Congestion Estimation Techniques in Sensor Networks: A Survey

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ABSTRACT

In WSN or in sensor network the congestion causes the various severe conditions as it causes, data packet loss, energy inefficiency and also it diminishes the lifespan of WSN. In WSN, the major challenge is to diminish the congestion problem in the transmission of data packets between sources to destination. In recent past time some researchers utilized different techniques for congestion estimation and these techniques are too utilized for controlling the congestion. There are lots of techniques are suggested by researchers which are non-fuzzy based and fuzzy based techniques for congestion estimation and controlling the congestion. In this review paper we introduce the various researches on congestion estimation and congestion control techniques. So the estimation of congestion is always a significant task in WSN.

Keywords

Congestion estimation; WSN (wireless sensor network); CH (Cluster Head); BS (Base Station)

1. INTRODUCTION

In today’s scenario WSN is known as one of the interesting technology for networking and communication. A WSN is a collection of various tiny sensor nodes which have low-energy, low-computational power and low-cost. The WSN arises, when sensor nodes are deployed in large numbers in a specific area. The sensor nodes are sensed and monitor the environmental condition such as sound, pressure, humidity, temperature etc.

There is one or more base station (BS) in a WSN and this sensor network contains hundreds of sensor nodes. These sensor nodes are deployed either randomly or manually. These sensor nodes sensed and gather the information over a specific area of interest and do some data processing then aggregate the data and forward this data to the BS.

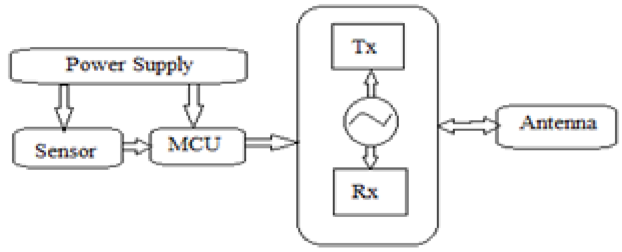

Fig.1 Wireless Sensor node’s hardware component parts

The BS is acts as a gateway to the other network and it has unlimited power and high capabilities. The working of BS is similar to the sensor nodes because it collects the data from sensor nodes and does some data processing and after that sends this processed data to their final destination via some other communication network such as internet.

The lifespan of WSN is very short since sensor nodes are battery operated. It is too unmanageable to replacement the batteries of sensor nodes.

So if researchers want to enhance the lifespan of WSN then they need to produce a better network topology in which the sensor nodes utilizes the low power when communicating or data transmitting. The sensor nodes generally exhausts the energy when they regularly alive long period. So to diminish this energy intake, researchers employ Sleep/Wake-Up mechanisms

Some researchers employ the clustering mechanism, to diminishing the power intake of sensor nodes.

There are various applications of WSNs such as Area monitoring, Air pollution monitoring, Greenhouse monitoring, Landslide detection, Machine health monitoring, Data Logging, Industrial sense and control WSN applications. Water/wastewater monitoring, Agriculture, Structural monitoring, Passive localization and tracking etc. [1, 2].

1.1 Transmission of Data in WSNs

When sensor nodes are spreads out in any WSN region like landslide detection, machine health monitoring etc. and if researchers get the information from that region then sensor nodes uses two types of transferring mechanisms.

In first mechanism, every sensor nodes (SN1, SN2, SN3…..) sends the data respectively to the base stations (BS). When researchers employ such type of mechanism, sensor node exhausts much power and the lifespan of WSN is belittle at time because the sensor nodes have restricted power.

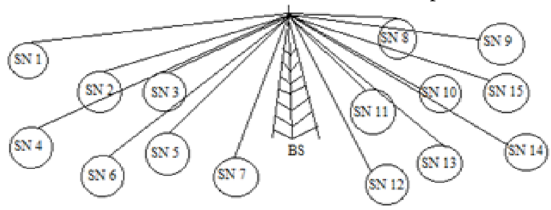

Fig.2 Transmission of data packets when sensor nodes singly interact with BS

For enhancing the lifespan of WSN researchers employ the second mechanism, named “Clustering”. In clustering mechanism WSN is divided into several clusters, there is a special node in every cluster known as cluster head (CH). The cluster head node is responsible for gather, aggregate and compressed the receiving data from the member sensor nodes (N1, N2, N3…..) of the same cluster [3]. As well all cluster head nodes done this same work. In clustering mechanism only cluster heads transfer the aggregate compressed data to the BS [4].

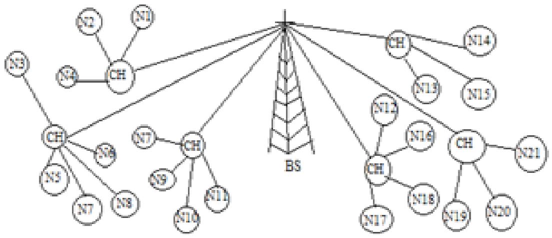

Fig.3 Transmission of data packets when clustering mechanism is used

1.2 Congestion

The universal meaning of congestion is excessive crowding. In WSNs, congestion takes place when any one sensor node holds too much data packets than their QoS drops. There are various problems generate when congestion is takes place in WSN as queuing delay, blocking and packet loss. Congestion is also affects the energy consumption of sensor nodes because generally congestion is takes place those sensor nodes which are carry data packets for a long time. So to carry data packets for long time is a reason of very energy wasting of sensor nodes; data packet loss, blocking of network and failure of network is too potential due to congestion in WSN [5].

In advanced technology, to belittle the effect of congestion, researchers employ congestion avoidance and congestion control techniques in WSN [6, 7]. The other technique is to belittle the effect of congestion is priority schemes known as PCCP (Priority Congestion Control Protocol).

In PCCP protocol [8, 9] the sensor nodes sensed the data from their area of interest and give some precedency to these data packets. Which data packets have the higher precedence are transferred first to the lower precedence data packets.

In WSNs, there are 2 types of congestion takes place. The first type of congestion is "node-level" [10]. It is induced when the buffer in the sensor nodes is overflowed and the result is raised queuing delay and packet loss. Packet loss is enhanced the retransmissions with using up of additional energy.

The second type of congestion is "link-level" congestion. Since, in WSNs the wireless channels are divided into various sensor nodes which are utilizing CSMA protocol (Carrier Sense Multiple Access protocol).

Then the collisions of data packets are happen when various active sensor nodes try to utilize the wireless channels at same time. This status of congestion enhances the packet service time and diminishes the uses of both links and overall throughputs, so this kind of congestion is too waste the energy of sensor nodes.

And energy efficiency of sensor nodes is affect by both types of congestion (link-level and node-level). Hence, congestion is diminishing the lifespan of WSN also.

1.3 Congestion estimation & detection

In papers [11, 12] researchers proposed that in WSNs there is utmost probability of congestion happening because the sensor nodes utilize the wireless channels to transferring data packets. If various sensor nodes transferring data packets at same time interval, then the congestion is happened, this is a reason of data packets loss.

When there is just single sink node and various number of source nodes which are transferring data packets at particular rate to single sink node and the single sink node should not bear all the data packets at the conquer rate then there is data packets loss is takes place at that single sink node because of congestion.

There is a very energy effective scheme known as Congestion Detection and Avoidance (CODA) for detecting the congestion problem. The CODA scheme has 3 mechanisms [13].

Congestion Detection: For detecting the congestion, the researchers want to discover out that where it does takes place? And they too examine that what are the current and previous wireless channel's traffic circumstances in the current sensor node. And besides study, the current tenancy of buffers in these sensor nodes. However, they too remained that they can't ever regularly listen the channel to evaluate the local loading since it is very high-energy consuming procedure. When congestion is found, then the sensor nodes transfer a signal to its upstream wireless sensor nodes via a back pressure process.

One-hop back pressure: When sensor node founds congestion, it transfers a back pressure signal to one-hop upstream. And if sensor node gets that back pressure signals it diminish its transferring data packet rate. When any upstream sensor node gets a back pressure signal it checks out its network condition, and if there is also congestion happen, it will further transfers the back pressure upstream.

Closed-loop, multisource regulation: If there are various source nodes and single sink node present, then there is a mechanism is required to apply known as closed-loop rate regulation for congestion control. According to this mechanism, every source node needs to compare its data packet rate to the uttermost throughput of the channel. If data packet rate is lesser than the throughput, it normally regularizes its rate and if the throughput is lesser than the data packet rate then there is a possibility of network congestion. In these circumstances, the closed-loop congestion control strategy is applied. And source node goes into the sink regularization and it utilizes the feedback from sink node to keep its data packets rate.

1.4 Parameters of Congestion Estimation

For estimating the congestion there are 2 most important parameters used in WSNs, P_{net} (net packet arrival rate) and S (buffer occupancy).
The net packet arrival rate (P_{net}) is calculated by the ratio of incoming packet rate to outgoing packet rate.

$$P_{net} = P_{in}/P_{out} \quad (1)$$

Where P_{in} is the incoming packet rate and P_{out} is the outgoing packet rate.

2. TECHNIQUES OF CONGESTION ESTIMATION

2.1 A Predictive Congestion Control MAC Protocol for WSNs

The Congestion estimation and control schemes which are available at present time are the examples of transport control protocol. When these are applied to WSN, there are large number of data packets are dropped & gives unfairness with wasted of energy due to various retransmissions. So if researchers want to fully utilize hop by hop feedback information, they use a novel, predictive & decentralized congestion control scheme called Distributed Power Control (DPC) [14].

DPC is able to utilize node queue and channel quality. And it is also provide energy efficient solutions to WSN.

2.1.1 Proposed Methodology

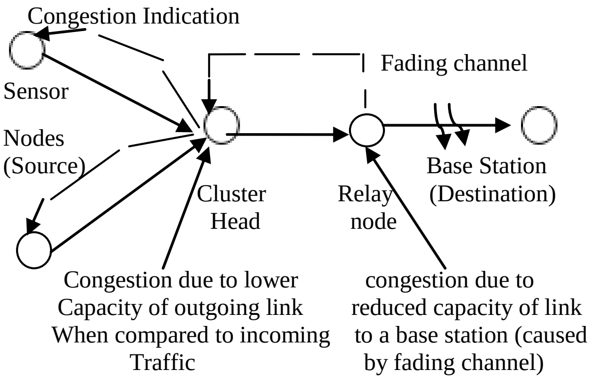

Fig.4 Congestion in Wireless Sensor Networks

2.1.2 Metric of Performance

When congestion is takes place in WSNs, the data packets are dropped due to buffer overflow. The packets are dropped from intermediate nodes due to low network throughput & decrease in energy efficiency. Then there is a metric for design protocol of data packets are dropped at intermediate nodes. And the second metric is the energy efficiency which is measured as number of bits transmitted/joule.

2.1.3 Congestion Strategy

To forecast the congestion, the appropriate scheme use queue utilization at every node with power required to send the data packets under the present channel condition. This is provided by the DPC (Distributed Power Control) algorithm.

The utilization of queue shows that there is a proper amount of incoming data packets flowing in comparison to outgoing rate. The WSN have the fading problem. In fading, the available bandwidth is diminishes & the outgoing rate of data packets will be let down.

The fading of channel, estimated by the feedback information used by the distributed power control algorithm through the power is required to the next data packet transmission. The distributed power control protocol estimate the channel state for the next transmission & calculate required power. If power is greater than the maximum threshold, then the channel is assumed to be in bad state and congestion control scheme is start back-off.

2.2 Congestion Control Scheme based on Data-Aggregation for WSNs

In paper [15] researchers proposed that WSNs have some key features such as data-aggregation & processing of data packets. So they propose a data-aggregation algorithm called Data-Aggregation Congestion Control algorithm. This algorithm is based on linear discrete time control theory. The DACC algorithm can be applied fully distributed way in WSN.

By using this approach every node is able to periodically evaluate the amount of aggregated data to control the transmission queue level.

2.2.1 DACC Algorithm

Fig.5 shows that the network architecture which is taken by the researchers for their work. There are many to one incoming hop by hop upstream flow to sensor node (sink node). To access the wireless channel, all nodes are considered to implement a CSMA protocol like Medium Access Control (MAC) Protocol. It is also considered that all sensor nodes are aware for their geographical locations. Every node has two types of traffic such as “source & transit”.

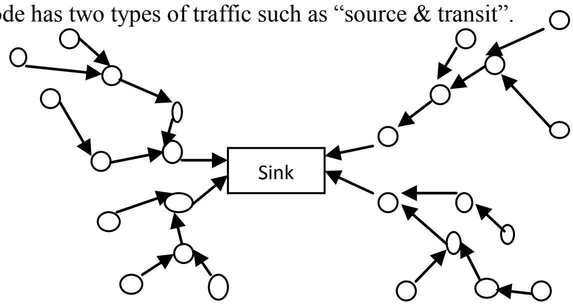

Fig.5 Network Topology

The source traffic is locally generated by the own sensor nodes and transit traffic is comes from other sensor nodes. When at MAC layer, the input rate of data packets at a node greater than the forwarding rate of data packets then data packets are stored in FIFO (First in First out) transmission buffer. So if there is no countermeasure is taken then the saturation of data packets forwarding rate, then the transmission queue is in its maximum limit & data packet losses increases due to congestion.

2.2.2 DACC Control Law

In this type of problem, the data-aggregation congestion control algorithm acts as fully distributed way which is able to decrease the number of queued data packets at every sensor nodes. It is able to remove the buffer overflow by aggregating the data packets contained in queued data packet.

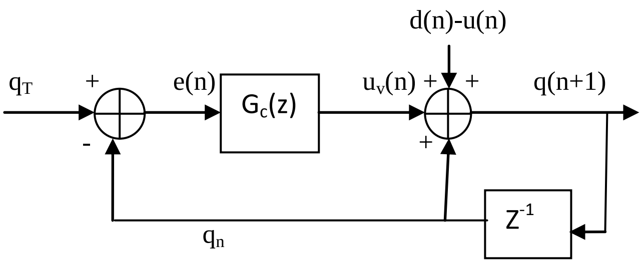

Fig.6 Block Diagram of Controlled System

Let $q_{(n)}$ be queue level and n is the sampling time. So in discrete domain, its dynamics is:-

$$q(n+1) = q(n)+d(n)-u(n)+u_v(n) \quad (2)$$

Where $d(n)\geq 0$, is the number of enqueued packets.
$u(n)\geq 0$, is the number of packets transmitted.
$u_v(n)\geq 0$, which is calculated by DACC algorithm.
$|u_v(n)|$ is the number of packet which are removed from the queue with the help of aggregation techniques.

2.3 Improved Multimedia Streaming over WSN using End-to-End Estimation of Wireless losses

In paper [16], there is several end to end congestion control protocols are used as networked application to avoid the congestion collapses. So there is a condition of link underutilization which suffers the transport protocols when there are wireless links, then there is not easy to distinguish the wireless losses from congestion losses. Because at present time the almost all networks are heterogeneous types which are mix of wired & wireless links.

So researchers proposed a novel equation based rate control method, as solution for this end to end problem, for Wireless Loss Estimation in IP DiffServ networks (WLED). WLED is able to enhance the performance of multimedia applications. It is able to directly estimating the congestion & wireless loss rate.

2.3.1 DiffServ Architecture

The DiffServ (Differentiated Service Architecture), is to enable QoS support in IP networks, is developed by Internet Engineering Task Force (IETF). The DiffServ is able to separate the user traffic into different class of services based on their requirements. Every data packet is marked to the treatment, at the edge of the network, called Per Hop Behavior (PHB). Assured forwarding (AF) is one of the standardized Per Hop Behavior (PHB).

There are three dropping properties with four AF forwarding classes, each dropping priority is defined the relative importance inside the AF class. The all drop priorities are defined by colors. Green for lowest drop, Yellow for middle drop & Red for the highest drop. Red with in & out (RIO) is AQM (Active Queue Management) mechanism which is suitable for the Assured Forwarding Per Hop Behavior (AF PHB).

2.3.2 WLED Algorithm

The algorithm is used to estimate the wireless loss rate when there is mild congestion; means there are using highest priority packets. Because they will not dropped at mild congestion. When there is heavy congestion it takes a conservative approach. WLED is not responsible for the protection of highest priority data packets inherent in the staggered (Red with in & out) RIO algorithm.

It means that, if the loss rate of the lowest priority data packets is not significant then researchers consider that the loss of highest priority data packets is highly co-related to the wireless loss rate.

2.3.3 WLED integration with Multimedia Rate-Control Protocols

There are several congestion control protocols are available but here researchers focus on equation based rate control protocols which use a TCP model. Here researcher wants a TCP model which is able to capture almost all ideal behaviors of TCP in wireless networks.

The ARC is the best model which is able to capture almost all ideal behavior of TCP wireless loss. It has the following equation:

$$S = \frac{1}{4RTT}\left[3+\sqrt{\left(25+\frac{24}{p_c}\right)}\right] \quad (3)$$

Where S is sending rate of packet/sec
RTT is round trip time
p_c is congestion loss probability &

$$p_c = (\pi-\omega)/(1-\omega) \quad (4)$$

Where π is calculated by total received packets & total lost packets after sequence number. And ω is tricky to calculate & ARC relies that lower layers are get this loss probability.

2.3.4 Estimation of Loss

It is the most important part of equation based congestion control mechanisms. Here researchers select an estimation method known as EWMA (Exponentially weighted moving average). It uses the following equation to calculating the $\hat{E}$ (estimated quantity) for current sample E.

$$\hat{E} \longleftarrow \alpha E + (1-\alpha)\hat{E} \quad (5)$$

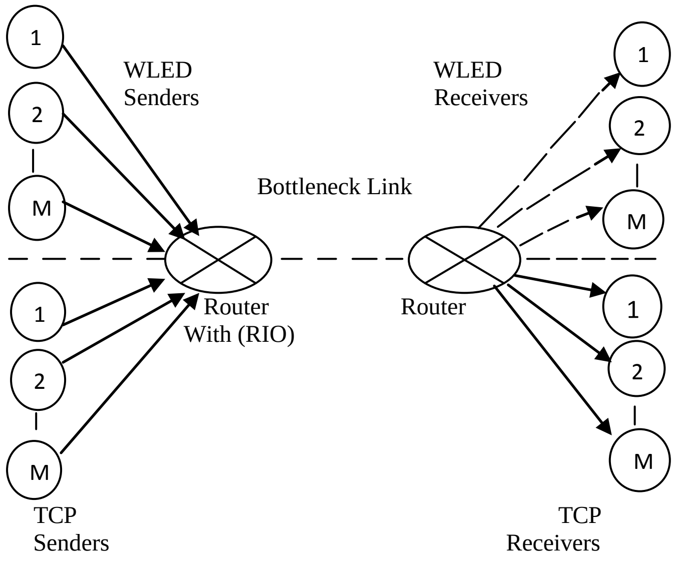

Fig.7 Mode-I: Default mode where TCP nodes are absent Mode-II: TCP nodes are present to compete for the bandwidth

Where α ϵ (0, 1) which is the responsiveness of the estimator & p_c is estimated & sent to sender after that it utilize directly in ARC rate equation.

2.4 Congestion Avoidance in Multi Sink WSNs

According to paper [17], Event tracking applications are some other very important applications of WSNs. In this application, researchers consider an event which is moving every time with triggering many sensor nodes continuously. And every sensor node sends their information to the centralized sink node. When there is a number of sensor nodes transmitting their data to the sink node, there is congestion condition is occurs.

Because of this congestion, packet loss is takes place & throughput is decreases. So to diminish this packet loss & increase the throughput loss, researchers proposed here a technique of multiple sinks which is able to distribute the traffic & thus congestion is reduced. Here for IEEE 802.15.4 sensor networks researchers develop an NS2 simulator & conduct several experiments, which are describe the performance of this algorithm.

2.4.1 Event tracking

The process of deciding the moving objects in the network is called the event tracking. The basic function of event tracking is sensing & collecting the dynamic of mobile event during long period such as their attributes, event trajectory etc. For this, the collaboration communication & computation of multiple sensors are needed. Because information acquired by a single sensor node is normally inaccurate & incomplete.

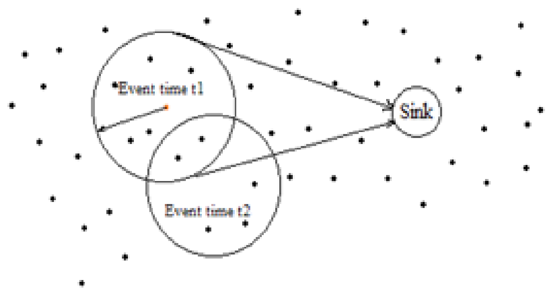

Fig.8 Event Tracking

The object tracking is also used for detection location, velocity and size of object and also share this information to multiple sensors & also inform to sink node. A sensor node which generates the signal of sensing object or target can also use the sensing modalities such as ultrasonic, seismic, infrared, radar, RF etc.

2.4.2 Congestion control

In the area of event tracking and multiple objects tracking several sensor nodes are spread simultaneously, so it causes a lot of message traffic. Because of sink node is a common end point of all sensor nodes then around the sink node the data traffic is heavier, so the area at the sink has a high possibility to get congested.

The buffer-based congestion avoidance is a scheme to control the congestion. In this scheme any sensor node sends their sensed data packets to another sensor node, if that sensor node has buffer space to hold that data packets. Similarly ESRT (Event to Sink Reliable Transport) is also provides the congestion detection & avoidance scheme [18]. This scheme is also based on buffer overflow.

2.5 A Congestion Detection & Avoidance (CODA) Algorithm for Multiple Class of Traffic in Sensor Network

According to paper [19] researchers proposed that in WSNs, congestion is the reason of loss of data packets, long time delay & low energy efficiency. And some applications such as images and multimedia needs large amount of data concurrently from several sensor nodes. These applications have many different QoS requirements & the problem of congestion is more significant in such applications. To face this challenge, researchers proposed a congestion control scheme which is energy efficient for sensor networks called (Enhanced Congestion Detection and Avoidance) ECODA [20], which have2 mechanisms:

(i) It uses weighted buffer difference with dual buffer thresholds for congestion detection &

(ii) It dynamically estimates the channel loading to periodically get channel information.

In CODA scheme, the load of channel is estimated by sensing the channel periodically and looking that how many times channel is found to be busy. This leads to wastages of energy. Here researchers proposed a scheme which estimates the channel status to avoid the channel sampling. The scheme can be dynamically optimize the channel utilization, based on current channel status (S0, S1 & S2).

S0 – lower channel loading & lower throughput.

S1 – higher channel loading & higher throughput.

S2 – higher channel loading & lower throughput.

Here are some rules and definitions which are used:-

(1) The dynamic priority (DP) of a packet is defined as

$$DP\ (packet) = \frac{\alpha * Hop + SP\ (packet)}{1 + \beta * Delay} \qquad (6)$$

Where, α & β are parameters for tuning system performance

Hop is the number of hops

SP is static priority for the packet

Delay is the time from current time to data packet generation time.

(2) If BI is the buffer incoming rate and BO is the buffer outgoing rate, then R = BO-BI is the buffer changing rate and weighted buffer changing rate WR is

$$WR = DP\ (BO) - DP\ (BI) \qquad (7)$$

EWMA (Exponential Weighted Moving Average) is a technique which is used to determine the BI and BO.

(3) Weighted queue length WQ is defined as

$$WQ = \sum_{j=1}^{N} DP\ (packet_j) \qquad (8)$$

Where N is total number of packets in buffer.

2.5.1 Rule

Let (p_1, p_2, p_3, -----) is a series of packets and their SP and DP are denoted as SP (p_1), SP (p_2), SP (p_3), ------ and DP (p_1), DP (p_2), DP (p_3), ----- respectively. If SP (p_1) <SP (p_2) <SP (p_3) -- - then also DP (p_1) <DP (p_2) <DP (p_3) -----.

If researchers combine the definition (1) and this rule then researcher conclude that the data packets which have the same SP have different DP and data packets which have higher SP have higher DP.

2.5.2 Congestion Detection

For measuring the local buffer level at each node, researchers propose a technique of dual buffer threshold & weighted buffer differences for congestion detection. The buffer is defined in 3 states, “accept”, “filter” & “reject state” as shown in fig.9 & also two thresholds Q_{max} & Q_{min} which are used to indicate the different buffer states.

Buffer length is denoted by Q. different channel loading is reflected by different buffer states. The following strategy is considered to accept or reject packets at different states. The “reject state” does not mean that it rejects all the incoming data packets; it means that when the utilization of buffer is too high then most of the data packets will be rejected.

Each node, which wants to send data packets, monitors its buffer state and piggybacks its WR (weighted buffer changing rate) and WQ (Weighted queue length) in its outgoing data packets. If a node has exceeds its certain threshold and if data packet has high priority among its neighborhoods then the congestion level bit is set outgoing packet header.

The weighted buffer which has length WQ(t), at Δt, it become

$$WQ(t+\Delta t) = WQ(t) + WR * \Delta t \qquad (9)$$

Fig.9 Buffer State

At time ($t+\Delta t$) the weighted buffer difference is

$$WQD_{nodei}(t+\Delta t) = \sum_{j=1}^{N} DP(packet_j) - Max(WQ_k(t+\Delta t)) \qquad (10)$$

Where N – total number of packets

$k \in$ neighbor ($node_i$)

if $WQD_{nodei}(t+\Delta t) \geq 0$ means the data of $node_i$ is the most important among its neighbors. If congestion occurs then the other nodes should lower their data packet sending rate to mitigate the $node_i$'s congestion level.

Table 1: Comparative Analysis of Congestion Estimation Techniques

Technique	Key Features
A Predictive Congestion Control MAC Protocol for WSNs	- It provides fully utilization of hop by hop feedback information. - It provides energy efficient solution. - It increases throughput, network efficiency & energy conservation.
Congestion Control Scheme based on Data-Aggregation for WSNs	- It is an innovative congestion control algorithm. - It allows the data to be processed & aggregated as it goes through to the network. - This algorithm is designed by linear discrete time control theory. - It can be applied in fully distributed way. - The estimation accuracy is significantly enhanced using this algorithm.
Improved Multimedia Streaming over WSN using End-to-End Estimation of Wireless los	- This technique works over wireless networks like UMTS. - This technique works together with equation-based congestion control scheme & estimates the wireless probability in an end to end fashion.
Congestion Avoidance in Multi Sink WSNs	- For reducing the congestion this technique provide multiple sinks strategy. By this technique the traffic is distributed among various sinks. - In the multiple sink technique if any sink failure then there packet loss is takes place. So with the help of this technique we are able to recover the sensor nodes which are connected with the failed sink.
An Enhanced Congestion Detection & Avoidance (ECODA) Algorithm for Multiple Class of Traffic in Sensor Network	- This technique achieves efficient congestion control & flexible weighted fairness for different classes of traffic. - It dynamically estimates the channel loading & optimizes the channel utilization with an implicit manner. - It is energy saving technique as compared to CODA. - It achieves higher channel utilization because it leads to fewer packet retransmissions & flexible fairness. - It can reduce the packet loss, improves the energy efficiency & achieve lower delay.

3. CONCLUSION

In WSNs congestion estimation and congestion control is always an important task. Because WSN have various sensor nodes, which are self-operated, and they too have very low storage capacity (memory), limited power, etc. If the battery power of sensor nodes is ends, then the sensor nodes are dead because batteries of sensor nodes are not possible to change. The information from source to destination is travels in the form of data packets. So if congestion takes place in sensor network, it'll result in unwanted energy wastage for holding these data packets or sometimes these data packets are dropped due to excessive congestion circumstances, at these situation sensor nodes retransmits the appropriate data packets to the destination sink nodes. In this paper, we introduce various knowledgeable inferences from the previous approach and what are their key features. After doing this survey, we recognize that these congestion estimation and congestion control techniques are very easy to implement and helpful to augment the lifetime of each sensor nodes present in a WSN and also reduces the retransmission and packet delay from source to destination.

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