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Dynamic Random Early Detection-Fuzzy Deep Neural Network Proportional Integral Derivative based Energy-aware Congestion Avoidance for WSN

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ABSTRACT: *Normally when traffic becomes higher than channel capacity, congestion detection and avoidance is one of the most important challenges in Wireless Sensor Network (WSN). This can cause high packet loss and energy consumption that degrades the entire network performance. As a result, DRED-FDNNPID-CA technique has been proposed to control the congestion by estimating network traffic and adjusting the transmission data rate. However, the network energy consumption was high which reduces the network lifetime. Hence in this article, an Energy-aware Congestion Avoidance (ECA) is a technique proposed to improve the network energy conservation. In this technique, Load-Based Allocation (LBA) is introduced based on the Statistical Time Division Multiple Access (STDMA) which uses time scheduler to collect sensor node information such as memory, battery and location and schedule the packets to each node. Based on the collected information, dynamic timeslots are assigned to the sensor nodes for transmitting the data packets with high energy conservation. In addition, this technique reduces the network congestion and improves the network lifetime. Finally, the simulation results show the performance effectiveness of the proposed technique compared to the existing technique.*
KEYWORDS : *Wireless sensor networks, Congestion avoidance, DRED-FDNNPID, Load based allocation, Statistical time division multiple access.*

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I. INTRODUCTION

Wireless Sensor Network (WSN) is a type of spatially distributed autonomous network that has many sensor nodes for forecasting the physical and atmospheric conditions. This kind of networks is mostly deployed in different applications like defense, healthcare, sports, etc. Specifically, WSN is deployed in medical areas for monitoring the patient's health conditions in a short duration. The collected data are broadcasted to the central unit of the network namely sink node (Gentili, C., et al. 2017). Such data transmission causes data explosion and congestion via intermediate nodes that affect end-to-end delay, packet loss, network lifetime, etc. As a result, congestion control or avoidance is the most crucial for broadcasting a patient's health information without any information loss and congestion through the network (Rajkumar, P. P., et al. 2013).

Over the past decades, different congestion control or congestion avoidance techniques have been proposed by many researchers (Dashkova, E., & Gurtov, A. 2012; Kharat, S. 2015). Among those techniques, Dynamic Random Early Detection-Fuzzy Deep Neural Network based Proportional Integral Derivative with Congestion Avoidance (DRED-FDNNPID-CA) achieves better congestion reduction. This technique was performed according to the priority of data packets and adjusting the network traffic or transmission rate if congestion was detected in the network. However, the network energy consumption was high which causes network lifetime. Therefore in this paper, CA is enhanced as an Energy-aware Congestion Avoidance (ECA). In this proposed technique, the LBA method is introduced to allocate the medium resources shared by different sensor nodes in the network based on the STDMA technique. Here, time scheduler is used in the PID controller that collects the memory information, battery information and location information of each sensor node. Then, the dynamic timeslots and medium resources shared by nodes are allocated according to the collected information. Based on the allocated timeslots and resources, the data packets are transmitted to the destination node successfully. Thus, this technique reduces both congestion and energy consumption in the network efficiently.

The rest of the article is structured as follows: Section 2 presents the literature survey related to the energy-efficient based congestion control mechanisms in WSN. Section 3 explains the proposed methodology. Section 4 illustrates the experimental results of the proposed mechanism. Finally, Section 5 concludes the research work.

II. LITERATURE SURVEY

Energy efficient Congestion Detection and Avoidance (CODA) (Wan, C. Y., et al. 2011) was proposed in sensor networks. This scheme was proposed based on the three mechanisms namely receiver-based congestion detection, open-loop hop-by-hop backpressure and closed-loop multisource regulation. In addition, three significant performance metrics such as energy, fidelity penalty and power were defined for evaluating the impact of this scheme. However, the packet drop rate was increased due to more hidden terminal collisions.

A Multipath Energy Efficient Congestion Control (MEECC) scheme (Chellaprabha, B., & Pandian, S. C. 2012) was proposed for reducing the packet loss due to congestion in WSN. In this approach, a combined congestion estimation technique was proposed by considering three main parameters namely queue size, contention and traffic rate. Moreover, a rate control technique and a multipath routing protocol were designed to control the congestion. However, the performance effectiveness of this scheme was not effective.

Class-based Optimized Congestion Management (COCM) protocol (Rezaee, A. A. et al. 2013) was proposed for healthcare WSN. This protocol has two major functions such as routing and congestion control. Specifically, this protocol was performed based on the four phases namely, request dissemination, event occurrence report, route establishment, data transmission and rate adjustment. The major objective of this protocol was avoiding or controlling the congestion in WSN by considering energy and delay. However, energy consumption was high.

Adaptive Congestion Control Protocol (ACCP) (Gadze, J. D., et al. 2013) was proposed for WSN. This ACCP was proposed to monitor the network utilization and adjust the traffic levels. In addition, network resources were increased for improving throughput and reducing energy consumption. The traffic congestion control protocol named DelStatic was proposed based on the backpressure mechanism into NO Ad-Hoc Routing Agent (NOAH). Moreover, a sink switching algorithm was used for triggering DelStatic or DSR feedback to a congested node according to its node rank. However, the performance efficiency of this protocol was less.

A congestion control algorithm (Chaudhari, Y., & Pawar, V. 2014) was proposed including energy saving and buffer management for reducing the loss of relevant packets. This approach was performed based on the requirements of time synchronization in order to determine the location or speed. Here, the energy consumption was reduced by transmitting the data rapidly without any congestion. However, an interference issue has occurred in this algorithm.

Energy-efficient predictive congestion control (Rajan, A. U., et al. 2015) was proposed for WSN. In this technique, a new approach was proposed to predict the congestion by using a probabilistic method and control congestion based on the new rate control methods. This probabilistic approach was proposed by using data traffic and buffer occupancy. Moreover, the rate control method was performed by using rate allocation schemes such as Rate Reduction (RR), Rate Regulation (RRG) and Split Protocol (SP) for improving throughput and reducing packet drop ratio. Additionally, an energy-efficient routing was proposed to find the best forwarding node for transmitting the data. However, this approach does not consider the packet delay when additional neighbor nodes were selected.

III. PROPOSED METHODOLOGY

In this section, the proposed DRED-FDNNPID-ECA technique is explained in brief. Initially, traffics are split into different priorities such as low, intermediate and high based on the aggregated weighted load metric in Service Differentiation Unit (SDU). Once the traffic classes are determined, the traffic estimation is performed to control the congestion quickly in Congestion Detection Unit (CDU). Then, the detected congestion signal can be transmitted to the intermediate nodes to adjust the transmission rate at congested nodes in Congestion Notification Unit (CNU) and Rate Adjustment Unit (RAU), correspondingly. In addition to this process, energy conservation is increased by allocating time slots and medium resources using a time scheduler to transmit the data packets effectively. The overall flow of the proposed system is shown in Figure 1.

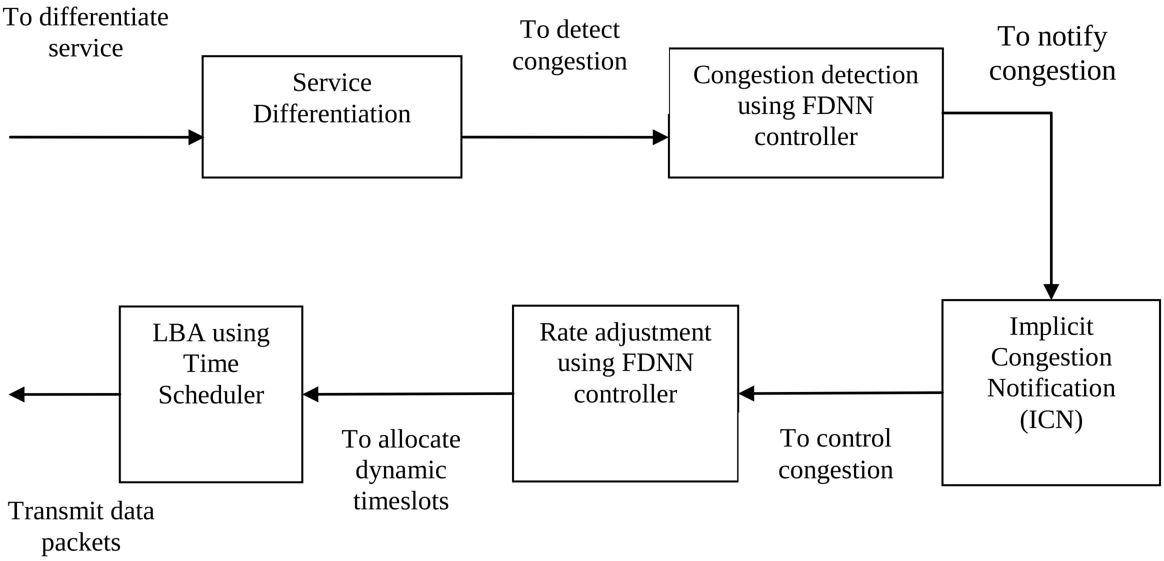

Figure.1 Overall Concept of the Proposed Mechanism

The time scheduler assigns timeslots to its joined sensor nodes with the help of STDMA. The STDMA acquires the sensor node's statistical information i.e., unique ID, batter information and location information. Once all the information are obtained from each sensor node, the time scheduler evaluates this statistical information and assigns dynamic timeslots to each sensor node for data transmission. This proposed technique comprises of LBA strategy to deal with energy consumption due to the allocation of timeslots for data transmission.

3.1 Load Based Allocation

In the LBA phase, time scheduler assigns timeslots to each sensor node in the network. The process of assigning timeslots is performed as follows:

- Each sensor node transmits a Type-1 Hello Packet (Type-1_Broadcast_Msg) to the time scheduler. This packet consists of different information i.e., node ID, battery information, location information, propagation time.
- Then, the time scheduler computes the distance between each sensor node to every other by using Time-Of-Arrival (TOA). Once the distance is calculated, the time scheduler assigns weight to each sensor node on the basis of distance and the information obtained in Type-1_Broadcast_Msg.
- Likewise, this technique uses the weighted value and broadcast_msg as a metric to assign the timeslots to each sensor node in the network. The weighted value of the specific node (ω) is computed as,

$$\omega = \left(\frac{1-(\mathrm{TOA})}{\mathrm{C}} \times 100\right) + \mathrm{K} \qquad (1)$$

In equation (1), K is the priority value of the candidate node and C is the cost i.e., statistical information of a node. The value of C is computed by averaging the statistical information of the i^{th} node.

$$\mathrm{Cost}(\mathrm{C_i}) = (\mathrm{BLT\ of\ a\ node} + \mathrm{LI\ of\ a\ node})(2)^{-1} \qquad (2)$$

In equation (2), BLT refers the battery lifetime and LI refers the location information of a node.

- Once the weighted value for each sensor node is calculated, this information is broadcasted in the network in the form of Type-II_broadcast_msg. This new broadcast message consists of node ID, starting time of data transmission, scheduling information, dynamic timeslots.
- Based on the receiving Type-II broadcast message, each node becomes an aware of each sensor node's information to transmit the data packets without any congestion.
- This mechanism continues until the last node of the network completes its data transmission.

3.2 Computation of Energy Consumption

Consider E_{ab} is the energy consumption of a^{th} node in b^{th} communication path. The overall energy consumption is denoted as,

$$\mathrm{E} = \sum_{a=1}^{N} \mathrm{E_{ab}} \qquad (3)$$

In this technique, each sensor node is assumed that it can transmit and receive the data packets with an equal battery power. Hence, the energy used by a sensor node is autonomously depending on the distance between neighborhood sensor nodes. As a result, the following energy model is considered for computing power consumption of sensor node in WSN.

$$P = E_{BR} + E_{BT} \quad (4)$$

In equation (4), E_{BR} and E_{BT} are the energy consumption of received bits and transmitted bits, respectively. Consider S_D is the total amount of data sensed by each sensor node and D_R is the amount of data received by a node, the amount of data transmitted by a node is denoted as follows:

$$\sum_{n=1}^{N} D_T = \sum_{n=1}^{N}\left(D_{R_n} + S_{D_n}\right) \quad (5)$$

Assume all the sensor nodes transmit data in multihop to the destination. Then, the relationship between the total amount of data received by all the nodes and the sum of hops is defined as,

$$\sum_{n=1}^{k} D_{r_n} = \sum_{n=1}^{k} H_n \quad (6)$$

In equation (6), H_n is the path from node n to its destination. If n itself is a sink node, then $H_n = 0$. According to this equation, the total energy consumption is measured in terms of the total sum of all hops from all the nodes to their destination as follows:

$$\sum_{n=1}^{k} P_n = \sum_{n=1}^{k} E_n\left(D_{T_n} + D_{r_n}\right) \quad (7)$$

In equation (7), P_n is the energy consumption of node n.

IV. RESULTS AND DISCUSSIONS

In this section, the performance effectiveness of the proposed DRED-FDNNPID-ECA is evaluated and compared with the previous technique i.e., DRED-FDNNPID-CA by using Network Simulator (NS2.35). The comparison is made in terms of Packet Loss Ratio (PLR), packet loss probability, mean end-to-end delay, mean queue length, transmission rate adjustment and mean energy consumption. The simulation parameters are listed in Table 1.

Table.1 Simulation Parameters

Parameter	Value
Network size	300×400sqm
Number of sensor nodes	30
Number of sink nodes	1
Packet size	512bytes
Packet rate	120packets/sec
Node's initial energy	5000Joule
Buffer size	100

4.1 Packet Loss Ratio (PLR)

It defines the number of packets lost during transmission per unit time.

$$PLR = \frac{\text{Number of packets lost}}{\text{Time taken}} \quad (8)$$

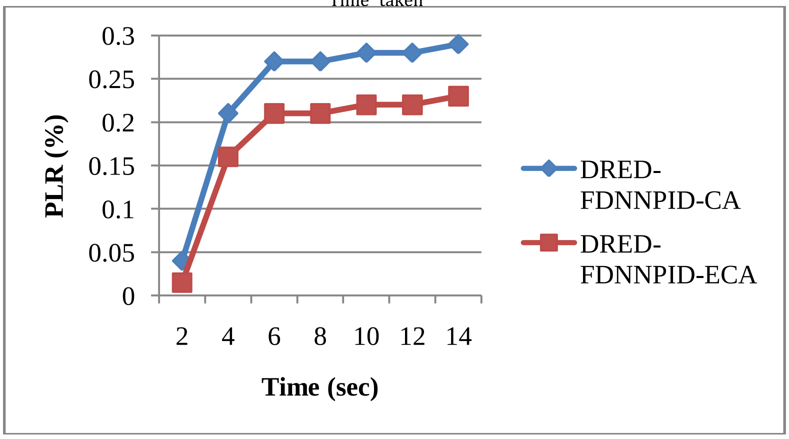

Figure.2 Comparison of PLR

Figure 2 shows the comparison of the proposed DRED-FDNNPID-ECA and DRED-FDNNPID-CA techniques in terms of PLR. It is noticed that when scheduling mechanism is employed, the PLR is reduced significantly. From the analysis, it is observed that the proposed technique reduces the PLR compared to the existing technique.

4.2 Packet Loss Probability

It refers to the fraction between the number of packets lost at the destination and the total number of packets transmitted from the source.

$$P_{loss} = \frac{\text{Number of packets lost at a destination}}{\text{Total number of packets sent from source}} \qquad (9)$$

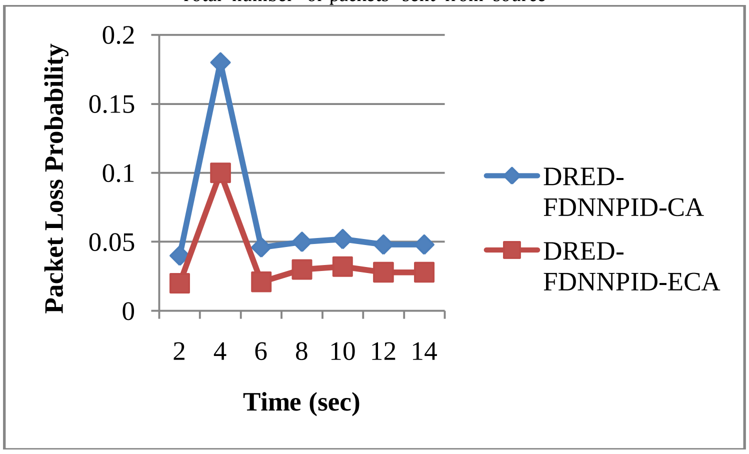

Figure.3 Comparison of Packet Loss Probability

Figure 3 shows the comparison of packet loss probability for both proposed and existing techniques. From the analysis, it is observed that the proposed DRED-FDNNPID-ECA technique has reduced probability of packet loss by using scheduling the timeslots to transmit the data successfully without any congestion.

4.3 Mean End-to-end Delay

It refers to the time taken to complete data packet transmission from source to destination.

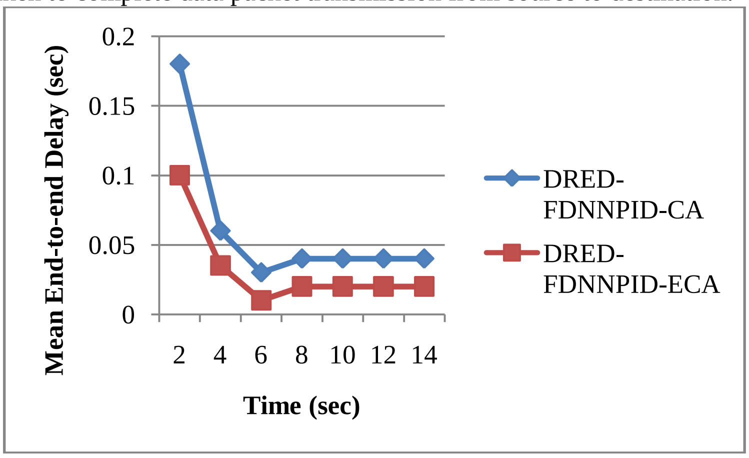

Figure.4 Comparison of Mean End-to-end Delay

Figure 4 shows the comparison of proposed and existing techniques in terms of mean end-to-end delay. From the analysis, it is noticed that the end-to-end delay of the proposed DRED-FDNNPID-ECA technique is decreased rapidly than the existing technique and less delay is the most crucial to transmit the packets without any congestion.

4.4 Mean Queue Length

It is the most essential metric to measure the delay and defines the number of packets in the queue.

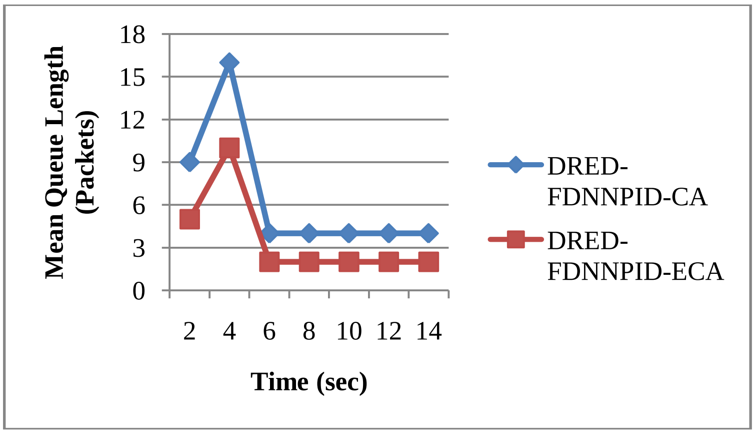

Figure.5 Comparison of Mean Queue Length

Figure 5 illustrates the comparison of mean queue length for both proposed and existing techniques with respect to time. It shows that the mean queue length of the proposed technique is less than 2packets/sec. Through the analysis, it is observed that the queue length of the proposed DRED-FDNNPID-ECA technique is controlled in order to avoid the congestion in the network.

4.5 Transmission Rate Adjustment

It defines the speed that the packets being transmitted from source to destination in a unit time.

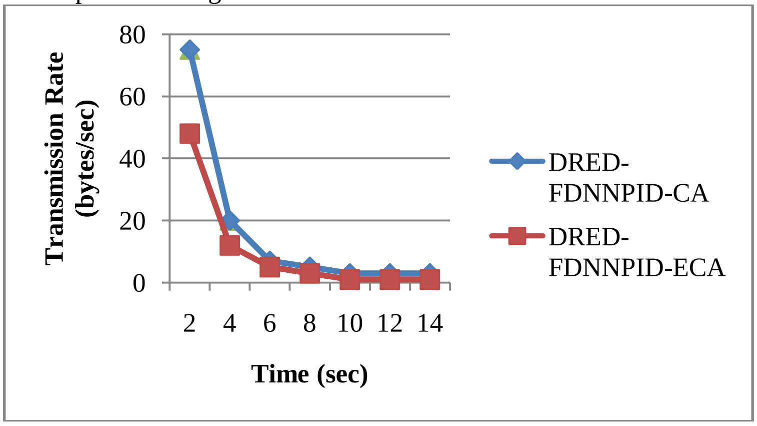

Figure.6 Comparison of Transmission Rate

Figure 6 shows the comparison of proposed and existing techniques in terms of the transmission rate. From the analysis, it is noticed that the transmission rate of the proposed DRED-FDNNPID-ECA technique is decreased in each time period rapidly than the existing technique. As a result, congestion through the network is controlled and avoided.

4.6 Mean Energy Consumption

It refers to the amount of energy consumed by each node during packets transmission.

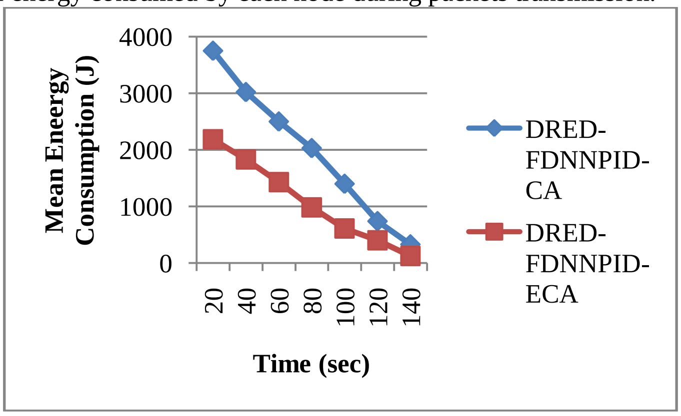

Figure.7 Comparison of Mean Energy Consumption

Figure 7 shows the comparison of proposed and existing techniques in terms of mean energy consumption for different time periods. From the analysis, it is concluded that the energy consumption of the proposed DRED-FDNNPID-ECA technique is reduced than the existing technique which enhances the network lifetime efficiently.

V. CONCLUSION

In this article, an energy-aware based DRED-FDNNPID-CA technique is proposed to avoid the congestion by minimizing energy consumption through the network. In this proposed technique, dynamic timeslots for each sensor node is allocated by LBA method which is performed based on the STDMA scheme. In this mechanism, the time scheduler is used in the PID controller to allocate the dynamic timeslots for each node by computing the weighted value of each node. This weighted value is computed according to the node's statistical information like battery information, memory information and location information. After that, the data packets are transmitted to the destination node successfully during the allocated timeslots without any congestion. Thus, this technique reduces both congestion and energy consumption in the network efficiently. Finally, the simulation results prove that the effectiveness of the proposed congestion control and avoidance technique compared to the existing technique.

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