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Research Article

A Design of a Congestion Control Scheme Based on Multichannel in Wireless Sensor Networks

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We propose a congestion control scheme on wireless multichannel sensor networks. The proposed congestion control scheme consists of a congestion detection strategy and two cases of congestion control strategies. The congestion detection strategy modeled in the Morkov chain provides two thresholds that can detect two congestion conditions, or light and heavy congestion conditions. The two congestion control strategies consist of a weak congestion control strategy that can control light congestion and a strong congestion control strategy that can control heavy congestion. In addition, the proposed congestion control scheme assigns a priority to a received packet according to their transmission distance, and it differentiates the number of useable channels when congestion occurs. We can reduce energy consumption due to retransmission because packets received from long distance can use more channels in the proposed scheme.

1. Introduction

Wireless sensor networks are local networks that collect information through deploying sensor nodes where direct observation is hard. Charging energy or changing the batteries of a sensor node is difficult in wireless sensor networks, so reducing the energy consumption of a sensor node is an important issue among others. Many researches on reducing the energy consumption of sensor nodes have been conducted, and researches on routing path, which minimizes the transmission path for reducing energy consumed for data transmission, are notable [1]. However, focusing on minimizing the transmission path leads to a problem of imbalance in energy consumption due to transmission path overlap and so on. For solving the problem, multipath transmission or similar data aggregation scheme has been proposed [2]. Because data collected by sensor nodes are always sent to a single sink or more, the bottleneck around sinks occurs frequently. Hence, congestion causes the rapid destruction of sensor networks by leading to too much additional energy consumption in sensor nodes in a short time. In particular, in the case of retransmission to a long distance, the energy consumption in sensor nodes is accelerated. Accordingly, we propose a congestion control scheme considering transmission distance, which can allocate a priority according to the transmission distance of received data and can use the different range of channels along with the different priority.

Recently, researches on techniques using multichannel for increasing transmission reliability in sensor networks are actively conducted [3]. Multichannel sensor networks can realize reliable and efficient transmission and can transmit data simultaneously without interference or collision because sensor nodes in the multichannel sensor networks use different channels with different frequencies. The proposed scheme can detect congestion by monitoring buffer occupancy rate and a threshold obtained from multichannel modeling.

This paper is organized as follows: Section 2 presents the related works, and Section 3 describes a congestion control scheme based on multichannel. The proposed scheme is divided into a congestion detection strategy and congestion control strategies which can control congestion according to congestion degree. Section 4 shows simulation results evaluating the performance of the proposed scheme. Finally, we present conclusions in Section 5.

2. Related Works

Many researches have been studied to reduce energy consumption of sensor nodes on wireless sensor networks. The authors in [2] proposed a data aggregation scheme based on a tree. Its main idea is to reduce energy consumption due to transmission of the sensor node used with maximum energy. Multihop hierarchical routing protocol (MHRP) to prolong the lifetime of wireless sensor networks is proposed in [1]. In this protocol, a cluster header was selected by considering the remaining energy of sensor nodes. In [4], energy-balanced parameter-adaptable cooperative protocol (EBPACP) discriminated between an intercluster and an intracluster and adjusted the size of cluster for improving energy balance. Authors in [5, 6] studied error recovery schemes to reduce energy consumption in wireless sensor networks. In [5], when retransmission is needed by a corrupted packet, the packet was divided into small subpackets, and retransmission was done for only the corrupted portion of the subpackets. An error control scheme in [6] used BCH coding following Hybrid ARQ on wireless sensor networks based on CDMA.

Many researches on congestion control which can be used in wireless sensor networks are actively conducted to increase the reliability of transmission. Congestion detection and avoidance (CODA) in [7] detected congestion based on buffer occupancy and the state of channel load and controlled congestion by an open-loop strategy or a closed-loop strategy according to congestion degree. Priority based congestion control protocol (PCCP) was proposed in [8]. In this protocol, packets were transmitted by priorities when congestion occurred. The priorities were assigned to sensor nodes in advance. In [9], authors referred to the imbalance of energy consumption due to transmission distance and traffic concentration around a sink node. Therefore, they researched improving the imbalance of energy consumption due to transmission distance in wireless sensor networks based on single channel.

MAC protocols based on multichannel which was able to use in wireless sensor networks were proposed to provide the high reliability of transmission [3, 10]. In [10], one of the N channels is a control channel, and the others are data channels. A guard channel scheme for mobile networks was proposed and extended in [11, 12]. In the guard channel scheme, channels were reserved for handoff calls and new calls; however, the number of channels reserved for each call was differentiated.

3. A Congestion Control Scheme Based on Multichannel

We propose a congestion control scheme based on multichannel. In the proposed congestion control scheme, congestion is classified as light congestion and heavy congestion according to congestion degree. Light congestion and heavy congestion can be detected through a comparison of value between buffer occupancy rate and two thresholds that are provided by multichannel modeling and extension of the modeling. Finally, the proposed scheme includes two congestion control strategies or a weak congestion control strategy and a strong congestion control strategy. A weak congestion control strategy and the other strategy can control light congestion and heavy congestion, respectively. For light congestion, senders reduce the number of sending packets by themselves, and a receiver assigns a priority to receiving packets according to transmission distance. In the strong congestion strategy, senders decide on whether they send packets by a random value.

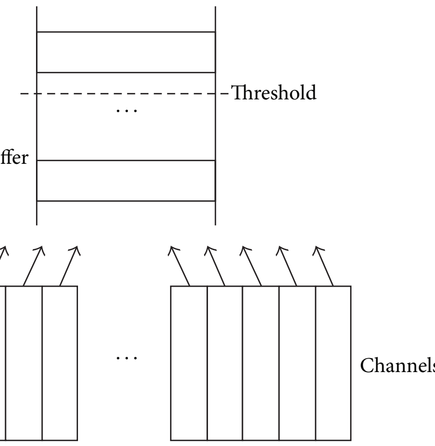


Figure 1: A structure of a sensor node for congestion detection.

3.1. Congestion Detection. To detect congestion, we consider the structure of a sensor node as in Figure 1.

In Figure 1, packets are stacked in the buffer after they are received through one of the channels. When the number of packets in the buffer exceeds a threshold, it is estimated that congestion occurs. To obtain the threshold, usable probabilities of each channel are to be gotten. The probabilities can be gotten in the way of the Markov chain modeling based on multichannel. For modeling, let n denote the number of channels in one sensor node. Arrival rate for receiving packets denotes λ according to the Poisson distribution. The channel holding time follows the exponential distribution with average $1/\mu$, and then $\rho = \lambda/\mu$ is defined [11]. Ph_j, a probability which will use the channel j, is found through the birth-and-death process in the Markov chain. We obtain Ph_j by

$$Ph_j = \frac{\rho^j}{j! \sum_{a=0}^{n} (\rho^a / a!)}. \quad (1)$$

$Ph_{\sum c} = \sum_{j=1}^{c} P_j$ is derived from (1). $Ph_{\sum c}$ is a probability used to the channel c. Hence, we detect light congestion in

$$B_{\text{occu}} \geq Ph_{\sum c}, \quad (2)$$

where B_{occu} denotes real buffer occupancy rate. In this paper, we estimate that light congestion occurs when real buffer occupancy rate exceeds a probability used from the first channel to the c channel. We can estimate the optimal c through a simulation.

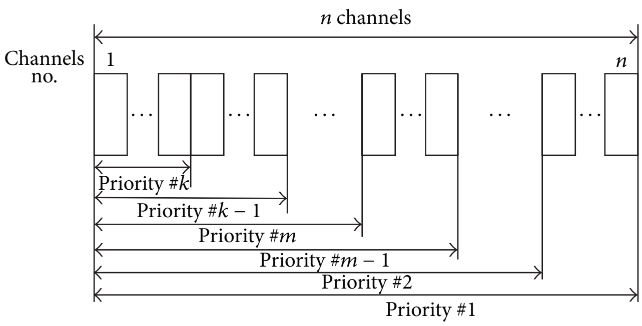


Figure 2: Usable channels according to priorities.

We assign a priority to receiving packets according to their received signal strength (RSS) when light congestion occurs. RSS can be measured in the physical layer whenever packets are received. If RSS of a received packet is weak, it means that the packet is sent from far away, and so the packet is assigned a high priority. RSS_{max} and RSS_{min} denote a maximum RSS and a minimum RSS. A packet's RSS is compared with RSS_{max} and RSS_{min}, and RSS_{max} and RSS_{min} can change whenever the packet is received. We obtain the priority of packet m in

$$P_m = \begin{cases} 1, & \mathrm{RSS}_{\min} \le \mathrm{RSS}_m \\ \left\lfloor \dfrac{k \times \left|\mathrm{RSS}_m - \mathrm{RSS}_{\min}\right|}{\mathrm{RSS}_{\max} - \mathrm{RSS}_{\min}} \right\rfloor + 1, & \mathrm{RSS}_{\min} < \mathrm{RSS}_m < \mathrm{RSS}_{\max} \\ k, & \mathrm{RSS}_{\max} \le \mathrm{RSS}_m, \end{cases} \tag{3}$$

where k denotes the number of priorities. A packet with a high priority can use more channels than that with a low priority. If a packet sent from far away is not received due to the number of insufficient channels, retransmission for the packet causes more energy consumption than that sent within short distance. Figure 2 shows the concept. In Figure 2, a packet with the priority 1 can use all channels and a packet with the priority 2 can use remaining channels but the last channel group.

We calculate rates according to the priorities of receiving packets for dividing usable channels per priority. The rate of priorities denotes $r_1, r_2, \ldots, r_k$, respectively. In Figure 2, the receiving packet with the lowest priority k can use channels from the first channel till the $1 + |r_1(n-k)|$th channel, and another packet with priority m can use channels from the first channel till $m + \sum_{i=1}^{k-m} |r_i(n-k)|$th channel. A packet with the highest priority can use all the channels. We stipulate arrival rates of packets $\lambda_1, \lambda_2, \ldots, \lambda_k$ according to the Poisson distribution to obtain a probability similar to (1) from the structure of channels such as in Figure 1. Also, λ is $\lambda_1 + \cdots + \lambda_k$. The channel holding time of each priority follows the exponential distribution with an average of $1/\mu$, and then $\rho = \lambda/\mu$ and $\rho_2 = \sum_{i=1}^{k} \lambda_i/\mu, \ldots, \rho_k = \lambda_k/\mu$ are defined. Ph_j, a probability which will use the channel j, is obtained by

$$Ph_j = \begin{cases} \dfrac{\rho^j}{j!} Ph_0, & 1 \le j \le 1 + |nr_1| \\ \dfrac{\rho^j \rho_2^{j-(1+|nr_1|)}}{j!} Ph_0, & 1 + |nr_1| < j \le 2 + \sum_{i=1}^{2} |nr_i| \\ \vdots \\ \dfrac{\rho^j \rho_2^{1+|nr_1|}, \ldots, \rho_k^{j-(k-1+\sum_{i=1}^{k-1} |nr_i|)}}{j!} Ph_0, & k - 1 + \sum_{i=1}^{k-1} |nr_i| < j \le n. \end{cases} \tag{4}$$

Equation (5) defines Ph_0 in (4):

$$Ph_0 = \frac{1}{\sum_{j=1}^{1+|nr_1|} (\rho^j/j!) + \sum_{j=2+|nr_1|}^{2+\sum_{i=1}^{2} |nr_i|} \left(\rho^{1+|nr_1|} \rho_2^{j-(1+|nr_i|)}/j!\right) + \cdots + \sum_{j=k+\sum_{i=1}^{k-1}|nr_i|}^{n} \dfrac{\rho^{1+|nr_1|} \rho_2^{1+\sum_{i=1}^{2} |nr_i| - |nr_1|} \cdots \rho_k^{j-(k-1+\sum_{i=1}^{k-1} |nr_i|)}}{j!}}. \tag{5}$$

$Ph_{\sum m} = \sum_{j=1}^{m+\sum_{i=1}^{m} |nr_i|} Ph_j$ is derived from (1). $Ph_{\sum m}$ is a probability used to the priority m. We detect heavy congestion in

$$B_{\mathrm{occu}} \ge Ph_{\sum m}. \tag{6}$$

In this paper, we estimate that heavy congestion occurs when real buffer occupancy rate exceeds a probability used to the channel $m + \sum_{i=1}^{m} |nr_i|$.

3.2. Congestion Control. The main goal of a congestion control is to recover from congestion quickly. However, on the contrary, network utilization is reduced quickly. So it is important to keep a balance between recovery time of congestion and network utilization for designing an efficient congestion control scheme.

In Section 3.1, we classified congestion into light congestion and heavy congestion according to congestion degree. A congestion control strategy must be classified into two cases in accordance with this. Therefore, we propose two cases of congestion control strategies, or a weak congestion control strategy and a strong congestion control strategy. A weak congestion control strategy controls light congestion by reducing the sending rate of sensor nodes, and a strong congestion control strategy controls heavy congestion by giving up transmission of several sensor nodes.

When it detects light congestion through (2), the receiver sends a light congestion notification (LCN) message to

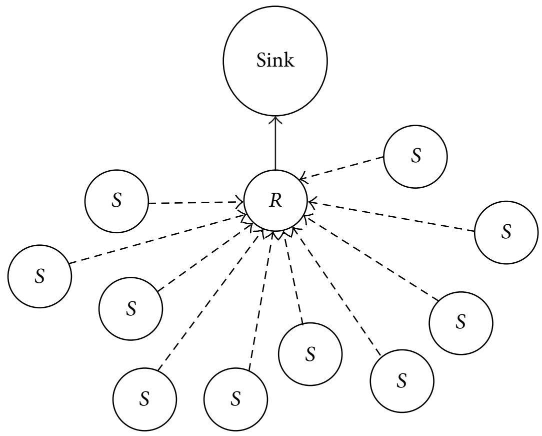


Figure 3: Simulation environment.

Table 1: Simulation parameters.

Parameter	Value
The number of channels per sensor node	8
Buffersize	64 packets
Data packet size	40 bytes
Burst duration time	20 sec
The number of priorities	4
Initial energy per sensor node	5 J
Energy consumption for device	50 nJ
Amplify energy	0.0012 pJ
Area	100 m × 100 m

senders. Therefore, the receiver assigns a priority to receiving packets according to their RSS. The number of usable channels is differentiated by priorities. Sensor nodes receiving the LCN message reduce their sending rate as much as S_w in (7). S_w is included in the LCN message

$$S_w = S_n \frac{B_{\text{occu}} - Ph_c}{N_{\text{sensor}}}, \quad (7)$$

where S_n and S_w denote sending rates before and after receiving the LCN message, respectively. N_{sensor} is the number of senders.

If congestion degree is heavy through (6), then a strong congestion control is required. When a receiver detects heavy congestion through (6), it is classified into two priorities such as

$$P_m = \begin{cases} 1, & \text{RSS}_m > \dfrac{\text{RSS}_{\max} - \text{RSS}_{\min}}{2} \\ 2, & \text{RSS}_m \leq \dfrac{\text{RSS}_{\max} - \text{RSS}_{\min}}{2}. \end{cases} \quad (8)$$

The receiver sends a heavy congestion notification (HCN) message to sensor nodes sending packets with a low priority. A sensor node receiving the HCN message generates a random number R from 1 to 100. If R is smaller than $(B_{\text{occu}} - Ph_{\sum m}) \times 100$ in (9), the sensor node gives up transmission. This means that congestion is strongly controlled because of reducing the number of senders,

$$R \leq \left(B_{\text{occu}} - Ph_{\sum m}\right) \times 100. \quad (9)$$

4. Performance Evaluation

In this section, we perform a simulation for evaluating the congestion control scheme based on multichannel proposed in this paper. On experiment, we construct a receiver, a sink, and ten senders such as in Figure 3.

Table 1 shows simulation parameters for performance evaluation.

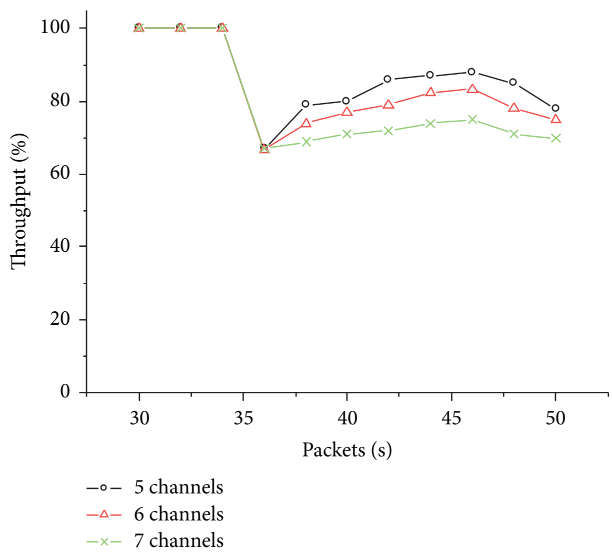
Figure 4(a) shows the throughput of the weak congestion control strategy. To obtain the optimal c in (2), we simulate three cases of 5 channels, 6 channels, and 7 channels while packets/sec change from 30 to 50. In Figure 4, light congestion occurs when packets/sec become 35.

In Figure 4(a), the case of 5 channels gives the best performance. However, the network utilization of the 5 channels is about 10% lower than that of the case of 6 channels because the sending rate of senders is reduced too much. This means that the sending rate is reduced too much because $B_{\text{occu}} - Ph_c$ in (7) is too large. Therefore, we find out that the number of optimal channels for (2) is 6.

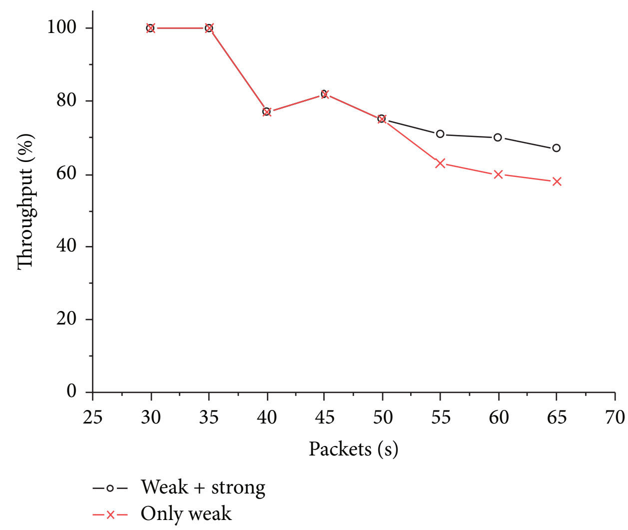
Figure 4(b) shows the performance of the strong congestion strategy. Figure 4(b) also presents the simulation results of using both the strong congestion control strategy and the weak congestion control strategy and only the weak congestion control strategy. Also, when packets/sec exceeds 50, the simulation environment is added to two new senders for heavy congestion. In Figure 4(b), when packets/sec is over 35, heavy congestion occurs. So, until packets/sec is 50, the performance does not change whether the strong congestion strategy is applied or not. If the strong congestion control strategy is applied, sensor nodes as many as $B_{\text{occu}} - Ph_{\sum m}$ in (9) do not send packets. Therefore, the throughput in the case of adding to the strong congestion control strategy is better than that in the other case because the number of packets received in the receiver is reduced.

In this paper, we assigned a priority to receiving packets according to their transmission distance. In sensor networks, there are huge variations of energy consumption according to transmission distance. A sensor node located in long distance consumes more additional energy than that located in short distance when they retransmit. We assigned a priority according to transmission distance to prevent additional energy consumption from retransmission.

Figure 5 shows energy consumption of three cases due to retransmission. The first case is that congestion control strategies are none, and this case is utilized as a criterion for comparison to other two cases. Therefore, the energy consumption caused by retransmission in this case is set to 100%. Other two cases are as follows: one where only the weak congestion control strategy is applied, and the other where the strong congestion control strategy is added to the second



(a) Using the weak congestion control strategy



(b) Using both the weak congestion control strategy and the strong congestion control strategy and only the weak congestion control strategy

Figure 4: Comparison of throughput according to the rate of packet generation.

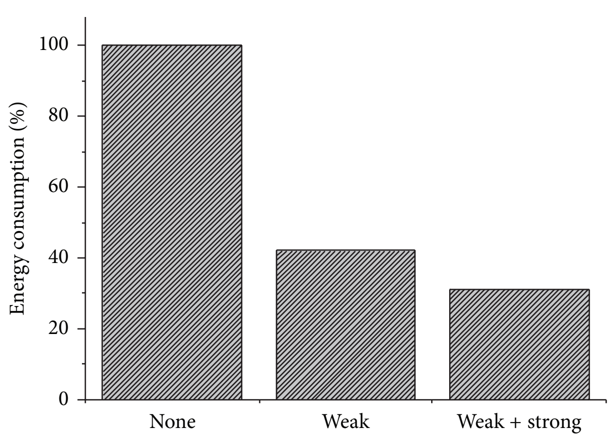


Figure 5: Comparison of energy consumption due to retransmission.

case. We utilize (10) proposed in [13] for estimating energy consumption caused by retransmission

$$E_{\text{node}} = b_{\text{sense}} E_{\text{sense}} + b_{rx} E_{rx} + b_{tx} \left(E_{tx} + E_{\text{amp}} d^{n} \right). \quad (10)$$

Equation (10) is a well-known energy consumption model which is frequently used to estimate energy consumption on wireless sensor networks. Equation (10) is used to calculate energy consumption due to retransmission during congestion period. The result is shown in Figure 5.

In Figure 5, one case of applying the weak congestion control strategy shows that energy consumption is 42% under the criterion, and the other case of applying the two strategies proposed in this paper shows that energy is consumed 31% as compared with the criterion. This means that the proposed scheme provides a stable transmission environment for senders that are far away from a receiver.

5. Conclusions

In this paper, we proposed a congestion control scheme based on multichannel in wireless sensor networks. The proposed scheme consists of congestion detection and congestion control; we also divided them into light congestion and heavy congestion according to congestion degree. For detecting two cases of congestion, we used two thresholds obtained by multichannel modeling. The two cases of congestion were controlled by the two congestion control strategies, or the weak congestion control strategy and the strong congestion control strategy.

We evaluated the performance of the proposed scheme through a simulation. We showed the results of throughput and energy consumption caused by retransmission.

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