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NOVEL ARCHITECTURE FOR DELAY REDUCTION IN THE BACK-PRESSURE SCHEDULING ALGORITHM

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Abstract: *In general, nodes in Wireless Sensor Networks (WSNs) are equipped with limited battery and computation capabilities but the occurrence of congestion consumes more energy and computation power by retransmitting the data packets. Thus, congestion should be regulated to improve network performance. In this paper, we propose a congestion prediction and adaptive rate adjustment technique for Wireless Sensor Networks. This technique predicts congestion level using fuzzy logic system. Node degree, data arrival rate and queue length are taken as inputs to the fuzzy system and congestion level is obtained as an outcome. When the congestion level is amidst moderate and maximum ranges, adaptive rate adjustment technique is triggered. Our technique prevents congestion by controlling data sending rate and also avoids unsolicited packet losses. By simulation, we prove the proficiency our technique. It increases system throughput and network performance significantly.*

Keywords: *Wireless Sensor Networks(WSNs),Congestion Prediction, Adaptive Rate Adjustment Technique.*

I. INTRODUCTION

A. Wireless Sensor Networks (WSNs)

The network with a group of tiny nodes with the abilities of sensing, computation and wireless communication is termed as Wireless Sensor Networks (WSNs). Each node is responsible of sensing and collecting various attributes such as temperature, pressure, sound and vibration from the sensing field. Finally, the collected information is forwarded to the Base Station (BS). [1] In order to monitor the real-world environment, numerous numbers of small devices with a potential of sensing, processing, and communication are present in the wireless sensor networks. In future, wireless sensor networks are capable of playing a major role in critical military surveillance applications, forest fire monitoring and building security monitoring. In immense field the operational conditions are often harsh or even aggressive and so numerous sensor nodes are deployed to monitor the field. [2]

B. Congestion in WSN

In general, sensor nodes are included with stringent computation capability, battery power and memory space. The occurrence of congestion in the network consumes an extra energy of the network by packet collapse and retransmission of packets. In dense network, the simultaneous transmission of packets causes interference and thereby packet drops due to congestion. [3] Some of the issues of congestion in WSN are described below,

- Due to congestion, there occur buffer drops and increased delays in the traditional wired networks and cellular wireless networks.
- The traffic from various parts of the network leads to congestion which in turn degrades the radio channel quality [4].
- For the nodes which traverse a significant number of hops, the traffic flow becomes unfair and this affects the performance and the lifetime of the network. There are certain limitations in wireless sensor networks based on the energy, memory and bandwidth [5].
- The link-level congestion causes increase in packet service time and decrease in link utilization. Energy efficiency and QoS is affected by both these congestions which decreases lifetime of the wireless sensor networks [6].

C. Congestion Control Techniques

A congestion control technique which uses the queue length as an indication of congestion degree was proposed named as Queue based Congestion Control Protocol with Priority Support (QCCP-PS). Priority index and current congestion degree are taken as main

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metrics for rate assignment to each traffic source [7].

II. RELATED WORK

C. Wang et al [11] have proposed a novel upstream congestion control protocol for WSNs, called Priority based Congestion Control Protocol (PCCP). Their PCCP innovatively measures congestion degree as the ratio of packet inter-arrival time along over packet service time. PCCP still introduced node priority index to reflect the importance of each sensor node. Based on the introduced congestion degree and node priority index, PCCP utilizes a cross-layer optimization and imposes a hop-by-hop approach to control congestion.

Joa-Hyoung Lee and In-Bum Jung [12] have proposed a new congestion control technique, named ACT. Their scheme is proposed based on an adaptive compression scheme for packet reduction in case of congestion. Compression techniques used in the ACT are DWT, ADPCM, and RLC. ACT first transforms the data from the time domain to the frequency domain, reduces the range of the data with the help of ADPCM, and then reduces the number of packets by using RLC before transferring the data to the source node. It then introduces the DWT for priority-based congestion control because the DWT classifies the data into four groups with different frequencies. Subsequently, it assigns priorities to these data groups in an inverse proportion to the respective frequencies of the data groups and defines the quantization step size of ADPCM in an inverse proportion to the priorities. RLC generates a smaller number of packets for a data group with a low priority. In the relaying node, the ACT reduces the number of packets by increasing the quantization step size of ADPCM in case of congestion.

Saeed Rasouli Heikalabad et al [13] have proposed a priority-based rate adjustment algorithm called joint priority algorithm (JPA), which guarantees weighted fairness in multi-path routing WSNs. In their scheme, intermediate nodes keep a record of the information on joint priorities (JP) of their neighbors. When congestion is detected, the sending rates of the upstream neighbors of the congested node are limited based on their joint priorities. In other words, upstream neighbors with important traffic will share more bandwidth than others when congestion occurs. Each data source, however, will send packets with its current equal rate when there is no congestion.

Jang-Ping Sheu et al [14] have proposed a Hybrid Congestion Control Protocol (HCCP), considering both the packets delivery rate and remaining buffer size of each node is proposed. The scheme does not need to maintain the global flow information and each node makes use of its current remaining buffer size and net flow size to calculate its congestion degree information. The congestion degree is defined to reflect the current congestion level at each node. Then, the congestion degree is exchanged periodically between neighbors. As such, each node can use its congestion degree and neighbors' congestion degrees to prevent the emergence of congestion.

III. PROPOSED SOLUTION

A. Overview

In this paper, we propose a congestion prediction and adaptive rate adjustment technique for Wireless Sensor Networks (WSNs). Periodically, each node estimates node degree, data arrival rate and queue length. These values are passed through the fuzzy logic system as inputs and congestion level is obtained. The congestion level is ranged as low (*A1*), medium (*A2*) and high (*A3*). The congestion level A1 does not require any congestion regulation mechanism. When the estimated congestion level is in the middle of *A2* and *A3*, the node triggers an adaptive rate adjustment technique. In this, the sender forwards congestion notification message to all its upstream nodes. By receiving notification message, each upstream node estimates its own congestion level. If the estimated congestion level is between *A2* and *A3*, then it estimates a new data sending rate and forwards back to the sender node. While receiving the feedback message, the sender regulates its data sending rate.

B. Fuzzy Based Congestion Estimation

1) Fuzzification: The mapping from a real-valued point to a fuzzy set is known as Fuzzification, which receives other robots information in order to convert it into fuzzy linguistic variable inputs. The fuzzy logic is chosen based upon the following two reasons: a) In between the normal and abnormal events, clear boundaries are not present, b) Fuzzy rules should level the normality and abnormality separation. The fuzzy set can be represented using the mathematical formation known as membership function.

Rule definition: Conditional statements are used to implement a membership function which characterizes a fuzzy set *A* in *x*. When the fuzzy statement in an antecedent is true to some degree of membership, the consequent of the same degree also proves to be true.

- Rule structure: If antecedent then consequent
- The rule: When both the variables have different values high and low, then we can get a generous output otherwise a malicious output is detected.

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For a fuzzy classification system, the case or an object can be classified by applying the set of fuzzy rules which depend upon the linguistic values of its attributes. The rule is functioned at the number given by the antecedent which has a value between 0 and 1. The input can be fuzzified by evaluating the antecedent and then essential fuzzy operators can be applied. The consequent obtains this result as the inference.

The estimation of input metrics is given in our previous paper. [10] With fuzzy logic, we assign grade values to our three variables. Our fuzzy set therefore consists of three fuzzy variables

$$\textit{Fuzzy set} = \{N, A, Q\} \qquad (1)$$

Fuzzy logic implements human experiences and preferences via membership functions and fuzzy rules. In this work, the fuzzy if-then rules consider the parameters: Average node degree, Average queue length and the net data arrival rate.

The fuzzy logic uses three input variables and one output variable. The three input variables to be fuzzified are *Average node degree (N), Average queue length (Q)* and the *net data arrival rate (A).* The inputs are fuzzified, implicated, aggregated and defuzzified to get the output. The linguistic variables associated with the input variables are *Low (L),* and *high (H).* The output variables use three linguistic variables *A1, A2,* and *A3,* where *A1* denotes less congestion, *A2* denotes Medium congestion and *A3* denotes High congestion.

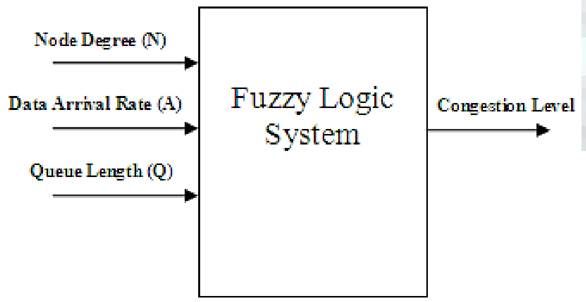

Figure 1: Fuzzy input and output variables

The first parameter Node degree *N* can be represented as a fuzzy set as

Node degree N = Fuzzyset [{A1, a},{A2,b},{A3,c}] (2).

Where, *a* is the membership grade for Less congestion in

The third parameter *Average queue length Q* can be represented as a fuzzy set as

Average queue length Q = Fuzzyset [{A1,g},{A2,{3,i}] (4)

Where, *g* is the membership grade for less congestion in Average queue length calculation.

node degree calculation.

b is the membership grade for normal congestion in node degree calculation.

c is the membership grade for High congestion in node degree calculation.

For eg: If *a= 0.2, b = 0.4* and *c = 0.6,* then the possibility of high congestion is more.

The second parameter Data arrival rate *A* can be represented as a fuzzy set as

Data arrival rate A = Fuzzyset [{A1,d},{A2,e},{A3,f}] (3)

Where, *d* is the membership grade for less congestion in data arrival rate calculation.

e is the membership grade for normal congestion in data arrival rate calculation.

f is the membership grade for high congestion in data arrival rate calculation.

For eg: If *d = 0.4, e = 0.3* and *f = 0.1,* then the possibility of lesser congestion is more.

If *N* is less, *A* is less, and *Q* is high, then Congestion level is *A2*.

If *N* is less, *A* is high, and *Q* is high, then Congestion level is *A3*

If *N* is high, *A* is less, and *Q* is less, then Congestion level is *A1*

If *N* is high, *A* is high, and *Q* is less, then Congestion level is *A3*

If *N* is less, *A* is high, and *Q* is less, then Congestion level is *A2*

If *N* is high, *A* is less, and *Q* is high, then Congestion level is *A2*

If *N* is high, *A* is high, and *Q* is high, then Congestion level is *A3*.

2) Defuzzification: The cosmos of fuzzy control action which were defined in a productive universe of dissertation can be mapped into a cosmos of non-fuzzy control actions.

Center of Area (COA): Here, the center of gravity of the output membership function is used for selecting the output crispy value.

$$U_o = \frac{\int w\propto(w)dw}{(w)dw} \qquad (5)$$

C. Congestion Control using Rate Reduction Technique

h is the membership grade for normal congestion in Average queue length calculation.

i is the membership grade for high congestion in

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Average queue length calculation.

For eg: If $g = 0.3$, $h = 0.6$, $i = 0.5$, then the possibility of normal congestion is more.

Table 1: Fuzzy set using Node degree, Queue length and Arrival rate

S.No	N	A	Q	Congestionlevel
1.	L	L	L	A1
2.	L	L	H	A2
3.	L	H	H	A3
4.	H	L	L	A1
5.	H	H	L	A3
6.	L	H	L	A2
7.	H	L	H	A2
8.	H	H	H	A3

If *N* is less, *A* is less, and *Q* is less, then Congestion level is *A1*.

Taking into account the level of congestion, a new data sending rate can be computed as,

$$A_{i+1} = A_i \nabla - N - Q \qquad (6)$$

Where, A_i is the existing data sending rate, ∇ is the softening factor that ensures stability, *N* and *Q* represents node degree and queue length respectively.

As discussed in previous section (section *III.B.1*), *A1* denotes low, while *A2* denotes medium and *A3* with high level of congestion. Once node *i* estimates its congestion level as *A1*, it does not perform any regulation in data sending rate. As *A1* indicates zero chance of congestion happening. If congestion level of node *i* is *A2* or *A3*, it immediately triggers rate control mechanism. Node *i* floods rate regulation notification message to all upstream nodes. (Figure-2)

$$\text{Node } i \xrightarrow{rateregulationmessage} \text{Upstream nodes}$$

The rate regulation message includes node id and congestion level such as *A2* or *A3*. By receiving rate regulation notification message, each upstream node measures its congestion level using fuzzy logic system. If congestion level in *A2* or *A3*, then they estimate a new data sending rate (6) considering existing data sending rate, node degree and queue length. Then feedback the new data sending rate to the sender node. By receiving new data sending rate, the sender node regulates its data sending rate.

$$\text{Node } i \xleftarrow{newdatasendingrate} \text{Upstream nodes}$$

IV. SIMULATION RESULTS

We use NS-2 [17] to simulate our proposed technique. In our simulation, the channel capacity of mobile hosts is set to the same value: 2 Mbps. We use the distributed coordination function (DCF) of IEEE 802.11 for wireless LANs as the MAC layer protocol. It has the functionality to notify the network layer about link breakage.

In our simulation the nodes are moved in a *1000 meter x 1000* meter region for 50 seconds simulation time. We assume each node moves independently with the same average speed. All nodes have the same transmission range of 250 meters. In our simulation, the transmission rate is varied from 100 to 500kb. The simulated traffic is Constant Bit Rate (CBR). our simulation settings and parameters are summarized in table 2

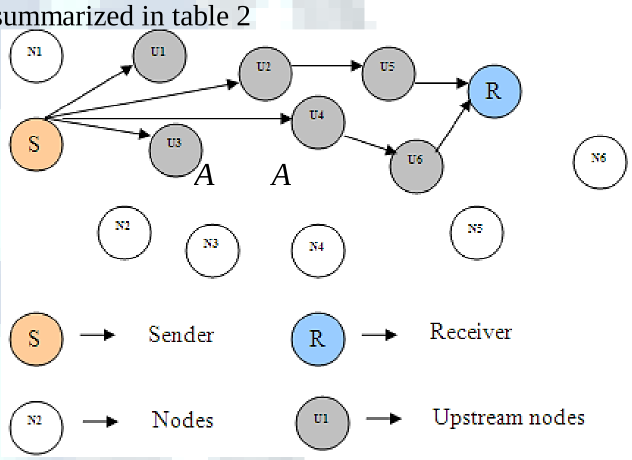

Figure 2: Congestion notification message is sent to upstream nodes

Algorithm-1

1. Let S be the set of sensor nodes S= {S_1, S_2, S_3 ... S_n} 2. Consider A1, A2 and A3 as the level of congestion that represents less, medium and high congestion respectively

3. S_i estimates node degree (N), arrival rate (A) and queue length (Q)

4. N, A and Q are made pass through the fuzzy system and congestion level is obtained

4.1 If (congestion level = A1) Then

4.1.1 The flow does not require any data rate regulation

4.2 Else if (congestion level = A2 && A3) Then

4.2.1 Then it requires data rate regulation

4.2.2 Rate reduction mechanism is triggered

5. End if

6. The sender forwards rate regulation notification message to upstream nodes

7. Upstream nodes estimate their congestion level

7.1 If (estimated congestion level = A2 && A3)

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Then

7.1.1 Measures it new data sending rate (as per equation 6)

8. New data sending rate is forwarded to the sender

9. The sender regulates its data sending rate according to the received new data rate

10. End if

Table2. Simulation Parameters

No. of Flows	2,4,6 and 8
Area Size	1000 X 1000
Mac	802.11
Radio Range	250m
Simulation Time	20 sec
Traffic Source	CBR
Number of Nodes	50
Mobility Model	Random Way Point
Rate	100 ,200 ,300 ,400 and 500Kb
Max.Packet in queue	50
Psize	512 bytes

A. Performance Metrics

We compare our CPARA technique with the HCCP [14] technique. We evaluate mainly the performance according to the following metrics.

Average end-to-end delay: The end-to-end-delay is averaged over all surviving data packets from the sources to the destinations.

*Average Packet Delivery Ratio***:** It is the ratio of number of packets received successfully to the total number of packets sent.

Drop: It is the number of packets dropped during the data transmission.

Received Bandwidth: It is the number of bits transmitted per second.

B. Results

1. Based on Flow

In our first experiment we vary the number of flows as 2, 4, 6 and 8.

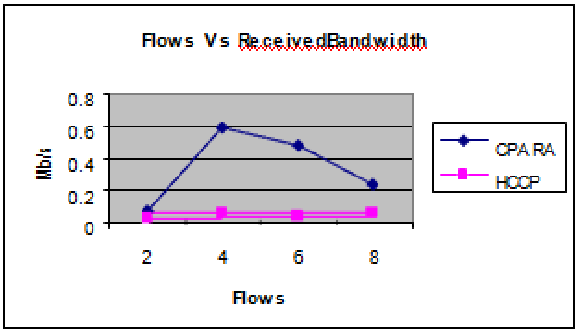

Figure 3: Flows vs Received Bandwidth

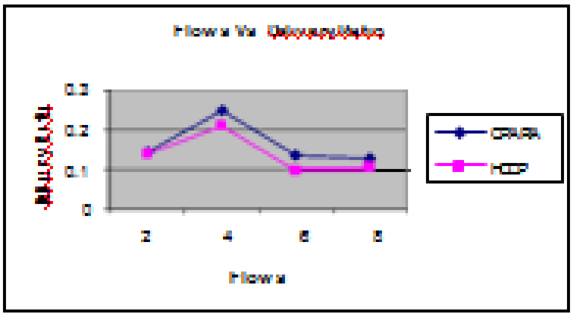

Figure 4: Flows vs Delivery Ratio

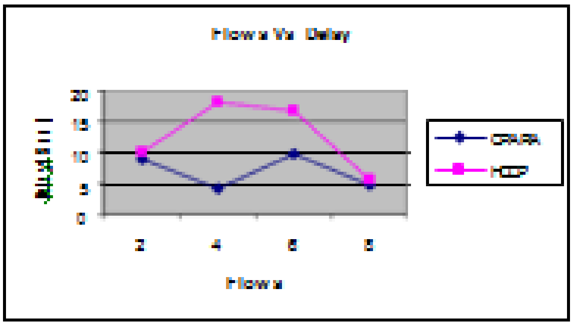

Figure 5: Flows vs Delay

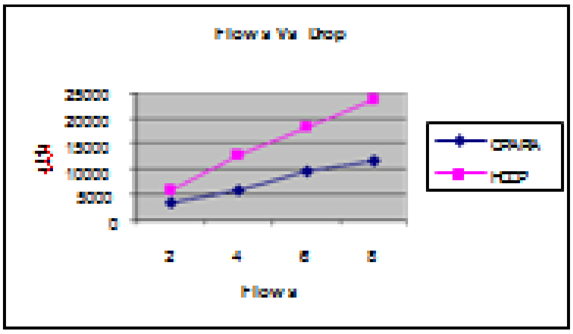

Figure 6: Flows vs Drop

From figure 3, we can see that the received bandwidth of our proposed CPARA is higher than the existing HCCP technique.

From figure 4, we can see that the delivery ratio of our proposed CPARA is higher than the existing HCCP technique.

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From figure 5, we can see that the delay of our proposed CPARA is less than the existing HCCP technique.

From figure 6, we can see that the packet drop of our proposed CPARA is less than the existing HCCP technique.

2. Based on Rate

In our second experiment we vary the transmission rate as 100,200,300,400 and 500Kb.

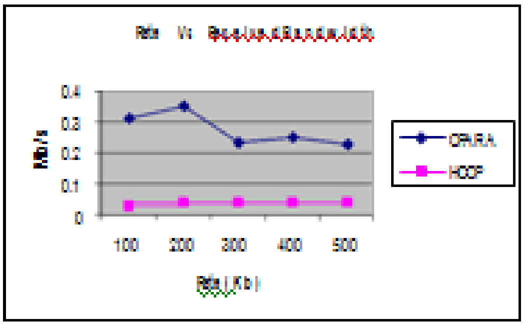

Figure 7: Rate vs Received Bandwidth

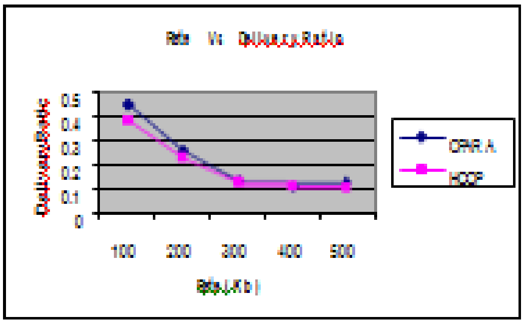

Figure 8: Rate vs Delivery Ratio

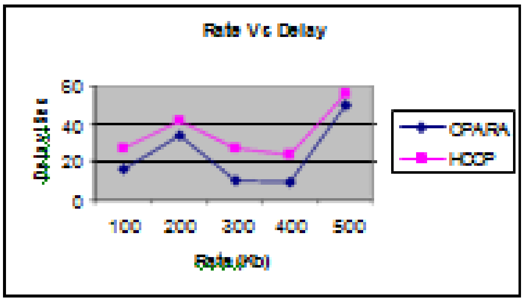

Figure 9: Rate vs Delay

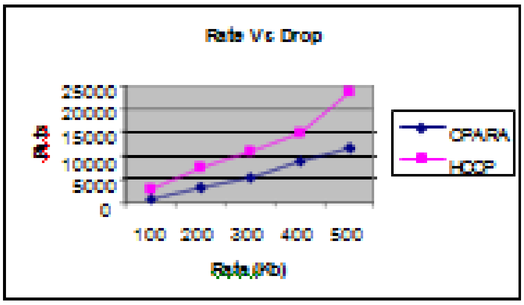

Figure 10: Rate vs Drop

From figure 7, we can see that the received bandwidth of our proposed CPARA is higher than the existing HCCP technique.

From figure 8, we can see that the delivery ratio of our proposed CPARA is higher than the existing HCCP technique.

From figure 9, we can see that the delay of our proposed CPARA is less than the existing HCCP technique.

From figure 10, we can see that the packet drop of our proposed CPARA is less than the existing HCCP technique.

V. CONCLUSION

In this paper, we have proposed a congestion prediction and adaptive rate adjustment technique for Wireless Sensor Networks (WSNs). The technique predicts congestion level using fuzzy logic system. Node degree, data arrival rate and queue length are taken as inputs to the fuzzy system and congestion level is obtained as an outcome. When the congestion level is amidst moderate and maximum ranges, adaptive rate adjustment technique is triggered. Upstream nodes of the sender estimate a new data sending rate and feed back to it. The sender regulates data sending rate considering received new data sending rate. Our technique prevents congestion by controlling data sending rate and also avoids unsolicited packet losses. The simulation results show the proficiency of our technique. It increases system throughput and network performance significantly. Our future work would focus on including MAC layer contention as one of the metrics for congestion detection and reducing the energy consumption.

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