

## A Novel Adaptive Congestion Avoidance Protocol for Wireless Sensor Networks

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### Abstract

Most researches on wireless sensor networks (WSNs) are focused on how to save the energy of the sensor nodes. However, in some applications of WSNs, such as in the monitoring of an earthquake or a forest fire, it is much more important to transmit emergency data packets to the sink node as soon as possible than to save power. This paper proposes a novel Adaptive Congestion Avoidance Protocol (ACAP) model to provide a feasible WSNs architecture that will save the energy of the sensor nodes in the normal situation, but will transmit emergency data packets in an efficient manner to the sink node. The simulation analysis shows that the ACAP provides superior performance during both normal and emergency conditions.

**Keywords:** wireless sensor networks (WSNs), power saving, emergency traffic

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### 1. Introduction

Wireless Sensor Networks (WSNs) have been implemented in many applications and are the subject of much research recently. The major restrictions of the WSNs are limited energy supply, limited computing power, limited buffer size, and limited bandwidth [1]. Most research on wireless sensing networks (WSNs) is focused on how to save the energy of the sensor nodes (SNs). However, in some applications of WSNs, especially during an emergency situation, delivering data packets to the sink node as soon as possible is much more important than saving power.

Communication in the WSNs occurs in different ways depending on the underlying application or mission of the network. As shown in Figure 1, we defined nodes A, B and C as uplink nodes of node D, since they are farther away from the sink node than node D, and node D is denoted as the downlink node of nodes A, B, and C. The data packets produced by a SN can be classified into three delivery types: clock-driven, event-driven and query-driven [2]. Clock-driven data packets are gathered by the SN, and are periodically sent to the sink node. In an emergency situation, when the sensing data is over the preset threshold value, the sensing node sends the event-driven data packets to the sink node as soon as possible. SNs may send query-driven data packets back to the sink. Event-driven data packets and query-driven packets have higher priorities to be delivered than the clock-driven data. For the query-driven data packets the querying mode of the sink is set as an emergency situation that must be responded to as soon as possible, and thus the query-driven data is assigned as event-driven data.

Sensor networks usually operate under light load and become active in response to the monitored event. The energy constraint and low buffer size are the two most important problems in SNs. It is hard to determine the sensing interval ( $\tau$ ) required for a SN to sense and transmit clock-driven data packets to the sink node. This is due to the fact that if the value of  $\tau$  is too short, the SN will produce and send data packets to the sink node more frequently. Consequently, the energy of the SN will be consumed more quickly. On the other hand, the SN can not send the real time status to the sink node if the sensing interval is too long. The other important problem in the design of the WSNs routing protocol is the low buffer size. In general, SNs will not send large amount of data packets to the sink node during normal situation. For example, in the monitoring of forest fires, the SN will send periodically (clock-driven) data

packets to the sink node, containing information regarding location, humidity and temperature. In the event-driven model, when the sensed temperature is higher than the threshold value set in the SN, the triggered SN will deliver a large amount of emergency packets to the sink node, which may cause congestion. In this situation, the emergency packets that are far away from the sink node may not be delivered successfully, since they have to compete with clock-driven data packets generated in the downlink path. Consequently, in real time, the sink node may be unable to respond to the entire WSNs situation.

The remainder of this paper is organized as follows. Section 2 discusses the relevant literature and section 3 details the algorithm of the proposed ACAP for the WSNs. Section 4 explains the performance simulation of the ACAP, and finally in section 5 we draw our conclusions.

## 2. Related Literature

Many researches have proposed to solve the above described problems. The buffer-based congestion avoidance algorithm [3] is an efficient scheme to prevent the occurrence of congestion in the WSNs. As shown in Figure 1, the downstream traffic from SNs toward the sink is many-to-one multi-hop convergent. Due to the convergent nature of the downstream traffic, congestion is more probable to occur in the downstream direction. The key for congestion avoidance in [3] is to make sure that the uplink sensor nodes ( $USN_i$ ) send data packets to their downlink sensor node D only when node D has the buffer space to hold the packet. Therefore, in case of congestion, the uplink nodes ( $USN_i$ ) should reduce data forwarding to their downlink node (node D).

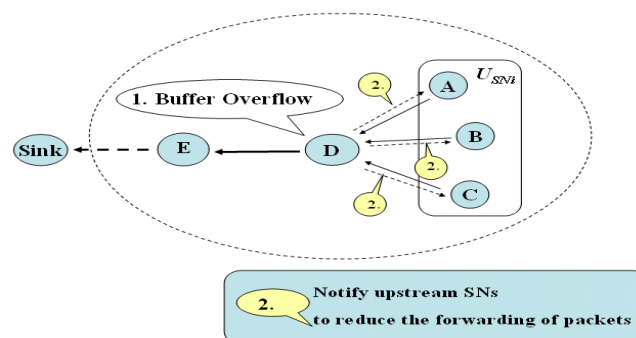


Figure 1. Buffer-based Congestion Avoidance Detection in [3]

The hybrid cluster (HC) WSNs model [5], based on the cluster-based WSNs scheme, provides different priorities of data packets and delivers the higher priority packets in a congested condition. However, the HC WSNs adopted fixed-time interval for reporting data packets can not prevent buffer congestion well in the SN when a burst of emergency event-driven traffic occurs. In the event-to-sink reliable transport (ESRT) [6], a sensor node places a congestion-notification (CN) bit in the packet header when its buffer is nearly full. The sink node recalculates any new reporting data periodically and will recognize the SN by its CN bit. Congestion and avoidance in SNs (CODA) [7] provides an open-loop hop-by-hop backpressure mechanism, and a close-loop multisource regulation mechanism to solve the congestion. Xu and Christos [8] proposed a dynamic sleep-time control in event-driven WSNs, but did not provide different priority traffic services. The Adaptive Sampling Protocol (ASP) [9] propose a scheme which can dynamically eliminate the redundancy and estimate the deficient data based on learned relations in a way to ensure low and balanced energy consumption. Alireza, etc. [10] propose an aware and punishment based cooperative adaptive sampling technique to satisfy both network life-time and data quality requirements. The SRPL [11] present a synchronous rich preamble listening protocol for WSNs deployed in the agriculture canopy to reduce the power consumption. Hii Pei-Cheng, etc. [12] proposed an integrated mobile healthcare monitoring system combining WSN and CDMA (Code Division Multiple

Access) technology which achieve the key drivers of mobility, flexibility, conveniency, and independency.

In this paper, we propose a Hybrid Flexible Congestion Avoidance Protocol, called the ACAP, which provides a hybrid priority for packet delivery and uses a flexible sensing interval according to the buffer length of the SNs in order to prolong the lifetime of the SNs and to transmit event-driven data packets to the sink node as soon as possible.

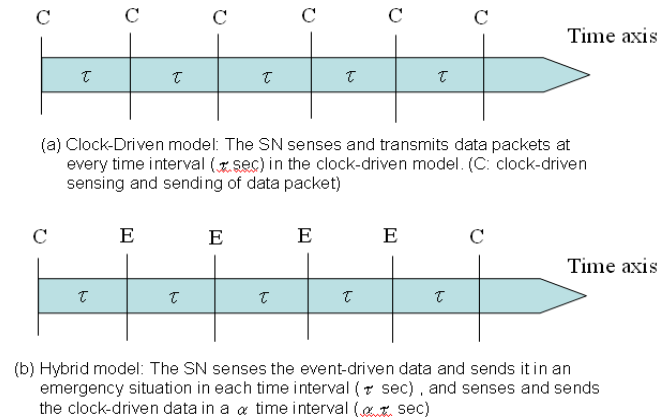


Figure 2. (a) Clock-driven model and (b) Hybrid model

### 3. Adaptive Congestion Avoidance Protocol (ACAP) for WSNs

In WSNs, a SN may transmit three types of data to the sink node; clock-driven, event-driven and query-driven data packets. Generally, the sensor nodes gather the clock-driven data packets and send them periodically to the sink node, as shown in Figure 2(a). In order to prolong the lifetime of the SNs in the ACAP, as shown in the Figure 2(b), the event-driven data packets may be produced or not depending on the sensing result in each time interval  $\tau$ . As we know, the energy to transmit a data packet is much more than the sensing energy. For example, the value of  $\alpha$  is 5 in Figure 2(b), which means that there are one clock-driven data packet and  $\alpha$  times event-driven data packets being sensed in a round. A clock-driven data packet will be produced once in each round, and the event-driven data packets will only be sent when the preset threshold in the SN is triggered. It is obvious that the SNs can save energy in a non-event condition.

#### 3.1. Construction Phase

We consider the case of multipath routing to the sink in the ACAP. A sensor, SN<sub>x</sub>, has to build the lists of its downlink neighbor nodes and uplink its neighbor nodes. D<sub>x</sub> is the list of the downlink neighbor nodes. SN<sub>x</sub> can use these nodes to forward packets to the sink node, and U<sub>x</sub> is the list of the uplink neighbor nodes. SN<sub>x</sub> may be used by the nodes in U<sub>x</sub> to be the packet forwarding node. There are four fields included in a beacon message, including beacon number (bn), beacon status (bs), sensor node id (Sn), and hop counter (hc). The beacon number is initiated by the sink node which to make out each of the beacon message. The beacon status has two different phases: "B" indicates the beginning of a new beacon and informs the receiving nodes to operate the building process of the lists of the neighbors. "E" indicates the ending of a beacon and informs the receiving nodes to update the lists of the neighbors. The hop counter is used to indicated that the beacon message is forwarding from the downlink nodes or backwarding from the uplink nodes. A forwarding beacon is rebroadcasted with the sensor node id of the rebroadcasting node and the hop counter is increased by one. The backwarding beacon will be terminated. The sensor node id in the forwarding beacon is put into the list of D<sub>x</sub>, and the sensor node id in the backwarding beacon will be put into the list of U<sub>x</sub>. The beacon message is periodically broadcasted by the sink node to help the sensor node to maintain the list of neighbors, U<sub>x</sub> and D<sub>x</sub>.

### 3.2. Congestion Avoidance Phase

In order to prevent a SN from being congested by a burst of emergency data packets, the congestion detection and avoidance scheme are involved in each SN. The value of the buffer length is used to detect if a SN may become congested due to an excessive amount of incoming data packets. While the detected buffer length  $b_k$  reach to the value of  $B_{max}$  as shown in the Figure 3, the SN will send out an implicit ACK [4], including a congestion notification (CN), to the uplink SNs in order to stop the downlink SNs transmitting data packet continuously in the next time interval. The  $b_k$  estimation is  $b_k = b_{k-1} + \Delta b_k$ , where  $\Delta b_k = (b_{k-1} - b_{k-2})$ . This means that the predicted value of  $b_k$  is the sum of the present buffer size and the increase in buffer size in the previous time interval.

### 3.3. Sensing-interval Adjustment-phase

In the congestion avoidance phase, the sending of the downstream data packets will be paused when the buffer length is predicted to be reaching the value of  $B_{max}$ . This avoidance scheme protects a sensor node from overflowing, but it will also inform the uplink nodes to block transmission message. When the buffer length is between the value of  $B_{min}$  and  $B_{max}$ , as shown in Figure 3, the sensing interval ( $\tau$ ) is adaptive between  $\tau_{min}$  and  $\tau_{max}$  according to the measured buffer length  $b$ . Longer sensing interval provide a lower power consumption. In the sensing interval adjustment phase, the sensing interval ( $\tau$ ) will be adjusted according to the buffer length before the buffer overflows. The value of  $\tau$  will be increased when the buffer length is predicted to increase and will be decreased when the buffer length is decreasing, as shown in Figure 3. Figure 4 shows the operation flow chart of the congestion avoidance phase and flexible sensing period adjustment phase in a sensor node. Sensing interval ( $\tau$ ) will be changed in each round as per the following rule according to the predicted length of the buffer ( $b$ ).

Case 1.  $b < B_{min}$ : The SN will notify its upstream SNs that the sensing interval ( $\tau$ ) is  $\tau_{min}$ .

The SN will transmit both of the clock-driven data packets and event-driven data packet toward the downlink nodes.

Case 2.  $B_{min} \leq b < B_{max}$ : The SN will block to transmit clock-driven data packets and the event-driven message sensing interval ( $\tau$ ) is prolong to  $\tau_{min} + \Delta\tau$ , where  $\Delta\tau = \frac{b - B_{min}}{B_{max} - B_{min}} * (\tau_{max} - \tau_{min})$

Case 3.  $B_{max} \leq b$ : When the buffer length reaches, or is more than  $B_{max}$ , the SN will send a congestion notification (CN) to its upstream SNs, and the upstream SNs will stop producing data packets.

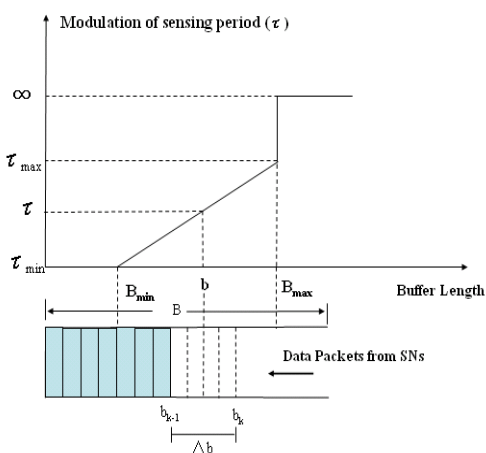


Figure 3. Sensing Interval ( $\tau$ ) Adjustment in the Sensor Node

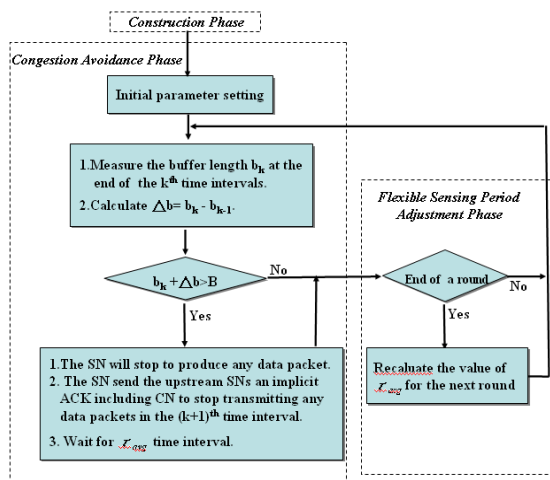


Figure 4. Operation Flow Chart in a Sensor Node

Table 1. Simulation Parameters

	Value
Networks size	100m*100m
<b>Number of sensing nodes (<math>N_{\text{sensing}}</math>)</b>	100
<b>Initial energy of the sensor node</b>	2J
<b>Buffer size (B) in SN</b>	22 packets
<b>Processing delay</b>	50 $\mu$ s
<b>Location of Sink</b>	(50,50)
<b>Data packet size</b>	512 bytes
<b>Transmission rate (<math>R_{\text{SN}}</math>)</b>	512 kbps
<b>Processing energy (<math>E_{\text{amp}}+E_{\text{elec}}</math>)</b>	50 nJ/bit
<b>Energy of sensing (<math>E_{\text{sensing}}</math>)</b>	0.05 nJ/bit
<b>Energy of data aggregation (<math>E_{\text{da}}</math>)</b>	5 nJ/bit/signal
<b><math>B_{\text{min}}</math></b>	10 packets
<b><math>B_{\text{max}}</math></b>	20 packets
<b>Minimum sensing interval (<math>\tau</math>)</b>	0.1 sec
<b>Maximum sensing interval (<math>\tau</math>)</b>	0.5 sec
<b><math>\alpha</math></b>	5

## 4. Performance Analysis

### 4.1. Simulation Environment

For evaluating the performance of the proposed ACAP, the NS2 simulator [14] was applied to the environment with the parameters listed as follows.

### 4.2. Simulation Analysis

The packet delivery ratio, accumulated number of dropped packets, and the number of alive nodes are the key factors in evaluating the performance of the WSNs. A lower packet delivery ratio or a higher accumulation of dropped packets mean that more packets were blocked or dropped in the forwarding path. In order to make sure that the sink node can maintain the actual state of all of the sensor networks, the sensor nodes must send more packets to the sink node. In the following simulations, we will measure the packet delivery ratio, the accumulated dropped packets and the number of alive nodes in the proposed ACAP scheme. The simulation results will be compared with the performance of the CODA backpressure scheme [7] and the no-congestion control (NCC).

Figure 5 shows the packet delivery ratio in ACAP, NCC, and CODA under the environment listed in Table 1 for the different rates of event packets. The simulation result shows that the delivery ratio of the event-driven packets in the ACAP is better than that of the CODA and the NCC because it sacrifices the clock-driven packets under congestion conditions. In addition, the packet delivery ratio in the NCC decreases dramatically when the event-data rate is over 30%.

In an emergency situation, the event-driven data packets will be blocked or dropped from the forwarding path if no congestion control scheme is involved. The backpressure scheme in CODA or the congestion avoidance in ACAP will prevent the intermediate nodes from a buffer overflow, but the emergency event-driven data packets to the nodes will also be discarded. The sensing interval adjusting scheme in the ACAP can solve these problems. Figure 6 shows the accumulated dropped packets in the ACAP, the NCC, and the CODA when the event-data rate is 50%. The simulation result shows that the ACAP drops substantially less event-driven data packets and clock-driven data packets than the NCC and CODA schemes.

Figure 7 shows the number of nodes which keep alive in the simulating process with 50 percent of the SNs randomly reporting event-driven data packets. The ACAP can keep more nodes alive because it is able to reduce the generating of event-driven data packets when the downlink nodes are in congestion.

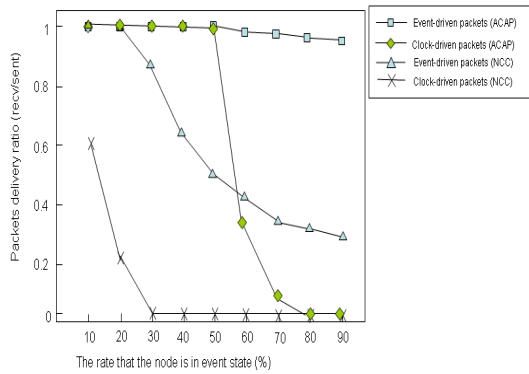


Figure 5. The Packet Delivery Ratios for Different Event-data Rates

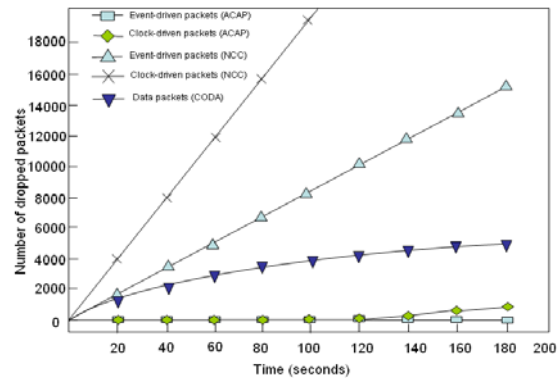


Figure 6. Accumulated Number of Packets Lost in a 50% Event-data Rate

To prolong the life of the WSNs under normal (non-event) conditions is one of the main goals of the ACAP model. It is easy to prolong the life of WSNs by extending the value of  $\alpha$  in the ACAP model. The tradeoff is that the system can not respond to the sensing information in real time if the value of  $\alpha$  is large.

Figure 8 shows the simulation result that compares the accumulated energy consumption of all sensor nodes under normal conditions. With the value of  $\alpha$  set as 3, the ACAP can reduce the energy consumption and extend the life time of the SNs to a greater extent than the CODA backpressure and NCC schemes.

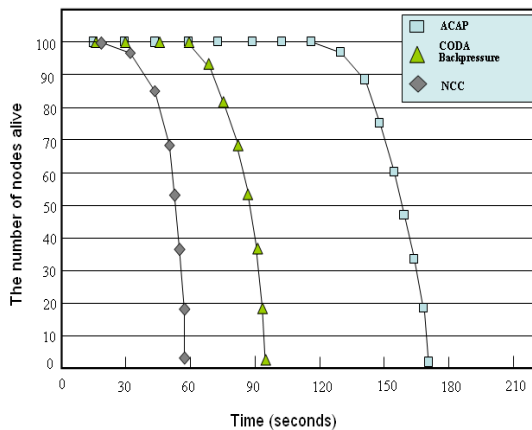


Figure 7. Comparison of the Number of Nodes kept Alive in the WSNs

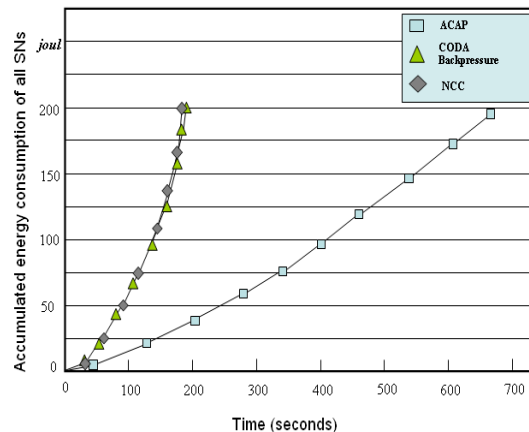


Figure 8. Comparison of the Accumulated Energy Consumption under Normal Conditions

**5. Conclusion**

Saving energy and delivering emergency data packets to the sink node as soon as possible are the two important issues in most WSN applications. The ACAP propose hybrid and flexible algorithm including different priorities data packets in order to report emergency message as soon as possible when congestion occurs. The simulation results show that the contributions of the proposed ACAP WSN model can be described as follows: firstly, in order to prolong the lifetime of the SNs, we use a hybrid reporting data packets to the sink; secondly, in order to reduce the data packets lose, we use the flexible sensing period strategy. Finally, the ACAP guarantees that the emergency packets will be transferred to the sink node as soon as possible by way of the two priorities packet Marker. The simulation results showed that the

proposed ACAP has a superior performance for energy efficiency and real time monitoring in WSNs.

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