Implementation and Evaluation of
a Reaction-Diffusion based Coding Rate Control
Mechanism for Camera Sensor Networks

Hiroshi Yamamoto, Katsuya Hyodo, Naoki Wakamiya, Masayuki Murata
Graduate School of Information Science and Technology, Osaka University

Camera Sensor Network

- Composed of sensor nodes with
  - video camera
  - wireless communication capability
- Video data are sent to a monitoring station via gateway nodes
- Useful for
  - town monitoring
  - remote surveillance

Camera Sensor Network

- Problems
  - Capacity of wireless network is limited
    - Network would be congested when all nodes generate high quality video data
  - QoS control is effective for lightly loaded network

⇓ Adaptive video traffic control is required

- Adjust video coding rate in accordance with importance of video data
  - Detecting target — High quality
  - Close to target — Medium quality
  - Far from target — Low quality
- Self-organizing mechanism is needed
  - low control overhead
  - robustness, adaptability, scalability

Reaction-Diffusion based Autonomous Control of Camera Sensor Networks [9]

- Focus on similarity between
  - mophogen concentration distribution in reaction-diffusion model
  - coding rate distribution in camera sensor network
- Adjust coding rate autonomously

Reaction-Diffusion model
• Mathematical model for pattern generation on surface of body of animals
• Heterogeneous distribution of mophogen concentration (pattern) appears

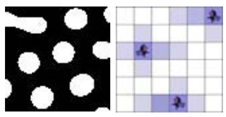
- Through exchanging control information among neighbor nodes and calculating reaction-diffusion equation, pattern appears

⇓

- Translate from mophogen concentration to coding rate

⇓

- Adjust quality of video in accordance with its importance



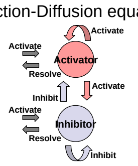
[9] K. Hyodo, N. Wakamiya, and M. Murata, “Reaction-diffusion based autonomous control of camera sensor networks”, in Proceedings of 2nd International Conference on Bio-Inspired Model of Network, Information, and Computing System (BIONETICS 2007), Dec. 2007.

Reaction-Diffusion model

- Each cell has 2 kinds of mophogens
  - Activator, Inhibitor
- Through activation, inhibition and diffusion, heterogeneous pattern appears
- Characteristics of activator and inhibitor

Activator : u	Inhibitor : v
activate mophogens	inhibit mophogens
diffuse slowly	diffuse fast

- Reaction-Diffusion equation



$$\frac{\partial u}{\partial t} = F(u,v) + D_u \nabla^2 u + E$$

$$\frac{\partial v}{\partial t} = G(u,v) + D_v \nabla^2 v$$

Reaction term | Diffusion term | Stimulus

Reaction-Diffusion based Coding Rate Control Mechanism (1/2)

- Each node operates asynchronously
- Listen continuously and receive control information from neighbor nodes
- At regular intervals
  - Set stimulus
    - Stimulus
      - Increment of activator concentration
      - In order to generate pattern centered at target
    - If the node detects target, stimulus is set in accordance with target speed
      - higher stimulus for faster target to generate wider spot
    - If the node is in the direction of target movement , stimulus is set in accordance with stimulus information from neighbor node

$$E_{own} = A \times E_{neighbor}$$ (*A*: attenuation)

●Example of mapping from speed to stimulus

Speed (km/h)	Max Stimulus	Min Stimulus
0	1960	830
0 – 2	1370	700
2 – 4	1010	440
4 – 6	620	390
6 –	360	260

Reaction-Diffusion based Coding Rate Control Mechanism (2/2)

- Calculate reaction-diffusion equation
  - By using control information from neighbor nodes
- Determine coding rate
  - In accordance with mophogen concentration
    - Example of mapping from mophogen concentration to coding rate

$u/\sqrt{v}$	coding rate
0 – 5000	0.75 Mbps
5000 – 10000	1 Mbps
10000 –	2 Mbps

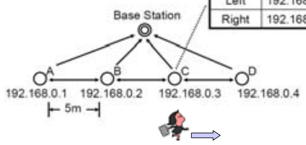
u: activator concentration
v: inhibitor concentration

- Broadcast control information

Overview of implemented system and experiment

- Sensor node: commercially available cameras and PCs
- Wireless: IEEE 802.11g, IEEE 802.11 IBSS (ad-hoc mode)
- Network: all nodes and base station belong to same IP subnet
- Control interval: 0.25 sec
- Video data:
  - Coding rate is determined based on $\frac{\text{activator}}{\sqrt{\text{inhibitor}}}$
  - In experiment, dummy traffic is used
  - Sent to base station by UDP single hop unicast
- Comparison:
  - Proposal (0.75 Mbps, 1 Mbps, 2 Mbps)
  - Low quality (0.75 Mbps)
  - High quality (2 Mbps)
- Target:
  - Direction: from A to D
  - Speed: 1.8 km/h

Position	Address
Left	192.168.0.2
Right	192.168.0.4



Evaluation measure

- Packet loss rate

$$\frac{\text{number of video packets which are not received at base station}}{\text{number of video packets sent by nodes}}$$

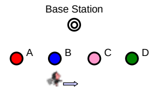
- PSNR (Peak Signal to Noise Ratio)

$$PSNR = 20\log_{10}\left(\frac{255}{\sqrt{MSE}}\right)$$

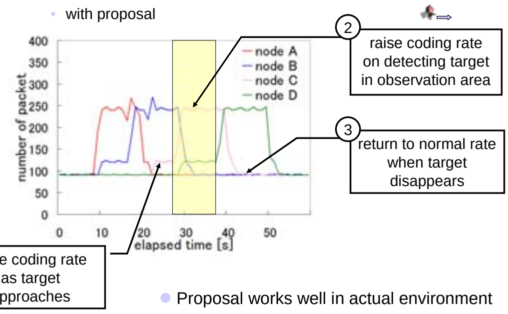
$$MSE = \frac{\Sigma(f(i,j) - F(i,j))^2}{mn}$$

  - Image size: $m \times n$ [pixel]
  - Original image's luminance at pixel (i, j): $F(i, j)$
  - Comparison image's luminance at pixel (i, j): $f(i, j)$

Result: number of emitted packets

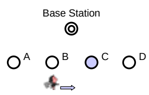


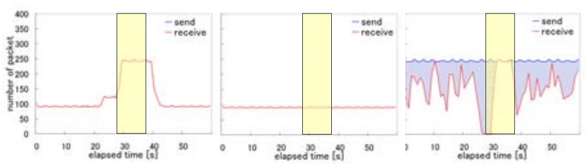
- with proposal



- Proposal works well in actual environment

Result: packet loss rate

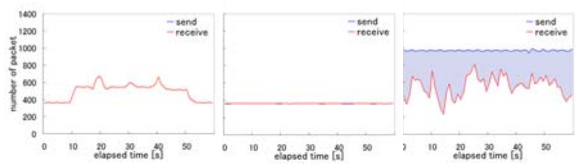




(a) proposal (b) low quality (c) high quality

- Proposal and low quality: almost all packets are received
  - proposal (0.01%), low quality (0%)
- High quality: many packets are lost
  - high quality (36.7%)
- Congestion is avoided and packet loss is suppressed

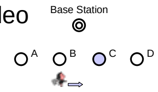
Result: total number of sent and received packets

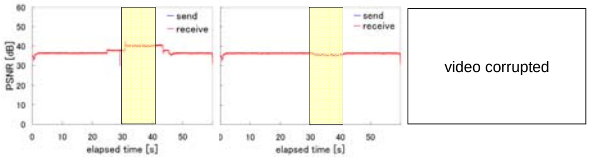


(a) proposal (b) low quality (c) high quality

- Average amount of received data in high quality (4.65 Mbps)
  ≒ network capacity
- Each node encodes at 2 Mbps, 1 Mbps, 0.75 Mbps, 0.75 Mbps in proposal
  ⇒ 4.5 Mbps
  ≒ network capacity
- Coding rate allocation is appropriately performed

Result: PSNR of sent and received video





(a) proposal (b) low quality (c) high quality

- Proposal: PSNR is enhanced in accordance with target movement
  - Not detecting target （36.7 dB） , Detecting target （40.0 dB）
- Low quality: PSNR remains low
  - Not detecting target （36.7 dB） , Detecting target （35.5 dB）
- High quality target monitoring is performed

Conclusion and Future work

- Conclusion
  - We implemented a reaction-diffusion based coding rate control mechanism and verified its effectiveness in actual environment
  - We showed effectiveness of proposal
    - Congestion was avoided
    - Video transmission satisfying application requirements was achieved
- Future work
  - Evaluation in larger network
  - Dynamic parameter adaptation
    - Target speed and stimulus mapping
    - Mophogen concentration and coding rate mapping