J. Electrical Systems 20-10s (2024): 6209-6218

**[1] Umashankar Pandey**

**[2] Saroj Kumar Chandra**

**[3] Gulshan Soni**

# Enhancing Sensor Node Lifespan in WSNs through Traffic-Adaptive Duty Cycle MAC (TDC-MAC) Protocol

***Abstract: -*** Extending the lifespan of sensor nodes remains a formidable challenge within the realm of Wireless Sensor Networks (WSNs). WSNs have seen a multitude of comprehensive research endeavors dedicated to the creation of energy-efficient Medium Access Control (MAC) protocols. In the collaborative landscape of WSNs, sensor nodes operate collectively to achieve a shared objective, drawing power from onboard battery cells. The utilization of duty cycles emerges as a pivotal mechanism in curtailing superfluous energy consumption among sensor nodes. Within this context, our paper introduces the Traffic-Adaptive Duty Cycle MAC (TDC-MAC) protocol, with a central focus on achieving reduced energy consumption while maintaining acceptable levels of packet loss and latency. The TDC-MAC protocol strives to prolong the sleep interval during periods of minimal data traffic, thereby significantly reducing energy consumption when contrasted with D2CMAC, SMAC, and tunable MAC protocols. Simulation results underscore the efficacy of TDC-MAC, showcasing a remarkable reduction in battery power consumption of up to 55% when compared to other similar protocols.

***Keywords:*** Wireless Sensor Networks (WSNs), Medium Access Control (MAC) protocols, Duty cycles, Sleep interval and Battery power consumption.

## I. INTRODUCTION

The MAC layer assumes a pivotal role in effectively allocating the common channel among neighbouring nodes during the contention period within WSNs. In such networks, nodes engage in contention for the shared channel, necessitating the implementation of collision avoidance strategies in the presence of a wireless channel. Notably, the IEEE 802.11 standard stands as the preeminent network communication standard in wireless networking, specifically Wireless Local Area Networks (WLANs), and enjoys widespread adoption as a globally embraced LAN and MAN solution. Over the course of recent decades, numerous researchers have drawn inspiration from this standard to propose a multitude of MAC protocols, thus addressing power consumption reduction challenges prevalent in WSNs [1].

The reduction of power consumption poses a critical and formidable challenge in WSNs, as well as in other wireless communication network technologies, including IoT. These networks predominantly rely on battery-powered nodes, thereby rendering periodic battery changes or replacements impractical. Moreover, the deterministic placement of sensor nodes in WSNs encounters significant obstacles rooted in two primary reasons [2]. Firstly, the target areas designated for sensor network deployment often encompass inhospitable or remote locations, thus impeding the realization of planned node placement strategies. Secondly, the sheer magnitude of sensor nodes within WSNs necessitates considerable increases in deployment costs and complexity. Nonetheless, the wide range of applications supported by WSNs, spanning from environmental monitoring to intelligent traffic management, smart home systems, and efficient grid management, underscores the profound importance of these networks in facilitating human-centric technologies.

WSNs inherently comprise a multitude of sensor nodes, each exhibiting distinctive power consumption characteristics across various radio modes. Figure 1 visually represents the power consumption patterns of the MICA2 mote in various states, including transmission, reception, idle listening, and sleep modes [3]. The analysis of Figure 1 reveals that sleep mode demonstrates minimal energy consumption, amounting to a mere 0.003 mW, in stark contrast to the other modes. Consequently, sleep mode emerges as an optimal choice for energy preservation

---

[1] *Umashankar Pandey : Department of Computer Science and Engineering, School of Engineering, O.P. Jindal University, Raigarh, India. Umashankar.pandey@opju.ac.in

[2] Saroj Kumar Cahndra : Department of Computer Science and Engineering, School of Engineering, O.P. Jindal University, Raigarh,

saroj.chandra@opju.ac.in

[3] Gulshan Soni : Dr. Shyama Prasad Mukherjee IIIT, Naya Raipur, India gsoni260@gmail.com

within WSNs. Nevertheless, the adoption of sleep mode entails certain constraints, including heightened packet drop rates, increased latency, and additional overhead associated with control packets.

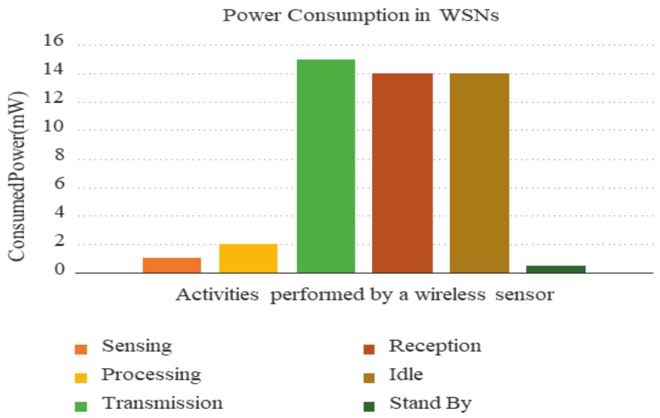


FIG.1-POWER CONSUMPTION IN WSN

The key contributors to energy wastage in WSNs [4], are illustrated in Figure 2.

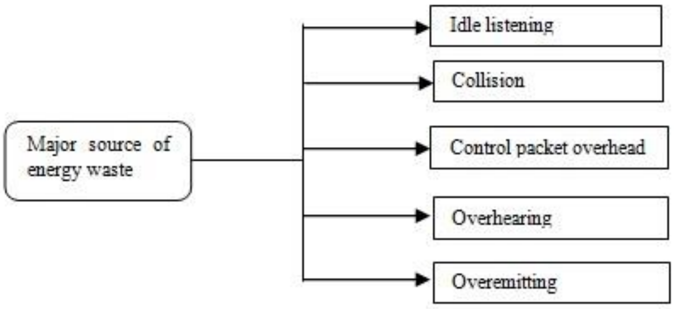


Fig.2- Key Contributor to Energy Depletion

This research paper places special emphasis on the data link layer, specifically highlighting the MAC sublayer. By delving into the MAC layer and its associated protocols, this research endeavors to address the challenges of power consumption reduction and efficient resource allocation in WSNs and other wireless communication networks.

The primary emphasis of this paper is lies in the adoption of a dynamic duty cycle approach, aimed at providing sensor nodes with increased sleeping time, thereby resulting in reduced energy consumption. The proposed Traffic-Adaptive Duty Cycle MAC (TDC-MAC) protocol introduces a variable sleep interval, specifically designed to operate efficiently under low data traffic conditions.

The paper is organized as follows in the following sections: Section 2 presents an overview of existing energy-efficient MAC protocols, discussing their advantages and disadvantages. Section 3 provides a comprehensive outline of the problem statement and introduces the TDC-MAC protocol. Section 4 details the simulation experiments conducted and presents a thorough analysis of the obtained results. Finally, in Section 5, the paper concludes by summarizing the key observations derived from the study.

## II. RELATED WORK

Numerous research efforts have been dedicated to the development of energy-efficient MAC protocols aimed at mitigating factors that significantly contribute to elevated energy consumption in WSNs. These influencing factors encompass issues such as idle listening, the necessity for retransmissions due to collisions, the problem of overhearing, and the overhead incurred by control packets.

Within the realm of MAC protocols, two predominant categories have emerged: contention-based and schedule-based. Contention-based MAC protocols facilitate decentralized access to the communication medium, obviating the requirement for a central coordinator. Conversely, schedule-based MAC protocols rely on pre-established schedules that dictate when nodes should engage in transmission, reception, and periods of dormancy.

In the context of WSNs, the S-MAC protocol [4] introduced Duty Cycle (DC) to extend node lifespans, albeit with increased packet delivery latency. Addressing this, the T-MAC protocol [5] introduced adaptive duty cycles, reducing idle energy wastage but facing an "early sleep" issue. To overcome this, FRTS and Full buffer priority were introduced.

D. Xu et al. proposed the EA-MAC protocol [6], employing a correlation-based flow adaptive approach. This considers node energy levels for channel access. However, EA-MAC may suffer delays and packet loss in remote deployments. Addressing idle listening in S-MAC, YW Kuo et al. [7] introduced a proactive scheme for status information exchange among sensor nodes, leveraging the physical layer. This mechanism aligns with synchronized MAC protocols.

In mission-critical applications, G. Sakya et al. presented MC-MAC [8], featuring an innovative regression-based adaptive duty cycle approach. This dynamic adaptation considers traffic conditions and remaining node energy. Notably, real-world testing of MC-MAC is lacking, raising questions about its practical efficacy. Lin et al.'s DSMAC protocol [9] manages the Duty Cycle dynamically. DSMAC achieves an energy-efficiency and latency balance while minimizing network overhead. Its support for multiple duty cycle schemes updated based on energy and delay considerations enhances its versatility.

Aydin et al. presented the Energy-aware Switching and Scheduling (ESS) algorithm [10] for dynamic WSN channels and traffic. ESS employs Lyapunov optimization, but its real-world efficiency regarding metrics like throughput and latency requires further exploration. Mihaylov et al. [11] proposed a decentralized RL approach for scheduling wake-up cycles in WSN nodes. This method enhances network efficiency and reduces collisions, especially in densely deployed networks.

Liang et al. introduced the Sleep Window MAC (SW-MAC) protocol [12], focusing on minimizing latency. SW-MAC uses "scout" packets and an adaptive sleeping scheme, allowing efficient transitions between sleep and wake-up states to enhance overall network efficiency. Bober and Bleakley introduced the BailighPulse MAC [13] for energy-efficient "mostly-off" WSN applications, enhancing sensor node Duty Cycle by up to 80% using a multi-hop wake-up scheme based on application-level scheduling.

Wang et al. introduced the Demand Sleep (DS) MAC protocol [14], which dynamically adjusts the duty cycle asynchronously based on received data packets and effectively mitigates overhearing concerns. However, variations in neighbors' wake-up predictions may impact network performance. Razaque and Elleithy developed the Border Node MAC (BN-MAC) [15], combining features from contention and schedule-based MAC protocols. This protocol ensures rapid medium access with a semi-synchronous contention scheme while mitigating collisions and overhearing through schedule-based elements.

Morshed et al. tackled dynamic traffic challenges in WSNs by proposing a traffic-adaptive duty cycle adaptation algorithm for the preamble sampling-based TR-MAC protocol [16], tailored for event-driven scenarios with low data rates and duty cycles. Annabel and Murugan introduced the TBEMAC protocol, although a missing reference [17] limits a comprehensive assessment of its details and effectiveness. TBEMAC operates in two phases: duty cycle adjustment, considering factors like data transmission, buffer status, and node battery status, and wake-up scheduling based on battery status and data transmission.

Guerroumi et al. introduced the MMSMAC protocol [18], which operates in synchronization, asynchronous, and hybrid modes. While promising, it requires further evaluation in specific network scenarios. Subramanian and Paramasivam introduced the PRIority in the Node (PRIN) protocol [19], a QoS-based MAC protocol for WSNs. It uses static priority values for communication medium access but faces throughput challenges due to interference. Nur et al. presented the DCD-MAC protocol [20] for mobility-based DWSNs. DCD-MAC synchronizes nodes before data transmission, optimally scheduling transmissions based on node direction and mobility to reduce packet collisions.

Sundararaj et al. developed the EDS-MAC protocol [21] for traffic-adaptive WSNs. This Protocol reduces energy consumption and delay by 50% and 72%, respectively, compared to IH-MAC. Trinh et al. proposed the RL Based Duty Cycle scheme [22] for Wireless Multimedia Sensor Networks (WMSNs). It adapts duty cycles and contention windows to enhance energy efficiency and meet QoS requirements in multimedia data transmission. Muzakkari et al. introduced the EEQ MAC protocol [23], dynamically adjusting a node's duty cycle based on packet queue size and priority. It minimizes latency for high-priority packets but adds some synchronization overhead.

Huang et al. [24] introduced a novel scheme using Q-Learning and linear regression to assess WSN node duty cycles, achieving low-latency and energy-efficient scheduling for varying traffic conditions. Ouaissa et al. [25]

introduced an adaptive duty cycle-based MAC protocol for M2M communication, reducing battery consumption during idle periods by adjusting the active period based on traffic load. Soni et al. [26] presented the D2CMAC protocol, which reduces energy consumption by extending sleep intervals during low-traffic periods, outperforming SMAC and tunableMAC.

In this extensive literature review, we have explored numerous strategies and methodologies aimed at mitigating battery power consumption in wireless sensor networks. Among these approaches is the utilization of a duty cycle, which involves periodically enabling and disabling a sensor node's radio. The duty cycle plays a pivotal role in regulating the duration a sensor node remains in sleep mode versus its active mode (for transmission or reception), thereby efficiently managing energy utilization.

## III. PROBLEM STATEMENT AND TDC-MAC PROTOCOL

This research paper introduces presents a novel framework known as the Traffic-Adaptive Duty Cycle MAC (TDC-MAC), specifically designed for sensor nodes deployed in wireless settings. In wireless networks, sensor nodes usually operate in two distinct modes: active and sleep. The active mode involves tasks related to packet transmission and reception, while the sleep mode serves to deactivate the radios in order to conserve energy efficiently.

The Duty Cycle (DC) serves as a mechanism that cyclically switches nodes between sleep and wake-up modes, with the primary goal of extending the lifespan of sensor nodes. It quantifies the ratio between a node's wake-up time and the total time it spends in both modes. For example, a 50% DC implies nodes evenly divide their time between sleep and wake-up modes, leading to greater energy preservation. Nevertheless, it's essential to recognize that this strategy is most beneficial in low data rate scenarios, as an extended sleep period may impact node performance.

The S-Mac protocol currently in use utilizes a static duty cycle mechanism, as depicted in Figure 3. A significant drawback of this protocol is its consistent duty cycle, which remains unchanged regardless of the network's traffic patterns. In response to this limitation, our proposed approach seeks to implement an intelligent dynamic duty cycle method. This method will adjust the duty cycle according to the current traffic conditions within the network, offering a more adaptive solution.

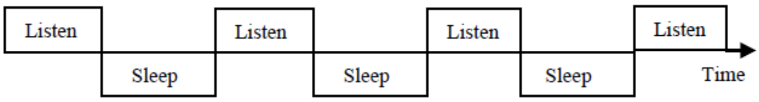


Fig. 3 Periodic listen and sleep

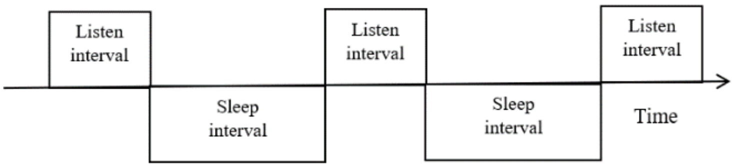
Figure 4 offers a graphical depiction of the functionality of our novel framework. This system categorizes network traffic into three clearly defined tiers: low, moderate, and high. Corresponding to these traffic categories, the duty cycle is divided into three categories as well, set at 25%, 50%, and 75%.

The fundamental concept behind our proposed approach is to assign the duty cycle ratio according to the observed traffic rate in the network, as detailed in Table 1.

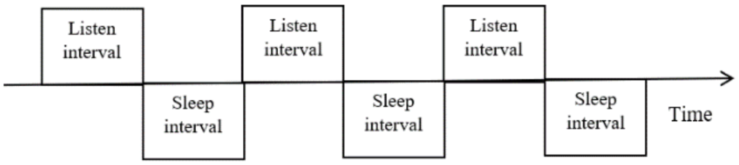
Table 1: Traffic and Duty Cycle Classification

| **S. No.** | **Traffic Rate** | **Duty Cycle** |
|---|---|---|
| 1 | Low | 25% |
| 2 | Moderate | 50% |
| 3 | High | 75% |

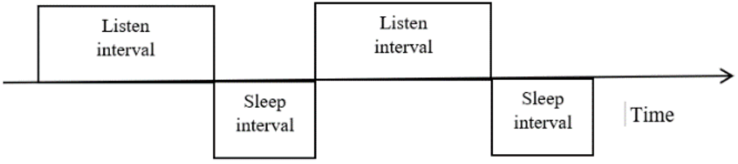
Figure 5 illustrates the functionality of the TDC-MAC protocol, which displays variations in its sleep interval behavior.



(a) Duty cycle = 25%



(b) Duty cycle= 50%



(c) Duty Cycle = 75%

Fig. 4: Illustration of the Traffic-Adaptive Duty Cycle

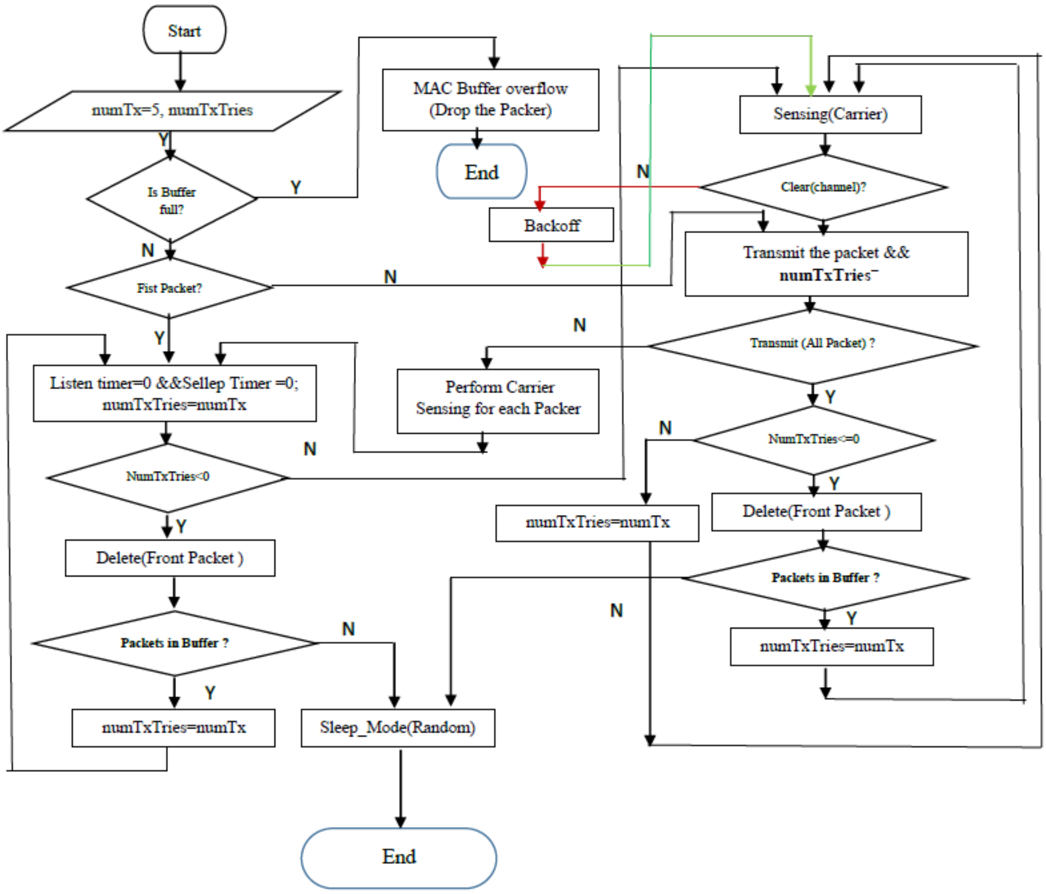


Fig 5: Flowchart for the TDC-MAC protocol

The TDC-MAC protocol operates in a distributed manner. Initially, it attempts to buffer incoming packets. However, if the buffer becomes full, it signals a MAC buffer overflow condition. When sensor nodes have packets to transmit, their sleep and listen timers will be canceled. The number of transmissions (numTx) is a crucial parameter throughout the MAC protocol procedure. The attempt to transmit a packet continues until it reaches the maximum number of allowed transmissions.

The node continuously monitors the channel for data traffic and classifies it into three categories: Low, Medium, and High data rates, corresponding to fixed duty cycles of 25%, 50%, and 75%, respectively. If the channel is found to be unoccupied, the node initiates packet transmission; otherwise, it enters a backoff state. The backoff represents a random duration during which the node must wait when the channel is busy to avoid concurrent transmission conflicts.

It provides the flexibility to choose between transmitting all packets in a single channel-sensing interval or sensing the channel before every packet transmission. After the successful transmission of all packets, the node can enter sleep mode.

## IV. SIMULATION AND RESULTS ANALYSIS

In this section, we delve into the simulation experiments conducted to evaluate the performance of our TDC-MAC protocol. Our primary objective is to measure and compare several key metrics, including average energy consumption, Packet Reception Ratio (PRR), and packet latency, against established protocols such as TunableMAC, SMAC, and D2CMAC.

### A. Simulation Environment and Network Topology Setup

We conducted our simulations within a controlled environment utilizing Castalia 3.3 [27] on the Ubuntu 16.04 platform. Our experimental setup employed a star topology, and for clarity, Figure 6 offers a graphical depiction of one instance in our simulation configuration. In this scenario, we designed a single-hop network consisting of four source nodes (labeled 1, 2, 3, and 4) and a single sink node (labeled 0). The source nodes generated packets directed towards the sink node, enabling us to perform comprehensive analysis and evaluation.

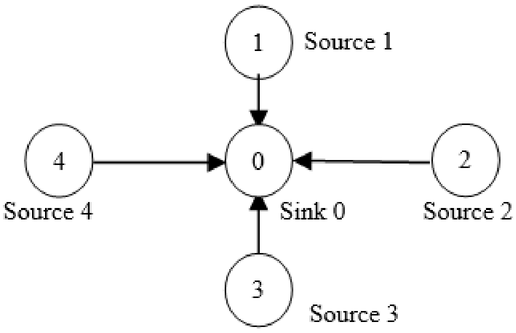


Fig. 6. The typical star Topology

During our simulation experiments, we examined two distinct scenarios to assess the performance of our TDC-MAC protocol. The first scenario involved maintaining a constant topology, as illustrated in Figure 6, while varying the packet transmission rate. In the second scenario, we held the packet transmission rate constant and manipulated the number of source nodes. For each of these scenarios, we computed the following performance metrics for the TDC-MAC, TunableMAC, SMAC, and D2CMAC protocols: average energy consumption (measured in millijoules, mJ), average Packet Reception Ratio (PRR), and average application-level latency (measured in milliseconds, ms).

### B. Parameter Configuration

Table 2 provides an overview of the essential parameters for the TDC-MAC, TunableMAC, and D2CMAC protocols. To facilitate the execution of experiments in the Castalia Simulation Tool. These parameters are crucial for each set of experiments conducted in our simulation environment. These parameter values were utilized in simulation experiments to evaluate the performance of the TDC-MAC, TunableMAC, and D2CMAC protocols in the Castalia Simulation Tool.

Table 2. Network simulation parameter

| **Simulation Parameters** | **values** |
|---|---|
| Duration | 30s |
| Field size | 200 * 200 m2 |
| Application Name | “ThroughputTest” |

| | |
|---|---|
| TxOutput Power | “-5dBm” |
| Application packet rate | 0.2 |
| Application constant Data Payload | 200bytes |
| Node initial energy | 18720 J |
| Idle listening consumption | 62mW |
| Transmit power | 62mW per packet |
| Receive Power | 62mW per packet |
| Sleep Power Consumption | 1.4mW |
| Listen Timeout (SMAC) | 100ms |

### C. Analysis of Experimental Results

In our simulation experiments, we maintained a fixed packet length throughout the entire duration. We focused on evaluating three crucial metrics: consumed energy, Packet Reception Ratio (PRR), and latency, within the context of two distinct scenarios.

In the first scenario, we kept the number of nodes constant while varying the packet rate (traffic). In the second scenario, we maintained a consistent packet rate (traffic) while varying the number of nodes. These two scenarios were designed to provide a comprehensive assessment of the performance of our TDC-MAC protocol and compare it with other existing protocols.

#### a. Evaluation of Consumed energy

Figure 7 presents an overview of the average energy consumption during different data traffic scenarios. As shown in the figure, TDC-MAC consistently demonstrates lower energy consumption in comparison to the TunableMAC, SMAC, and D2CMAC protocols. This observation highlights that when data traffic is at a minimum, the TDC-MAC protocol excels in energy efficiency, thereby significantly prolonging the lifespan of the sensor network. Specifically, TDC-MAC consumes approximately 9% less energy compared to TunableMAC, 30% less energy compared to SMAC, and 4% less energy compared to D2CMAC.

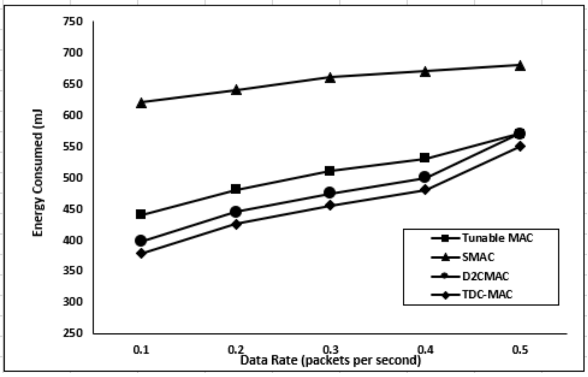


Fig. 7 energy consumed (scenario 1)

Figure 8 presents the average energy consumption as the number of nodes varies. It highlights a substantial improvement in energy efficiency for the TDC-MAC protocol compared to the TunableMAC, SMAC, and D2CMAC protocols.

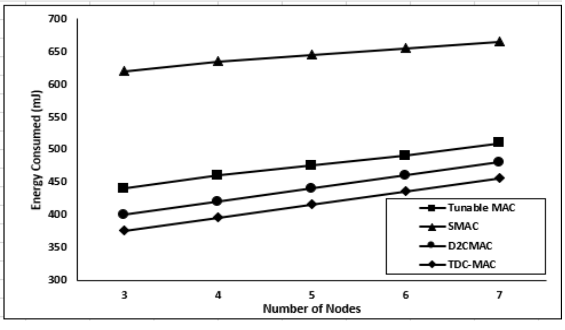


Fig. 8 energy consumed (scenario 2)

### b. Evaluation of Packet Reception Rate

Packet Reception Ratio (PRR) is a critical metric that quantifies the successful delivery of packets from multiple source nodes to the sink node, effectively indicating the packet loss rate. Figure 9 visually presents the PRR results, demonstrating that the TDC-MAC protocol consistently maintains a PRR ranging from 85% to 93%. These PRR values fall well within an acceptable range, even when the packet transmission rate undergoes variations. This suggests that TDC-MAC maintains reliable packet reception performance across different traffic scenarios.

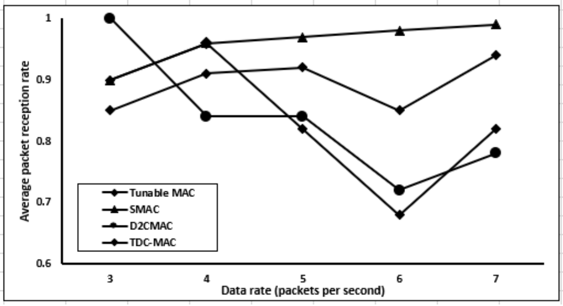


Fig. 9 packet reception rate (scenario 1)

Figure 10 provides further confirmation that TDC-MAC consistently achieves a notably high PRR when compared to TunableMAC, SMAC, and D2CMAC. In particular, as illustrated in Figure 10, TDC-MAC maintains an impressive PRR of approximately 89%. This robust performance in maintaining a high PRR emphasizes the reliability and effectiveness of the TDC-MAC protocol in various network conditions.

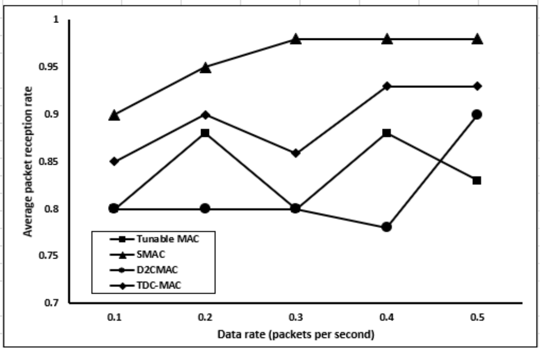


Fig. 10 packet reception rate (scenario 2)

### c. Evaluation of packets latency

Figure 11 visually portrays that the TDC-MAC protocol consistently achieves lower data packet latency in comparison to TunableMAC, SMAC, and D2CMAC, even when subjected to varying data packet conditions. This observation highlights the efficiency of the TDC-MAC protocol in minimizing packet latency, contributing to improved data transmission performance.

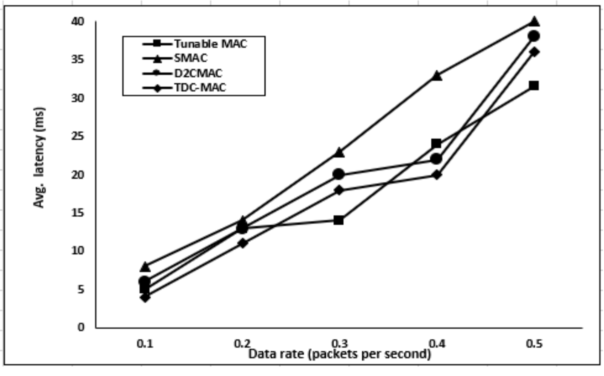


Fig. 11 packet latency (scenario 1)

Figure 12 provides a graphical representation of the average latency under varying numbers of nodes. It's evident from the figure that TDC-MAC consistently achieves lower latency compared to TunableMAC, SMAC, and D2CMAC in this context. This result underscores the effectiveness of the TDC-MAC protocol in minimizing latency, regardless of the network size, which is crucial for timely data transmission and responsiveness.

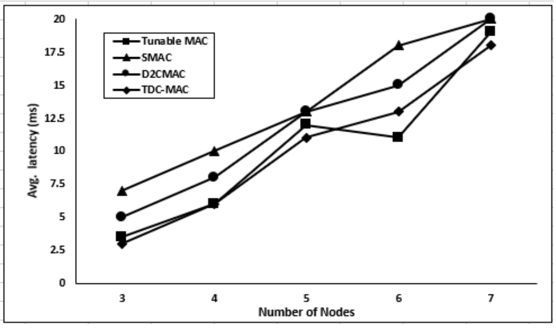


Fig. 12 packet latency (scenario 2)

## V. CONCLUSION

Our research primarily revolved around the design of a MAC protocol intended for Wireless Sensor Networks (WSNs) with the primary objective of minimizing energy consumption in sensor nodes. The TDC-MAC protocol was introduced to address the issue of idle listening, a significant contributor to energy depletion in WSNs. In experiments conducted under low data traffic conditions, our TDC-MAC protocol outperformed comparable MAC protocols by achieving a remarkable 55% reduction in energy consumption. Future work includes implementing the TDC-MAC protocol in a real-world testbed for further analysis and practical application.

## REFERENCES

[1] U. S. Pandey, G. Soni and S. K. Chandra, "Dynamic duty cycle based MAC protocols-A Comprehensive Survey," 2022 OPJU International Technology Conference on Emerging Technologies for Sustainable Development (OTCON), Raigarh, Chhattisgarh, India, 2023, pp. 1-6.

[2] S. Slijepcevic and M. Potkonjak, “Power efficient organization of Wireless Sensor Networks,” in Proc. IEEE International Conference on Communications. Conference Record (Cat. No. 01CH37240), vol. 2 Helsinki, Finland, 2001, pp. 472–476.

[3] V. Rajendran, K. Obraczka, and J. J. Garcia-Luna Aceves, “Energy- efficient collision-free Medium Access Control for Wireless Sensor Networks,” in Proc. 1st international conference on Embedded networked sensor systems, Los Angeles, California, USA, 2003, pp. 181–192.

[4] W. Ye, J. Heidemann, and D. Estrin, “An energy-efficient MAC protocol for Wireless Sensor Networks,” in Proc. 21st Annual Joint Conference of the IEEE Computer and Communications Societies, vol. 3, New York,NY, USA, 2002, pp. 1567–1576.

[5] T. Van Dam and K. Langendoen, “An adaptive energy-efficient MAC protocol for Wireless Sensor Networks,” in Proc. 1st international conference on Embedded networked sensor systems, Los Angeles, California,USA, 2003, pp. 171–180.

[6] D. Xu and K. Wang, “An adaptive traffic MAC protocol based on correlation of nodes,” EURASIP Journal on Wireless Communications and Networking, vol. 2015, no. 1, pp. 1–13, 2015.

[7] Y.-W. Kuo and K.-J. Liu, “Enhanced sensor Medium Access Control protocol for Wireless Sensor Networks in the ns-2 simulator,” IEEE systems journal, vol. 9, no. 4, pp. 1311–1321, 2014.

[8] G. Sakya and V. Sharma, “MAC protocol with regression based dynamic duty cycle feature for mission critical applications in WSN,” Int. J. Adv. Comput. Sci. Appl, vol. 8, no. 6, pp. 198–206, 2017.

[9] P. Lin, C. Qiao, and X. Wang, “Medium Access Control with a dynamic duty cycle for sensor networks,” in Proc. IEEE Wireless Communications and Networking Conference (IEEE Cat. No. 04TH8733), vol. 3,Atlanta, GA, USA, 2004, pp. 1534–1539.

[10] N. Aydin, M. Karaca, and O. Ercetin, “Energy-optimal scheduling in low duty cycle sensor networks,” in Proc. International Symposium on Performance Evaluation of Computer Telecommunication Systems, The Hague, Netherlands, 2011, pp. 119–126.

[11] M. Mihaylov, Y.-A. Le Borgne, K. Tuyls, and A. Nowe, “Decentralised Reinforcement Learning for energy efficient scheduling in Wireless Sensor Networks,” International Journal of Communication Networks and Distributed Systems, vol. 9, no. 3-4, pp. 207–224, 2012.

[12] L. Liang, X. Liu, Y. Wang, W. Feng, and G. Yang, “SW-MAC: A low-latency MAC protocol with adaptive sleeping for Wireless Sensor Networks,” Wireless personal communications, vol. 77, no. 2, pp.1191–1211, 2014.

[13] W. Bober and C. J. Bleakley, “BailighPulse: a low duty cycle data gathering protocol for mostly-off Wireless Sensor Networks,” Computer Networks, vol. 69, pp. 51–65, 2014.

[14] G. Wang, J. Yu, D. Yu, H. Yu, L. Feng et al., “DS-MAC: An energy efficient demand sleep MAC protocol with low latency for Wireless Sensor Networks,” Journal of Network and Computer Applications, vol. 58, pp. 155–164, 2015.

[15] A. Razaque and K. M. Elleithy, “Low duty cycle, energy-efficient and mobility-based boarder node MAC hybrid protocol for Wireless Sensor Networks,” Journal of Signal Processing Systems, vol. 81, no. 2, pp.265–284, 2015.

[16] S. Morshed, M. Baratchi, and G. Heijenk, “Traffic-adaptive duty cycle adaptation in TR-MAC protocol for Wireless Sensor Networks,” in Proc. Wireless Days (WD), Toulouse, France, 2016, pp. 1–6.

[17] L. S. P. Annabel and K. Murugan, “Traffic-based energy efficient MAC protocol for Wireless Sensor Networks,” International Journal of Information and Communication Technology, vol. 8, no. 2-3, pp.249–262, 2016.

[18] M. Guerroumi, A.-S. K. Pathan, A. Derhab, N. Badache, and S. Mous-saoui, “MMSMAC: A Multi-Mode Medium Access Control protocol for Wireless Sensor Networks with latency and energy-awareness,” Wireless Personal Communications, vol. 96, no. 4, pp. 4973–5010, 2017.

[19] A. K. Subramanian and I. Paramasivam, “PRIN: A priority-based energy efficient MAC protocol for Wireless Sensor Networks varying the sample inter-arrival time,” Wireless Personal Communications, vol. 92, no. 3, pp. 863–881, 2017.

[20] Nur, F.N., Sharmin, S., Razzaque, M.A. et al. A Low Duty Cycle MAC Protocol for Directional Wireless Sensor Networks. Wireless Pers Commun 96, 5035–5059 (2017).

[21] V. Sundararaj, S. Muthukumar, and R. Kumar, “An optimal cluster ormation based energy efficient dynamic scheduling hybrid MAC protocol for heavy traffic load in Wireless Sensor Networks,” Computers Security, vol. 77, pp. 277–288, 2018.

[22] B.-N. Trinh, L. Murphy, and G.-M. Muntean, “A reinforcement learning- based duty cycle adjustment technique in Wireless Multimedia Sensor Networks,” IEEE Access, vol. 8, pp. 58 774–58 787, 2020.

[23] B. A. Muzakkari, M. A. Mohamed, M. F. Kadir, and M. Mamat, “Queue and priority-aware adaptive duty cycle scheme for energy efficient Wireless Sensor Networks,” IEEE Access, vol. 8, pp. 17 231–17 242,2020.

[24] H. Y. Huang, K. T. Kim, and H. Y. Youn, “Determining node duty cycle using Q-learning and linear regression for WSN,” Frontiers of Computer Science, vol. 15, no. 1, pp. 1–7, 2021.

[25] M. Ouaissa, M. Ouaissa, and A. Rhattoy, “Enhanced and Efficient Multilayer MAC Protocol for M2M Communications,” in Proc. International Conference on Innovative Computing and Communications, Delhi,India, 2021, pp. 539–547.

[26] Soni, Gulshan, and Kandasamy Selvaradjou. "Performance evaluation of MAC protocols with static and dynamic duty cycle in WSNs." In Advanced Computing and Intelligent Engineering: Proceedings of ICACIE 2018, Volume 2, pp. 403-416. Springer Singapore, 2020.

[27] Boulis, A.: Castalia—a simulator for wireless sensor networks and body area networks. NICTA, User’s Manual Version 3.2 (2011).