Design, Proposal, and Experiments of a Wireless Sensor Network Architecture for Urgent Information Transmission

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Abstract

Wireless sensor networks used as a social infrastructure must be capable of differentiating and prioritizing transmission of urgent sensor information over other non-urgent information. In this paper, we developed a novel and simple network architecture, in which sensor information is classified into three traffic classes and each node activates one or more of several simple, self-organizing, and fully-distributed mechanisms in accordance with the scale of an emergency for fast and reliable transmission of urgent sensor information. In the demonstration, we show the operation of preferential transmission of urgent information under this architecture in a wireless sensor network.

1 Introduction

Wireless Sensor Network (WSN) technology is expected to play an essential role for our society in the near future. A WSN used as a social infrastructure to make our life safe, secure, and comfortable is one of the most promising among a wide variety of applications. This sort of WSNs is supposed to carry various types of information, such as temperature, humidity, fire alarm, intrusion warning, image, and sound. The urgent information, a fire alarm for example, has to be transmitted through a WSN with higher reliability and lower latency than other non-urgent information. Since the capacity of a wireless network is limited, a WSN must be capable of differentiating and prioritizing packets depending on their urgency and importance of embedded sensor information, which are defined by an application. Furthermore, in the event of a large scale event, such as an earthquake attack, a lot of nodes detect the emergency and send urgent information at the same time. A WSN should mitigate a serious congestion caused by this simultaneous emission of a lot of emergency packets, especially around a base station (BS).

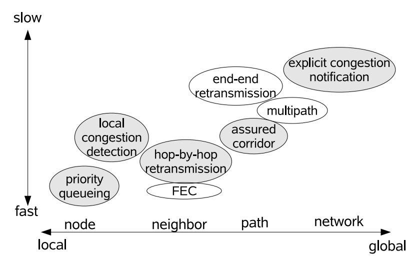

Figure 1. Examples of control mechanisms.

We design and propose so-called UMIUSI (aUtonomous Mechanisms Integrated for Urgent Sensor Information) architecture by incorporating several simple mechanisms above the network layer to offer fast and reliable transmission of urgent information. Each node activates one or more of the control mechanisms in accordance with locally observed conditions, and as a result, a series of appropriate controls take place from locally to globally adapting to the scale of an emergency ranging from a small event like a gas leakage to a catastrophic event such as an earthquake attack.

2 Design Methodology

In this paper, we consider a WSN deployed in a building or a house to monitor and control a living and working environment. A WSN consists of one BS and a number of immobile sensor nodes. Although the mechanisms proposed here work above the network layer and do not depend on any specific lower layer protocols, we assume a contention-based MAC protocol and a multihop routing protocol.

Each node observes the environment and reports obtained sensor information to the BS at regular intervals. Once an emergency occurs, an appropriate series of actions take place to deliver urgent information to the BS. For the sake of scalability, there is no centralized control in our architecture and decisions are made by a node itself. Those nodes which are not involved in the emergency keep their

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normal operation.

In summary, our design objectives of a WSN architecture for transmission of urgent sensor information are:

- *High reliability and low latency*. The reliability and latency of transmission of urgent information are the most important issues. We consider that energy efficiency can be sacrificed to some extent for transmission of urgent information during emergency.

- *Self-organizing and localized behavior*. The type and scale of an emergency and the number of simultaneous emergency events are unpredictable and dynamically change as time passes. Therefore, a centralized architecture is infeasible. We need an architecture which is fully-distributed, self-organizing, and adaptive. A globally-organized behavior of a WSN against detected emergencies should emerge as a consequence of localized reactions of each sensor node.

- *Simplicity*. Since a node has limited computational capacity and a small amount of memory, mechanisms to support fast and reliable transmission of urgent information must be simple enough.

To satisfy these requirements, a sensor node should have several simple control mechanisms (see Fig. 1), which work in different spatial and temporal levels, instead of applying a single and complex mechanism to all types and scale of emergency. One or more mechanisms are activated in response to the local conditions and emergency-dependent control emerges from local to the whole.

3 UMIUSI Architecture

3.1 Details of the Architecture

We construct UMIUSI architecture for transmission of urgent sensor information in a WSN following the design policy stated in the previous section. First, we consider three classes of sensor information as one normal class and two emergency classes as follows and prioritize emergency class information over normal class information.

Any non-urgent information belongs to *normal class*. Normal class information is gathered to the BS at regular intervals of t_{norm}. *Important class* is for urgent information, but an application can tolerate loss and delay of important class information to some extent. *Critical class* is for the most urgent and important information which requires highly reliable and fast transmission to the BS. The emission intervals of these two emergency classes, t_{imp} and t_{cri} respectively, are shorter than t_{norm}, but t_{imp} could be regulated to be larger than t_{norm} to mitigate congestion.

As stated in the previous section, mechanisms leveraged in UMIUSI must be simple, work independently of other schemes and protocols, and function in different temporal and spatial levels. From these points of view, we incorporate following five mechanisms into UMIUSI (Fig. 2).

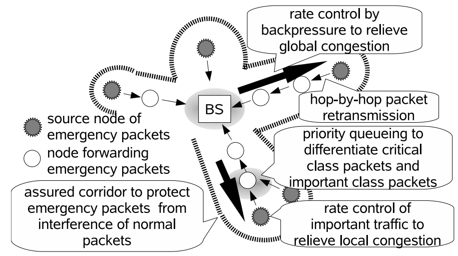

Figure 2. The mechanisms leveraged in UMIUSI.

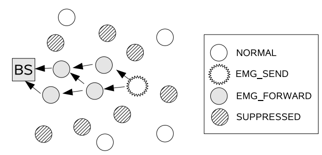

Figure 3. An assured corridor.

Assured corridor mechanism (ACM) The main purpose of this mechanism is to avoid loss of emergency packets caused by collisions with normal packets. In addition, ACM contributes to avoiding delay caused by sleeping nodes. An assured corridor consists of awake nodes, which is on the path from the source node to the BS, and surrounding silent nodes, which are in the range of the radio signals of awake nodes (Fig. 3). All nodes in a WSN follow the state transitions among four states: *NORMAL*, *EMG_SEND*, *EMG_FORWARD*, and *SUPPRESSED*. In normal operation, all nodes are in the *NORMAL* state and operate in accordance with a data gathering scheme. Once a node detects an emergency, it moves to the *EMG_SEND* state and begins to periodically emit packets labeled as a critical packet or important packet. On receiving an emergency packet, a node on the path to the BS moves to the *EMG_FORWARD* state, cancels its sleep schedule to keep awake, and immediately relays emergency packets it receives. A node which is not on the path moves to the *SUPPRESSED* state and stops sending normal packets. Details of ACM with simulation results can be found in [2].

Retransmission In order to recover a lost emergency packet and provide differentiated services, we introduce a prioritized scheduling algorithm of hop-by-hop retransmissions. A node retransmits an emergency packet when it detects a loss. The hop-by-hop acknowledgement can be easily done by, for example, overhearing a packet sent by a next-hop node.

Priority queueing Each node has a priority queue for emergency packets, with which important packets are served only when there is no critical packet queued. This means that fast transmission of critical packets is accomplished at the sacrifice of longer transmission delay of important packets.

Rate control by local congestion detection To mitigate congestion as fast as possible by local control, we introduce a rate control mechanism which is triggered by detection of local congestion. We assume here that the reporting rate can be regulated independently or dependently on sensing frequency. In order to keep the reporting rate of critical information at $1/t_{\mathrm{cri}}$, the rate control is applied only to important class traffic. In our implementation, a node detects local congestion by monitoring packet reception rate. As a rate control algorithm, we employ a TCP-like AIMD (Additive Increase and Multiplicative Decrease) algorithm for its simplicity.

Rate control by backpressure In an event of a large emergency such as an earthquake, the rate control with local congestion detection cannot fully mitigate congestion around a node belonging to multiple paths and around the BS, where many emergency packets concentrate on. We adopt a mechanism in which a backpressure message is sent back to source nodes from a point of congestion by piggybacking on an emergency packet to regulates the emission rate of important packets. When a node detects congestion, it sets an explicit congestion notification (ECN) bit in the header of important packets which it relays toward the BS. By means of overhearing, a congestion notification propagates to the source node. On receiving the notification, the source node reduces the emission rate of important packets, and the congestion is mitigated.

3.2 Contribution of the mechanisms

Contribution of the mechanisms to fast and reliable transmission of urgent information in a large scale event, for example, is summarized in Fig. 4, which is verified through simulation experiments (results are not shown in the paper due to space limitation). One major objective of this work is to see how these simple mechanisms which work different temporal and spatial levels cooperate and how much fastness and reliability can be accomplished. It implies that we can incorporate other effective mechanisms such as data aggregation at an intermediate node, multi-path routing, forward error correction and so on.

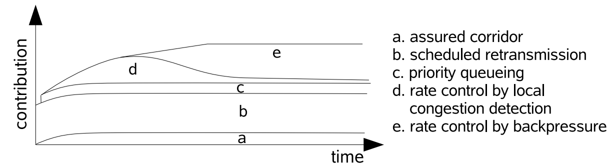

Figure 4. The contribution of each mechanism for a large scale event

4 Demonstration

In the demonstration, we show the basic behavior of a small WSN consisting of several sensor nodes and a BS. Nodes are provided by OKI Electric Industry Co., Ltd. They are equipped with ARM7 MPU, 512 Kbytes ROM, and 32 Kbytes RAM, and adopt IEEE 802.15.4 non-beacon mode for MAC layer. We implemented UMIUSI and, for network layer, the synchronization-based data gathering scheme [1]. The total code size is about 170 Kbytes.

In the normal operation, sensor data from all nodes are collected to the BS with an interval of 10 seconds. When a node detects an event, it begins to emit emergency packets with a shorter interval. The state transition at each node can be monitored with LEDs. We also introduce a laptop connected to the BS to monitor packet reception. The average delivery ratio of critical information in a large scale emergency is about 99.5 % in preliminary experiments.

5 Conclusion

Urgent sensor information is needed to be transmitted preferentially in a WSN used as a social infrastructure. In this paper, we presented a network architecture called UMIUSI designed for fast and reliable transmission of urgent information in wireless sensor networks. Sensor information is categorized into three traffic classes. In order to prioritize transmission of the critical class, five simple mechanisms, *i.e.*, ACM, retransmission, priority queueing, rate control by local congestion detection, and rate control by backpressure, collaborate consistently.

References

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