Event-Triggered Sliding Mode Controller for Cognitive Internet of Things

Abhijit Biswas, Subhrajyoti Deb, Nirmalya Kar, Joy Lal Sarkar, and Ayan Mondal

***Abstract*—Cognitive Radio (CR)-based solutions have been suitable for efficient spectrum sharing among the unlicensed and licensed Internet of Things (IoT). Consequently, keeping a careful balance among several priority class users ensures that network congestion is avoided. In order to regulate data transmission and interconnectivity among various IoT devices, this paper proposes an event-triggered sliding mode controller for congestion maintenance, abbreviated as ETSMCC. The suggested controller improves the disturbance rejection capabilities and robustness in an IoT protocol stack for cognitive networks. Using this method, unscrupulous spectrum sharing and efficient congestion control is achieved. Our approach reduces energy expenditures and computational difficulties in the IoT protocol stack. ETSMCC with IoT protocol stack achieves an average distortion rate of 0.009%, throughput of 256 Kbps, 23% packet loss, delay with 0.32 ms and packet delivery ratio of 7.21%. ETSMCC performs better than state-of-the-art schemes, such as context-aware congestion control (CACC) and dynamic, driven congestion control (DDCC).**

***Index Terms*—IoT, IoT protocol stack, cognitive networks, event triggered sliding mode controller, congestion maintenance, network congestion.**

I. INTRODUCTION

The layer 2 of the Internet of Things (IoT) protocol stack faces key challenges such as heterogeneous characteristics of devices, traffic patterns, and access patterns, as well as issues related to scalability [1], [2]. Within this context, IoT covers a broad spectrum with full capability that calculates nodes for highly constrained devices. Additionally, the availability of energy resources is restricted for carrying out processing and communication tasks [3]. Various initiatives have been undertaken to optimize protocols at each protocol stack layer to reduce energy consumption [4]. The link layer is significantly influenced by physical transmission variations, retransmissions, and the Media Access Protocol (MAC) [5]. A substantial amount of energy is sent to repair the transmission lost by the MAC layer. Recently, the channel access characteristics of IoT have evolved, leaving a mark on network expansion beyond conventional boundaries through the introduction of new protocol stacks. The structured approach of wide area network (WAN) and local area network (LAN) is predominantly utilized for implementing new environments like industrial flooring, oil fields, marine platforms, mines, wells, power grids, vehicles, locomotives, and even the human body. The scalability of IoT technologies in wireless contexts presents intriguing challenges for the link layer of the protocol stack [6].

An inefficiency in spectrum utilization exists, attributed to the growing prevalence of wireless communication, leading to the development of various approaches to spectrum access. Cognitive Radio (CR) represents an effective method of spectrum utilization, leveraging available bands more efficiently than traditional spectrum assignment techniques [7]. The algorithms for managing congestion are adjusted dynamically based on licensed user activity, considering the fluctuating network's capacity to handle multiple packet transmissions. If a higher number of packets are communicated above the network's capacity, congestion will occur, leading to ineffective utilization of limited resources. Therefore, it needs a new mechanism to avoid congestion, including network capacity improvement and licensed user activity [8]. Moreover, proper spectrum allocation plays a crucial role in congestion avoidance, underscoring its significance. For the opportunistic utilization of the spectrum, the reliability requirements should be needed [9]. Among the recent challenges of communication networks, congestion control in cognitive radio is considered an integral part [10]. Therefore, developing congestion control mechanisms that ensure efficient spectrum utilization is essential [11], [12]. Strategies for designing these mechanisms encounter difficulties due to shared spectrum utilization, which complicates network structures with dynamic parameters and functions [13].

Sliding mode control (SMC) is a robust control method that ensures system stability and performance in the presence of disturbances. SMC operates by driving the system's state trajectory towards a predefined sliding surface and maintaining it on this surface despite external disturbances. This is achieved through a high-frequency switching control law, which effectively rejects disturbances and uncertainties. In the context of IoT networks, SMC is particularly useful for handling dynamic and unpredictable network conditions. The robustness of SMC ensures that the system can maintain desired performance levels even in the face of varying traffic loads and device behaviours. Event-triggered control mechanisms aim to reduce computational overhead by updating control actions only when specific events occur rather than at fixed time intervals. This approach minimizes unnecessary control updates, conserving energy and computational resources.

In a cognitive radio system, the congestion control mechanism is important in the present communication system. The

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congestion control mechanism should be efficiently and effectively designed for resource allocation. The intricate nature of network structures, parameters, and services adds complexity to the design process of congestion control mechanisms [14]. The modern communication network is evolving with dynamic models to support the advancement of congestion control strategies in cognitive radio networks, enhancing spectrum utilization and network performance within the IoT protocol stack. The congestion management approach within the IoT protocol stack incorporates the use of Cognitive Routing Protocol (CORPL) as a network layer protocol, complemented by a novel event-triggered sliding mode controller to facilitate CR applications. Cutting-edge congestion control techniques such as Context-aware congestion control (CACC) and Dynamic driven congestion control (DDCC) are utilized for comparative evaluation.

In order to enhance the efficacy of traffic congestion management mechanisms within IoT protocol stacks of Cognitive Radio Networks (CRNs), the Event Triggered Sliding Mode Congestion Control (ETSMCC) with IoT has been devised. The proposed method provides efficient broadcasting, reliable communication, and interoperability in IoT applications. In ETSMCC, the event-triggered mechanism is integrated into the sliding mode controller to enhance efficiency further. The control actions are triggered based on deviations from desired network conditions, such as congestion levels. By dynamically adjusting control parameters only when needed and minimizing unnecessary control updates, ETSMCC maintains robust performance while minimizing energy consumption and computational load. The technique conserves energy and extends the operational lifespan of battery-powered IoT devices. The computational efficiency of ETSMCC ensures that it can be deployed in large-scale IoT networks without causing performance bottlenecks. A comparative analysis of the performance of this proposed method against existing congestion control strategies such as CACC and DDCC has been conducted.

ETSMCC is designed to be implemented on standard IoT hardware, including resource-constrained devices. ETSMCC is compatible with existing IoT protocols such as MQTT, CoAP, and TCP/IP. This compatibility ensures seamless integration into current IoT infrastructures, allowing for easy deployment and interoperability with other IoT systems. The model's design considers the layered structure of the IoT protocol stack, ensuring that it can be implemented without significant modifications to existing protocols. The control algorithms are optimized to run efficiently, ensuring they do not impose substantial computational demands on the devices. The proposed algorithm makes ETSMCC suitable for a wide range of IoT applications, from simple sensors to more complex devices.

Rest of the paper is organized as follows: Section II outlines the related works, Section III delves into the system model and its control strategies, Section IV presents the results and discussions, and finally, Section V offers the conclusion and outlines directions for future research.

II. RELATED WORKS

The issues in the congestion control mechanism for CRN was presented in [13]. A method named MAQ was introduced based on multiple model predictive control (MMPC) within an active queue management (AQM) algorithm. The primary goal of this approach is to stabilize the TCP queue at the base station (BS) in the presence of disturbances caused by secondary users with varying time service capacity. The approach of MAQ was tested with widespread simulation experiments under several circumstances of background traffic and the configurations of the system/network. Mitra et. al.[15] have proposed an Emotional Intelligent Terminal Sliding Mode Controller (EITSMC) developed to enhance robustness in nonlinear systems with unknown disturbances. Combining fast terminal sliding mode control (FTSMC) with an adaptive, model-free framework improves system performance, reduces dependency on prior knowledge, and demonstrates superior control in simulations and experiments. In [16], authors have conducted a study that addresses state estimation and tracking control for nonlinear systems under adversarial sensor manipulation. It proposes an event-triggered data strategy, a continuous-discrete observer, and a backstepping-based tracking controller validated through rigid aircraft simulation to enhance state-tracking resilience and efficiency. In another article [17], the authors have addressed frequency deviation in microgrids by combining a sliding mode controller (SMC) and integral controller optimized with linear matrix inequality (LMI) and particle swarm optimization (PSO). The proposed microgrid, powered by renewables and hybrid storage, achieves robustness against disturbances and load variations. In [18], authors have explored consensus tracking for second-order multi-agent systems affected by channel fading. An event-triggered sliding mode controller reduces network load by incorporating channel fading into error measurements. Theoretical analysis confirms system reachability, stability, and avoidance of Zeno behaviour, with simulation results validating the approach.

In [19], an event-triggered sliding mode approach for Cognitive Radio Networks incorporating a nonlinear congestion controller was proposed. It aimed to obtain the favourite QoS of the system possessing optimal bandwidth allocation and resource utilization. The sampled signal is controlled and updated by the predefined condition, which is violated to ensure the system's closed-loop behaviour, which is an acceptable range. Discrete-Time Markov Chain (DTMC) was used for modelling Secondary User Blocking Loss (SBL) was presented in [20]. Furthermore, a novel congestion control mechanism called T-CRSN was introduced, distinguishing packet losses caused by congestion from those due to primary user activities. Experimental evaluation using COGNS and simulation within the NS2 framework for CRN showcased the superior performance of this method compared to existing approaches. Another innovative method, End-To-End Congestion Control (ECCO), was presented in [21], focusing on multi-hop CR in ad hoc networks with unique features such as channel rendezvous, spectrum sensing, and interactions with licensed users. A comprehensive analysis of round trip time for average packet transmission in multi-hop CR ad hoc networks was conducted, demonstrating the improved performance of this method over state-of-the-art techniques in terms of system throughput. Three different robust congestion control strategies were introduced in [22] to effectively utilize spectrum resources in CRNs, enhancing system resilience and disturbance rejection by implementing a sliding mode controller. This method decreases energy utilization costs and execution complexities. Various simulation experiments supported the adequacy of the controller. The Dynamic-driven congestion control and segment re-routing (DD-CCSR) method presented in [23] aims to mitigate flow and signal congestion rates while improving monitoring and path adjustment processes. Through the implementation of the Deleroi Superimposed method, segment rerouting, and forward-backwards interface method, the IMS Core platform was configured, which is used to examine the quality metrics like rate of throughput and delay of transmission. The method minimizes transmission and signalling congestion rates to meet the demands of the media zone. The signalling traffic and the rate of congestion are probed and considered to be two principles of superposition that were derived for minimizing the rate of transmission and signalling congestion for achieving the media zone demands. In the topology of the dense network and sparse network, IoT protocol stack was utilized in [24] that incorporated the protocol of application layer and transport layer like MQTT (Message Queuing Telemetry Transport), CoAP (Constrained Application Protocol), UDP (User Datagram Protocol) and TCP (Transmission Control Protocol) respectively. RPL protocol was utilized for analyzing the transport layer. Z1 motes and Sky motes were used for the analysis of the physical layer. Performance metrics like radio responsibility cycle, power intake, and average inter-packet arrival time evaluated the protocol stack. Another study [25] compared IoT protocols for data transfer in constrained networks, highlighting the challenges of establishing networks with numerous physically interconnected IoT devices. Effective support for machine-to-machine (M2M) communication was demonstrated in constrained IoT networks, emphasizing the difficulty in selecting appropriate protocols for IoT applications, ultimately utilizing CoAP and MQTT for optimal outcomes. A novel approach involving lightweight CoAP/UDP with Context-aware congestion control (CACC) was presented in another study [26], addressing IoT traffic dependencies. The literature on cognitive Internet of Things (IoT) and sliding mode control demonstrates a broad range of applications and security considerations. Nair and Nair [27] discuss the essential security aspects within the IoT protocol stack, highlighting potential vulnerabilities and mitigation strategies. Alghazzawi et al. [28] focus on congestion control in cognitive IoT-based wireless sensor networks (WSNs) for smart agriculture, proposing efficient solutions to manage data traffic. Majumder et al. [29] explore cognitive radio-based resource management for smart transportation, utilizing a sliding mode control approach to enhance system reliability and efficiency. In the domain of robotic manipulators, Saeedi et al. [30] present a resilient event-triggered terminal sliding mode control design, emphasizing its robustness against disturbances. Ma and Wang [31] introduce an adaptive type-2 fuzzy sliding mode control for steer-by-wire systems, integrating event-triggered communication to optimize performance. Additionally, Miglani and Kumar [32] investigate a blockchain-based matching game for content sharing in content-centric vehicle-to-grid network scenarios, while their systematic review [33] addresses blockchain management and machine learning adaptation for IoT environments in 5G and beyond networks, underscoring the synergy between advanced technologies and modern communication frameworks. The updates of the controller were based on a periodic sampled data system. These are the main reasons for increased complexities and energy expenses. The adequacy of the controller is also not maintained according to a threshold value in the existing system. This paper proposes this method, ETSMCC, to rectify these problems.

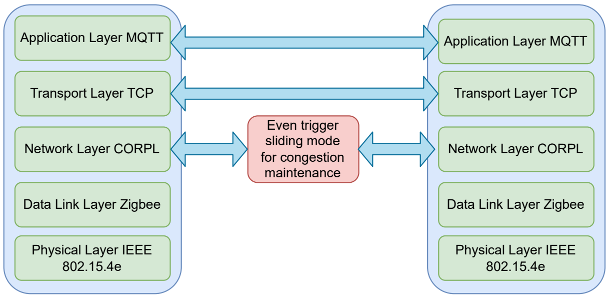

Fig. 1. Block diagram of different Events triggered in sliding mode for congestion control with the IoT protocol Stack

III. System Model

The proposed method of the Event Triggered Sliding Mode for Congestion Control (ETSMCC) with the IoT protocol Stack perspective is described in Fig. 1 as follows, and algorithm 1 gives the details of the proposed algorithm.

A. Methodology

1) IoT protocol stack: The protocol stack of IoT has fully confirmed the effectiveness of wireless networks. The application layer of the protocol stack presented in the literature is used to connect things and IETFs CoAP, IBMs MQTT, XMPP, and AMQP applications of the end-user to the internet. The protocols of the transport layer are UDP and TCP. The network routing protocol usually considered are IPv6, ROLL RPL, and 6LoWPAN with encapsulating facilities. The standard data link layer protocols are BLE, Z-Wave, ZigBee, Home Plug GP, and Dash7 for a shorter range of wireless communications with lower power consumption. Recent IEEE 802.15.4-2006 PHY layers are used from the perspective of the physical layer, and its improvement develops the efficiency of energy.

This research uses the Message Queue Telemetry Protocol (MQTT) protocol as the application layer protocol. Efficient communication will be ensured to provide services by the IoT application layer with reduced cost and power for the resource-constrained IoT devices. Applicability, QoS, security, flexibility, and responsiveness are important for the IoT application layer when deploying IoT applications. MQTT is necessary to establish communication in remote/cloud places. For lightweight-constrained communication, highly utilized protocols are CoAP and MQTT. In order to achieve the highest efficiency of battery-run devices, MQTT is the best protocol. Dial-up connections, satellite links, and mobile communication with a shorter range are some of the application scenarios of MQTT. The transmission is processed with data packets, reliability, compact size, and less power consumption. The utilization of the MQTT protocol has decreased the network's bandwidth; this protocol is a real-time data transfer protocol. In this protocol stack, TCP is used to control transmission. Cognitive Routing Protocol (CORPL) has been used as a network layer protocol with the event-triggered sliding mode controller as a novel modification and allows CR applications.

Two key steps are introduced for the development of the forwarding approach to address challenges in the Cognitive radio. The first step involves forwarder set selection, where every node in the network chooses multiple next-hop neighbors, and the second step employs a coordination approach to ensure optimal packet reception (exclusive forwarder selection). This forwarding approach enhances end-to-end reliability and network throughput. Subsequently, the focus shifts to lossy networks, with forwarder set selection posing a significant challenge.

In CORPL, each node maintains a forwarder set for opportunistic selection of forwarding nodes (next hops). The forwarder set creation is enlarged later. CORPL uses the approach of the cost function for the dynamic prioritization of forwarder set nodes. CORPL will take the opportunistic approach of forwarding set to support high- priority delay-sensitive alarms, which is essential for gateway arrival previous to the deadline provided, and also, the paths are selected with lower interference to PU receivers. The protection of the PU transmitter is assured by the optimal transmission time of the secondary network subjected to interference restraint. The spectrum does not sense the re- ceive/forward packets because of the engagement of nodes. Thus, the performance of the network is degraded as per end-to-end throughput, delay, and packet loss ratio. The sensing spectrum of various nodes improved the overall performance of the network.

The data link layer protocol known as ZigBee has been used for communication in long-range. Reliable and secured LAN connectivity, automated homes, MAC, and PHY layer coverage are provided by Home Plug GP. The operating band and data rate are 2.4GHz ISM and 250Kbps, respectively. From the perspective of the PHY layer, IEEE 802.15.4-2006 PHY layers and their improvement suit concerning the efficiency of energy.

2) Event triggered sliding mode for Congestion Control: The Primary Users (PU) and Secondary Users (SU) of the source possess their respective equipment buffer the user for storing their data packets. These data packets are transferred by CORPL protocol in the network layer of the protocol stack. The forwarded set was selected, node j is considered as the forwarded set, and the receiver is considered as node i. Multiple forwarding scenarios for primary users (i) and secondary users (j) are considered. The channel considered for this work is a band-limited Gaussian channel having fixed maximum capacity (C_{max}). The capacity of the channel varies between the transmission of data packets. PU transmits data packets over the channel assigned with no hindrance, while a secondary user will pursue the availability of spectrum. The dedicated channel's utilization to prioritize PU class that changes from minimum to maximum values based on the incoming data packet's rate of arrival. The capacity of the channel remained for secondary users undergoing fluctuation prejudiced by the arrival rate of PU. The channel sharing amongst various priority class users enhances the spectrum's efficiency and requires strict monitoring to avoid the network's congestion. The network's congestion will happen at the transmitting node, intermediate stage, or in the reception node. The technique for controlling congestion is known as Sliding Mode Control (SMC). The designing method of SMC comprises two steps; the function of suitable switching function was designed to provide desired performance, and it is limited. A switching control at high frequency is utilized in the establishment of traditional SMC to restrict the system. Practically, the higher frequency switching control produces congestion that causes instability in the system. Communication is going to be established between the primary users and secondary users. To establish the reliable transferring of data packets and resource allocation, three basic conditions; are explained as follows: The surface variable with the tunable controller gain is needed for the sliding controller to achieve a good performance; it is given as follows:

$$\sigma(t) = -Gsign[\sigma(t)] \tag{1}$$

Where surface variable is explained as $\sigma(t)$ and G is gain of tunable controller. The initial time is considered to be zero, so the obtained reaching time is given as follows:

$$t_r = \frac{\sigma(0)}{G} \tag{2}$$

If the tunable gain increases, then the Eq. 1 is change into Eq. 3 as follows:

$$\sigma(t) = -G_i sign[\sigma(t)] - G_j\sigma(t) \tag{3}$$

$G_j\sigma(t)$ increases the convergence rate for relatively large value of $\sigma(t)$. The reaching time will be represented as follows:

$$t_r = \frac{1}{G_j}[ln\frac{G_i + G_j|\sigma(0)|}{G_j}] \tag{4}$$

The reaching speed and convergence speed are necessary for achieving a sliding manifold. The high reaching speed expresses as it is farther from the manifold of switching, and the lowest speed of reaching as the state is closer to the manifold. The exponent component $alpha$ decides the convergence speed, this changes the reaching time, and it is expressed as follows:

$$t_r = \frac{1}{G_j}[\frac{\sigma(0)^{1-\alpha}}{1-\alpha}] \tag{5}$$

Then the power rate is expresses in equation (6) as follows

$$\sigma(t) = -G_j|\sigma(t)|^{\alpha} sign[\sigma(t)] \tag{6}$$

3) Primary User services: The congestion control goal for PU is to track the desired queue length by allocating the highest accessible capacity animatedly, for keeping the variable the coefficient weights as $\lambda_i(t)$. Where i is taken as the primary user. From the control theory of sliding mode [19], $\sigma_i(t)$ is considered as, surface variable with respect to the error variable described as $e_i(t) = x_i(t) - x_{iref}(t)$ is given as follows:

$$\sigma_i(t) = e_i(t) = -K_i(t)\frac{(x_i(t))}{(1 + x_i(t))} + \lambda_i(t) - x_{iref}(t) \quad (7)$$

The controller design has been formulated as follows:

$$K_i(t) = \frac{1 + x_i(t)}{(x_i(t)}[\lambda_i(t) + G_j(t)|\sigma_i(t)|^{\alpha} sign\{\sigma_i(t)\} - x_{iref}(t) \quad (8)$$

Where $x_{iref}(t)$ is the operator's reference value selected.

4) Secondary User Services: The aim of controlling congestion for SU is used for maintaining the queue length reference through the flow of data regulation into the network depending on the channel's residual capacity. Where j is taken as the secondary user. The control signal is provided as $\lambda_j(t)$ and it is expressed as follows:

$$\sigma_j(t) = e_j(t) = K_j(t)\frac{x_j(t)}{1 + x_j(t)} + \lambda_j(t) - x_{jref}(t) \quad (9)$$

The coefficient weights for the secondary user is established as follows:

$$\lambda_j(t) = K_j(t)\frac{x_j(t)}{1 + x_j(t)} - Gsign\{\sigma_j(t)\} + x_{jref}(t) \quad (10)$$

5) Dynamic event triggered sliding modes: The classical sampled data system considers the controller's periodic update after the achievement of control objectives. The conventional periodic control mechanism frequently updates the control signals, resulting in unessential energy consumption and actuator detrition. Spectrum utilization is not efficiently utilized in the traditional method. An event triggering scheme is used for efficient resource utilization and is digitally implemented. This method is preceded by lower cost and reduced consumption of energy. The controller's implementation was done digitally and its discretization error is signified as $\epsilon(t) = x(t) - x(t_j)$, and the sample is considered at each instant of j. The trajectories of the system move towards the sliding surface by updating a control, and the band has remained bounded. The equation for the controller with Dynamic event-triggered sliding mode is given as follows:

$$\mathcal{K}_{\rangle}(\sqcup) = \frac{1 + x_i(t_j)}{x_i(t_j)}[\lambda_i(t_j) + Gsign\{\sigma_i(t_j)\} - x_{iref}(t_j) \quad (11)$$

A dynamic triggering rule is established as follows:

$$t_{j+1} = \inf\{t\epsilon[t_j, \infty] : G_i|e_i(t)| + G_j|(e_i(t))|^2 \geq k_0 + k_1\text{exp}^{-\beta t}\} \quad (12)$$

Here $G_i = 0.5$, $G_j = 0.3$, $k_0 = 0.01$, $k_1 = 0.3$, and $\beta = 10.0$.

These parameters are meta-heuristically selected. The parameters G_i, G_j, k_0, k_1, and β were determined through a combination of theoretical analysis and empirical testing where G_i and G_j parameters represent the weights assigned to different error components in the control mechanism. k_0 and k_1 set thresholds for control updates where k_0 sets a baseline threshold while k_1 adjusting threshold dynamically. β controls the exponential decay rate of the threshold, balancing control updates frequency and energy consumption.

The selected parameters of c_0 and c_1 in which the state independent quantity is the threshold value, samples accumulated are avoided at a specific instant. Small k_1 and large β increases the rate of convergence at the cost of triggering huge events, when the k_0 is large it decreases the number of triggering events at larger off-set cost. The efficiency and the performance are balanced by tuning these parameters. Triggering rules possesses the weights G_i and G_j and it can select it in the arbitrary manner. The energy expenses and requirements for updating the controlling mechanism has been reduced by the dynamic triggering setting. This method uses time-varying threshold value and it is set as $k_0 + k_1\text{exp}^{-\beta t}$. The inequality represented below is good for inter-event time with finite lower bound and it is represented as follows:

$$t_{j+1} - t_j = T_j \quad (13)$$

Where the inter-event time be T_j. The above equation also describes the existence of a inter execution time of positive values and admissible instants of triggering. The event-based control produces the discretization error and it is estimated as follows:

$$\epsilon_i = x_i(t) - x_i(t_j) \quad (14)$$

During the controlling mechanism, the instant of sampling j^{th} and $(j+1)^{th}$ was used for the discretization error is non-zero. The discretization error uses time as T_j for rising zero to a few finite values.

Depending on the fixed threshold, the error variable is responsible for calculation and updates. Once the threshold values are fixed and exceeded, the event will happen. This threshold value is responsible for events and congestion in the network. When the threshold is considered very small, the error measurement frequently crosses the threshold and creates the need to update the controller. This occurrence creates an increment in the energy cost and complexities in computation. Therefore, it creates a need to update $K_i(t)$ and $\lambda_j(t)$. So, it results in changes in forwarding packets. Data transmission by $\lambda_j(t)$ is forwarded to the source of the SU to regulate the transmission rate. It results in recurrent data transmission from the controller to the destination, which produces congestion. By considering another condition of the larger threshold value, the control mechanism will be reduced, and the packet accumulation will be low, with lower congestion and improved QoS, resulting in lower computational complexities and lower energy costs. Therefore, the time-varying threshold values by event-triggering sliding mode decrease the transmission and computational complexities. Using an IoT protocol stack, this proposed system performs well in terms of congestion control in cognitive radio networks.

IV. RESULTS AND DISCUSSION

The ETSMCC is executed by NS2 simulation software. This software is an event-driven simulation tool to obtain knowledge about communication networks. The network topology

Algorithm 1 Event Triggered Sliding Mode Controller

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INPUT: Initialize $\mathcal{PHY}_{\text{IEEE}}802.15.4\text{-}2006$, $\mathcal{DLY}_{\text{Zigbee}}$, $\mathcal{NL}_{\text{CORPL}}$, $\mathcal{TL}_{\text{TCP}}$, $\text{ApL}_{\text{MQTT}}$
OUTPUT: Establish network communication.
if Next hop = 1 then
    Forward set =1;
    Primary user = $\mathcal{PU}_{\rangle}$;
    Secondary user = $\mathcal{SU}_{|}$;
else
    Next hop=0;
end if
if $G_r < 1$ then
    $\sigma(t) = -Gsign[\sigma(t)]$;
    $t_r = \frac{\sigma(0)}{G}$;
else
    $\sigma(t) = -G_i sign[\sigma(t)] - G_j \sigma(t)$;
    $t_r = \frac{1}{G_j}[ln\frac{G_i+G_j|\sigma(0)|}{G_j}]$;
end if
while $ControlUpdate > 1$ do
    Power rate $> \alpha$;
    $\sigma(t) = -G_j|\sigma(t)|^{\alpha} sign[\sigma(t)]$;
    $t_r = \frac{1}{G_j}[\frac{\sigma(0)^{1-\alpha}}{1-\alpha}]$;
    $\sigma_i(t) = e_i(t)$
    $\sigma_i(t) = e_i(t) = -K_i(t)\frac{(x_i(t))}{(1+x_i(t))} + \lambda_i(t) - x_{iref}(t)$
    $K_i(t) = \frac{1+x_i(t)}{(x_i(t)}[\lambda_i(t) + G_j(t)|\sigma_i(t)|^{\alpha} sign\{\sigma_i(t)\} - x_{iref}(t)$
    $\lambda_j(t) = K_j(t)\frac{x_j(t)}{1+x_j(t)} - Gsign\{\sigma_j(t)\} + x_{jref}(t)$
end while
if $ControlUpdate = 1$ then
    $K_i(t) = \frac{1+x_i(t_j)}{(x_i(t_j)}[\lambda_i(t_j) + Gsign\{\sigma_i(t_j)\} - x_{iref}(t_j)$;
    $t_{j+1} = \inf\{t\epsilon[t_j, \infty] : G_i|e_i(t)| + G_j|(e_i(t))|^2 \geq k_0 + k_1\text{exp}^{-\beta t}\}$;
    $q\epsilon_i = 1$;
    $Congestion = 0$;
else
    $K_i(t) = 0$;
    $\epsilon_i = 1$;
    $Congestion = 1$;
end if
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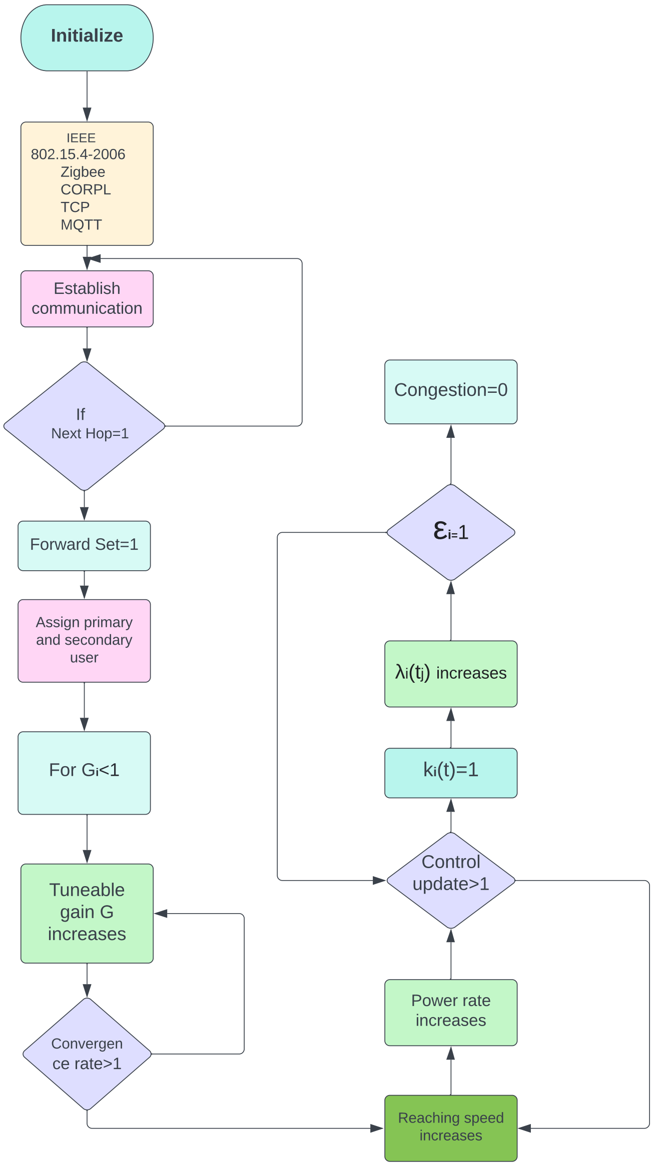

Fig. 2. Flowchart of the proposed algorithm.

consisted of 50 nodes with a combination of primary users (PU) and secondary users (SU) arranged in a mesh network configuration. With a transmission power of 0.1 W, the simulation parameters used a node density of 10-50 nodes covering static and dynamic mobility patterns with a data Packet Size of 512 bytes. The topology was designed to simulate a realistic IoT environment with varying traffic loads and network conditions. Different traffic patterns were simulated to evaluate the performance of ETSMCC under various conditions. These patterns included periodic, bursty, and random traffic to mimic real-world IoT scenarios. The traffic loads were adjusted to test the model's robustness in handling congestion and maintaining network performance. Each simulation run was conducted for 1000 seconds to ensure sufficient data collection for performance analysis. Multiple simulation runs were performed to validate the consistency and reliability of the results. Each simulation run was conducted for 1000 seconds to ensure sufficient data collection for performance analysis, resulting in over 500,000 data packets. Each data packet included metadata such as timestamp, source and destination nodes, packet size, and transmission status. Multiple simulation runs were performed to validate the consistency and reliability of the results.

The performance of the proposed method ETSMCC with the IoT protocol perspective has been compared with the existing congestion control strategies like Context-aware congestion control (CACC), Dynamic driven congestion control (DDCC). Average Distortion, Delay, Packet Delivery Ratio (PDR), Packet Loss, and Throughput are the parameters considered for analyzing the performance of the cognitive network.

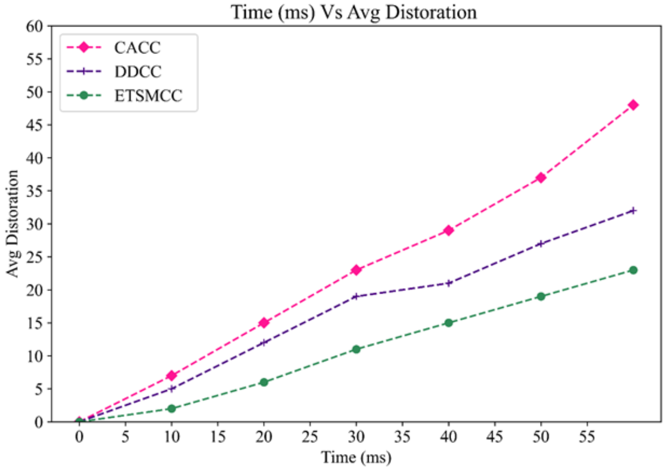

Fig. 3. Average Distortion Comparison

A. *Average Distortion Calculation of the Network*

Average distortion is defined as the deviation in the original value. Distortion is usually unwanted and eliminated or minimized. In some situations, however, distortion may be desirable. Fig. 3 the average distortion calculation of the network compares CACC, DDCC, and ETSMCC. Time (ms) is represented on the X-axis, and on the Y-axis, average distortion is represented. In the figure, the red color indicates CACC, the green color represents DDCC, and ETSMCC is represented in blue color. From the figure, it is proved that ETSMCC provides a lower distortion rate.

B. *Delay Calculation of the Network*

Network delay refers to the time required for the packet transmission from source to destination. Fig. 4 represents the delay calculation of the network that compares CACC, DDCC, and ETSMCC. In X-axis, time (ms) is represented, and on the Y-axis, Delay (ms) is represented. In this figure red color indicates CACC, the green color represents DDCC, and ETSMCC is represented in blue color. From the figure, it is proved that ETSMCC has lowered Delay.

C. *Packet Delivery Ratio (PDR) of the Network*

It is defined as ratio of total number of arrived data packets to the total number of transferred packets. Fig. 5 represents the PDR calculation of the network, which compares CACC, DDCC, and ETSMCC. On X-axis, Simulation time (ms) is represented, and on Y-axis, the packet delivery ratio (PDR) is represented. In the figure, the red color indicates CACC, the green color represents DDCC, and ETSMCC is represented in blue color. The figure proves that ETSMCC provides a high packet delivery ratio.

D. *Calculation of the Network's Packet Loss*

Packet loss describes lost packets of data not reaching their destination after being transmitted across a network. Fig. 6 indicates the packet loss calculation of the network,

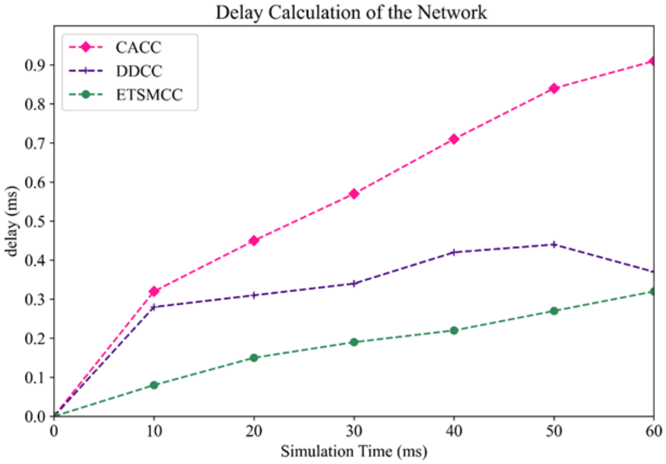

Fig. 4. Delay Comparison

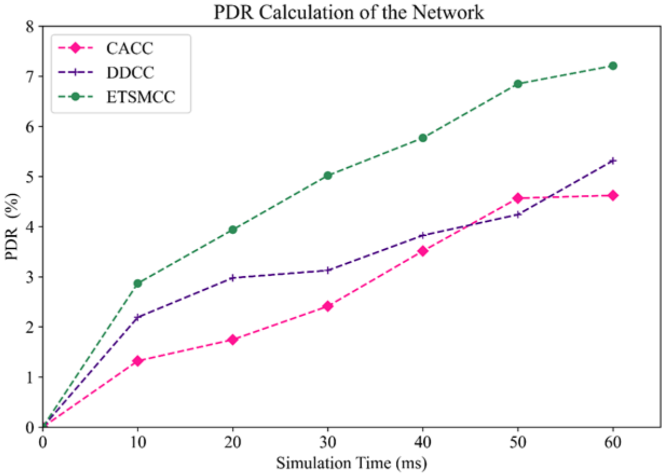

Fig. 5. PDR Calculation

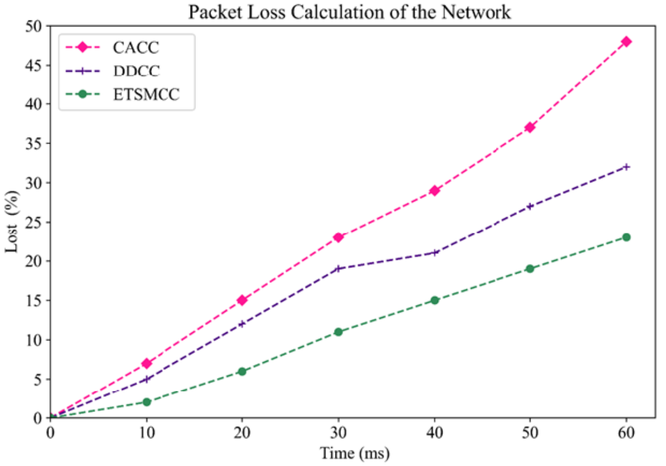

Fig. 6. Packet Loss calculation

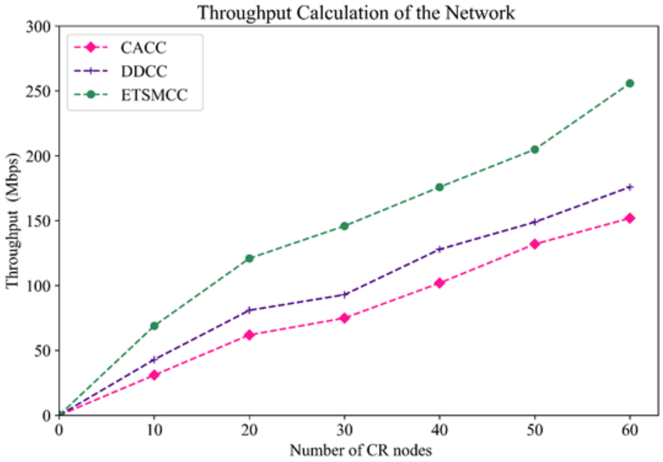

Fig. 7. Throughput Comparison

TABLE I
Overall Comparison of the Network.

Parameters	CACC	DDCC	ETSMCC
Delay	0.91 (ms)	0.37 (ms)	0.32 (ms)
Average Distortion	0.039(%)	0.017(%)	0.009(%)
Throughput	152 (kbps)	176 (kbps)	256 (kbps)
Packet Loss	48 (%)	32 (%)	23 (%)
Packet Delivery Ratio	4.624 (%)	5.316 (%)	7.210 (%)

and it compares CACC, DDCC, and ETSMCC. Time (ms) is represented on the X-axis, and packet loss is represented on the Y-axis. In the figure, the red color indicates CACC, the green color represents DDCC, and ETSMCC is represented in blue color. The figure shows that ETSMCC provides a lower packet loss, ensuring more reliable communication.

E. Throughput Comparison

Throughput is the actual rate at which information is transferred. Fig. 7 compares the throughput calculation of the ETSMCC network with CACC and DDCC. The X-axis represents the number of CR nodes, and the Y-axis represents throughput (Mbps). The red color indicates CACC, the green color represents DDCC, and ETSMCC is represented in blue color. The figure proves that ETSMCC provides a higher throughput rate, demonstrating its superior data handling capacity.

F. Overall Parameter Analysis of the Proposed ETSMCC

ETSMCC outperforms CACC and DDCC due to its dynamic and adaptive control mechanisms. Unlike CACC, which relies on static control parameters, ETSMCC adjusts its control actions based on real-time network conditions, providing more responsive and efficient congestion control. DDCC, while dynamic, lacks the event-triggered precision of ETSMCC, leading to higher computational overhead and energy consumption.

The Overall parameter analysis of the proposed ETSMCC is defined in Table I.

The table compares various parameters with the existing methods like CACC and DDCC. The proposed ETSMCC with IoT protocol stack perspective achieves an average distortion rate of 0.009%, a throughput of 256 Kbps, 23% packet loss, a delay of 0.32ms, and a packet delivery ratio of 7.21%. This ETSMCC method shows 0.71ms lower delay than CACC and 0.05ms lower delay than DDCC. It also decreases the average distortion by 0.030% compared to CACC and 0.008% compared to DDCC. The throughput increases by 104 Kbps compared to CACC and 80 Kbps compared to DDCC. Packet loss decreases by 25% compared to CACC and 16% compared to DDCC. The packet delivery ratio increases by 2.586% compared to CACC and 1.894% compared to DDCC. The proposed method shows improvement due to the larger threshold value, reducing the control mechanism, packet accumulation, congestion, and computational complexities, and improving QoS.

One probable limitation of ETSMCC may be its scalability. While the model performs well in small to medium-sized networks, scaling it to larger networks could introduce challenges such as increased computational overhead and potential bottlenecks in data processing. ETSMCC's performance may be influenced by specific network conditions, such as high mobility or varying traffic loads. To mitigate these dependencies, adaptive mechanisms that dynamically adjust control parameters based on real-time network feedback could be developed. This would ensure robust performance across diverse network scenarios.

V. CONCLUSION

This paper presented an event-triggered sliding mode controller for congestion maintenance (ETSMCC) based on the IoT protocol stack for cognitive networks. The proposed model improves disturbance rejection capabilities and robustness, reducing energy expenditures and computational difficulties. NS2 simulations validated the model's performance, showing significant improvements over existing methods like CACC and DDCC. In this, the proposed ETSMCC with IoT protocol stack perspective achieves an average distortion rate of 0.009%, the throughput of 256 Kbps, 23% of packet loss, delay of 0.32ms, and packet delivery ratio of 7.21%. The performance of the ETSMCC is high as compared to the state-of-art methods. In future studies, it is planned to design some other efficient controller for transmission purposes.

The proposed ETSMCC model presents several opportunities for further research and development:

- Integration with Emerging Technologies: Future work could explore integrating blockchain technology to enhance security and data integrity in cognitive radio networks.
- Machine Learning Optimization: Applying machine learning techniques to optimize the ETSMCC model dynamically for various network conditions could improve performance.
- Real-World Implementation: Testing the ETSMCC model in real-world IoT environments to assess its scalability and adaptability.
- Hybrid Models: Developing hybrid models that combine ETSMCC with other congestion control techniques could provide more robust and versatile solutions.

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