "Beyond capacity"
  - "*-ties" other than mean delay, throughput, packet loss probability…

Manageability **Complexity** **Reliability** **Availability**

Adaptability **Dependability**

Reconfigurability **Sustainability**

- "Quantity-rich network" to "quality-rich network"



New Approach for Designing New-Generation Networks

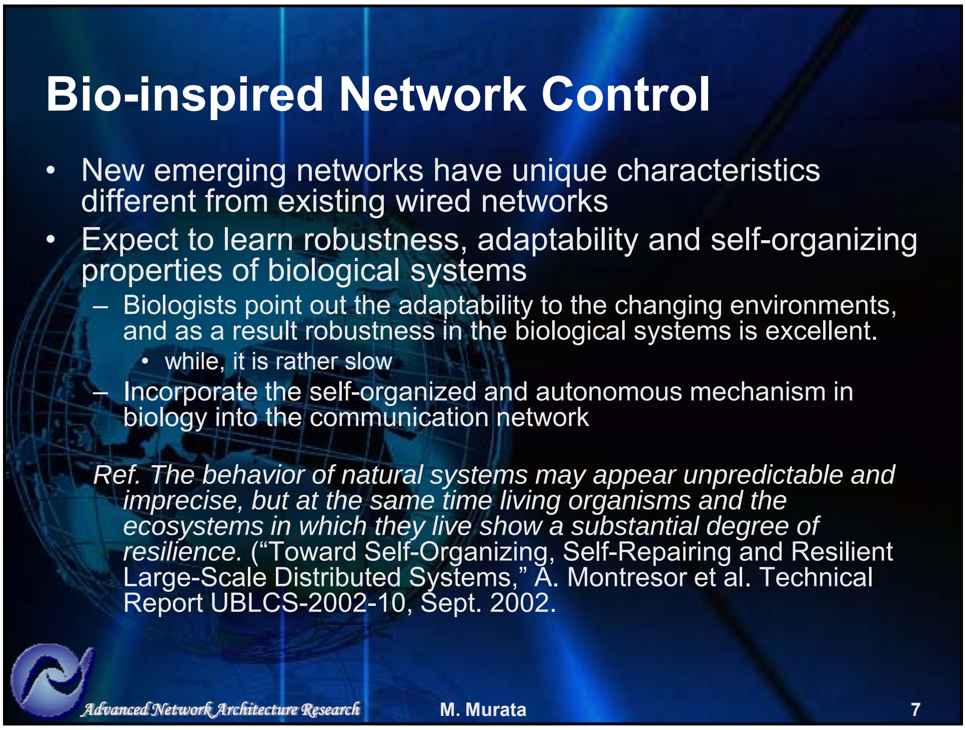
of simultaneous failures, degree of environmental changes/influences of failures、

survivability
↓
sustainability
↓
dependability

Our approach

Self-organizing networks based on bio-inspired approaches

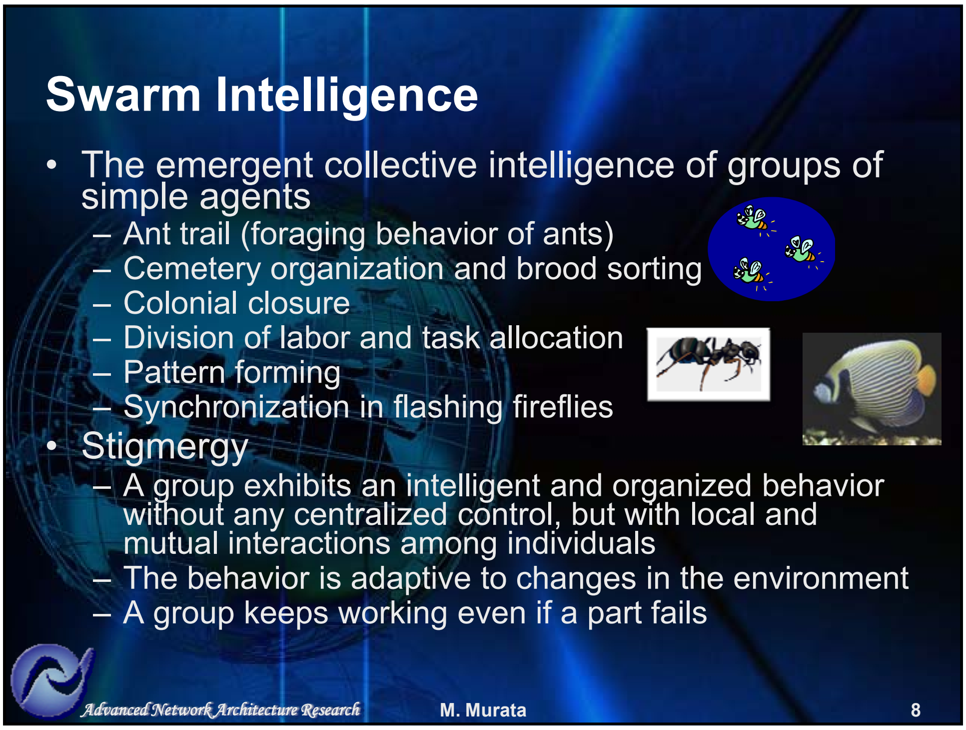
Principles: interaction, feedback, randomness



Bio-inspired Network Control

- New emerging networks have unique characteristics different from existing wired networks
- Expect to learn robustness, adaptability and self-organizing properties of biological systems
  - Biologists point out the adaptability to the changing environments, and as a result robustness in the biological systems is excellent.
    - while, it is rather slow
  - Incorporate the self-organized and autonomous mechanism in biology into the communication network

Ref. The behavior of natural systems may appear unpredictable and imprecise, but at the same time living organisms and the ecosystems in which they live show a substantial degree of resilience. (“Toward Self-Organizing, Self-Repairing and Resilient Large-Scale Distributed Systems,” A. Montresor et al. Technical Report UBLCS-2002-10, Sept. 2002.



Swarm Intelligence

- The emergent collective intelligence of groups of simple agents
  - 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
- Stigmergy
  - A group exhibits an intelligent and organized behavior without any centralized control, but with local and mutual interactions among individuals
  - The behavior is adaptive to changes in the environment
  - A group keeps working even if a part fails

Bio-inspired Examples

- Overlay Network Symbiosis
  symbiosis of different cells, organisms, groups, and species
  - Waveform Synchronized Data Gathering in Sensor Networks
    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

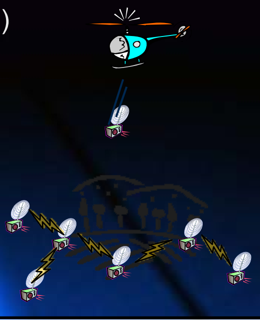
Case Study 1: Waveform Synchronized Data Gathering in Sensor Networks

based on synchronized flashing in a group of fireflies

Sensor Networks

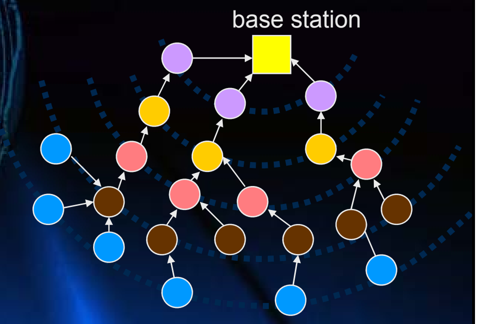
- Sensor nodes are equipped with sensor (heat, temperature), wireless transmitter, battery unit
- Applications:
  - Health and welfare (vital signs, safety)
  - Crime prevention and security
  - Disaster prevention (fire, landslide, flood, earthquake)
  - Environment (weather, water/air pollution)
- Requirements:
  - large number of nodes required
  - deployed in an uncontrolled and unorganized way
  - may halt due to depletion of the battery or failure

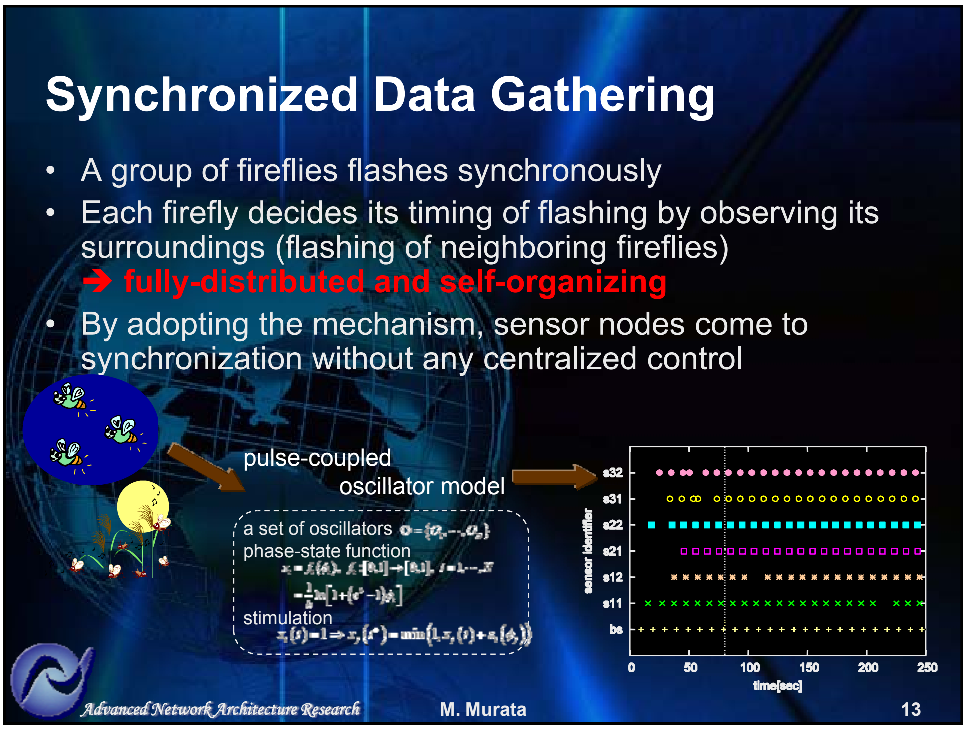

MOTE2
Crossbow Technology, Inc.



Periodic Data Gathering

- Collect sensor information from all sensor nodes at regular intervals
- Save energy consumption by multi-hop communication
  - sensor information propagates from the edge to the base station
- Each node receives information from more distant nodes, aggregates it with its own information, and sends it to the next node
- Information is propagated in concentric circles





Synchronized Data Gathering

- A group of fireflies flashes synchronously
- Each firefly decides its timing of flashing by observing its surroundings (flashing of neighboring fireflies)
  ➔ **fully-distributed and self-organizing**
- By adopting the mechanism, sensor nodes come to synchronization without any centralized control

pulse-coupled
oscillator model

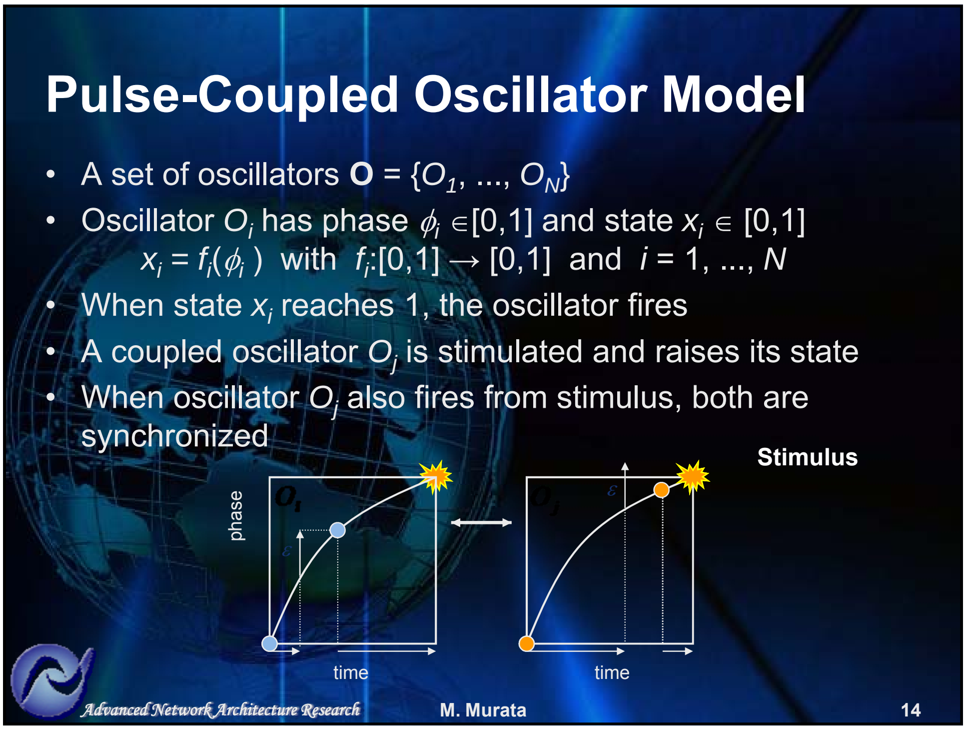
a set of oscillators $\mathbf{O}=\{O_1,\cdots,O_N\}$

phase-state function

$$x_i = f_i(\phi_i),\ f_i:[0,1]\rightarrow[0,1],\ i=1,\cdots,N$$
$$=\frac{1}{b}\ln\left[1+(e^b-1)\phi_i\right]$$

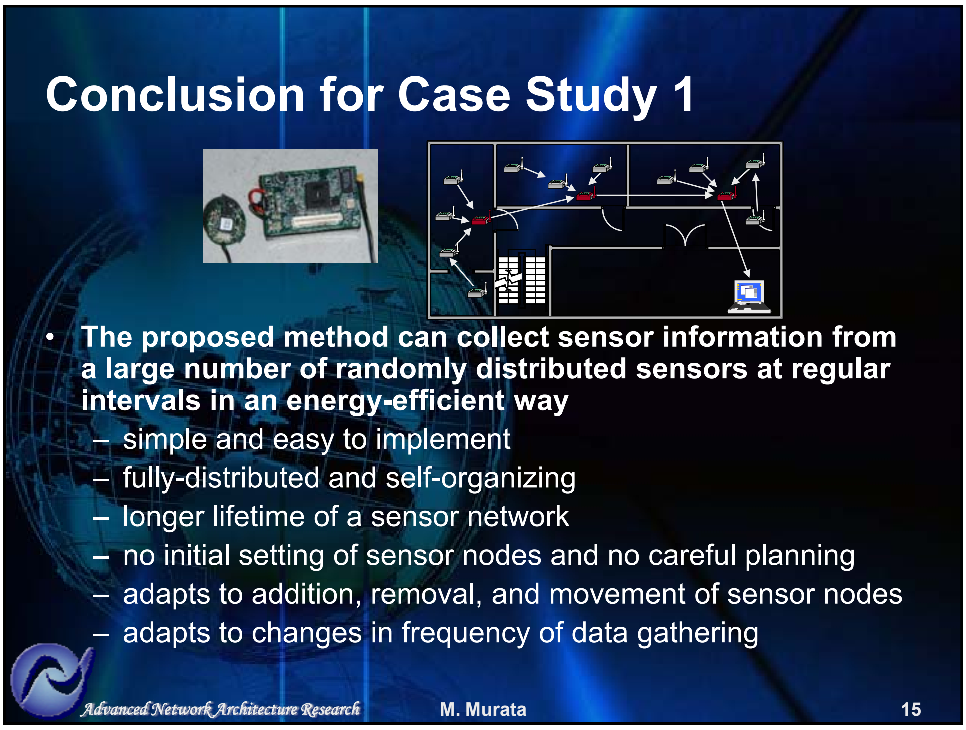
stimulation

$$x_i(t)=1 \Rightarrow x_j(t^+)=\min\left(1, x_j(t)+\varepsilon_i(\phi_j)\right)$$



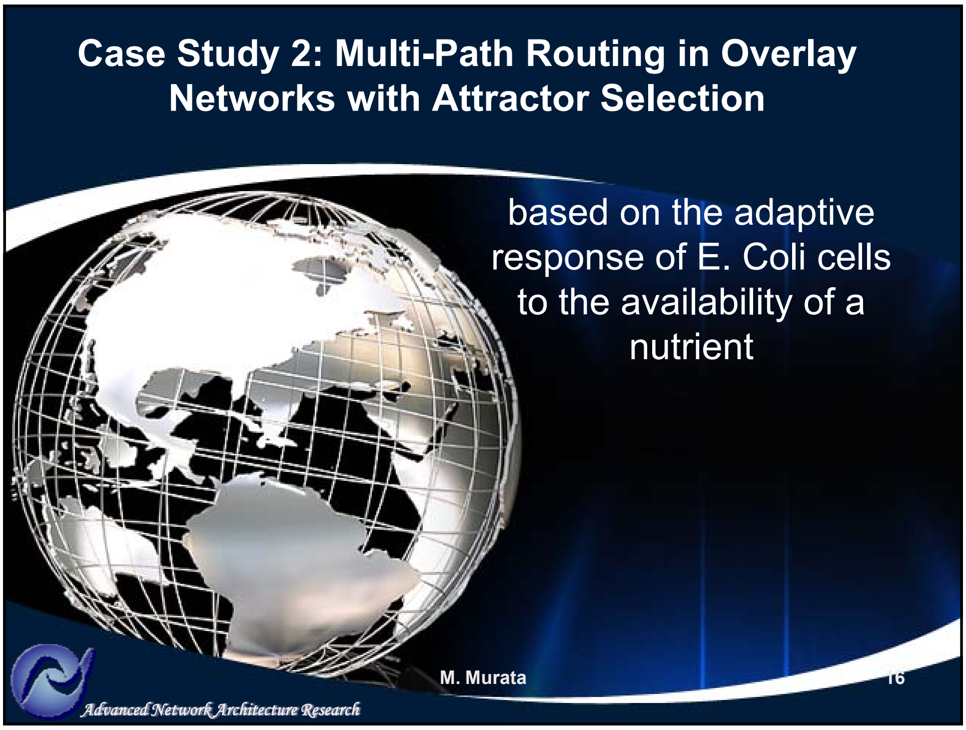
Pulse-Coupled Oscillator Model

- A set of oscillators **O** = {O_1, ..., O_N}
- Oscillator O_i has phase $\phi_i \in [0,1]$ and state $x_i \in [0,1]$
  $x_i = f_i(\phi_i)$ with $f_i:[0,1] \rightarrow [0,1]$ and $i = 1, ..., N$
- When state x_i reaches 1, the oscillator fires
- A coupled oscillator O_j is stimulated and raises its state
- When oscillator O_j also fires from stimulus, both are synchronized



Conclusion for Case Study 1

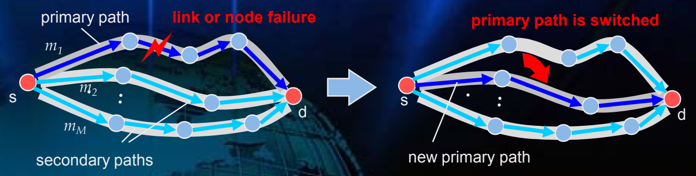
- **The proposed method can collect sensor information from a large number of randomly distributed sensors at regular intervals in an energy-efficient way**
  - simple and easy to implement
  - fully-distributed and self-organizing
  - longer lifetime of a sensor network
  - no initial setting of sensor nodes and no careful planning
  - adapts to addition, removal, and movement of sensor nodes
  - adapts to changes in frequency of data gathering



Case Study 2: Multi-Path Routing in Overlay Networks with Attractor Selection

based on the adaptive response of E. Coli cells to the availability of a nutrient

Our Objective



- Select paths in a multi-path overlay network environment
- Apply randomization in path selection to reduce selfishness
- Consideration of *primary* and *secondary* paths with transmission rates m_i
- Inline measurements of path metrics (e.g. RTT)
- Original model for E. coli cells to adapt to changes in the availability of a nutrient

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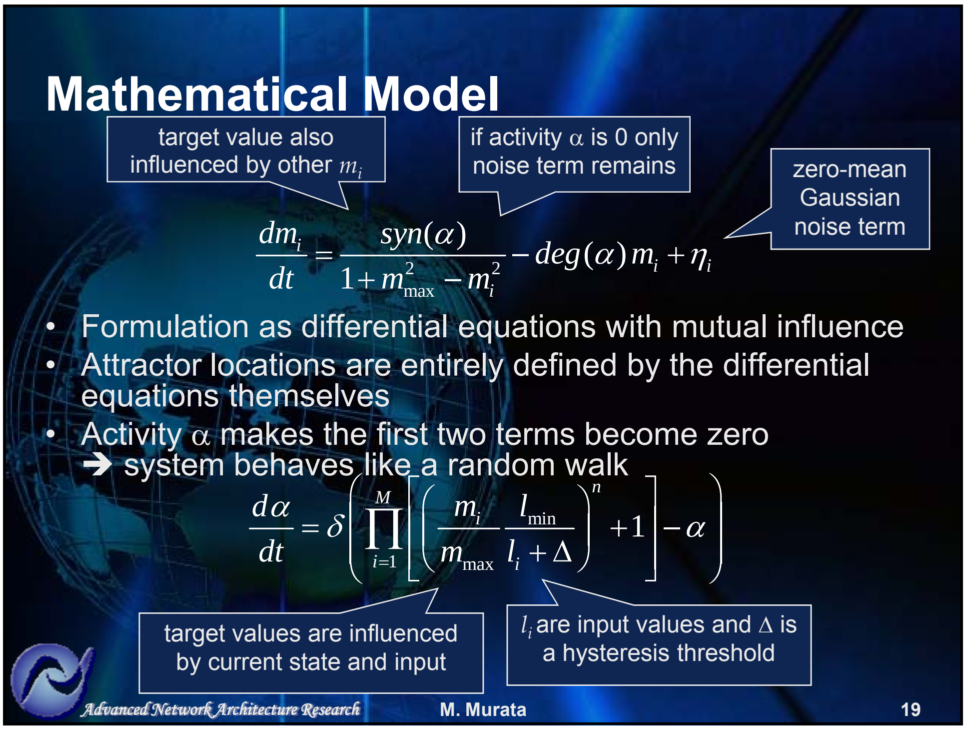
Adaptive Response by Attractor Selection

- Basic mechanism:
  - consider state space with magnets (attractors)
  - solution is a metal ball which is constantly in motion but stays locked at an attractor
  - activity influences which magnet is activated and the strength of the noise influence
- ARAS can be seen as a mapping of an input space (environment) to a set of discrete points (attractors)



Mathematical Model

target value also influenced by other m_i

if activity α is 0 only noise term remains

zero-mean Gaussian noise term

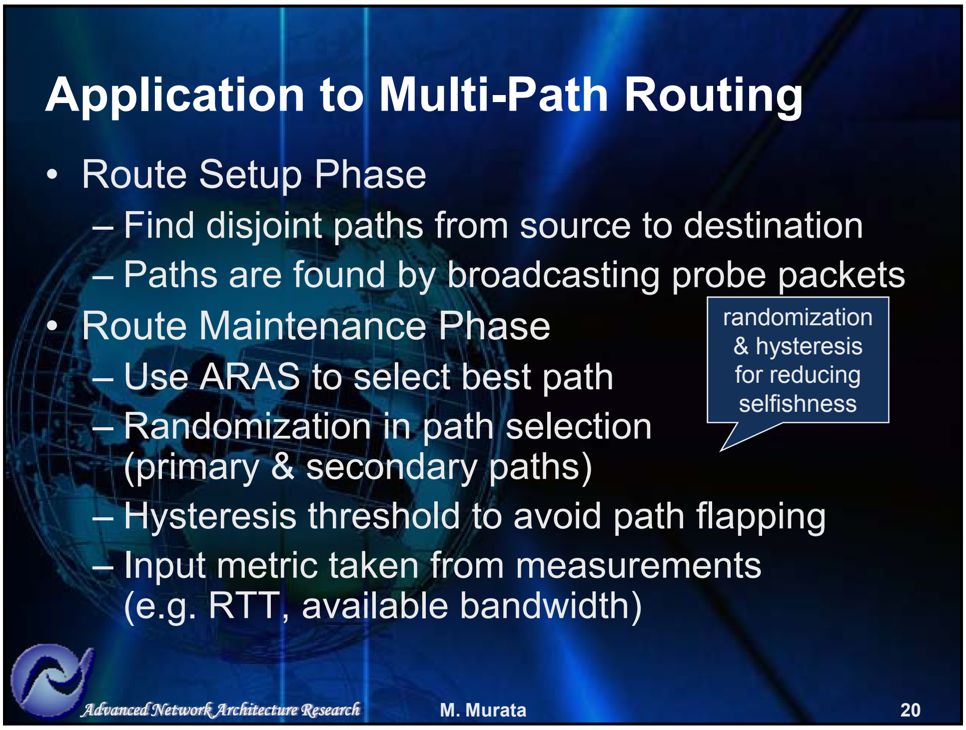
$$\frac{dm_i}{dt} = \frac{syn(\alpha)}{1+m_{\max}^2 - m_i^2} - deg(\alpha)\, m_i + \eta_i$$

- Formulation as differential equations with mutual influence
- Attractor locations are entirely defined by the differential equations themselves
- Activity α makes the first two terms become zero
  ➔ system behaves like a random walk

$$\frac{d\alpha}{dt} = \delta\left(\prod_{i=1}^{M}\left[\left(\frac{m_i}{m_{\max}}\frac{l_{\min}}{l_i+\Delta}\right)^n + 1\right] - \alpha\right)$$

target values are influenced by current state and input

l_i are input values and Δ is a hysteresis threshold



Application to Multi-Path Routing

- Route Setup Phase
  - Find disjoint paths from source to destination
  - Paths are found by broadcasting probe packets
- Route Maintenance Phase
  - Use ARAS to select best path
  - Randomization in path selection (primary & secondary paths)
  - Hysteresis threshold to avoid path flapping
  - Input metric taken from measurements (e.g. RTT, available bandwidth)

randomization & hysteresis for reducing selfishness

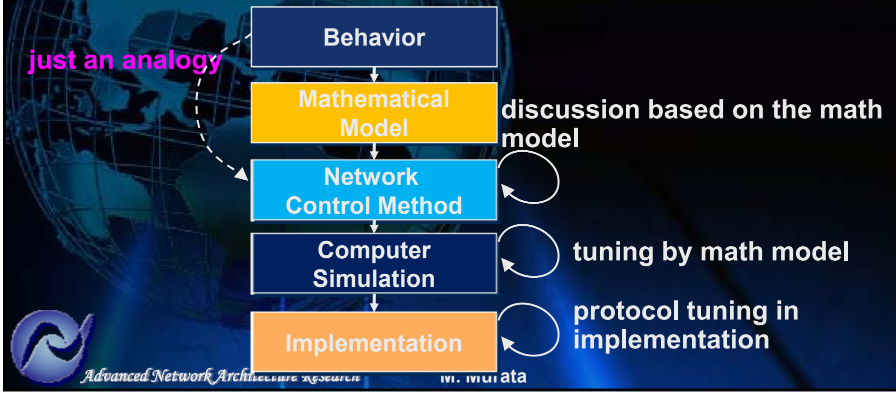
Conclusion for Case Study 2

- **The proposed method can choose the best path in a self-adaptive and efficient way and can be tuned to reduce the selfish behavior of overlay routing**
  - Path selection scheme based on biological attractor selection model
  - Parameters of the model are chosen such that selfishness is reduced
  - Interactions of flows leads to symbiotic solutions
  - Future work:
    - Large scale network experiments
    - Investigation of different input metrics or their combinations
    - Application to mobile ad hoc/sensor networks

Perspective and Caveats

- By getting inspiration from biological systems, we can establish fully-distributed and self-organizing techniques
- However, we have to consider,
  - the rate of adaptation is rather slow
  - they do not necessarily provide the best performance

We should refrain from simply mimicking biology!



discussion based on the math model

tuning by math model

protocol tuning in implementation