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Energy Efficient Congestion Control in Duty-Cycled Wireless Sensor Networks

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***Abstract*--In wireless sensor networks, the low duty cycle achieves low energy operation, but this usually causes performance degradation. In this paper, we propose ADCC, an energy efficient congestion control scheme using duty-cycle adjustment for wireless sensor networks. The ADCC scheme uses both a resource control approach and a traffic control approach for the variance of network traffic. Therefore, ADCC can achieve reliability and energy efficiency by congestion control in duty-cycled wireless sensor networks.**

I. INTRODUCTION

Because sensor nodes operate with limited power based on a battery which cannot be easily replaced, it is very important to reduce the energy consumption of each sensor node. One of the primary mechanisms for achieving low energy operation in energy constrained wireless sensor networks is the duty cycle operation. However, a low duty cycle usually causes performance degradation in latency and Throughput [1]. Especially, if the network becomes congested, performance is degraded more significantly.

Network congestion can be alleviated either by traffic control or by resource control. Traffic control approaches avoid congestion by controlling incoming traffic as the offered resource and achieve fairness among traffic flows. However, traffic control can violate the fidelity level required by applications. Resource control approaches satisfy the requirements of each flow by increasing the resource of the node, thus it can not only support fidelity but also avoid congestion [2]. It is also one of the resource control approaches that increase the active time of the duty-cycle of a node.

In this paper, we propose the ADCC(Adaptive Duty-cycle Based Congestion Control) scheme, an energy efficient congestion control using duty-cycle adjustment for network traffic in wireless sensor networks. The ADCC scheme achieves reliability and energy efficiency by congestion control in duty-cycled wireless sensor networks.

II. ADAPTIVE DUTY-CYCLE BASED CONGESTION CONTROL

The ADCC scheme is simply implemented above a MAC layer. ADCC periodically calculates the required service time using the incoming packet information of child nodes in the MAC layer and then infers whether there is congestion or not through reading the calculated service time. Finally, the scheme adjusts its own duty cycle in order to reduce congestion in the case that congestion is below a certain threshold. On the other hand, if congestion occurs above the threshold, ADCC notifies the child nodes of the congestion for adjustment transmission rate of the child nodes. Fig. 1 shows the operations of ADCC.

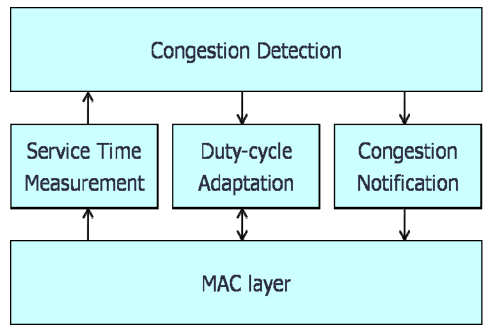

Fig. 1. Operations of ADCC

In ADCC, congestion was detected by the difference between the required service time $s(x)$ and the duration of active state in the duty cycle, that is D_{ACTIVE} . Equation (1) shows $d(x)$ that is the congestion degree of node x . If $d(x)$ is below 0, that means congested. Equation (2) shows $s(x)$ that is the required service time. The required service time is calculated by monitoring the packet inter-arrival times of child nodes. The $D_{CYCLE}(x)$ means the duration of the duty-cycle of node x and N means the set of childe nodes of node x .

$$d(x) = D_{ACTIVE}(x) - s(x) \tag{1}$$

$$s(x) = D_{CYCLE}(x) \times \sum_{i=1}^{N} \frac{1}{t_{INTER-ARRIVAL}(i)} \tag{2}$$

In order to maintain energy efficiency, the maximum active time of the duty-cycle must be defined. When congestion is detected, ADCC checks if $s(x)$ is between D_{MIN_ACTIVE} and D_{MAX_ACTIVE} , the lower threshold and upper threshold of D_{ACTIVE} . In the case that $s(x)$ is within the threshold, ADCC updates $D_{ACTIVE}(x)$ as calculated $s(x)$ that means ADCC performs resource control. Otherwise, ADCC notifies congestion to the child nodes in order to reduce the traffic rate of the child nodes. ADCC uses explicit congestion notification through broadcasting the congestion message to the child node. Fig. 2 shows the format of the congestion message in ADCC.

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seq	type	src_id	D_cycle	D_active	change_inter_arrival

Fig. 2. Congestion message format of ADCC

In the congestion message, the *type* field is set to the type of message and the *src_id* field contains the address of source node. The *D_cycle* field and the *D_active* field contain duty-cycle parameters of the congestion node. The *change_inter_arrival* field means the requirements of changing the packet transmission rate of the child nodes. Equation (3) shows the calculation of the *change_inter_arrival* value. The node that receives the congestion message sets the new transmission rate by multiplying its transmission rate by the *change_inter_arrival* value. Fig. 3 shows the pseudo code of the ADCC scheme.

$$change\_inter\_arrival = \frac{s(x)}{D_{MAX\_ACTIVE}} \tag{3}$$

```
FOR EACH i IN Children
        s = s + (D_CYCLE * 1 / inter-arrival(i))
ENDFOR
d = D_ACTIVE - s
IF   d > 0 THEN
        D_ACTIVE = max(D_MIN-ACTIVE, s)
ELSE
        IF s <= D_MAX-ACTIVE THEN
                D_ACTIVE = min(D_MAX-ACTIVE, s)
        ELSE
                D_ACTIVE = D_MAX-ACTIVE
                c = s / D_MAX-ACTIVE
                broadcast(c)
        ENDIF
ENDIF
```

Fig. 3. Pseudo code of ADCC scheme

III. PERFORMANCE

We present the evaluation of ADCC on the basis of the experiments using TinyOS [3] implementation. For our experiments, we used an indoor testbed of Moteiv's Telosb Motes [4]. The adjusted active time of receiving node is shown in Fig. 4. When traffic is not congested, the receiving node reduces active time to the minimum in order to increase energy efficiency. Since node *A* starts to transmit packets at the third congestion control period, the receiving node adjusts the active time to the incoming traffic. At the sixth congestion control period, since node *B* also participates in the transmission, the required service time exceed D_{MAX_ACTIVE}. Therefore, the receiving node adjusts the active time to the maximum in order to exploit the most available resource.

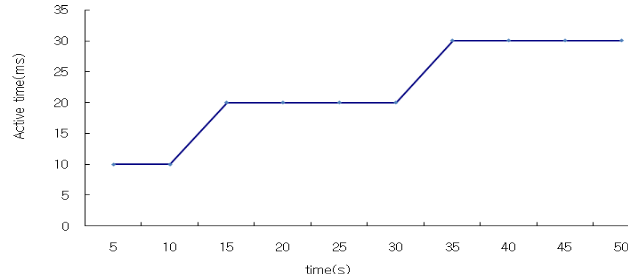

Fig. 4. Active time adjustments of receiving node

Fig. 5 shows the controlled transmission rate of the sending nodes by the ADCC scheme. By the 30 seconds, node *A*'s transmission rate is preserved as 100ms. However, when node *B* starts its transmission, the sending nodes receives congestion message; as a result, their transmission rates are changed.

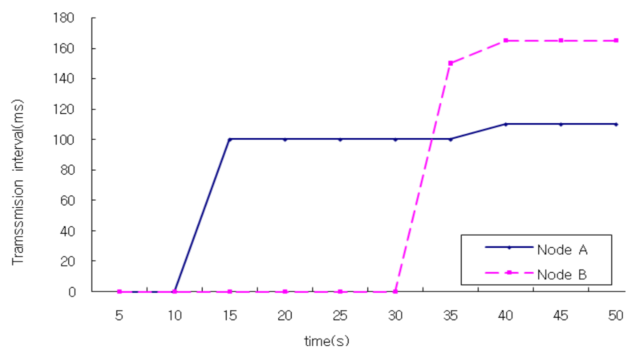

Fig. 5. Transmission rate adjustments of sending nodes

IV. CONCLUSION

This paper proposes the ADCC scheme, a duty-cycle based congestion control scheme for wireless sensor networks. The ADCC scheme can reduce the frequency of changing transmission rate and reduce control packet overhead by increasing the packet reception rate of the receiving node and decreasing the packet transmission rate of the sending node. ADCC has the advantage of not only supporting fidelity but also avoiding congestion. Our experimental results show that the ADCC scheme operates on duty-cycled MAC and can achieve congestion avoidance. We anticipate the further development of energy efficient mobile wireless devices by using the ADCC scheme.

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