CLI-WSAN:AN ENHANCED DELAY REDUCTION MECHANISM FOR THE NETWORKED CONTROL SYSTEM

V.Gnanasekar[1*], Dr. S. Solai Manohar[2] and Dr. M. Senthil Kumaran[3]

[1]Assistant Professor, Department of Electrical and Electronics Engineering, Misrimal Navajee Munoth Jain Engineering College, Chennai, Tamil Nadu 600097, India. Ph.: 044 2496 0101

[2]Professor, Department of Electrical and Electronics Engineering, Arulmigu Meenakshi Amman College of Engineering, Kanchipuram, India.

[3]Associate Professor, Department of Electrical and Electronics Engineering, SSN College of Engineering, Chennai, India.

Abstract— **Reducing the latency of Networked Control System (NCS) is the demanding and critical task in recent days. Because, the communication in NCS is performed between the actuators, sensors, and controllers. So, different mechanisms are developed in the traditional works for improving the performance of the network with reduced latency. But, it lacks with the limitations of inefficient data transmission, reduced packet delivery rate, and reduced Quality of Service (QoS). To solve these problems, this paper aims to develop a new architecture, namely, Closed Loop Industrial Wireless Sensor and Actuator Network (CLI-WSAN) for improving the overall performance of the network. Here, the data aggregation is performed to increase the overall efficiency of NCS, and the optimal weighting time distribution is performed to reduce the network latency. In this environment, the inter-cluster model is created between the cluster head and sink, and the intra-cluster model is created between the cluster member and cluster head. Based on the data rate and time slot, the internal clusters are formed, then the data aggregation is initiated from the cluster head to the members. Here, the aggregate function is utilized to filter the packets before forwarding it to the other nodes, and the enhanced Markovian Decision Process (MDP) is used to select the relay for a better communication. Consequently, the gathered data are collected and the errors are predicted, based on this the actuator control is forwarded. During simulation, the performance results of the proposed framework is evaluated by using different parameters. Moreover, it is compared with the existing frameworks for proving the efficacy of the CLI-WSAN architecture.**

Index Terms— **Networked Control System (NCS), Data Aggregation, Markovian Decision Process (MDP), Closed Loop Industrial Wireless Sensor and Actuator Network (CLI-WSAN), Data Propagation Latency,**

I. INTRODUCTION

NETWORKED Control System (NCS) is a kind of spatially scattered systems, where the communication is performed among the sensors, actuators, and controllers[1]. The major reasons of using this network are reduced system wiring, easy maintenance, simple system diagnosis, and increased agility[2, 3]. Thus, the NCS is used in a wide range of applications that includes industrial control, automation, and software applications. Data aggregation is one of the essential process in NCS, which maintains the data delivery of the network with reduced energy consumption [4]. Also, it is mainly used to determine the relationships between the energy, timeliness, and degree of aggregation. Traditionally, the data aggregation protocols are classified into types, which includes structured and structured free. In the network initialization phase, the structured solutions use a tree based or cluster based structure in order to attain an efficient data gathering. It performs well in a constant environment, where the nodes are properly operated. But, in a real-worldsetting, the nodes could move or failed, so it required to compensate the construction and maintenance overhead. Also, it is highly critical to create an alarm in event driven application during serious situations, and it requires to take an appropriate action at that time. Moreover, it is important to provide a guarantee

A. *Problem Identification*

In an industrial WSN, the components that include sensors, actuators, and controllers are mainly used to monitor the conditions and current status of machines. So, the data aggregation is one of the demanding and crucial task in this environment. The network delay can occur, when the sensors, actuators, and controllers exchange the information across NCS. It reduces the overall performance of the control system by destabilizing it. Also, the controller does not have the ability to access the output updates at the time of control calculation. Moreover, the node failures and message collisions can drop the network packets. So, it is highly important to reduce the delay[5], and collision[6] in the NCS, because it affects the entire network. For this purpose, different control architectures and protocols are developed in the traditional networks[7]. In general, the SMITH controller is used in NCS, in which the input is manually provided to the actuator. Also, it is fully dependent on the circuit, and it works based on a static slot scheduling. Moreover, the same information can be repeated during communications, which leads to increased collision. To solve these issues, this paper aims to develop a controlling strategy for a NCS. Here, the traditional SMITH controller is replaced as a PI controller.

B. *Objectives*

The research objectives of this work are as follows:

- To increase the energy efficiency of the network by reducing the amount of transmitted information, the data aggregation is performed.
- To reduce the data propagation latency, the processes of data aggregation scheduling and optimal distribution of weighting time is accomplished.
- To attain an increased data accuracy, the number of nodes that participated in the aggregation process are increased.
- To ensure the data freshness, the data collected at same period are aggregated.
- To avoid collision, the optimal data path is selected and the scheduling based transmission is performed by the use of Time Division Multiple Access (TDMA).

C. Organization

The rest of the sections that structured in the paper are as follows: the existing techniques and protocols related to NCS are investigated with its advantages and disadvantages in Section II. Then, the detailed description about the proposed NCS architecture and its corresponding flow illustration are presented in Section III. The simulation results of the existing and proposed protocols are analyzed and compared in Section IV. At last, the paper is concluded and the future enhancement that can be implemented in the next work are stated in Section V.

II. RELATED WORKS

In this segment, the present architectures and protocols used in a NCS are surveyed with its advantages and disadvantages.

Ahmadi, et al [8] implemented a sliding mode observer for estimating the rotor speed and torque level of the network system. This paper mainly focused to reduce the cost function, and to stabilize the sensor failure. Here, the problem of bilinear matrix inequalities were solved by determining the parameters of optimal controller. Also, the delay and data packet dropout were estimated for investigating the robustness of the controller. The major tasks that involved in this paper were, measured data sending to PC, Pulse Width Modulation (PWM) generation, and sending PWM signal to the power board. However, this paper required to improve the overall efficiency of the network system. *Araujo, et al* [9] implemented a wireless control system architecture for improving the stability and minimizing the energy consumption of the network. In this paper, two simple solutions were suggested for compensating the power delay, which includes event triggered control, and self-triggered control. Here, the scheduling policies were implementation for three different communication systems, which includes event based communication, predictive communication, and hybrid communication. The advantage that observed from this paper was, it offered a reduced network latency and computational load. But, it failed to prove the effectiveness of the suggested system.

Han and Qiao [10]introduced a Self-Organizing Radial Basis Function Neural Network (SORBFNN) for solving multi-objective optimization problem. Also, a Non-linear Model Predictive Control (NMPC) for reducing the solution time of optimal control problems. Here, both the network structure and parameters were changed by using the SORBENN technique. This architecture contains three layers such as input layer, hidden layer, and output layer, in which the Relative Mutual Information (RMI) was used to analyze the connectivity of these layers. Moreover, the maximum number of iterations that required to reach the optimal solution were reduced by using the fast gradient technique. The drawback that observed from this paper was, it required to improve the performance of online tracking. *Banos, et al* [11] implemented a time-varying and Linear Parameter Varying (LPV) to maintain the stability of the control system with the use of network based reset control system. This work mainly focused to investigate the potentials of discrete time reset control systems with varying time delays. Here, the potentials of reset control was analyzed with the reference tracking during the simulation of closed loop step response. Still, this work required to reduce the delay at the sensor sampling period. *Zeng and Chow* [12]suggested a resilient control distribution algorithm for detecting the misbehaving agents in a Network Control System (NCS). It includes the following phases: detection, mitigation, identification, and update. The effectiveness of this mechanism was validated by analyzing the robustness and convergence of the network. However, this paper failed to analyze the success and failure conditions of the suggested technique under various network architectures. *Vollmer and Manic* [13] utilized the dynamic virtual honeypots for examining the network characteristics. This paper focused to manage the complexity of Dynamic Virtual Hosts (DHV) by creating and maintaining the self-updating model. The advantages of this work were as follows: reduced operator interaction, increased robustness, independent view of hosts and services. *Andreasson, et al* [14]designed a distributed Proportional Integral (PI) controller for networked dynamical systems. Here, a class of nonlinear consensus protocols were utilized, in which the equilibria was categorized for both first order and second order consensus. Also, a decentralized frequency controller was utilized to analyze the frequency of the system. During simulation, the authors used temperature control, and frequency control for evaluating the performance of the power system.

Lai and Hsu [15] suggested a Perfect Delay Compensation (PDC) technique for reducing the network-induced time delay. Here, the suitable sampling period of the networked control system was defined by considering the delay factor. Also, the robust and state feedback methods were considered in this network for reducing the effect of network load. However, this paper failed to prove the effectiveness of the overall networked control system, which was the major drawback that observed from this paper. *Pang and Zhou* [16]addressed the problem of data based network control system by reducing the delay and packet dropout. It includes three parts such as Parameter Estimator (PE), Network Delay Compensator (NDC), and Control Prediction Generator (CPG). Here, the closed loop stability was guaranteed and a zero steady state output tracking error was reduced by using the modified model free adaptive control algorithm. *Wu, et al* [17] implemented an Event Triggered Control (ETC) strategy for reducing the communication traffic in control networks.

The channels such as Sensor to Controller (S-C) and Controller to Actuator (C-A) were considered in this communication network. Also, the Linear Matrix Inequality (LMI) based stability analysis was performed to evaluate the effect of network induced delay. *Wu, et al* [18] implemented an enhanced control scheme for reducing the random time delay and packet dropouts by solving the stabilization problem. At the controller side, the series of control signals were generated by the use of integrated online database. In this paper, the smith predictor was utilized in the time delay systems for obtaining the knowledge of network conditions. However, this work required to improve the Quality of Service (QoS) of the networked control system.

Ojaghi and Rahani [19] designed a robust predictive load frequency control to attain the better performance in a closed loop system. Here, the frequency deviation was regularized with minimum control effect by solving the optimization problem. Also, this paper employed a Model Predictive Control (MPC) strategy for handling hard constraints, uncertainties, input and output disturbances. Moreover, the decentralized LFC was implemented to reduce both the storage and computational complexity in a large scale power system. *Sun and Zhao* [20] suggested a Networked Predictive Control (NPV) method for analyzing the stability of the network. The motive of this paper was to increase the efficiency of the network and to analyze the delay mismatch of networked control system. Here, the numerical illustration was provided to prove the effectiveness of the suggested system. *Hassan, et al* [21] suggested a predictive PI controller that is a kind of deadtime compensator implemented for a wireless networked control system. The motive of this paper was to handle an integrated processes with fewer tunable parameters. Based on the ratio of the time constant and system delay, the behavior of the predictor was determined in this paper. *Abdelzaher, et al* [22] constructed an analytical model for analyzing the relationships between the energy, timeliness, and degree of aggregation. The authors of this paper stated that reducing the delay, energy expenditure, and packet collisions was one of the critical task. Moreover, these measures were evaluated with respect to the traffic load. However, the suggested scheme was not highly efficient, which was the major drawback of this paper.

Mantri, et al [23] introduced a Sink Mobility and Nodes Heterogeneity Aware Cluster-based Data Aggregation Algorithm (MHCDA) for reducing the energy consumption and communication cost of WSN. Also, the spatial and temporal correlation between the packets were analyzed based on the additive and divisible aggregation functions. The drawback that obtained from this paper was, it failed to consider the parameters such as mobility and heterogeneity. *Yue, et al* [24]designed an event triggering mechanism for avoiding the effect of network transmission delay. In this scheme, the feedback gain and trigger parameters were estimated based on the LMI to analyze the stability of the network. But, this paper required to prove the effectiveness of the suggested technique by evaluating different performance measures.

From the study, it is investigated that the existing techniques have both advantages and disadvantages, but it mainly lacks with the following limitations:

- Increased delay or latency
- Inefficient packet transmission
- Reduced Quality of Service (QoS)

To solve these problems, this paper aims to develop a new aggregation protocols for identifying the current status and conditions of the machineries.

III. PROPOSED METHOD

In this sector, the clear description about the proposed data aggregation protocol is presented with the detailed flow representation. This paper motives to reduce the delay of NCS, when disseminating the packet to the base station. Also, it focuses to improve the energy efficiency, reduce the propagation delay, increase the data accuracy, avoid the collisions, and ensure the aggregate freshness. For this purpose, the Closed Loop Industrial Wireless Sensor and Actuator Network (CLI-WSAN) architecture is introduced in this paper. Also, the Markovian Decision Process (MDP) is utilized to perform the data aggregation, routing, opportunistic transmission, and relay selection. The architecture of the proposed NCS is shown in Fig 1, and its flow representation is depicted in Fig 2.

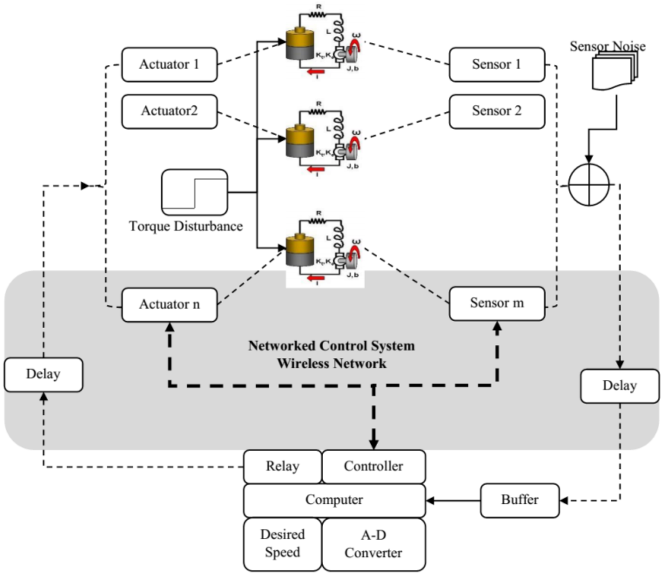

Fig 1. Architecture of the CLI-WSAN

As shown in Fig 2, the network is created at first with grid structured sensor nodes, then the grid is split into clusters based on its corner.

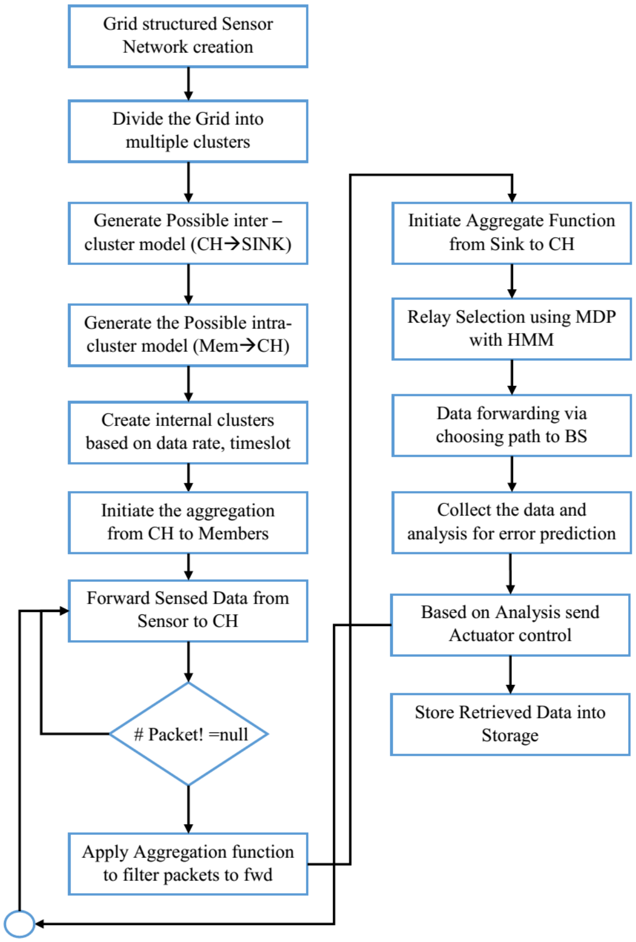

Fig 2. Flow of the proposed system

After that, the inter-cluster model (i.e. Cluster Head → Sink) and the intra-cluster model (i.e. Member → Cluster Head) are generated, in which the internal clusters are formed based on the parameters of data rate and time slot. Sequentially, the data aggregation is initialized from CH → members, and the sensed data is forwarded from the sensor to the CH. If the packet is not empty, the aggregation function is applied to filter the forwarded packets for further processing. Again, the aggregation function is initiated from the sink node to the CH, then the MDP with Hidden Markov Model (HMM) is applied to select the relays for forwarding the data through the base station. During this process, the data are collected and analyzed for predicting the errors, if it is error free, the data is forwarded to the actuator. Finally, the retrieved data is stored into the storage server.

A. Data Aggregation Protocol

The induced delay in NCS affects the entire performance of the network, so it must be reduced for a better communication. For this purpose, the data aggregation is used in this work, which helps to reduce the medium access contention as well as the number of transmitted packets. Here, the centroid based clustering is performed, and the connection between the cluster head and sink nodes are established by using the two tier aggregator model. Then, the error packets are removed at the aggregation level for providing the error free data. The independent data forwarding allowed in this network by placing the dedicated nodes for aggregation. When multiple hosts aim to access a common router, the congestion can be occurred on a shared network. So, the HMM is used to select the multiple CHs for avoiding the collision in the network. Moreover, the proposed data aggregation protocol considers the following objectives for reducing the delay of the network:energy efficiency, data propagation latency, data accuracy, aggregation freshness, and collision avoidance. Typically, the wireless networks suffer due to the energy consumption of the nodes, and energy resource limitation. So, the aggregation protocol is used to save the energy by reducing the number transmitted packets. Also, the data aggregation scheduling synchronizes the communication between the nodes, which leads to reduced time consumption. Then, the data propagation latency is also considered as an important factor in the applications of security surveillance, and real time target tracking. Here, the data aggregation protocol ensures the network scalability by gathering the data from different number of nodes based on the frame length. Also, it reduces the weighting time at each node for minimizing the data propagation latency. By using this protocol, there is no need to reduce the amount of nodes in the network, which reduces only the amount of data transmission for ensuring an increased data accuracy. The data collected at the same period are aggregated together, which ensures the aggregation freshness. The collision of the network is avoided by selecting the best optimal path for communication, which is done by the aggregation protocol.

Here, the node begins with the time based aggregation phase, which contains m number of data samples such as $x_1, x_2 \dots x_m$. It is gathered in the time period of $[t_1, t_m]$, which are aggregated into a portion of data X. Formerly, the node$p$ reports the aggregated data X_p to the cluster head. It is illustrated as follows:

$$X = \beta_0 + \beta_1 \frac{t_1+t_m}{2} \tag{1}$$

Where, X is the piece of data, β_0 and β_1 are the coefficients of regression, $t_1 and\ t_m$ is the time period. After that, the cluster head takes control of the aggregation, where the$k$ pieces of data i.e. $X_p(1), X_p(2), \dots X_p(k)$ are received from the cluster member p = 1, 2, … n. Then, the cluster head aggregates that data into the piece of $\overline{X_p}(k)$ based on the following equations:

$$\overline{X_p}(k) = \frac{1}{k}\sum_{i=1}^{k} X_p(i)\,, p = 1,2 \dots n \tag{2}$$

$$\begin{aligned}\overline{X_p}(k) &= \frac{1}{k}\sum_{i=1}^{k} X_p(i) \\ &= \frac{k-1}{k}\overline{X_p}(k-1) + \frac{1}{k}X_p(k), p = 1,2,\dots n\end{aligned} \tag{3}$$

Then, the cluster head computes the correlation coefficients of $X_p$and $X_q$are computed as follows:

$$R_{pp} = \frac{1}{k}\sum_{i=1}^{k} X_p(i)X_p(i) \tag{4}$$

$$R_{pq} = \frac{k-1}{k}R_{pq}(k-1) + \frac{1}{k}X_p(k)X_q(k) \tag{5}$$

Where, R_{pp} is the correlation coefficient of X_p, and R_{pq} is the correlation coefficient of X_q. Subsequently, the cluster head estimates the mean square deviation σ_p^2 for each sensor in the network based on the following equation:

$$\sigma_p^2 = R_{pp} - R_{pq}, p = 1,2 \dots n \tag{6}$$

At last, based on the optimal weights W_1, W_2, .. W_n, the cluster head aggregates the n pieces of data $\bar{X}_1(k), \bar{X}_2(k) \dots \bar{X}_n(k)$into $\bar{X}^w$ with the minimum mean square deviation $\bar{\sigma}_{min}^2$, which is illustrated in the following equation:

$$\bar{X}^w = \sum_{p=1}^{n} W_p \bar{X}_p(k), \sum_{p=1}^{n} W_p = 1 \tag{7}$$

Moreover, the cluster head compress the data by using the proposed data aggregation algorithm before reporting it into the base station.

B. Controller Design

The MDP is a kind of optimization technique that is mainly used to efficiently improves the entire QoS of the network by concentrating the followings:

- Data aggregation and routing
- Opportunistic transmission strategy
- Relay selection

In this work, the traditional Smith controller is replaced as a PI controller, which eliminates the time delay based on the equation of the closed loop system. It has the ability to handle an unstable and integrated processes. Here, the predefined scheduling is performed as follows:

$$\dot{\omega}(t) = \frac{1}{\Re(t)} - \frac{\omega(t)\omega(t-\Re(t))}{2\Re(t-\Re(t))} p(t - \Re(t)) \tag{8}$$

$$\dot{q}(t) = \frac{\omega(t)}{\Re(t)} \mathrm{I}(t) - C \tag{9}$$

Where, $\dot{\omega}(t)$ and $\dot{q}(t)$ indicates the time variant of $\omega(t)$ and $q(t)$, $\omega(t)$ denotes the expected top packet size, $q(t)$ is the expected packet length in queue, C defines the link capacity, I is the load factor that depends on the number of TCP rounds, p defines the probability of packet dropping, $\Re$ is a round trip time (i.e. $q(t)/C + d_p$, d_p is the propagation delay). Based on these equations, the transfer function of TCP flow obtained from the linearization of equation (1) and (2) is shown in below:

$$f(s) = f_{tcp}(s) f_q(s) = \frac{C^2/2\mathrm{I}}{(s+2\mathrm{I}/\mathrm{C}\Re^2)(s+1/\Re)} \tag{10}$$

$$F(s) = f(s)e^{-\Re s} = \frac{Ke^{-\Re s}}{(T_1 s+1)(T_2 s+1)} \tag{11}$$

Where, $K = \frac{(\Re C)^3}{4\mathrm{I}^2}$,$T_1 = \frac{\Re^2 C}{2\mathrm{I}}$ $and\ T_2 = \Re$, K_1 is defined as a steady state gain, T_1 and T_2 are the time coefficients.In this structure, the traditional smith controller is modified with the followings: ProgrammableController (PC) (f_c), feedback controllers (f_{c1} and f_{c2}), which is proportionalorproportional-derivative type. Here, f_{c1} hasthe keypart in alleviating anunstableor integrating system, and f_{c2} is employed to avoid the disturbances. If $f_{c1} = f_{c2} = 0$ the traditional smith controller is obtained. The setpointanddisturbanceare given as follows:

$$Y(s) = Y_r(s)\Re(s) + Y_L(s)L(s) \tag{12}$$

Where, $Y_r(s) = \frac{f f_c e^{-\Re s}}{1+f(f_c+f_{c+1})}$

$$Y_L(s) = \frac{f e^{-\Re s}}{1+f(f_c+f_{c+1})} \frac{1+f(f_c+f_{c1})-f f_c e^{-\Re s}}{1+f f_{c2} e^{-\Re s}} \tag{13}$$

These equations are used to incorporate the PC controller with the MAC scheduler based on the load response from the set point.

IV. PERFORMANCE ANALYSIS

In this sector, the simulation results of the existing and proposed techniques are evaluated by using different performance measures such as power consumption, average delay, success probability, throughput, and reliability. Moreover, the superiority of the proposed technique is proved by comparing it with the existing Slotted Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA), IEEE 802.15.4, Dynamic Properties (DP) & Dynamic Duty Cycle (DDC) techniques.

A. Power Consumption

It is defined as the amount of power consumed by all the nodes in the network for transmitting the data with respect to varying loads.Then, the load contributed within the network is the average load that implicitly added in the MAC layer. The power consumption of the network is estimated as follows:

$$Power\ Consumption = \frac{E_{avg}}{P_s C} \tag{14}$$

The graphical illustration of this analysis is illustrated in Fig 3, where the power consumption is analyzed in terms of micro joules/bits. Among the existing methods, the DP & DDC provides the minimum amount of power consumption of 1.95$\mu j/bit$ at the probability of load 0.8, which follows the slot based route discovery for forwarding the data packets.When compared to this technique, the proposed CLI-WSAN effectively reduces the power consumption to 1.89 $\mu j/bit$ for the load probability of 0.8. The comparison between these techniques clearly exposes the effectiveness of the proposed method.

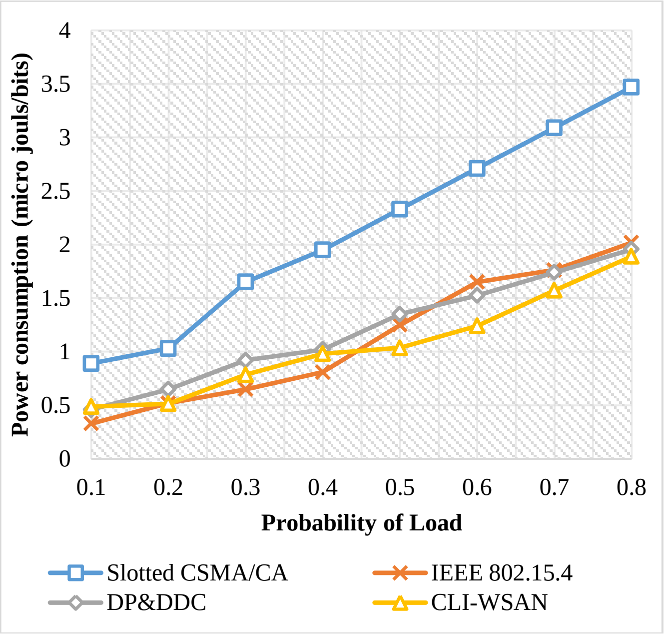

Fig 3. Power consumption

B. Average Delay

The data transfer between the controller and sink node can induce the delay,which must be reduced for a reliable communication.

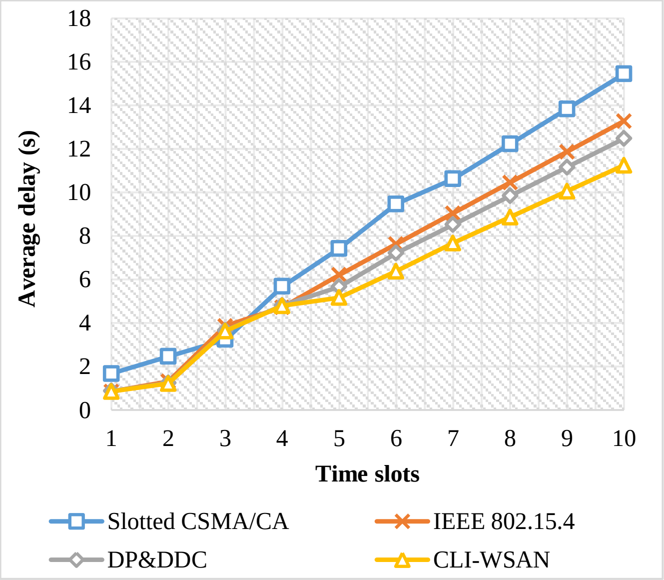

Fig 4. Average delay

The average delay is defined as the required amount of time that a system holds a packet in the network. Fig 4 shows the latency of existing and proposed techniques with respect to different time slots ranged from 1 to 10. In this analysis, it is proved that the delay of NCS is efficiently reduced, when compared to the existing approaches. Because, during data transmission, the relay selection is performed by the use of HMM and MDP.

C. Success Probability

The measure of success probability P_s accomplished typically replicates the total number of successful transmissions realized within the network with respect to the load offered from the MAC layer of the network. The mathematical formulation is derived as,

$$P_s = {}^{T}/_{L_{mac}} \qquad (15)$$

The success probability rate gets linearly decreased as the load increases in a corresponding manner within the network. Though, the exposed success probability is higher than other prevailing methodologies by 8%. Fig. 5 illustrates the success probability inferred with respect to the load offered in comparison with other prevailing methodologies.

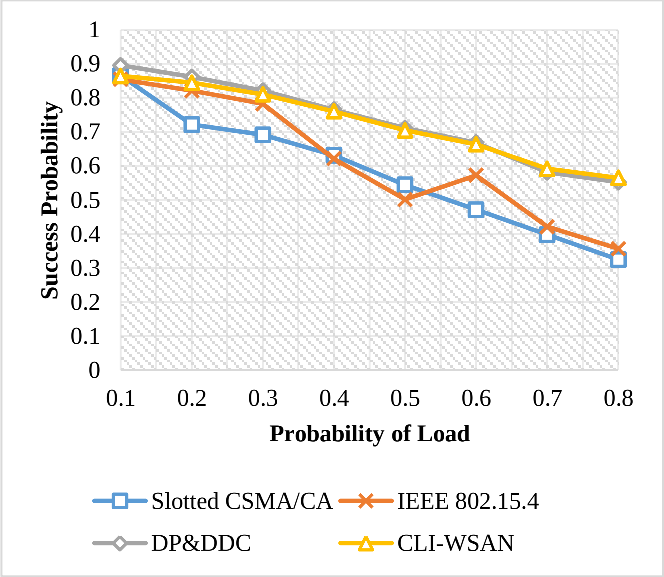

Fig 5. Success probability

D. Throughput

The throughput is the positive rate of data delivery over the secure routing medium. Fig 6 shows the analysis of throughput for both existing and proposed methods with respect to varying simulation time ranges from 10ms to 100ms. In this evaluation, it is proved that the proposed CLI-WSAN technique provides an increased throughput, when compared to the other techniques. Because, the MDP takes an optimal routing decision for improving the QoS of the network. Moreover, both the medium access contention and the number of transmitted packets are minimized by the use of MDP, which leads to increased throughput. It is estimated as follows:

$$Throughput = \frac{Number\ of\ data\ packets\ recceived\ (bits)}{Simulation\ time\ period\ (secs)} \qquad (16)$$

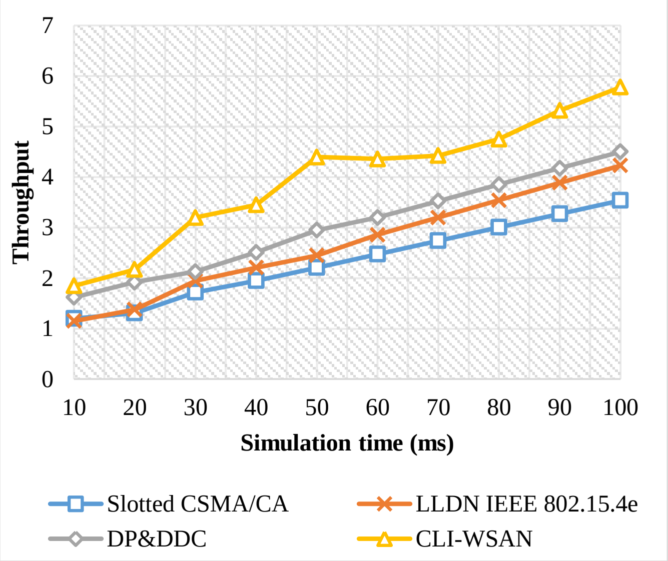

Fig 6. Throughput

E. *Reliability*

Fig 7 illustrates the reliability analysis of the existing and proposed methods with respect to varying number of nodes. The reliability of the network is measured based on the packet length realized for being transmitted from the sink node to CH. The reliability of the proposed methodology is maintained in a constant level for the increasing number of nodes that persistently added into the network. But, the existing methods such as LLDN IEEE 802.15.4 and DP & DDC are also maintained the reliability in a constant level with slight deviation, and the slotted CSMA/CA has the reduced reliability compared than the other techniques.

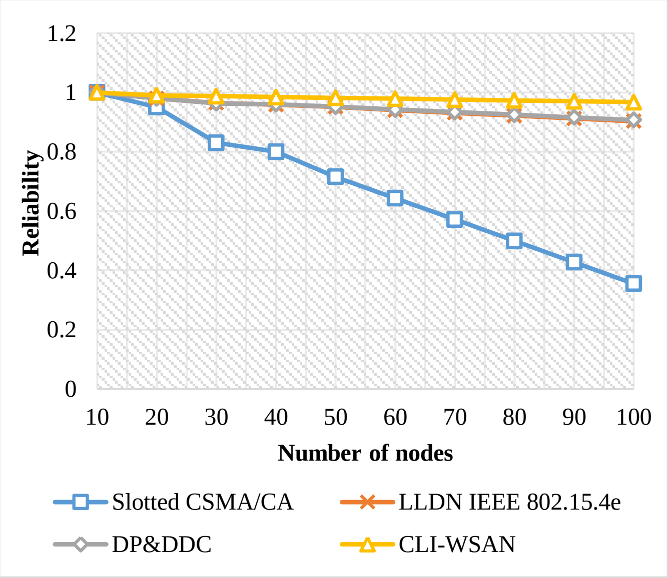

Fig 7. Reliability

F. *Control Signal*

The control signal that generated by the existing and proposed controllers with respect to varying time are illustrated in Fig 8. The controllers that considered in this analysis are Programmable Peripheral Interface (PPI), Proportional Integral Derivative (PID) and proposed PC, in which the PPI is adopted for NCS that is characterized based on the network induced delay and dead time. This controller has the ability to handle the integrated processes with few tunable parameters. Then, PID is the most commonly used controller in an industrial applications, which is mainly used to reduce the design complexity. When compared to these controllers, the PC controller that used in the proposed system efficiently generates the control signal with respect to varying time.

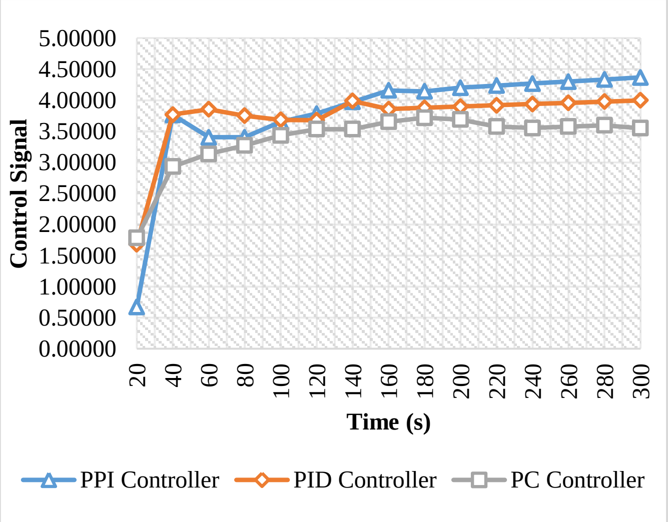

Fig 8. Control signal

V. CONCLUSION AND FUTURE WORK

Here, a new framework, namely, CLI-WSAN is designed for ensuring the better QoS in NCS. The motive of this paper is to reduce the latency and to improve the energy efficiency of the network by performing the data aggregation process. For this purpose, the number of transmitted packets and the medium access contention are reduced in order to provide a better communication. The QoS of the network is improved in this work by considering the factors of relay selection, opportunistic transmission strategy, and data aggregation. In this environment, the error free packets are forwarded by eliminating the error packets at the aggregation level. Also, the multiple CHs are selected by using the HMM for avoiding the collisions in the network. The parameters that considered in the proposed data aggregation are propagation latency, accuracy, data freshness, energy efficiency, and collision avoidance. Moreover, in this work, the traditional smith controller is replaced as the PI controller. The simulation results of both existing and proposed systems are evaluated and compared based on the measures of PDR, throughput, reliability, control signal, success probability, delay, and power consumption. From the analysis, it is proved that the proposed CLI-WSAN provides the better results, when compared to the other techniques by reducing the amount of packet transmission.

In future, this work can be enhanced by designing a new controller circuitfor a real time application in order to verify the delay of a system.

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