Design Methodology of a Wireless Sensor Network Architecture for Urgent Information Transmission

T. Kawai, N. Wakamiya, and M. Murata
Graduate School of Information Science and Technology, Osaka University

Outline

1. Introduction
2. Design Methodology
3. UMIUSI Architecture
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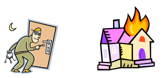
5. Conclusion

Wireless Sensor Networks as a Social Infrastructure

- Sensor nodes are deployed in a region to monitor and collect environmental information
- Sensor nodes have limited computational capabilities and power resources
- Based on unstable radio communications
- Carry various types of information
  - Security, disaster, weather, health, ...
- Need to transmit urgent information with higher reliability and lower latency



→ differentiated and prioritized services

Overview of the Architecture

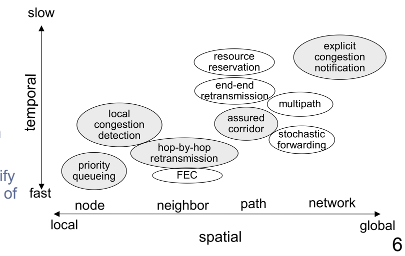
	Normal situation	Emergency situation
Requirements	✓scalability ✓fault tolerance ✓long lifetime	✓scalability ✓reliability and latency ✓adaptability to situation
Application layer	Building automation, public surveillance, ...	
		QoS control mechanisms
Network and MAC layers	existing algorithm / data gathering scheme *e.g.* directed diffusion, S-MAC ...	

Design Objectives

- High reliability and low latency
  - Urgent information should be preferred according to their importance
- Self-organizing and distributed behavior
  - A WSN should be adaptive to the scale of an emergency and dynamically changing conditions
  - A globally-organized behavior emerges as results of reactions to the surroundings of each node and local interaction among nodes
- Simplicity
  - A sensor node has limited resources

Design Methodology

- Combining simple mechanisms working in different spatial and temporal levels
  - Mechanisms are implemented on each node
  - Mechanisms work independently with each other
  - Mechanisms of appropriate levels come into effect responding to the surrounding situation
  - No additional mechanisms to identify the scale or situation of the event



Overview of UMIUSI

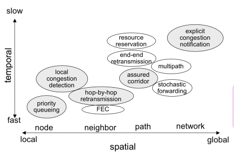
Application Layer	Building automation, public surveillance…
Our architecture	UMIUSI Architecture aUtonomous Mechanisms Integrated for Urgent Sensor Information
Network Layer	Data gathering scheme Multihop routing + Sleep scheduling
MAC Layer	Contention based MAC

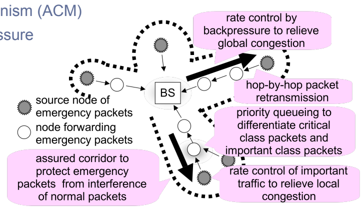
UMIUSI Architecture

- Sensor information is categorized into three traffic classes
  - Normal
    - Non-urgent
    - Tolerate loss and delay in emergency
    - Gathered at an interval of t_{norm} in normal situation
  - Important
    - Urgent but tolerate loss and delay to some extent when the network is overloaded
    - Transmitted at an interval of t_{imp} ($< t_{norm}$) but the sending rate is regulated in case of congestion
  - Critical
    - Most urgent and important
    - Transmitted at an interval of t_{cri} ($< t_{norm}$) and the sending rate is not regulated by the rate control mechanisms to retain the reporting rate

UMIUSI Architecture (contd.)

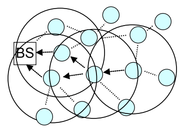
- Five mechanisms are incorporated
  - Priority queueing
  - Rate control by local congestion detection
  - Hop-by-hop scheduled retransmission
  - Assured Corridor Mechanism (ACM)
  - Rate control by backpressure

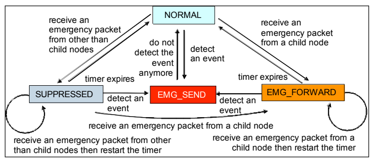




"Assured Corridor" Mechanism

- Keep surrounding nodes quiet
  - Avoid packet loss caused by collisions
- Keep forwarding nodes awake
  - Avoid delay caused by sleeping of forwarding nodes





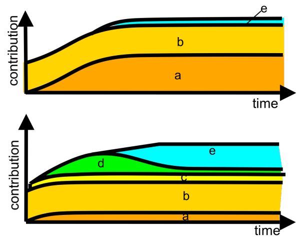
State transitions

[11] T. Kawai, N. Wakamiya, and M. Murata, "ACM: A transmission mechanism for urgent sensor information," in proceedings of IEEE IPCCC 2007, pp.562-569, April 2007.

Contribution of Mechanisms

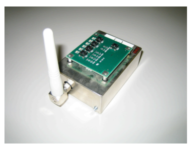
- In a small-scale event
  - It takes a while for ACM to take effect
  - Priority queueing and rate control do not help much
- In a large-scale event
  - ACM does not work since collisions occur among emergency packets
  - Rate control is effective to mitigate congestion

a. assured corridor
b. scheduled retransmission
c. priority queueing
d. rate control by local congestion detection
e. rate control by backpressure



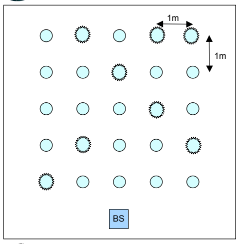
Experiments (Testbed A)

- 25 nodes in a 10 m x 6 m room
- Lower layer protocols
  - 802.15.4 non-beacon mode MAC
  - Synchronization-based data gathering scheme [10]
- $t_{imp} = t_{cri}$ = 0.5s (rate = 2 packets/s)
- Scenarios
  - Small-scale event with one *EMG_SEND* node
    - Repeat twice for each of randomly chosen 8 *EMG_SEND* nodes
  - Large-scale event with 8 *EMG_SEND* nodes
    - one critical and seven important class nodes
    - Repeat twice for 8 sets of randomly chosen 8 *EMG_SEND* nodes
  - Five variants: KA, ACM, ACM+RT, ACM+RT+PQ, FULL



[10] S. Kashihara, N. Wakamiya, and M. Murata, "Implementation and evaluation of a synchronization-based data gathering scheme for sensor networks," in proceedings of IEEE ICC 2005, pp.3037-3043, May 2005.

Node layouts in Testbed A

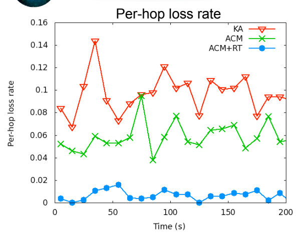


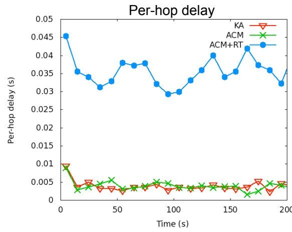
critical important

- 4 hops to the BS at maximum
- In normal operation, delivery ratio: between 65-80% without any retransmission

Small Scale Event

KA keep awake
RT retransmission

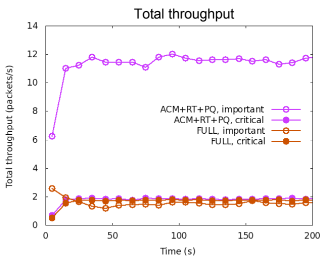




- ACM improves reliability of transmission
- Retransmission further lowers the loss rate
- But introducing retransmission incurs increase of delay

Large Scale Event

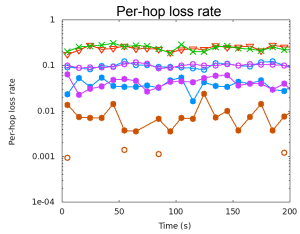
RT retransmission
PQ priority queueing
FULL all five mechanisms

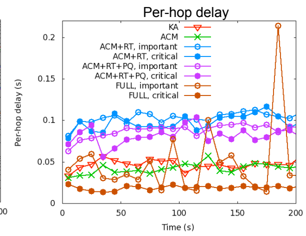


- In FULL, the total throughput of important class decreases in 30 seconds as the important traffic is regulated by the rate control mechanisms

Large Scale Event

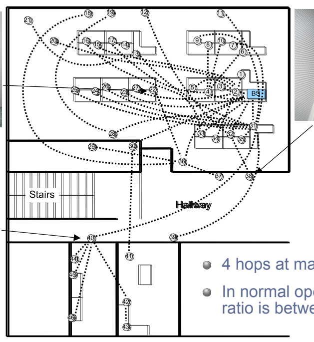
KA keep awake
RT retransmission
PQ priority queueing
FULL all five mechanisms





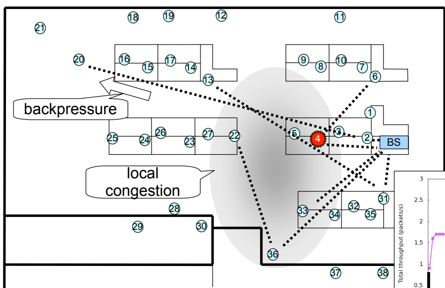
- Suppression of normal packets has little contribution
- Retransmission and rate control are effective to improve reliability
- In FULL, loss rate and delay decreases in 30 seconds as the important traffic is regulated by the rate control mechanisms

Experiments (Testbed B)



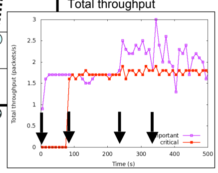
- 4 hops at maximum
- In normal operation, delivery ratio is between 65-75%

Large Scale Event



NORMAL
SUPPRESSED
EMG_SEND (critical)
EMG_SEND (important)
EMG_FORWARD

Total throughput



Loss rate critical class: 0
important class: 0.6%

Conclusion

- We propose a design methodology of a sensor network architecture supporting differentiated and prioritized services for urgent information
  - Several simple mechanisms working in different time and topological ranges are integrated to adapt to the scale of emergency
- We propose UMIUSI architecture
  - Sensor information is classified into three classes and five mechanisms collaborate to prioritize urgent information
- Results of practical experiments show that UMIUSI successfully improved the delivery ratio and the delay of emergency packets

Thank you