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An Artificial Intelligence Based Quorum System for the Improvement of the Lifespan of Sensor Networks

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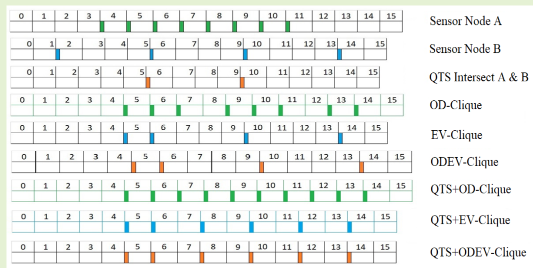
***Abstract*— Artificial I ntelligence-based Q uorum s ystems a re used to solve the energy crisis in real-time wireless sensor networks. They tend to improve the coverage, connectivity, latency, and lifespan of the networks where millions of sensor nodes need to be deployed in a smart grid system. The reality is that sensors may consume more power and reduce the lifetime of the network. This paper proposes a quorum-based grid system where the number of sensors in the quorum is increased without actually increasing quorums themselves, leading to improvements in throughput and latency by 14.23%. The proposed artificial intelligence scheme reduces the network latency due to an increase in time slots over conventional algorithms previously proposed. Secondly, energy consumption is reduced by weighted load balancing, improving the network's actual lifespan. Our experimental results show that the coverage rate is increased on an average of 11% over the conventional Coverage Contribution Area (CCA), Partial Coverage with Learning Automata (PCLA), and Probabilistic Coverage Protocol (PCP) protocols respectively.**



***Index Terms*— Artificial Intelligence, Sensor network, Quorum system, Network Lifespan, Coverage rate, Neighbor discovery, Weighted quorum system and Graphical abstract.**

I. Introduction

ENERGY is a primary concern in sensor networks for reliable data transfer that occurs due to the usage of non-rechargeable sources in many recent applications. An Artificial Intelligence (AI) based quorum system is projected to be a technology that will lead the innovation of complex super Artificial Intelligence. There are fundamental limitations to Deep Learning and other monolithic AI techniques and distributed AI provided a solution for those problems. Unlike traditional AI methods that employ a large network to perform a single task. There is a need for a system that will interact with one another on the energy platform with the ability to optimize themselves for a variety of tasks, including tasks which the system has not been explicitly trained to perform. This approach makes it much easier to build a good AI system that will improve the lifespan of sensor networks. And once built, it's easier to modify different protocols for different purposes or to inspect and replace individual functions as needed. We have recently seen that in sensor networks, constrained devices are now outnumbering devices that are not constrained, thus leading an active research area in being able to improve energy and computational consumption in sensor networks as a whole. One of the ways of achieving a reliable data transfer is through using medium access control (MAC) protocols in a distributive manner when thousands of nodes are employed between areas of interest. The MAC protocol improves energy-saving mechanisms, reliability, scalability, latency, quality of service, and many other factors as well. The role of MAC is through two main purposes:

1) controls when and how each node can transmit in wireless channels
2) solves the problem of contention and collision

Quorum based duty cycling schemes are introduced and applied in the sleep and wake-up during the scheduling process of the sensor node. In a quorum-based duty cycling scheme, the time slots are organized as quorum systems. The slot in which a sensor node is in the wake-up of the state is referred to

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as quorums. Any two neighbouring nodes that have quorums as their wake-up schedules should hear each other at least once within their bounded time slots. This wake-up schedule pattern repeats during every n time intervals, where n is the cycle length. Thus, a quorum system is a system in which any two-time slots of communicating nodes form a nonempty intersection.

The following constraints have to be satisfied in the design of the quorum-based power-saving MAC protocols [1]. For instance, the sleep and wake-up periods should be adaptable depending on the remaining packets and traffic patterns. It should also allow the sensor nodes to be in the wake-up state simultaneously. To achieve this, the quorum concept, that is, both fixed quorum and adaptive quorum can be chosen. Therefore, the contributions of this paper include:

- We proposed an artificial intelligence-based quorum grid system that solves the issue of energy conservation where the number of the quorum is increased without increasing quorums used by throughput.
- We proposed a scheme that reduces the latency of the network by 14.23% as an improvement from known estimates, and this is due to the increase of the number of time slots compared to other conventional algorithms.
- The energy consumption is reduced by weighted load balancing, thereby improving the network lifespan.
- A realistic evaluation of sensor operation in smart grid by evaluating all results on real data and with a Partial Coverage with Learning Automata (PCLA) were presented.
- We evaluated the results showing that the coverage rate is increased on an average of 11% when compared with conventional Coverage Contribution Area (CCA) and by using Probabilistic Coverage Protocol (PCP).

The rest of the paper is organized as follows: Section II describes the related work and the details of the specific problems in the smart grid. Section III describes the proposed system model; Section IV is the performance analysis of our AI approach, Section V is the results and discussion of our practical evaluation and Section VI gives the conclusion drawn from the work.

II. Related Work

The main objective of this paper is to solve the issue of energy conservation using artificial intelligence. The energy issue can be minimized by using a proper clustering scheme [2] based on the position of centroids which determines the convergence time. The author proposed the lighthouse scanning method by proving proper clustering with a fewer number of iterations.

Artificial Intelligence [3] optimization techniques such as the genetic approach scheme, particle swarm intelligence, ant colony technique, and elephant herding algorithms were reviewed to find the best optimal solution based on the initial population. A proficient bee colony [4] was proposed to increase the life span of the nodes by proper selection of cluster head by considering parameters like the energy of the nodes, nodes degree, and the distance from cluster head to sink node.

The connectivity of sensor node matters in mobile wireless sensor networks [5]. The authors proposed a firefly algorithm to improve the connectivity problem. It is based on insect fireflies, which may have a unique feature of providing light at different levels. The main advantage of their proposal is that the less bright sensor depends on the bright sensor for information transmission. The authors in [6] proposed a locally optimized grey wolf as a cluster optimization scheme. This scheme is prone to local minima and premature convergence having significant variables. Their scheme used a tabu search along with this optimizer and compared it with various data sets.

For a quorum-based system to have reliable data transfer, minimize energy conservation [7], [8] and maximize the lifetime of the network [9], [10], the following methods were adopted. To reduce energy conservation, some characteristics such as the passing of messages, wake-up/sleep approaches, adaptive listening design, collision prevention, and delay minimization were implemented. Meanwhile, Chao and Lee [11] had proposed a single-channel quorum MAC based on grid quorum. According to the authors, the network life span is increased by providing considerable sleep periods. The collision cannot be prevented due to the single-channel approach and collision retransmission of packets taken place, which reduces network lifetime. According to the traffic pattern, grid size variants are proposed in this scheme. Predictive-wakeup MAC [12] is an asynchronous receiver-initiated protocol. It minimizes sensor energy consumption by enabling the sender in predicting receiver wake-up periods. The sender must know the pseudo-random generator from the receiver to enable wake-up times. The disadvantage of this protocol is that the sender node has to generate a beacon signal irrespective of holding data or not. Periodically, the pseudo-random generator increases the overhead.

Tree-based channel assignment (TMCA) [13] protocol is a scheduled based multi-channel model used for the application of data collection. The author describes the protocol that all nodes are rooted in the sink by dividing the whole network into subtrees. When any node needs to transmit, the data uploads the packet in the subtree and reaches the sink node. The main disadvantage of this protocol is that it cannot be used for broadcasting and aggregation of data due to the partition of a tree structure.

Cooperative communication MAC (CMAC) according to the author in [14], is a protocol for wireless LANs enchanting 802.11e via cooperation by spatial diversity. The author introduces two types of radio: wake-up radio and half-duplex radio. The leading role of wake-up radio is that the receivers are awake by a series of pulses, whenever the sender requires transmitting a packet, and the channel is managed before actual communication. This protocol requires two transceivers for individual sensor nodes instead of synchronization. The main drawback is managing the control channel which increases the complexity of the network when many nodes request for the channel. Multi-channel Lightweight MAC (MC-LMAC) defined and applied by the authors in [15], is a protocol designed for improving energy efficiency as primary and utilizing bandwidth and throughput as secondary importance. It is a multi-channel synchronization schedule-based algorithm using a single radio frequency by switching the nodes to the channel dynamically. The main drawback of their approach is the overhead created due to control messages as density increases, the network gets jammed. The authors in [16] propose multiple frequency media access control for wireless sensor networks (MMSN). The authors argue that their protocol is the first multi-channel using four frequencies. Therefore, they proposed a congestion reduction by utilizing synchronization to provide broadcast support. The drawback of this protocol is that it creates a fixed b ack-off t ime. E nergy-aware M AC protocol (EM-MAC) [17] is initiated by multi-channel asynchronous protocol through a method of anticipating the wake-up channel and the time of the receiver. Meanwhile, a sensor contention will be created by using a pseudo-random generator twice to access the channel and overburdens the overhead.

With medium access control of S-MAC and Z-MAC protocol in single-hop wireless sensor network (WSN) results in reducing overheads and its complexity [18]. To characterize the WSN, the different kinds of scheduling algorithm were proposed to wake-up the network using three different schemes such as asynchronous, synchronous, and hybrid [19]. To identify the deteriorating node in WSN, a method was proposed that re-configures the network with a new approach named Detection and Replacement of Failing Node (DFRN) to establish the connectivity which enables better performance by covering extensive network and at the same time consumes fewer energy [20]. A new Node Stability-based Routing algorithm (NSR) with an entropy function was proposed [21] to extract overall network stability of node and to expand the network performance in WSN a new Node. To identify node location in WSN, the grid service, quorum-based location service will be formed by square and master-slave configuration in a squared layout. The column and row metric were framed to identify the node location, and the same will be updated in server [22]. Many approaches have been reported with radio chipset in radio networks to save time and energy in WSN. Low-cost hardware has been demonstrated to provide high reliability, excellent support for mobility, and low energy consumption [23]. The sensor nodes have less energy and resource capacity since they are limited by battery [24], and cannot be replaced in various environmental conditions.

Data aggregation plays a vital part in the Internet of Things integrating wireless sensor networks [25]. Most of the MAC layer protocols address information aggregation in large area networks in which the payload is unaware. The proposed scheme were considered based on signaling, traffic conditions, and physical layer. A simple codebook is created for encoding and decoding the data and increasing the security feature in which eavesdropping observes only partial information on the channel. In designing a communication wireless sensor protocol, energy conservation [26] is the primary concern so that the collision of packets and idle listening can be minimized by proper implementation of the duty cycle. Conventional algorithms focus on fixed d uty c ycle, t hereby end-to-end delay is increased, but it should be variable based on network conditions. An adaptive duty cycle mechanism is proposed giving priority to the packet in the queue based on real-time information on which the duty cycle is made adaptive. This approach reduces energy and latency, and compared with existing protocols improves its network lifetime. A decentralized adaptive duty cycle is framed for wireless sensor networks for slotted ALOHA [27] using the Markov decision estimation procedure. The work employed Q-learning concepts for providing a solution for optimization, which increases the throughput of the packet in the channel.

The authors in [28] improved network lifetime by using Adaptive MAC along with artificial intelligence to improve duty cycle when compared with conventional algorithms. Internet of Thing utilizes wireless sensor networks as data-driven networks considering the improvement of network parameters such as latency, throughput, efficient energy utilization [28] Reliable information of the transmission is one of the principal vital roles in a resource-constrained environment. The MAC-based ZigBee protocol for data transmission using data survivability with an energy efficiency scheme that improves energy effectively compared with the traditional algorithms is discussed. This protocol compares its result with two existing techniques such as decentralized erasure code for data survivability and decentralized erasure code encode and disseminate outperforms in terms of network life span. The Structure of the Wireless Sensor network is framed in an adhoc fashion, and the nodes report the data to the base station. IoT has been developed with WSN along with smart technologies [29]. Most of the researchers developed an energy-efficient protocol with cost reduction focusing on static nodes alone without considering mobile nodes. The proposed model considered clusters with a non-overlapping pattern of clusters and providing data transmission in multi-hop routing using the architecture of blockchain, showing significant improvement in results.

In Industry 4.0 and the Internet of Things, sensor networks have a vital role with regards to security [30]. This paper reveals the security performance of the physical layer in large scale sensor networks, considering interfering nodes using a passion point process. The parameters considered for evaluating the performance are fading, path loss, etc. Results prove that large scale WSN imparts on the intensity of the node and the transmission power. For irregular WSN profiles in a pre-determined geographic area, a quorum-based sink location service has been followed for the transmission of packets. The proposed model shows better transmission over other models significantly and guarantees the delivery of packet [31]. The multi-packet reception (MPR) scheme followed in WSN, during runtime gradually adjust the scheme of transmission based on probability on the neighbour node selection. The model is estimated with various terms in unknown network population like identifying the neighbour thorough announcement and its efficiency, establishing, completion time, and slot wasted ratio time [32]. Wireless networks play a vital role in the Internet of Things in terms of safety and intelligent transport system and efficient energy conservation [33] for vehicle and infrastructure management using Multi-Input Multi-Output (MIMO) schemes by employing backpropagation neural network.

III. Proposed System model

The goal of the proposed AI-based quorum system is to boost the discovery of neighboring sensor nodes and to reduce network latency. Furthermore, the intersection time of the neighbors is increased by creating a condensed grid without increasing time slots of the quorum system.

The assumptions made in this paper are in three folds:

1) Sensor nodes are deployed randomly.
2) The learning is inbuilt in every sensor node which enables the node to take appropriate decisions to increase the ability to discover neighbors and be connected.
3) The nodes are selected randomly from the neighbour node to reduce the wait time from the available sensor node.

This paper uses the energy-efficient MAC protocol formulated by Yuxin [34] for minimizing delay in sensor networks. The approach utilizes more time slots from the far node thereby reducing delay for packet transmission and decreasing latency. By increasing the time slots it prolongs the duty cycle and so the latency can be reduced. Their proposed protocol increases the lifetime and dramatically increases the latency of the network.

TABLE I: Notations and their description

Notation	Description
R	Network Radius
ρ	Node density
r	Node Transmission Radius
k	No of rings
l	Width of the ring
E_i	Energy consumption of node i
E_{int}	Initial Energy
D	Delay
E_{left}	Residual Energy
d	Transmission distance
λ	Packet Rate
ϖ_t	Transmission power
ϖ_r	Reception power
ϖ_s	Sleeping power
ϖ_b	Beacon window power
ζ	Time slot
ζ_b	Beacon window size
δ	Packet size
n	Cycle length
ϵ	Duty cycle
α	Learning rate
γ	Discount factor
s	Set of states
E_1	Energy split in first ring
a	Set of actions
τ	Time slot size
ε	Duty cycle
n	Cycle length
B	Channel rate
B_k^r	Number of packets received
B_k^t	Number of packets transmitted
χ	Number of quorum time slots in a cycle
T_r^i	Time slots per cycle to receive data
T_t^i	Time slots per cycle to transmit data
	Network growth ratio
W	Condense cycle length
υ	Number of forward set of the k^{th} slot
E_{left}^i	Remaining energy of the nodes i^{th} ring
θ_i	End-to-end delay
P_k	Probability of successful transmission
Q_i^{Δ}	Probability of successful transmission
A_i	Active slots
$\overline{A}$	Upper active slots
A_q	Slot with many nodes
$\underline{A}$	Lower active slots
u	Upper maximum unselected vertices
b	Lower maximum unselected vertices

A. Q-Reinforced learning

A reinforced algorithm in an uncongenial environment has improved both coverage and connectivity between the nodes. This type of Q-learning is due to the lack of training which reduces the lifespan of the network; the AI-based Q-learning implemented optimizes the sensor network. The value of Q gives fairest to sensor node agents to maximize coverage and connectivity. The value of Q at timestamp $(t = 1, 2, 3, 4 \ldots n)$ is determined by the below equation and put in matrix form [34]–[38]. The sensor node agent starts with random values of $Q(s, a)$.

$$\begin{aligned} Q_{t+1}(s_t, a_t) &= (1 - \alpha_t) Q_t(s_t, a_t) \\ &+ [r_t + \gamma \max_a Q_t(s_{t+1}, a)] \end{aligned} \tag{1}$$

$$\begin{aligned} Q_{t+1}^i(s_t, a_1, a_2, a_3, \ldots .a_n) = (1 - \alpha_t) \\ Q_t^i(s_t, a_1, a_2, a_3, \ldots .a_n) \alpha_t [r_t^i + \gamma N Q_t^i(s^*)] \end{aligned} \tag{2}$$

$$N Q_t^i(s^*) = \Pi^1(s^*) \ldots\ldots \Pi^n(s^*) \cdot Q_t^i(s^*) \tag{3}$$

where s is the set of states; a, the set of actions; r, reward; α learning rate; and γ discount factor. α -learning rate lies between 0 and 1, if α = 0, agent learns nothing and if α = 1, agent considers only recent information. α = 0.1 is considered for exploration. γ-discount factor, lies between 0 and 1, the γ larger value of represents that agent is going to explore the entire environment. γ = 0.9 is considered.

B. Artificial Intelligence Reinforced Learning

During the learning from the most randomly selected nodes that lie inside the grid, this can compute the percentage of coverage redundancy and perform actions such as active, sleep, customize the sensing range and also assign a local reward to the sensor node agent. The node agent controls the coverage area, and update the Q-values. The number of nodes with maximum positive reward values forms the coverage set to assign global reward if the global optimum is greater than the threshold and then take it as input for connectivity maintenance learning. During the learning from the most randomly selected nodes that lie inside the grid, we can compute the percentage of coverage redundancy and perform actions such as active, sleep, customize the sensing range and assign a local reward to the sensor node agent as a coverage area, and update the Q-values. The number of nodes with maximum positive reward values forms the coverage set. We can assign global reward as coverage rate and save the state action if the global optimum is greater than the threshold and then take it as input for connectivity maintenance learning.

Moreover, if the input is taken from coverage maintenance, we then initialize and employ training from the leftmost selected grid. The neighbors that are connected through 1-hop assign a local reward to the sensor node and update the Q-values after exploiting each sensor node. The nodes with reward value from a set of active nodes are then assigned global reward as the total number of active nodes. If there are no 1-hop neighbors to identify them, the covered set to perform suitable actions either make the beacon node active or hibernate. After getting the nearest 1-hop neighbors, we update the Q-values and assign the global reward as the total number of active nodes.

The next action is to initialize the number of agents, their states and actions, and set Q-values to zero. The states are

Sleep state, Beacon window state, active state etc., are the operating states of every sensor node reported in [34]–[38]. Repeat this action until a global optimum has been achieved for each sensor node agent at time t. Assume that the rewards for coverage and connectivity maintenance where the updated Q-values are using global reward r. The purpose of Q value in Q-learning is to learn an optimum policy for an agent to choose its best action that can maximize the overall reward value. Reward r is the feedback by which the success or failure of an agent's selected action is measured. For example: the coverage rate provided by the active sensor nodes is reward. If the coverage rate C_r is greater than or equals to threshold coverage rate ς ($C_r > \varsigma$) then it is a positive reward otherwise negative reward. Reward can be categorized as local reward and global reward. Coverage area provided by an agent is stated as local reward and the coverage rate provided by the active number of sensor nodes in one scheduling round is stated as global reward.

The collection of data is concentrated in the three different zones. When it is far from the base station, it concentrates on the front portion, which means excluding the front portion of time slots. When the collection is made in the middle region, it concentrates on the middle portion, which means it can exclude the middle portion of the time slot. Furthermore, when it is closer to the base station, it concentrates on the back portion of the cycle, which refers that it can exclude the back portion of the time slot.

The time slots of the quorum are increased then the intersection periods of the neighbor is also increased. Enormous energy is leftover in the far region from the base station. This may increase the time slots of the quorum system, and the efficiency will also be increased. The requirements of wake-up periods are the following:

1) Neighbor Discovery
2) Maximizing node sleep schedule
3) Wake-up periods to be matched with the duty cycle of the battery.

C. Quorum Grid system

For a universal set given as $U = \{1, 2, 3, \dots n-1\}$, the quorums are defined as $Q = \{1, 2, 3, \dots n-1\}$ and grid quorum set is defined as if and only if the two quorums satisfy the intersection property $Q_1 n Q_2 \neq \phi$.

OD-clique's grid quorum system is given by $OD_{Clique}(u, x_1, a, b) 1 \leq x_1 \leq (\sqrt{n}-a)^2/\sqrt{n}$, $0 \leq u \leq n-1$ and $1 \leq a = b \leq \lfloor \sqrt{n}/2 \rfloor$. Excluding the selecting periods of the first row and first column represented by the pair (a, b). The mathematical equation is given by

$$OD_{Clique}(u, x_1, a, b) = \left\{ \begin{array}{c} (i\sqrt{n} + j + x_1 + u) mod(\sqrt{n} - a)^2 \\ if(i = 0, 1, \dots x_1 - 1; j = 0, 1, \dots \sqrt{n} - 2); \\ ((x_1\sqrt{n} - 1) + j + x_1 + u) mod(\sqrt{n} - a)^2 \\ if(i = x_1, j = 0, 1, \dots x_1 - 1) \end{array} \right\} \quad (4)$$

And EV–clique's grid quorum system is given by $EV_{Clique}(v, x_2, a, b)$, let us assume $1 \leq x_1 \leq (\sqrt{n}-a)^2/\sqrt{n}$, $0 \leq u \leq n-1$ and $1 \leq a = b \leq \lfloor \sqrt{n}/2 \rfloor$. Excluding the selecting periods of the first row and first column represented by the pair (a, b). The mathematical equation is given by

$$EV_{Clique}(u, x_1, a, b) = \left\{ \begin{array}{c} (j\sqrt{n} + ix_2 + v) mod(\sqrt{n} - a)^2 \\ if(i = 0, 1, ..x_2 - 1; j = 0, 1, ...\sqrt{n} - 2); \\ ((j\sqrt{n} - 1) + ix_2 + v) mod(\sqrt{n} - a)^2 \\ if(i = x_2, j = 0, 1, ...x_2 - 1) \end{array} \right\} \quad (5)$$

ODEV-Quorum grid system is defined by four given integers x_1, x_2, u, v by combining OD_{Clique} Quorum having periods and EV_{Clique} Quorum system having periods, Mathematically represented as

$$ODEV_{grid}(u, v, x_1, x_2) = \left\{ \begin{array}{c} (i\sqrt{n} + j + x_1 + u) mod(\sqrt{n} - a)^2 \\ if(i = 0, 1, ..x_1 - 1; j = 0, 1, ...\sqrt{n} - 2); \\ ((x_1\sqrt{n} - 1) + j + x_1 + u) mod(\sqrt{n} - a)^2 \\ if(i = x_1, j = 0, 1, ...x_1 - 1) \\ (j\sqrt{n} + ix_2 + v) mod(\sqrt{n} - a)^2 \\ if(i = 0, 1, ..x_2 - 1; j = 0, 1, ...\sqrt{n} - 2); \\ ((j\sqrt{n} - 1) + ix_2 + v) mod(\sqrt{n} - a)^2 \\ if(i = x_2, j = 0, 1, ...x_2 - 1) \end{array} \right\} \quad (6)$$

Equations 4, 5, and 6 represent the OD-clique, EV–clique, and ODEV Quorum grid system respectively. In general, we can say that these equations represent the selection of time slots in the neighboring nodes based on the ring number.

1) Time slot Quorum condense matrix: This protocol matrix is formed by condensing $\sqrt{n}$ x $\sqrt{n}$ to an $(\sqrt{n} - a)$ x $(\sqrt{n} - b)$ thereby increasing the intersection of neighbors without increasing the time slots of quorum due to this increase in the intersection of neighbors, network latency is reduced. The period number in the quorum system is defined by the $(\sqrt{n} - a) \times (\sqrt{n} - b)$ grid and its necessary to know the exact time- period number z when convert it into $\sqrt{n} \times \sqrt{n}$ actual grid depending on the location where the node is located. Let us consider to exclude $v1$ rows and $v1$ columns and need to determine exactly the serial number of the time slot in $\sqrt{n} \times \sqrt{n}$. The time- period serial number can be determined by the following equation

$$K = vn + b + \lfloor z/(\sqrt{n} - v) \rfloor n + z mod(\sqrt{n} - v) \quad (7)$$

In this proposed mechanism the ODEV-Quorum grid system defined by $(\sqrt{n} - a) \times (\sqrt{n} - b)$ matrix whose time-period number is converted into the original gird matrix of the order $\sqrt{n} \times \sqrt{n}$.

The method to find the exact initial locality of the condensing matrix and also determine the size of the condensing matrix. Let us assume the time at which the node i^{th} transmits or receives the data initially is denoted as t_i^I and the same beacon node i^{th} sends the packet at the final time is denoted as t_i^F.

The energy of the node which is far away from the base station node can be utilized for increasing the intersection of time slots of the beacon nodes without increasing the time-periods of the quorum systems thereby reducing latency. It necessary that we have to determine the consumption of energy to increase the number of time slots in the quorum system.

During transmission and reception, the number of real-time and non-real-time information packets in a given time slot in the i^{th} ring is calculated as

$$B_i^{Tx} = \frac{\lambda(k^2 - i^2)}{2i - 1} + \lambda \tag{8}$$

$$B_i^{Rx} = \frac{\lambda(k^2 - i^2)}{2i - 1} + \lambda \tag{9}$$

Where λ is source rate, i.e. each slot probability of information packets of a node.

Let the number of the time-periods slot in a quorum per cycle be $\hbar$ A sensor node at i^{th} ring information packets that are transmitted and received per cycle is $T_T^i = \partial n B_i^{Tx}/B\tau$, $T_R^i = \partial n B_i^{Rx}/B\tau$ and respect and their energy consumed is during time slots of transmission, reception, remaining and sleep are given as $T_T^i \tau \varpi_T$, $T_R^i \tau \varpi_R T_b^i(\tau_d \varpi_b + \varpi_s(\tau - \tau_d))$ and $(n-\partial)\tau\varpi_s$. Therefore E_1 energy spent in nodes of ring 1st is the summation of all including transmission, reception, remaining, and sleep periods.

$$E_1 = T_T^1 \tau \varpi_T + T_R^1 \tau \varpi_R + T_b^i(\tau_d \varpi_b + \varpi_s(\tau - \tau_d)) + (n-\partial)\tau\varpi_s \tag{10}$$

Similarly, for nodes at i^{th} ring energy spent can be given by

$$E_1 = T_T^1 \tau \varpi_T + T_R^1 \tau \varpi_R + T_b^i(\tau_d \varpi_b + \varpi_s(\tau - \tau_d)) + (n-\partial)\tau\varpi_s t \tag{11}$$

So the energy left at the i^{th} node is calculated by

$$E_{Remain}^i = E_1 - E_i \tag{12}$$

$$\begin{aligned} E_{Remain}^i = {} & (T_T^1 - T_T^i)\tau\varpi_T + (T_R^1 - T_R^i)\tau\varpi_s \\ & + (T_b^1 - T_b^i)(\tau_d \varpi_b + \varpi_s(\tau - \tau_d)) \end{aligned} \tag{13}$$

The increase in the number of time-periods of quorum in the 1^{st} ring will also increase the time slot quorums in each other rings. Increased time slot quorum at the i^{th} ring is given by

$$TSQ_{Increase}^i = \frac{E_{Remain}^i}{(\varpi_b - \varpi_s)\tau_d} \tag{14}$$

2) Proposed MAC Protocol: The proposed model is explained in Algorithm 1 as follows

Algorithm 1 Proposed Model

Initialize:
N-Total no of Nodes are randomly deployed and arranged in ring fashion k-No of hops
Begin
for `each node` N_i **do**
  Select OD_{Clique} and EV_{Clique} based on ring number.
    Quorum time slot Allocation for node $N_i b_i = \lfloor t_i^e \sqrt{N} \rfloor$
    Size of Condense matrix $w * w$
    $w_i = (\sqrt{n} - x) * \sqrt{n} - y) \lceil (t_i^l - t_i^e)/(\sqrt{n} - b_i) \rceil$
  Calculate OD_{Clique} and EV_{Clique}
    Quorum time slot increment $Q_i^{\Delta} = \frac{E_{left}^i}{\varpi_s \tau_d}$
end for

Fig. 1 shows the proposed model of the 4×4 grid. Consider that two nodes A and B select two rows and one column, there is an intersection at the time- periods 6 and 10. The first row and column are excluded from the quorum time slots in OD and EV cliques, and now there are two more extra quorum time slots.

The created ODEV clique has four intersections $(5, 6, 10, 14)$ with the exclusion of rows and columns. Then we have calculated the quorum incremental time slots for the ODEV clique. In total, we have six quorum time slots intersection $(5, 6, 8, 10, 12, 14)$ when compared with the normal quorum system which has only two intersection time slots, due to this the latency of packets can be minimized as well as network lifetime can be prolonged.

3) Quorum pattern graph: A quorum pattern can be represented in the form of a graph pattern $G(V, E)$. There are four components in the graph. They are vertices, subgraph, abut and proficient graph

1) Vertices: Active time slots
2) Subgraph: All vertex to a particular node.
3) Proficient graph: Subgraph representing all beacon nodes.
4) Abut Active slots representing the same two vertexes.

Fig. 2 demonstrates an example of a quorum pattern graph as shown. Let us consider there are four nodes A, B, C, D and five universal time slots. Every node in the quorum will have their time slots to wake-up. The figure represents four subgraphs of the nodes A, B, C, D nodes, vertices denote active pattern time slots.

Framework:

The bequest quorum system enables all the nodes to discover their neighbors through the rendezvous path. The beacon nodes depend on the surrounding atmosphere and need to be continuously configured. The quorum schedule time pattern should be varied when they join or leave the cluster or network, and also, we have to consider the battery life of every node is different. To extend the life span and to save energy of the beacon nodes, we propose a weighted quorum graph pattern method which also considers the battery energy level. Based on the following observance, the weighted quorum graph pattern method is proposed.

1) Tractability: Optimization of the active quorum schedule.
2) Mobility: Reconfiguration of active nodes.
3) Energy conservation: Activating nodes with high energy.

TABLE II: Simulation setup

Parameter	Value
Window size	200*200
Initial Energy	14J
Transmission Power	55mW
Reception Power	85mW
Sleeping Power	50µW
Channel rate	250kbps
Time Slot	150ms
Source Rate	1 packet/second
Cycle Length	40
Packet size	90 bytes
Transmission Range	30-150m
Learning rate	0.1
Discount factor	0.7

We assumed a row-wise connection in the quorum graph and disconnections would be made if the node has less energy and will be transferred to the node having higher energy. We propose a determining factor for each row vertices x_i by the

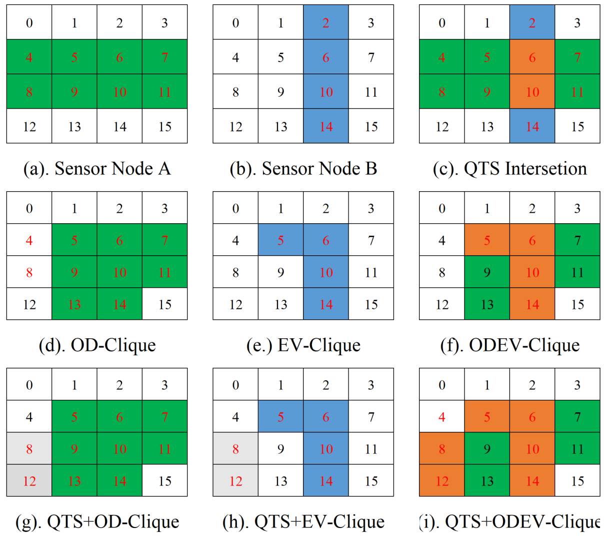


Fig. 1: Proposed Quorum System.

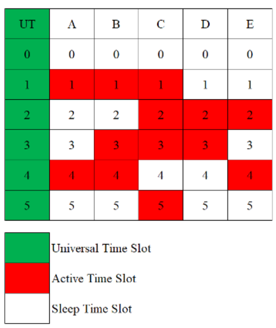


Fig. 2: Weighted quorum pattern.

mathematical expression.

$$f(x_i) = (1-\alpha)b_{x_i} + \alpha a_{x_i} \qquad (15)$$

where b_{x_i} is the Energy condition of the node, a_{x_i} is the Wake-up period accumulator, α is the System factor, and $f(x_i)$ is the determining factor to select the best among the vertices.

The following procedure is done in weighted quorum graph pattern

Algorithm 2 Weighted Quorum Graph Pattern

Initialize:
N-Total no of nodes
M-No of allocated time slots

Begin
$f(x_i) = (1-\beta)bx_i + \beta ax_i$
$f(y) = (1-\beta)b_y + \beta a_y$
  Active slots $A_i = [A_1, A_2, A_3, ..., A_m] = [\overline{A}, A_q, \underline{A}] =$
  $\overline{A} = [A_1, A_2, A_3, ..., A_{q-1}]$
  A_q - slot with many nodes
  $\underline{A} = [A_{q+1}, A_{q+2}, A_{q+}, ..., A_M]$
Calculate Vertices set
Upper Vertex $u = argmax[\overline{A_j} - A_q]1 \leq j \leq q-1 and A_q \subset \overline{A_u}$
Lower Vertex $b = argmax[\underline{A_j} - A_q]q+1 \leq j \leq M and A_q \subset \overline{A_b}$
End

Weighted quorum graph pattern is explained with an example as shown in Fig. 3. The details are given in Algorithm 2. Let us assume there are five nodes A, B, C, D, E, and node status of energy are given as $0.9, 0.7, 0.9, 0.8, 0.8$, respectively. To increase the performance, we cannot consider a universal time slot of 5 since there is only one vertex. The universal time slot 3 is selected as the postulate row, this demanded row is taken as a super graph, and it is divided into two subgraphs as upper and lower subgraphs as shown in the figure. Now, using the demanded row, we have to find the next demanded row for the upper subgraph using the determination function. The values are 0.75, 0.85, and 0.8 since the value 0.85 is greater than the other two and has more vertices, universal time slot 1 is selected as the next postulate row as shown in the figure, and the same procedure is carried out for the lower subgraph. Fig. 3 shows the final result with reduced time slots using the energy balancing technique. In the conventional quorum system, the energy decreases as the number of rings increases but our proposed QMAC protocol improves the performance in terms of network latency and network life span. The reason is that energy conservation depends on the first ring number. Experimental settings show that removing a time slot that does not perform data operations outside condense matrix, conserves energy and prolongs the network life span. However, the QMAC makes use of the remaining energy of the nodes in the area far from the sink node, thereby increasing the duty cycle and reducing latency, that is why the condensing quorum time slot only removes the quorum time slots outside the condense matrix.

IV. Performance Analysis

This section analyzes the QOECMAC protocol concerning prolonging network lifespan and improving the latency of the sensor network.

A. Network Latency

The network consist of k rings with the nearest ring numbered 1, while the farthest ring is numbered k. The average

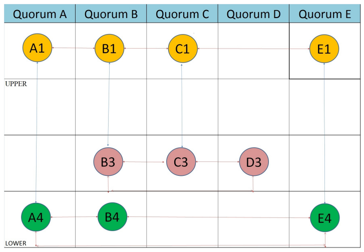


Fig. 3: Weighted load balancing scheme.

delay for forwarding the data packets for a beacon node in the k_{th} ring is determined by

$$d_k = \sum_{i=1}^{(1-\varepsilon)n-1} i\varepsilon(1-\varepsilon)^{(i-1)} P_k + \sum_{i=(1-\varepsilon)n}^{n-1} i\varepsilon(1-\varepsilon)^{(1-\varepsilon)n} P_k + n(1-P_k) \tag{16}$$

Where $P_k = \frac{n(1-(1-\varepsilon)^u)}{\rho \Sigma r \mu_k}$ and $\mu_k = \delta n B_k^t / B\tau + \delta n n(1 - P_k) B_k^r / B\tau$.

The information data can arrive at the beacon node at any possible time for slot k. If the particular slot is active, it may send the data packets, or the packet is not sent successfully in n time slots when these packets are dropped. Here, duty cycle ε is the time slots of the quorum that are active, and $(1-\varepsilon)$ is the sleeping slots of a node. The probability of successful transmission is P_i, unsuccessful is $1 - P_i$ and the delay is $n(1 - P_i)$.

B. Network Lifespan

The proposed protocol decreases the delay by utilizing the remaining energy of the farther node than that of the closest node to the sink, thus increasing the network lifespan. If there is no data transmission, then the allocated quorum system is made to sleep, which will further increase the lifetime of the network by minimizing the network latency.

The conventional energy consumption E_i each node is given by

$$E_i = T_t^1 \zeta \omega_t + T_r^1 \zeta \omega_r + T_b^1 (\zeta_d \omega_d + \omega_s(\zeta - \zeta_d)) + (n - \chi)\zeta \omega_s \tag{17}$$

Where $T_t^1 = \delta n B_1^t / B\zeta$, $T_r^1 = \delta n B_1^r / B\zeta$ and $T_b^1 = (\chi - T_t^1 - T_r^1)$.

The energy consumption of each node is mathematically represented as

$$\phi_i = T_t^1 \zeta \omega_t + T_r^1 \zeta \omega_r + \left(\frac{\chi\omega}{\sqrt{n} - T_t^1 - T_r^1}\right) * (\zeta_b \omega_b + \omega_s(\zeta - \zeta_d)) + (n - (\chi\omega)/\sqrt{n})\zeta \omega_s \tag{18}$$

The network life time $T = E_{int}/\phi_i$. Where E_{int} is the initial Energy of the node and ϕ_i is the Energy of ring 1 nodes. The network life time ratio $TR = \frac{E_{int}}{\phi_1} / \frac{E_{int}}{E_1}$ Where E_1 is the conventional Energy quorum system at ring 1 nodes.

The growth network ratio can mathematically be given by

$$\phi = \frac{T_t^1 \omega_t + T_r^1 \tau \omega_r + (n - Nw/\sqrt{n})\tau \omega_s}{T_t^1 \omega_t + T_r^1 \tau \omega_r + \delta + (n - N)\tau \omega_s} + \frac{((Nw)/\sqrt{n} - T_t^1 - T_r^1 \tau \omega_s}{T_t^1 \omega_t + T_r^1 \tau \omega_r + \delta + (n - N)\tau \omega_s} \tag{19}$$

Where $T_t^1 = \delta n B_1^t / B\tau$, $T_r^1 = \delta n B_1^r / B\tau$ and $\delta = (N - T_t^1 - T_r^1)\tau \omega_s$.

In comparison to previous protocols, this research has the following main novelties:

1) It selects more Quorum time slots (QTSs) than previous protocols in the area that is far from the sink according to the energy consumption in WSNs to decrease the network latency
2) It allocates QTSs only when data are transmitted to further decrease the network latency.

Theoretical analyses and experimental results indicate that the QTSAS protocol can greatly improve network performance compared with existing Quorum-based MAC protocols.

V. Results and Discussions

A. Average Energy Consumption in Coverage Set and Coverage Rate

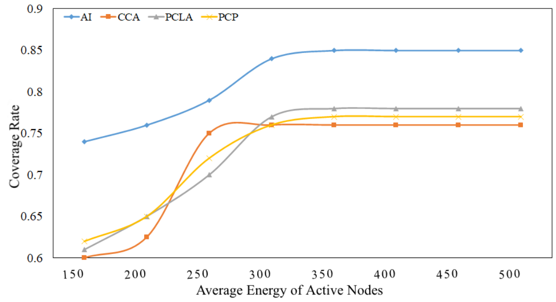
The objective of using AI learning is to increase the coverage rate and connectivity of the network. Fig. 4a shows the graph between the coverage rate and the active nodes. The proposed AI algorithm outperforms when compared with CCA, PCLA, and PCP protocols with an average coverage rate percentage of 11.7%, 10.58%, and 10.84%, respectively. Fig. 4b shows the average energy consumption in each cover set when compared with CCA, PCLA, and PCP protocols. The proposed algorithm performs better on the average increase in energy by 30.6%.

B. Addition of Quorum Time Slot

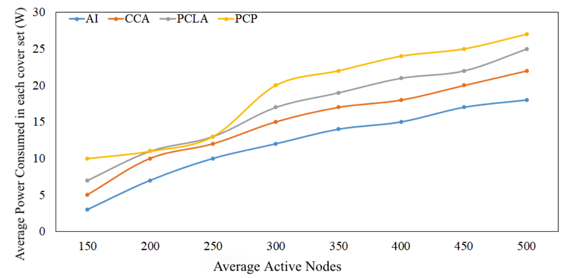
The Simulation results show that the energy dissipation nearer to the sink is higher than the far away from the sink node. Fig. 4c exploits that the average energy consumption the nearer to the sink is about 23.3% and 0.76% in the faraway node in ring numbers 1 and 12, respectively. The experimental results show very prominently that the energy in the far distance from the sink remains unused and this energy can be used to increase the number of quorum time slots in the region nearer to the sink for different values of λ. On average there is a 31.8% increase in quorum time slots that can be added in the nearer region to the sink.

C. Duty Cycles

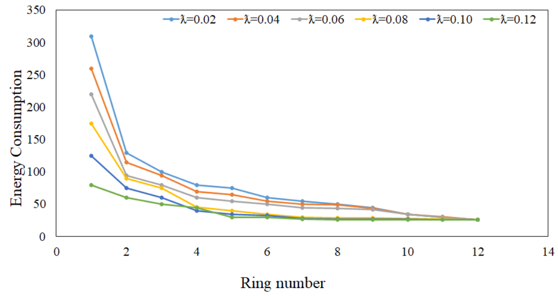
The sensor node duty cycle is increased as the traffic load is increased; however, energy consumption increases slowly, since sensor nodes use multiple channels to transmit data. The wake-up time intervals of sensor nodes will overlap only twice per duty cycle. Fig. 4d shows the comparison of duty cycles of quorum time slots and increasing the time slots by utilizing the remaining energy. The duty cycle is increased by 0.27% and 1.61% for $\lambda = \{0.015, 0.02\}$ respectively, and it is increased by making use of the remaining energy from the farther node compared to the nearer node where the duty cycle can be increased. This proves that the protocol improves not only the network performance but also increases the network timespan. The change from running (wake-up) to sleep and sleep to



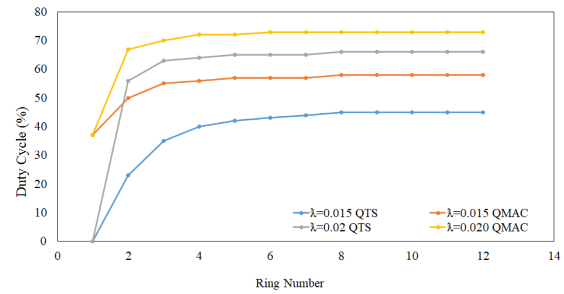
(a) Coverage Rate.



(b) Average power consumed in each cover set.

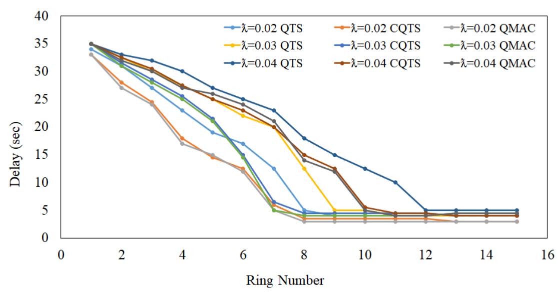


(c) Energy consumption with ring number.

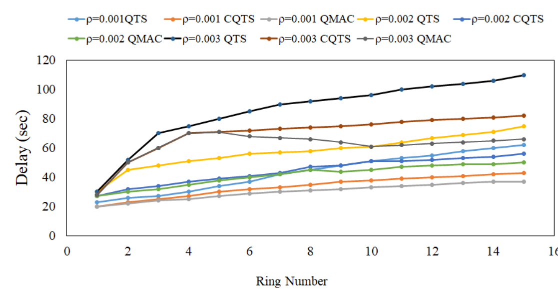


(d) Duty cycle with ring number.

Fig. 4: (a) Coverage Rate (b) Power Consumed (c) Energy Consumed (d) Duty Cycles



(a) Delay.



(b) End-to-end delay.

Fig. 5: Overall and End-to-End Delay

running (wake-up) in a sensor node has been represented as a duty cycle. If there is no communication or data transfer in WSN with others, the layer changes from operation running (wake-up) to sleep mode, then the node will be represented as a sleep mode. So, there will no communication like transmitting or receiving until the respective node becomes active. This duty cycle mechanism automatically puts the node to be active whenever needed and put inactive whenever not needed.

D. Delay

The proposed protocol considers single-hop delay and end to end delay. The transmission of data from a node to the next ring node; this delay is called a single-hop delay that considers forward delay and queue delay. The proposed protocol considers single-hop delay by 2.94% to 75% with an average reduction of delay by 14.23%. There is an increase in the quorum tie slots in the farther region, which is higher than the region nearer to the sink. When the packets arrive at the node having less traffic, then a single-hop delay will create a forwarding delay. Fig. 5a shows that the delay is almost constant and equal above ring number 12. The single-hop delay is due to heavy load at a node, and queue delay.it is noted that single-hop delay is heavier nearer the sink and farther from the sink. The end to end delay is lesser for a larger duty cycle and vice versa, as shown in the figure. The simulation results present the end to end delay for various values of ρ. The intercepts show that the end to end delay will become maximum when the node density increases. The proposed protocol reduces end-to-end delay by 2.32% to 38.67%, as shown in Fig. 5b. Fig. 5b represents the simulations of end-to-end delays concerning radius r. This demonstrates a larger radius will have a larger end to end delay, and this is due to the increase in the rate of collision. The end to end delay of the proposed method decreases from 3.70% to 43.10% and the average end to end delay is reduced by 21.54%. We assume the size of the $\sqrt{n} \times \sqrt{n}$ ($\sqrt{n}$=7), total no of slots is 49. In a conventional quorum system, we select 2 rows or columns. No of quorum time slots $= 14$, the duty cycle$= \frac{14}{49} = \frac{2}{7}$. We propose a Quorum MAC protocol, that condenses the quorum time slots in periods and uses the same time slots as the conventional quorum systems but condenses the grid into a $w \times w$ grid system. The proposed protocol utilizes the time slots that are far from the sink to increase the quorum time slots. In our experiment we use the network scale $k = 12$, now the grid of the original 7×7 is condensed into a 6×6 grid excluding the last column and row for the node far from the sink and the first column and row for the node nearer to the sink. When we condense the grid of 6×6, then the duty cycle $\frac{14}{36} = \frac{7}{18}$, the condense grid will increase the duty cycle without increasing the quorum time slots, and however, the energy is utilized from the area far from the sink. This improves the overall network performance. Fig. 6a shows the energy consumption with conventional quorum time slots. We can infer from Fig. 6a when compared to Fig. 4c that the energy decreases as the ring number increases without the addition of quorum slots. Fig. 4d shows the comparison of added quorum time slots with the proposed protocol in terms of ring number.

The addition of time slots is due to the addition of remaining energy far from the sink and the proposed algorithm not only uses the remaining energy but also uses a condensed grid so that the number of quorum time slots is increased due to this the duty cycle is increased further. In the proposed quorum MAC protocol 7×7 grid is reduced or condensed to a 6×6 matrix grid to have larger duty cycles. Thus, an increase in the duty cycle minimizes the delay which intern improves the performance of the network. The single-hop delay represents the period between ith ring to its next-hop neighbour. It is due to the forwarding delay and queuing delay. The forwarding delay is the delay of forwarding the data that includes receiving data from the network and transmitting data to the next-hop port and re-sending data if lost. Queuing delay is a delay caused due to the waiting time to send the packet. The single-hop delay is drastically reduced in the proposed model is due to the number of quorum time slots are increased for an area far from the sink. When the data production is larger, larger the packet size and the delay. Single hop delay is mainly due to forwarding delay and the forwarding delay is equal at each node. Larger the duty cycle smaller the end–end delay. When the node is far from the sink, the larger the end-end delay. As the distance increases in each ring, the end-end delay also increases. There is a possibility of an increase in data collisions that may cause more data to be re-transmitted.

The energy consumption for different values of λ for various protocols such as the quorum system, condensed quorum systems, and proposed MAC quorum systems are shown in Fig. 6a.

$$E_{total} = E_{node} + E_{syncnode} + E_{clusterhead} \tag{20}$$

In our energy consumption model, the real measurements of the node are needed to determine the energy consumption in terms of the data collection and CPU, because different device usually have different data and signaling traffic requirements as well as diverse durations of service. Average energy consumption is reduced by 61.09% in the proposed quorum MAC when compared with the quorum system and condensed quorum systems for various values of λ. Considering a single case for $\lambda = 0.4$, it is seen that as the ring number increases the energy consumption reduces to a maximum of 82.25% for ring number 15 in normal quorum system and condensed quorum systems.

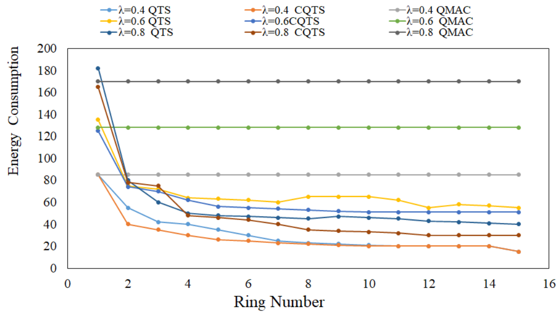
The proposed methodology is evaluated, and comparative analysis is made through various protocols such as DISCO, EQS, QS, and Proposed Weighted Quorum graphical pattern mechanism. In our analysis, mobile nodes were randomly distributed over an area of $100m \times 100m$, having transmission capacity from $2-200$m, and the mobile density was calculated with a neighbor in the range of $5-60$. Each simulated experiment was echoed 20 times, and their average is taken into account.

E. Analysis of Network Life Span over Node Population

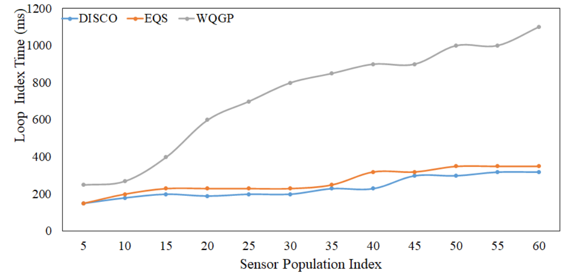
A comparative analysis is made on the conservation of energy from the weighted quorum graph pattern algorithm over other protocols like DISCO, an Extended quorum system. Fig. 7 shows the average duty cycle time to sensor population index. The average duty cycle is higher for DISCO protocol in that it takes higher active time at the initial stage as the number of rings prolongs and decreases the active time slots. As a result, only the average duty cycle fluctuates at lower rings. The conventional DISCO protocol shows larger at the beginning provides a greater advantage to its neighbors with small primes. Throughout simulation discovery of neighbors wake-up at numerous time slots. Discovery toward the start of the simulation is larger than later. It is observed that the shorter the duty cycle, the better the performance. Our proposed algorithm has the lowest duty cycle compared to DISCO and the extended Quorum systems. Our experimental results prove that low duty cycles of the weighted quorum system perform 84.94% than DISCO and 78.86% than Extended Quorum systems due to this conservation of energy can be maximized.

The loop index is the number of iterations of the loop. The number of loop index is calculated for different sensor population. For better performance and resourcefulness apportionment, the loop index should be high. Loop index time The loop index time is reduced in the proposed weighted quorum mac due to the use of the remaining energy of the nodes in the area far from the sink node, thereby increasing the duty cycle and reducing latency and the energy is compared with the neighbouring nodes. In this way, the energy is balanced when compared with other algorithms like EQS and DISCO. To extend the life span and to save energy of the beacon nodes, we propose a weighted quorum graph pattern method which also considers the battery energy level. Based on the following observations, the weighted quorum graph pattern method is proposed.

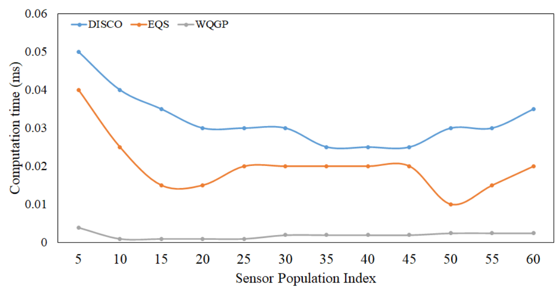
Traceability: Optimization of an active quorum schedule. **Mobility**: Reconfiguration o f a ctive n odes. E nergy conservation: Activating nodes with high energy. We assume row-wise connection in the quorum graph and disconnections would be made if the node has less energy and will be transferred to the node having higher energy. The DISCO protocol has a higher loop index time than other protocols because the distribution shows a larger discovery rate in the beginning; the protocol gives an advantage to neighbors with distinct smaller primes.



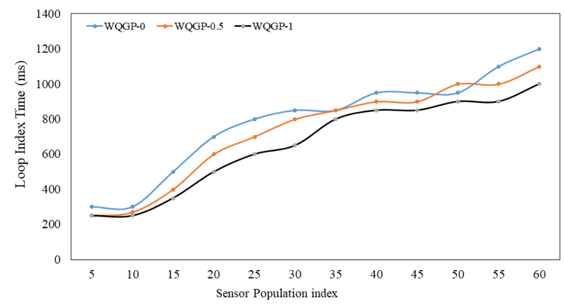
(a) Energy consumption pattern.



(b) Average Loop Index



(c) Computational time.



(d) Decision factor.

Fig. 6: (a) Energy Consumption Pattern (b) Loop Index (c) Computational Time (d) Decision Factor

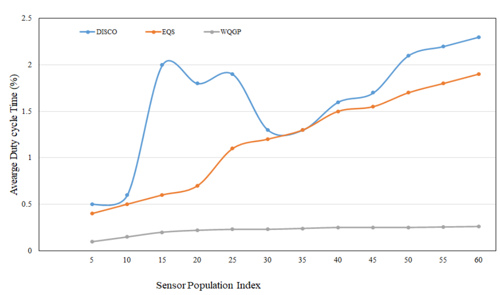


Fig. 7: Average Duty cycle.

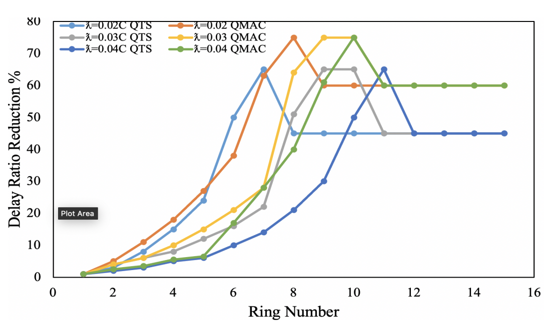


Fig. 8: Delay Ratio reduction.

Throughout the simulation, neighbors with smaller primes are simultaneously awake in numerous slots; however, we only count the first such slot for discovery.

Fig. 6b shows the loop index versus sensor population index. The mean loop index is compared with DISCO, EQS, and WQGP. Results show that the weighted quorum graph pattern algorithm has the highest loop times average when compared with the existing methodologies like DISCO and EQS. over performs on an average of 63.42% and 58.84% respectively.

In a mobile environment, even though the node can move dynamically in the network, our proposed algorithm stands rigid when a device enters the network. Fig. 6c shows the DISCO and EQS with a rapid variation of computational time concerning sensor population index. On average, the computational time decreases drastically when compared with our proposed scheme concerning DISCO. This even usually shows that the DISCO protocol has a very shorter duration to reschedule the node because of its larger computation time when compared with the EQS system. The proposed model reduces single hop delay, there is a largest reduction in hop delay from 1% to 70% and on an average delay is reduced by 21.34% as shown in Fig. 8.

F. Optimal Decisiveness Action

Our main objective is to put an optimal solution to energy conservation, and it is observed that for an optimal solution, the system factor plays a major role. Fig. 6d shows the variation of loop index time over the sensor population index. For different values of decision factors, the plots are given. It is visualized that there is a minimum deviation of 8.5% when $\alpha = 0.5$ and $\alpha = 0$. The deciding factor is varied from $\alpha = 0.5$ to $\alpha = 1$, there is a deviation of 9.6% and compared between $\alpha = 0$ and $\alpha = 1$, the deviation caused by an average of 17.2%. To have maximum loop index time. We should opt for the minimum value of decisiveness action α.

VI. Conclusion

A novel artificial intelligence-based quorum time management system is proposed to minimize the delay of packets, improve the coverage rate and connectivity, thereby increasing network life span and energy efficiency. There are three contributions in this paper; the first is that we improved the coverage rate and connectivity by applying Artificial Intelligence-based Q-learning; the second is the condensation of quorum time slots which significantly reduces the network latency and the third being energy utilization performed from the remote nodes to the sink to prolong the duty cycle and network life span. The proposed protocol utilizes the time slots that are far from the sink to increase the quorum time slots. In our experiment, we used the network scale $k = 12$, with the grid of the original 7×7 condensed into a 6×6 grid excluding the last column and row for the node far from the sink and the first column and row for the node nearer to the sink. When we condensed the grid of 6×6, the duty cycle changes from $\frac{14}{36} to \frac{7}{18}$. The condensed grid increases the duty cycle without increasing the quorum time slots. The delay can also be reduced and the energy utilized from the area far from the sink. This improves overall network performance. The simulation results perform better when compared to other quorum algorithms presented in the literature in terms of network latency, delay, energy efficiency, and network life span. In the future, we shall consider applying AI to an automated smart grid, ensuring a two-way flow of energy and limiting the rise in peak electricity load on the grid to only 1 percent.

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