VOL. 17, NO. 3, FEBRUARY 2022 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

TRAFFIC PRIORITY AND BANDWIDTH-AWARE ADAPTIVE RATE ADJUSTMENT WITH ROUTING STABILITY MEASURE FOR CONGESTION AVOIDANCE IN WSNS

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ABSTRACT

In Wireless Sensor Networks (WSNs), a mixture of Real-Time (RT) and Non-RT (NRT) packets are not effectively handled with different level of traffic class priorities due to its limited bandwidth allocation. This causes congestion through the network that leads high packet delay and less throughput. To effectively handle these packets and avoid congestion, a Combined Traffic, Bandwidth and Congestion Adaptive Rate Control (CTBCARC) algorithm has been designed that considers the Difference of Differential Rate (DDR) of a specified node including the joint notions of the traffic class priority, the proper bandwidth distribution and Active Queue Management (AQM). The traffic flow of each active queue was controlled by deciding weight value of priorities. But, the path stability was not considered to avoid the congestion efficiently. Therefore in this article, CTBCARC with Route Stability (CTBCARC-RS)-based algorithm is proposed for guaranteeing the path stability and avoiding the undesirable DDRs. In CTBCARC-RS algorithm, the long-term RS of WSN is measured by determining different factors such as the utilization rate of Relative Routing Path (RRP), distinct successive hop and Switching Frequency Counts (SFC). These factors are sampled regularly and reprocessed from prior data in the queue that do not want additional overhead. The utilization rate of RRP is used to identify the major routing junction spots in WSNs. The utilization rate of distinct successive hop corresponding to an independent origin is used for detecting the majority next hop from the minority next hops. Similarly, SFC is used for computing the reliability of the majority next hop corresponding to the source node. Based on these parameters, the path stability is measured to avoid the congestion and likelihood of path failure. Finally, the efficiency of CTBCARC-RS algorithm is evaluated with the conventional algorithms through the simulation results.

Keywords: congestion handling, CTBCARC, route stability, traffic class priority, WSN.

1. INTRODUCTION

This template is designed to help you in preparing your manuscript in expected format. The guidelines include complete descriptions of the fonts, spacing and related information for creating your proceedings manuscripts. Please follow them properly. During the last few centuries, a huge variety of applications and the increased necessity for WSNs are entirely feasible since they provide minimum resource use and connectivity. Usually, WSNs are uniformly distributed autonomous sensors that are equipped together to measure the specific environmental changes.

Every node provides all the required elements for data transfer [1-3]. Even if nodes are spatially distributed or have an excessive traffic, the congestion leads to packet delay, inflexibility and inadequacy. This might be the main challenge in data transfer during earlier centuries of WSN researches [4]. Congestion should always be detected and handled for enhancing the WSN capacity during packet transfer [5]. Many congestion detection and avoidance techniques [6-9] have been proposed and the controlling of network traffic is a prime concern for congestion avoidance. Congestion Detection and Avoidance (CODA) [10], Priority-based Congestion Control Protocol (PCCP) [11], AQM [12-13] and Fairness Rate Control (FRC) [14] are most popular congestion control techniques. Such techniques are built based on the notions of priority, load balancing and fair bandwidth usage. However, it poses a major issue to avoid congestion whilst distributing all RT and NRT packets.

For this purpose, a DDR Control (DDRC) algorithm has been designed on the basis of DDR between sink and the source nodes. Also, a Weighted Priority-based DDRC (WPDDRC) algorithm has been developed using the combination of the traffic class's WP and DDR at the sink [15]. The key purpose of this algorithm was handling the RT as well as the combination of RT and NRT packets. The total priority was changed via distributing the traffic class's WP with a higher order derivative rate control associated with different nodes for obtaining the RT traffic class dominant over NRT packets. On the other hand, the priority for different traffic classes was irrespective of bandwidth allocation and congestion handling. To avoid this problem, a CTBCARC algorithm was suggested depending on the joint notions of the traffic class priority, the fair bandwidth allocation and the notion of AQM [16]. In CTBCARC algorithm, the notion of DDRs was taken into consideration with the traffic class priority, proper bandwidth distribution and AQM to fine-tune the data rate and avoid the congestion through the network. To achieve fair bandwidth allocation, the weighted fair queue scheduler and average input bandwidth of various traffic class priorities were considered.

Besides, the bandwidth requests and grants were allocated by each node in a round-robin way in which the number of distributed bandwidth is associated with the number of traffic flows weighted based on their priorities. A weight value for each active queue was chosen for controlling the traffic flow and avoiding the congestion. However, the path stability was not considered to control the congestion rate.

Hence in this article, a CTBCARC-RS-based algorithm is proposed to ensure the path stability and prevent the redundant DDRs. In CTBCARC-RS algorithm, the long-term RS of WSN is determined based on different factors: the utilization rate of RRP, distinct successive hop and SFC. These factors are sampled regularly, reprocessed from prior data in the queue. The utilization rate of RRP is used to identify the major routing junction spots in WSN. The utilization rate of distinct successive hop corresponding to an independent origin is used for detecting the majority next hop from the minority next hops. Similarly, SFC is used for computing the reliability of the majority next hop corresponding to the source node. Thus, the path stability is taken into account based on different parameters for detecting and avoiding the congestion.

The rest of the article is prepared as follows: Section 2 surveys the works related to this research work. Section 3 explains the proposed methodology and Section 4 portrays its efficiency. Section 5 summarizes the research work.

2. LITERATURE SURVEY

Reliable, Efficient, Fair and Interference-Aware Congestion Control (REFIACC) scheme [17] was proposed for maximizing the throughput. The interferences in the network were prevented and a high fairness of bandwidth usage was ensured among various nodes via scheduling the transmission. The obstruction and the intervention in inter- and intra-routes have been prevented via considering the divergence among path's facilities during scheduling task. Linear programming has been employed for attaining optimal usage efficiency of the highest accessible bandwidth. However, average throughput was still less and traffic priority was not considered.

A Packet Priority Intimation (PPI)-based congestion avoidance method [18] was proposed in which a PPI bit was introduced in each packet for reflecting its significance. The main goal of this method was transmitting higher priority packets with the reduced delay. In this method, an Ad-hoc On-demand Distance Vector (AODV) routing strategy [19] was applied to discover a route between the source and destination. But, computational complexity and overhead were high.

A two-stage cognitive network congestion method [20] was proposed using TOPSIS and response surface strategy. First, downstream node's buffer occupancy rate was computed and congestion level in the MAC layer was also estimated. After that, the estimated values were transmitted to the upstream nodes which use the TOPSIS for ranking all adjacent and choose the successive forwarding node. Moreover, the transfer rate was adjusted via an optimized regression analysis using response surface strategy. But, it has high computational complexity and less energy efficiency.

A novel congestion avoidance method called Extended Logarithmic Increase and Multiplicative Decrease (ELIMD) [21] was proposed for maximizing the throughput, QoS and fairness during multicast transmission. In this method, the congestion was handled based on the queue delay, packet loss and network throughput. Also, a framework was used for steady-state throughput of a multicast source based on the Adaptive IMD (AIMD) strategy after receiving the destination's receiver. However, the performance was not effective in terms of stability, fairness and security.

A new congestion handling method [22] was proposed for providing energy-efficient data transfer on optimized rate. In this method, the rate-based congestion handling method was used on the basis of cluster routing for minimizing energy use in the network. At first, nodes were clustered using the hybrid K-means and Greedy best first search algorithms. Then, the rate adjustment was executed by the firefly optimization for achieving the maximum packet delivery ratio. At last, data was transmitted with the highest throughput by ant colony optimization-based routing. However, energy efficiency was not effective.

Fuzzy Sliding Mode congestion Controller (FSMC) [23] was designed using a novel cross-layer congestion handling framework between transmission and MAC layer through considering a channel's Signal-to-Noise (SNR) fraction in TCP structure. After that, FSMC was proposed by fusing fuzzy and SMC to regulate the queue size in congested nodes and avoid the effect of external uncertain interferences. But, the network reliability was less.

Network Status-Aware Congestion Control (NSACC) [24] scheme was designed to accurately predict the severity of congestion and regulate the transfer rate based on the congestion level. The fuzzy controller was employed to infer about the severity of the congestion using runtime, dynamic parameters like buffer occupancy level, packet transmission rate and priority of nodes. According to this decisive data, the transfer rate was adjusted for reducing the collision and congestion. But, the network throughput was not effective.

Jellyfish Dynamic Routing Protocol (JDRP) [25] was proposed to preserve the location security and congestion control with the minimum delay. First, the entire network was split into various subfields and a target region for every subfield was chosen by determining its communication distance. The number of radial line and radius of the virtual ring were conjointly computed for finding the transfer route between the node and sink. Also, the radial line routes were routed directionally and bell nodes were routed with angular directions probabilistically. At last, the data were collected from the tentacle nodes to the dynamic sink. But, it has still high energy consumption and computational difficulty.

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3. PROPOSED METHODOLOGY

In this section, CTBCARC-RS algorithm is described in detail. Figure-1 illustrates the overall framework of CTBCARC-RS algorithm in WSNs.

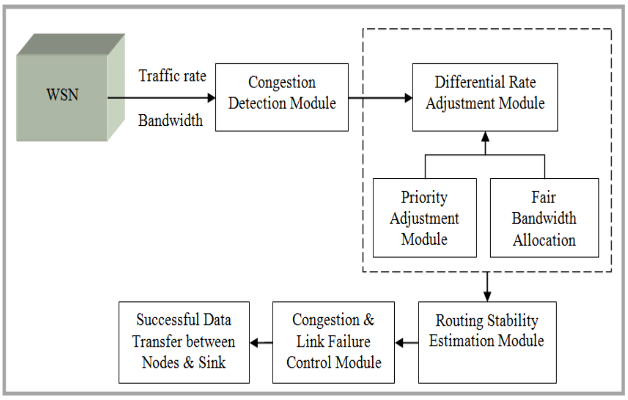

Figure-1. Overall framework of CTBCARC-RS algorithm.

In CTBCARC-RS algorithm, the successive hops in the RPs corresponding to the independent origins are forecasted for analyzing efficiency of routes. The utilization rate of RRP, distinct successive hop and SFC among distinct successive hops are suggested as RS indictors. Initially, the WSNs are designed for operating in 2.4GHz Industrial, Scientific and Medical (ISM) radio frequencies with data rates up to 250Kbps and transmission power of 0dBm. A mesh topology is applied in which nodes can transmit explicitly, implicitly and without hierarchy by reducing the dependence on a certain node. Also, it uses an AODV protocol where RPs from the source to the destination are generated simply on request and controlled by the WSN routers. The RP having the minimum route cost is chosen. The route cost is defined as the node's total path costs and determined by the Path Quality Indicator (PQI) as:

$$cost\{\mathcal{R}\} = cost\{\sum_{i=1}^{H} PQI_{n_i n_{i+1}}\} \quad (1)$$

In Eq. (1), $\mathcal{R}$ denotes the route cost, H denotes the amount of hops in the RP and PQI represents the route cost among node (n_i) and its successive hop in the direction of target (n_{i+1}). The PQI in Eq. (1) refers to a representation of the Received Signal Strength Indication (RSSI) performed for each accepted data as an integer between 0 and 255. PQI ranges of 0 and 255 are related to the minimum and maximum quality signals, accordingly wherein the PQI range is equally allocated among these bounds.

3.1 Router's Utilization Rate of RRPS

The router is considered as a portion of RPs for number of cases. The estimated P unique paths are expected from separate routers. Unusually, the maximum rate of RP utilization is detected on specific routers than another in the same areas. The path with the minimum hop from the destination is decided if the route costs of all promising routing choices are similar. Whilst building a RP, if the destination node is within the communication region, then the router is decided for direct transfer.

Likewise, nodes that are outside the communication region of the destination are liked to routers that are at the boundary of destination's communication region. This is performed for reducing the overall hop count. Based on this, the routers at the boundary of the destination's communication region are frequently considered as a forwarding node for remote nodes.

3.2 Utilization Rate and Majority Successive Hops

The phenomenon of unusually maximum rate of RP utilization is known by acquiring a view nearer at the distinct successive hops of independent origins. Distinct successive hops are defined as the routers detected over a time which are decided via a routing strategy as the initial hops from the origin to the destination. The utilization rates and unsuccessful Neighbor Table (NT) rates of distinct successive hops are determined from the RPs as follows:

To get the path quality data, NT and Routing Table (RT) data are mined from routers occasionally. A router's NT comprises the data regarding its adjacent nodes with their address, corresponding RSSI range, distance, link to the router and component category. If node A is discovered in node B's NT, A and B are reputable transmission in the last 60sec. At the same time, if a formerly existing node A is not discovered in B's NT, transmission between them is unsuccessful. Also, the router maintains data regarding the condition of reputable RPs corresponding to itself and required targets. This data is accumulated as RT inputs having the target and successive hop addresses. NT and RT data are sampled from routers at an about 25 minutes constantly for desired number of days. RPs in the direction of the destination is calculated from considered router's NT and RT. To gather nodes which generate an independent connection including RPs, an algorithm is given below:

Algorithm for Collecting Node-to-Node RPs from Sampled NT and RT
Input variable: Source node S, Destination node D, Next hop H, Relay node R, RT, NT, RP P
$P = \{S\}$;//Initializing the RP with the address of S
Given a list of NT and RT of 10 minutes window interval;
$R = S$; //Substitute Sas R;
$while(D\ is\ discovered\ in\ RT\ of\ R)$
$P = \{P, H\}$; //Add next hop address into P
$R = H$; //Substitute H as R
$end\ while$
$if(D\ is\ discovered\ in\ both\ NT\ and\ RT\ of\ R)$
$P = \{P, D\}$; //P towards D is discovered
$else$
$P = \{P, "unsuccessful"\}$; //$P$ is not discovered

The above algorithm is described the following: initially RP is assigned with the address of S and S verifies for D in its RT. If a target is discovered, then origin can transmit the data to the successive hop via either explicit or implicit link with the target. This is continued until the target is not discovered. After that, the recent successive hop can verify its NT for a destination. If a target is discovered, then RP between the actual origin and target is collected. Or else, a set of RP is represented as failure i.e., no RP is accessible between origin and target during packet query.

In WSN, keep-alive signals are transmitted by routers each 15sec for notifying the node that it is active. The previous path among routers is reported as lost when 4 successive signals are not accepted i.e., 60sec. If true, al data related to the adjacent is removed from the NT and RT. For instance, if 4 successive keep-alive signals from A are unnoticed, then B eliminates each A's associated data from its NT and RT. It is expressed as modifications or faults in the determined RPs. Thus, the RPs between origin and target are discovered.

Origin contains several distinct successive hops and their utilization counts may differ between 0.5% and 100%. A distinct successive hop having 100% utilization count indicates that the corresponding origin simply consists of single path in the direction of the destination. The maximum utilization count of majority successive hop indicates highly robust path than the minority successive hop. Also, it describes why specific routers contain higher RP utilization rates.

3.3 Likelihood of Path Fault Depending on Utilization Rate of Distinct Successive Hops

The amount of faults detected in distinct successive hops is described for the duration in which a specific successive hop is absent in the corresponding origin's NT. Also, the amount of adjacent differs continuously in its lifespan. The likelihood of undergoing NT fault is increased while decreasing the utilization rate of distinct successive hops. Reducing utilization count recommends that nodes are used simply prior to switching back to the majority successive hop. Raising the NT fault with reducing utilization count stands for the disrupted successive hops are short-lived and unmanageable owing to weak node-to-node link. Because a router can be employed as a forwarding node, the minority successive hop has possible node faults. As a result, it is essential for detecting them so that suitable measures can be set for reducing their utilization.

3.4 Robustness of Majority Successive Hops

The SFC estimates the number of cases the successive hops corresponding to the origin modifies. A develop in SFC indicates the recurrent path faults and retransmission among the disrupted origins. The origin comprising comparatively low SFC has reliable paths with its majority successive hops. If the path fault is occurred, the minority successive hops are considered as routing discrimination; however simply used for an interval prior to switching to the majority successive hop. Such majority successive hops are found for providing the long-term routing decisions than the minority successive hops. The RPs having greater majority are identified to consist of greater path constancy and less faults.

Thus, if two routing decisions are evaluated to have similar path quality, then a number of majority successive hops are selected depending on utilization count, because the minority successive hops are highly possible to be unsuccessful. Also, the congestion due to path fault or high data rate is avoided.

4. SIMULATION RESULTS

This section shows the performance analysis of CTBCARC-RS algorithm by implementing it using Network Simulator version 2.35 (NS2.35) and comparing with the existing algorithms: REFIACC [7], PPI [8], ELIMD [10] and CTBCARC [6] in terms of throughput, packet loss, packet delay, received bandwidth, fairness, and network lifetime. The simulation parameters are provided in Table-1.

Table-1. Simulation parameters.

Parameter	Range
No. of nodes	50
Simulation region	1500m×1500m
MAC layer	IEEE802.11
Communication range	300m
Traffic source	CBR
Packet size	200bytes
Data rate	2Mbps
Transmission power	285.63mW
Operating frequency	5GHz
Routing protocol	AODV
Mobility model	Random walk
Mobility speed	10m/s
Simulation time	120sec

4.1 Throughput

It defines the amount of data effectively forwarded to the sink.

VOL. 17, NO. 3, FEBRUARY 2022 ISSN 1819-6608
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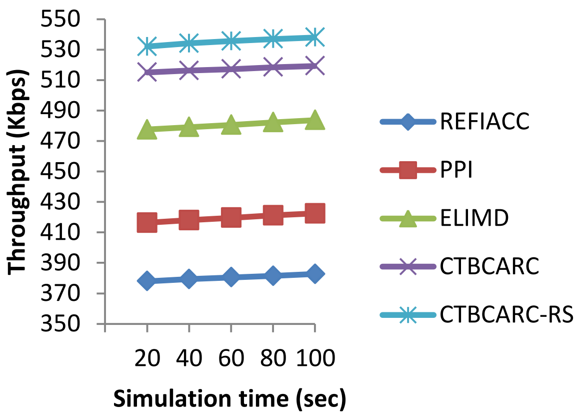

Figure-2. Throughput vs. Simulation Time.

Figure-2 portrays the throughput (in Kbps) of different congestion control algorithms under varying simulation time. This analysis signifies the CTBCARC-RS achieves the highest throughput as compared to the all other algorithms. For 100sec simulation, the throughput of CTBCARC-RS is 3.6% increased than the CTBCARC, 11.23% increased than the ELIMD, 27.37% increased than the PPI and 40.58% increased than the REFIACC algorithms. This is because the CTBCARC-RS selects only the majority successive hops for transmitting the data without any congestion.

4.2 Packet Loss

It defines the amount of packets missed when performing the data transfer.

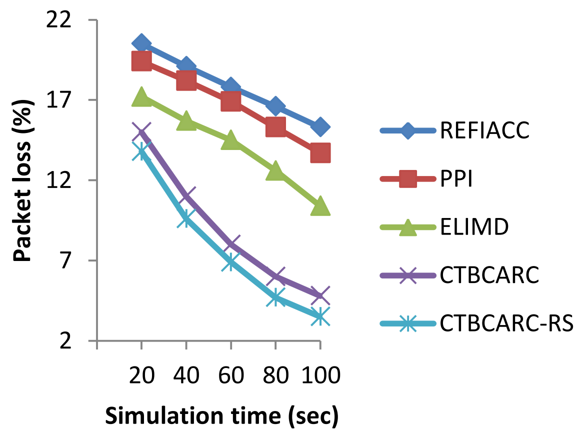

Figure-3. Packet loss vs. simulation time.

Figure-3 demonstrates the packet loss (in %) of congestion avoidance algorithms for varying the simulation time. Through this analysis, it observes the CTBCARC-RS algorithm reduces the packet loss as compared to the other algorithm. The packet loss of CTBCARC-RS for 100sec is 27.08% reduced than the CTBCARC, 66.35% reduced than the ELIMD, 74.45% reduced than the PPI and 77.12% reduced than the REFIACC algorithms. The improvement in throughput results in the reduction in the packet loss using CTBCARC-RS protocol during data transfer through the network.

4.3 Packet Delay

It refers to the time consumed for data transfer from source to sink or destination.

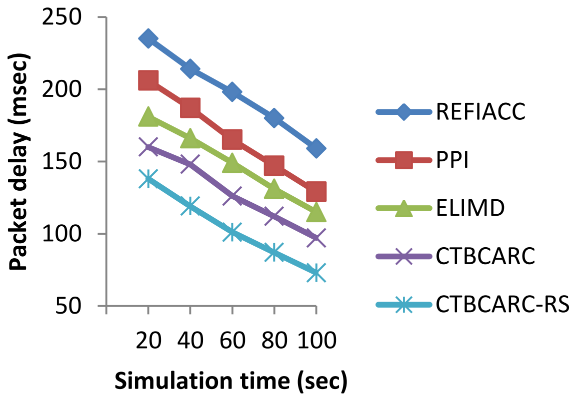

Figure-4. Packet delay vs. simulation time.

Figure-4 shows the packet delay (in milliseconds (ms)) of congestion avoidance algorithms for different simulation time. This analysis indicates the CTBCARC-RS achieves the minimum packet delay than the all other algorithms. The packet delay of CTBCARC-RS for 100sec is 24.74% less than the CTBCARC, 36.52% less than the ELIMD, 43.41% less than the PPI and 54.09% less than the REFIACC algorithms. This is because of selecting the majority successive hops for data routing by the CTBCARC-RS protocol.

4.4 Received Bandwidth

It defines the amount of data rate received at every destination.

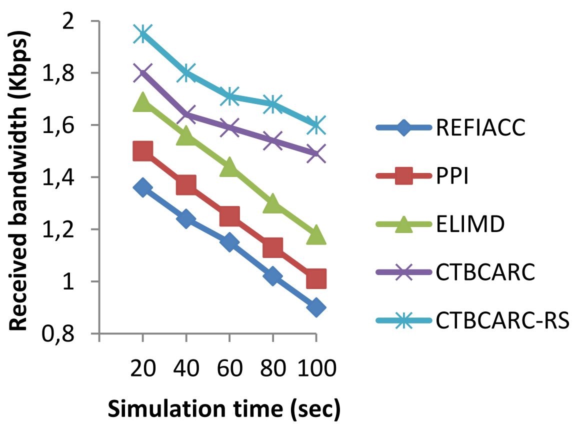

Figure-5. Received bandwidth vs. simulation time.

Figure-5 portrays the received bandwidth (in Kbps) of different congestion control algorithms under varying simulation time. This analysis indicates the CTBCARC-RS algorithm increases the received bandwidth as compared to the other algorithms. The received bandwidth of CTBCARC-RS for 100sec is 7.38% higher than the CTBCARC, 35.59% higher than the ELIMD, 58.4% higher than the PPI and 77.78% higher than the REFIACC algorithm. Because of identifying the majority successive hops and preventing congestion, the received bandwidth of CTBCARC-RS protocol is improved

4.5 Fairness

It refers to the average amount of received packets at every destination.

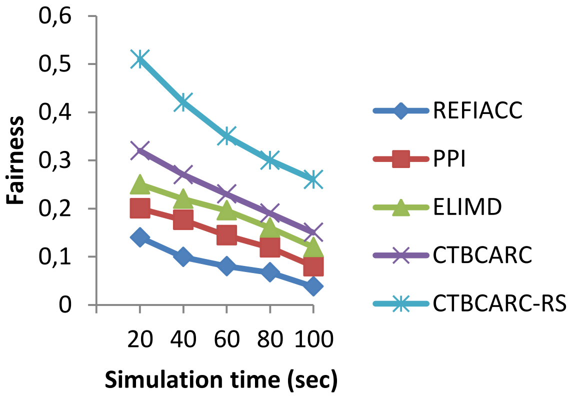

Figure-6. Fairness vs. simulation time.

Figure-6 depicts the fairness of different congestion control algorithms under varying simulation time. Through this analysis, it is identified that the CTBCARC-RS achieves higher fairness than the all other algorithms. The fairness of CTBCARC-RS for 100sec is 0.26 which is greater than the all other algorithms i.e., the fairness of REFIACC, PPI, ELIMD and CTBCARC algorithms are 0.038, 0.08, 0.12 and 0.15, respectively. This is because of increasing the throughput, received bandwidth while transferring the data without congestion using CTBCARC-RS protocol.

4.6 Network Lifetime

It is the time taken for constructing the network up to the initial node dies.

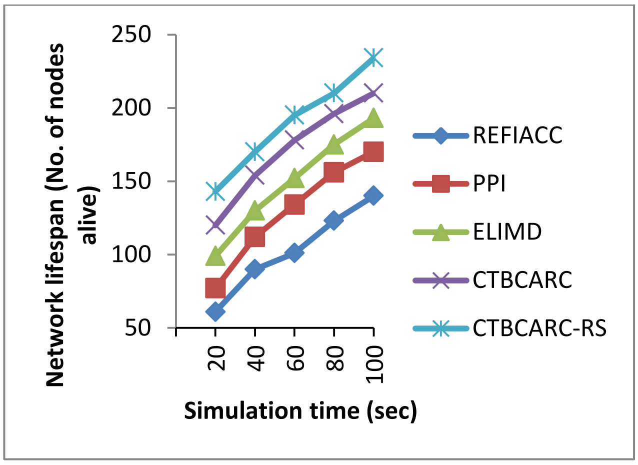

Figure-7. Network lifetime vs. simulation time.

Figure-7 shows the network lifetime (in no. of nodes alive) of different congestion control algorithms under varying simulation time. This analysis indicates the CTBCARC-RS algorithm increases the network lifetime i.e., the number of nodes alive in the network as compared to the other algorithms. The network lifetime of CTBCARC-RS for 100sec is 11.43% higher than the CTBCARC, 21.24% higher than the ELIMD, 37.65% higher than the PPI and 67.14% higher than the REFIACC algorithm. Due to the selection of majority successive hops to prevent congestion and routing, the number of nodes alive in the network is increased efficiently by the CTBCARC-RS protocol.

5. CONCLUSIONS

In this article, a CTBCARC-RS-based algorithm is proposed that measures the long-term RS of WSN by computing the utilization rate of RRP, distinct successive hop and SFC. The computed values are sampled regularly and reprocessed from prior data in the queue without any extra overhead. The utilization rate of RRP is used to identify the major routing junction spots in WSN. The utilization count of distinct successive hop corresponding to an independent origin is used for detecting the majority successive hop from the minority successive hops. Similarly, SFC is used for computing the reliability of the majority successive hop corresponding to the origin. Based on these measures, the path stability is ensured to avoid the congestion and likelihood of path fault. At last, the simulation outcomes proved the CTBCARC-RS algorithm achieves higher throughput, fairness, received bandwidth and less packet loss, packet delay than the other existing algorithms.

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