Wireless sensor networks based efficient drip irrigation monitoring systems

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ABSTRACT

Cotton has profound significance in the textile industry due to its versatility, comfort and ease of care. But the main problem with conventional cotton farming is that it uses more water. These issues are made more difficult by conventional irrigation methods, such as drip irrigation. To address this problem researchers are using traditional farming techniques with advanced wireless sensor network (WSN) protocols to resolve catastrophic issues, such as pipe bursts or blocked emitters which are detected early to save the water. This paper introduces efficient WSN architecture using priority-based directed information sharing (DIS) protocol for efficient utilization of water. The proposed architecture was implemented using TinyOS sensor network (TOSSIM) simulators. Exceptional quality of service (QoS) is achieved using new routing protocol exclusively for catastrophic failures. The proposed architecture is compared with standard protocols such as topology geographic greedy forwarding (TPGF), link carrier sense avoidance (LinkCSA) and tiny carrier sense avoidance (TinyCSA). Due to implementation optimized priority, DIS latency has been reduced from 11.3% to 11.02% and packet delivery ratio (PDR) is enhanced by 35% to 78% concerning benchmark protocols. The experimental results proves drastic improvement in PDR and delay performance as compared to the existing WSN protocol.

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1. INTRODUCTION

Growing cotton is a major contributor to the world's textile industry. Cotton crops have high water demand, most areas are scarce due to deforestation, and pollution leading to sudden change in the climate. Precision agriculture has become an innovative method in the field of agricultural practices in the past years and in the future. The primary objective is to monitor the land's physical and historical characteristics to maximize crop output while preserving the environment, and energy [1]. As a solution to this, wireless sensor networks have been used in the agriculture industry [2]. In the conventional approach, sensor nodes are deployed underground to monitor parameters like soil moisture, water, and mineral content, and they are linked to a wireless transceiver through physical cables [3], [4].

Nevertheless, ensuring dependable wireless communication in underground environments remains a recent subject of exploration for researchers in the field of precision agriculture. To monitor farmland, the most effective irrigation strategy for water conservation is the drip irrigation system, particularly when combined with wireless sensor networks (WSNs). In addition to this, a potential malfunctioning monitoring system has been incorporated for early detection of catastrophic failures. The main challenges are getting accurate data on time, reducing harm to the environment, setting up reliable ways to share information, and dealing with system breakdowns. The main goals are to set up fast real-time communication and to test how well it works through simulations [5].

This research work aims to improve a priority-based DIS protocol within a wireless sensor network to enhance water use efficiency in cotton farming. By optimizing the protocol, it will detect and address major irrigation system breakdowns, ensuring faster responses and more reliable packet delivery compared to traditional WSN methods. The enhanced protocol focuses on minimizing water supply disruptions, reducing crop stress and boosting productivity. Prioritizing critical data improves communication speed and success rates, allowing for better irrigation management, efficient water usage, and increased operational resilience in cotton farming.

This article is organized as follows: section 2 discusses related work designed for efficient irrigation systems. Section 3 discusses drip irrigation system design and priority-based routing protocol. In section 4, the results of our proposed scheme through simulations and experiments are presented. In section 5, we conclude the work and provide future perspectives.

2. RELATED WORK

This section explores the latest research on issues and challenges in automated irrigation systems, focusing on system inefficiencies and technological limitations. Key challenges include unreliable sensor data, communication delays, and system breakdowns that disrupt water distribution. While potential solutions like improved sensor accuracy and fault detection algorithms exist, they have drawbacks such as high costs and complex implementation. Addressing these challenges is crucial for enhancing the effectiveness of automated irrigation in precision agriculture.

The specialized literature has not proposed utilizing WSN with a priority-based routing protocol to monitor the malfunction of drip irrigation systems. The following section discusses the work related to irrigation system control [6], [7]. The studies [8], [9] proposed an energy-saving technique for wireless sensor transmission in smart agricultural irrigation systems. This technique lessens radio interference while conserving energy for the node. Another study proposed a computerized irrigation scheme centered on WSN technology to improve water usage in agriculture [10]. The method used two sensors to gather information on water content and soil temperature in the area where the plant roots are located. To gather sensor data, turn on actuators, and deliver the data to an online app, a gateway was used. To regulate the flow of water, the scientists then programmed a system into an embedded system and established precise temperatures and moisture in the soil threshold values.

The contribution in study [11] is to the design and implementation of a low-cost energy-efficient irrigation management system combining measuring devices and actuators within a WSNs. In their concluding observations, the authors stress the importance of placing sensor nodes in farms and suggest that reducing the separation among the sensor nodes is essential for enhancing system efficacy. However, the fact that the research used just five sensors is a major drawback of the work. Kumar *et al.* [12] aim to propose a comprehensive irrigation solution catered to present requirements within the backdrop of associated research initiatives. The key issue raised today is how to create a fully autonomous irrigation system that optimizes water wastage while being financially feasible. Sakthivel *et al.* [13] does not delve into the specifics of how much energy the automated irrigation system might consume a factor, for sustainability and cost efficiency. Moreover, there is no mention of the issues or factors [14] to consider when it comes to maintaining and calibrating the sensors in the sensor networks crucial for precise data gathering and decision-making. It barely explains how to enhance the system to cover bigger agricultural areas or different crop types [15].

Miya *et al.* [16] is shallow in its review of the possible downsides and difficulties that would inherently stem from using wireless gadgets for water supervision purposes among agricultural ecosystems. The paper does not provide insight into the scalability of the water monitoring system being proposed, which holds certain repercussions for how it can be practically managed on a wider scale. Kumar *et al.* [17] deals only with long range and internet of things (IoT) in auto irrigation systems specifically while they mention nothing about other smart technologies that can be combined to enhance the smart agriculture systems effectively. Although the paper states the necessity of monitoring the environmental parameters in agriculture, they fail to deeply discuss the potential cybersecurity threats and data privacy concerns related to smart agriculture systems implemented using IoT devices and wireless sensor networks which are significant factors to consider in the implementation. The aim of the paper [18] is to show how WSN and IoT are being applied in managing water needs on farms, but it does not go into any details about difficulties encountered while implementing them. The research paper underscores several advantages of using an IoT-based system in farming although it fails to extensively evaluate possible privacy issues and cyber menaces that may stem from adopting IoT devices in a field setting.

Most of the author's main contribution is developing a groundbreaking wireless sensor network design that includes a priority-based disaster information sharing (DIS) protocol to boost water productivity in cotton farming. The author makes a big impact on the area of smart agriculture by making water management methods better for growing cotton. However, the mentioned works do not address the reliable solution to the current irrigation system failures and less scope has been given to quality of service (QoS). The extensive literature survey shows a high demand for priority-based protocols for the aforementioned problems.

3. PROPOSED METHOD

This section describes a new wireless sensor and actuator network (WSAN) model for optimizing drip irrigation systems. By applying improved carrier sense aware-multipath geographic routing (CSA-MGR) protocol characteristics and functionality to the proposed model and leveraging the dual traffic levels concept to boost throughput and delay, the performance of the proposed model is improved. Our proposed model employs dual traffic levels to ensure reliable data delivery in drip irrigation systems. First, traffic is generated by sensors like temperature and soil sensors. The second is based on priority which is generated by pressure sensors, which is more crucial and needs immediate attention to prevent wastage of water and damage to the crop. To improve the performance of the proposed system, features and functionality of the CSA-MGR protocol have been considered by utilizing the concept of dual traffic levels to enhance throughput and delay. Figure 1 shows the flow diagram of the proposed system.

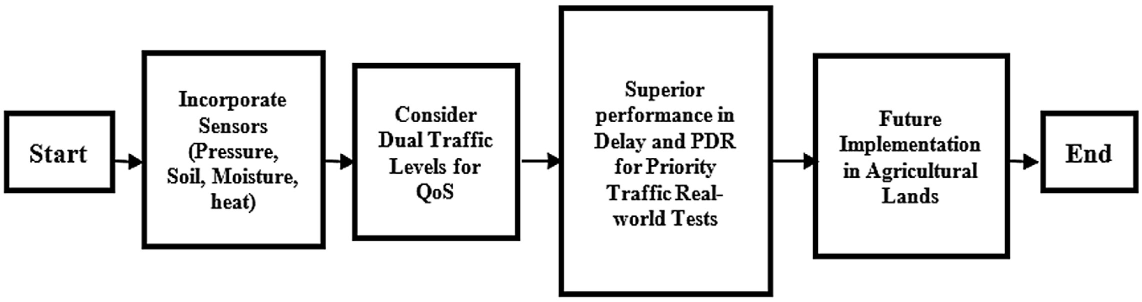

Figure 1. Flow diagram of the proposed work

3.1. Working principle of the proposed system

The first approach is drip irrigation, which involves the utilization of pipes containing emitters to deliver water directly to the roots of the plants. This system comprises essential elements such as a water source, a primary pipeline, and a series of secondary pipes linked to the main one through manual or automated valves. The second technique is known as sprinkler irrigation, where pressurized water is pumped and subsequently directed to nozzles that disperse water into the air. But this method is less competent because of the wastage of water owed to evaporation and runoff which is. Consequently, the drip irrigation method emerges as the superior choice for our design. Figure 2 shows the deployment and data flow between sensor nodes and actuators [19].

The model we propose employs a closed-loop methodology, wherein the system consistently observes its reactions and utilizes the input to enact necessary modifications in its control mechanisms. This model is crafted with a focus on tailored irrigation for specific sites, enabling adjustments in crop watering that account for both temporal and spatial considerations. The proposed design's main goal is to address the shortcomings of the current drip irrigation method. Variations in soil type, crop variety, and weather patterns are the causes of these discrepancies, along with a focus on addressing the issues associated with drip irrigation setup malfunctions. To address these challenges, it becomes essential to continuously monitor the water flow rate within the drip irrigation system and at the same time water the crops with a balanced quantity of water [20], [21].

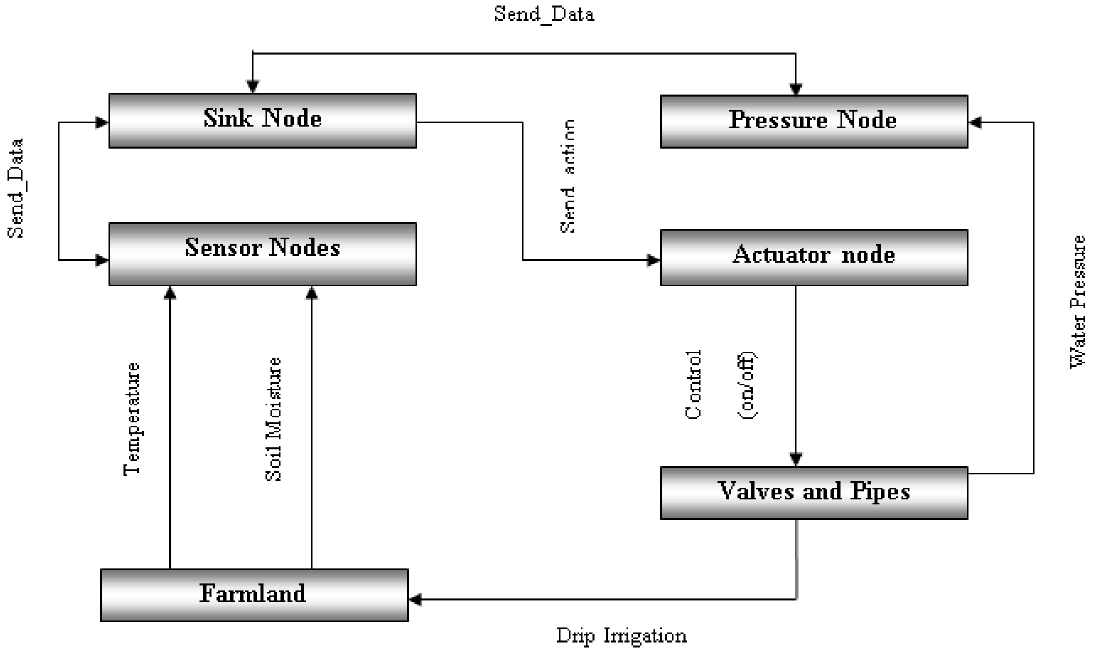

Figure 2. Deployment of sensor nodes and actuator networks

3.2. Priority-based DIS

In the proposed protocol, two primary sorts of traffic are produced by the sensors. Temperatures and soil moisture are the first category, which we describe as typical traffic because no immediate action is needed. The next kind, which is obtained from sensors that measure pressure, is categorized as priority traffic since any difficulties that are discovered must be resolved right away, either by closing the primary valve or needing human assistance. Whenever multiple traffic types are operating at the same time, it is obvious that priority traffic focuses on dependability and punctuality over regular traffic [22]. As a result, to complete the quality-of-service criteria for each traffic type and prevent collisions among many different sources of traffic, a suitable forwarding procedure must be used. In this work, an explanation for how pathways with various traffic priorities might be built to meet these issues is provided in the sections that follow.

3.3. Mathematical model for priority based DIS protocol

Priority-based DIS improves communication by setting priority levels for different conditions or QoS depending upon its requirements. This protocol provides interference suppression from different nodes, accessing of spectrum, dynamically setting up of priority and guaranteed QoS. A simplified mathematical model for multipath priority-based DIS can be formulated as an optimization problem. Let N be the total number of nodes in the system, pi is the priority level for the node where $i = 1, 2, 3, \ldots, N$ and the range of priority value is [1, M] where M is the maximum priority. $\theta i, \tau i, \Omega i$ and λi represent interference experienced, the requirement of data rate, QoS requirement and available spectrum resources of the ith node respectively.

The proposed model is represented in six stages assignment of priority, interference suppression, allocation of resources, guaranteed QoS, allocation of data rate and dynamic adjustment. Assignment of priority (p_i): Priority is denoted by pi which is determined based on requirement of service requested from the ith node. Setting up of priority is formulated as a function of node's requirement which is given by (1),

$$p_i = f(requirement\ of\ the\ user_i) \quad (1)$$

The function f takes different values based on fixed, dynamic and user specific priority

$$p_i = \begin{cases} K\ constant\ value\ for\ ficed\ priority \\ g(real_{time})\ realtime\ value \\ h(User_{specific}) Specified\ by\ the\ user \end{cases}$$

- Interference suppression (θ_i): This can be modeled using power-controlled strategy. Let P_j denotes transmitted power of the j^{th} device and G_{ij} represents channel gain between i^{th} device and j^{th} device so that (2),

$$\partial_i = \sum_{j \neq i} P_i G_{ij} \qquad \text{where i, j} = 1,2, \ldots .. \text{N} \tag{2}$$

Equation (2) represents interference experienced from all other nodes to i^{th} node as a sum of products of their transmitted power and channel gain. To suppress θ_i one must control the power and adjust values dynamically with objective is to minimize the power. The objective function to suppress θ_i can be w. Algorithm 1, implementation of priority DIS protocol.

$$\theta_i = min \sum_{i=1}^{N} \theta_i \tag{3}$$

subjected to condition $P_{min} \leq P_i \leq P_{max}$ where P_{min} and P_{max} are maximum and minimum power of the device. The equation (3) minimizes the total interference consumed by all nodes with respect to power levels.

- Resource allocation (λ_i): Allocation of required resources in proposed model can be done by considering spectrum of resources λ_i to each node i by fulfilling Ω_i at data rate τ_i. The whole resource allocation process can be formulated as a problem of optimization subjected to goal of maximizing system utility based on availability of spectrum and node's requirement, utility of each node can be expressed as a function of its allocated spectrum resource, say $U_i(\lambda_i)$. Next, aim is to maximize the allocation of resources using (4),

$$\lambda_i = maximize \sum_{i=1}^{N} U_i(\lambda_i) \tag{4}$$

with a constraint

$$\{\sum_{i=1}^{N} \lambda_i \leq \lambda_{total} , \Omega_i (\lambda_i) \geq \Omega_{min,} \tau_i(\lambda_i) \geq \tau_{min}, \lambda_{min} \leq \lambda_\text{i} \leq \lambda_\text{max} \}, \forall \text{ i=1, 2, ………., N.}$$

Using (4) protocol, we are able to allocate the spectrum of resources to all nodes so that overall utility is maximized.

- Quality of service (Ω_i): Quality of service in proposed model is achieved by maximizing the utilities derived from allocated resources. The primary goal of the model is to achieve higher packet delivery ratio and minimum delay in delivery of a packet. To achieve the goal let us consider Ω_i is the quality of the service requirement of i^{th} node where i =1, 2, …, N. Guaranteed QoS can be formulated as (5),

$$\Omega_i = maximize \sum_{i=1}^{N} U_i(\lambda_i) \tag{5}$$

with a constraint

$$\left\{\sum_{i=1}^{N} \lambda_i \leq \lambda_{total}, \Omega_i(\lambda_i) \geq \Omega_{min}, \tau_i(\lambda_i) \geq \tau_{min}, \lambda_{min} \leq \lambda_i \leq \lambda_{min} \right\}, \forall\, i = 1,2,3 \ldots N.$$

Using (5) protocol can allocate the resources so that system utility is maximized while maintain QoS.

- Data rate allocation (τ_i): Data rate τ_i allocation in the proposed architecture is achieved by maximizing system throughput without disturbing user requirements. Let τ_i denote data requirement of i^{th} node where i = 1, 2, …, N. Objective function to maximize data rate is given by (6),

$$\tau_i = maximize \sum_{i=1}^{N} \tau_i \tag{6}$$

with a constraint

$$\left\{\sum_{i=1}^{N} \lambda_i \leq \lambda_{total}, \tau_i(\lambda_i) \geq \tau_{min}, \lambda_{min} \leq \lambda_i \leq \lambda_{max} \right\}, \forall\, i = 1,2,3 \ldots N.$$

- Dynamic adjustment: dynamic adjustment is achieved by changing data rate τ_i and interference θ_i adaptively. Depending upon the conditions of network priority scheduling will be done. This is achieved by maximizing the system performance,

$$maximize \sum_{i=1}^{N} U_i(\lambda_i) \quad (7)$$

with a constraint

$$\{\theta_i \leq \theta_{max}, \tau_i(\lambda_i) \geq \tau_{min}, \Omega_i(\lambda_i) \geq \Omega_{min}, \lambda_{min} \leq \lambda_i \leq \lambda_{max}\}, \forall\, i = 1,2,3 \ldots . N$$

From (7) overall system performance will be enhanced by ensuring the interference range is within the desired range.

Algorithm l. Implementation of priority DIS protocol

```
1. Definition:
       HPQ: High Priority Queue
       LPQ: Low Priority Queue
       Node: A device in a network
       MAT: Time of message arrival to a node.
       NSI: Information about length of queue, network states.
       MsgInt: Message interval at nodes exchange the information.
2. Initialization:
       Initialization of HPQ and LPQ at each node
       Node initialization to keep track of queue length and status of queue.
3. Message Arrival:
       While network is in operation:
               If message Priority =- High
                 HPQ enqueue (message)
               Else:
                 LPO enqueue (message)
               Update NSI
4. Exchange of information:
       At each interval:
       Exchange NSI information with neighboring node.
               Update NSI
5. Propagation of message
       If HPQ is not empty:
         Prioritize the sharing of high priority message from HPO
       Else:
         sharing of high priority message from LPQ
6. Dynamic Adjustment: Dynamically adjust the frequency of propagation messages based on
   current load and queue length
       If length HP)>>length (LPO):
         Increase the frequency of high priority messages
       If length (LPQ)>length (HPQ):
         Increase the frequency of low priority messages.
7. Congestion Control:
       If congestion Detected
         Signal the neighbor
         Adjust the propagation rate or reroute message
       Update NSI
8. Stop
```

The above-described algorithm is implemented using the TOSSIM simulator to model the behavior of the priority DIS protocol in a controlled environment. TOSSIM allows for precise testing of message prioritization, queue management, and dynamic adjustments in network load. The protocol's performance under different congestion scenarios is evaluated by simulating real-world conditions. The experimental results, which will be detailed in the next section, highlight the protocol's efficiency in handling high-priority messages and controlling network congestion.

4. EXPERIMENTATION AND RESULT ANALYSIS

4.1. Experimental setup

The experiment was conducted using the TOSSIM simulator, utilizing the TelosB mote configuration outlined in Table 1. This setup ensures accurate simulation of network behavior under the proposed protocol. Figure 3 visually illustrates the network layout, highlighting the placement and configuration of nodes for comprehensive testing and performance evaluation.

The network topology includes two sources (mote 1 and 2), 12 intermediate motes, and a single sink (mote 15). The sink is powered via a universal serial bus (USB) cable connected to a main personal computer (PC), and all motes are programmed through the USB port. A USB hub with 13 ports is used to compile multiple motes simultaneously using a shell script. An additional mote serves as a remote control to ensure synchronized startup of all network motes. This mote is programmed with NESC code to broadcast a special packet at high transmission power, prompting any receiving mote to perform a system reset. Debugging was conducted on the central PC, with motes sending debug messages via USB interfaces. Although this setup represents a small-scale sensor network, the experiment is valuable as it demonstrates protocol behavior in a real hardware environment. The TOSSIM simulator retains the physical and link-layer properties of WSNs, providing a realistic environment for evaluating various protocols and algorithms [18]. We utilize the Cutecom tool to record the testbed’s performance in a trace file, specifically tracking the packet delivery ratio and the average packet delay between the source and destination. Additionally, the protocol allows for the accumulation of noise, which can either increase or decrease the link gain. To address this issue, our protocol is adjusted as follows: during the discovery period, every node keeps track of the count of hello packets received from each neighbor within its internal memory. This is accomplished by computing the percentage difference between the total number of hello messages that are received by the total amount that was anticipated. The subsequent hop is selected throughout the routing procedure depending on the connection’s trustworthiness, with a predetermined threshold. In the situation at hand, 70% is the necessary and sufficient percentage. Tiny carrier sense avoidance (TinyCSA) is an altered variant of the CSA-MGR protocol in which every starting node just creates a single pathway to the endpoint.

Table1. Configuration parameters

Sl. No.	Parameter	Specification
1	MAC layer framework	IEEE 802.15.4
2	Path loss exponent	4.7
3	Distance	3 meters
4	Path loss at reference distance	56.4 dB
5	Packet size	54 bytes
6	Frequency	2.4 GHz

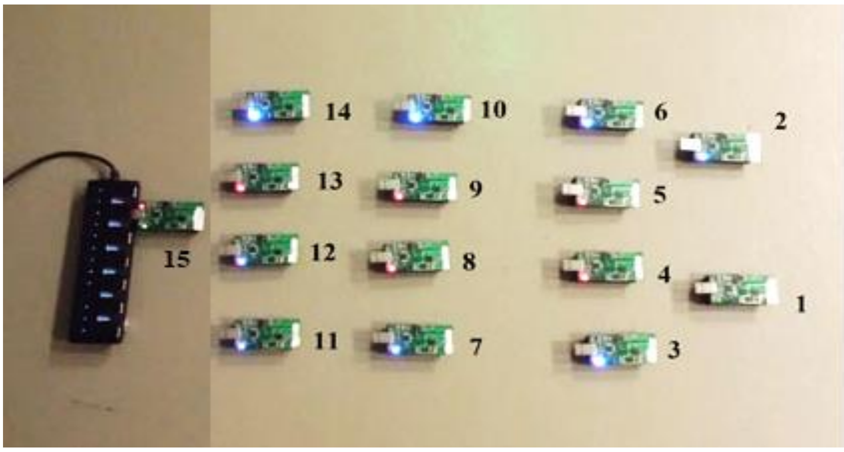

Figure 3. Experimental topology

4.1. Result analysis

In simulating wireless communication systems, key parameters like delay and latency are critical, especially for applications such as irrigation wireless sensor networks. These factors determine how efficiently data is transmitted. High delays can lead to inefficient water management and system failures [23], [24].

4.1.1. Key metrics

Average delay: calculated as the average time taken for packets to travel from the source to the destination. Packet delivery ratio (PDR): The ratio of successfully delivered packets to the total number of packets sent. The proposed protocol exhibited lower average delays compared to other protocols, indicating efficient data transmission and reduced latency. This finding supports the objective of enhancing communication efficiency in WSNs. The average delay is written as (9),

$$avg\_delay = \frac{\sum_{i=1}^{N} d_i}{N} \quad (9)$$

where N is the total number of packets received and d_i does i^{th} packet experience the delay. It is not easy to measure directly but can be estimated using the traffic load of a network. Packet-delivery-ratio can be calculated as (10).

$$PDR = \left(\frac{Number\ of\ Packets\ received}{Number\ of\ pakets\ sent}\right) \times 100\% \quad (10)$$

Table 2 compares average delay percentages between CSA-MGR and the priority DIS protocol across different protocols like topology geographic greedy forwarding (TPGF), LINK Aware, TinyCSA, and Tiny Hop, measured at varying packets per second (PPS) rates. The results show that priority DIS consistently reduces delay compared to CSA-MGR, particularly in TPGF, where delays drop significantly from 20% to 13% at 10 PPS and from 32% to 26% at 21 PPS. Across all protocols, priority DIS demonstrates better delay performance, improving network efficiency. The PDR was measured across different protocols such as TinyCSA, LINK-Aware, and TPGF.

- TinyCSA: Demonstrated superior PDR performance, effectively avoiding the carrier sense effect. This suggests that TinyCSA is more reliable for applications requiring high data integrity.
- LINK-Aware protocol: showed relatively good PDR performance, considering link reliability during path construction. This indicates a balanced approach between reliability and performance.
- TPGF protocol: displayed lower PDR results due to its greedy forwarding approach, which prioritizes paths closest to the sink. This highlights a trade-off between path optimality and reliability.
- Tiny-hop protocol: Had the lowest PDR, attributed to acknowledgement and retransmission issues, emphasizing the need for robust acknowledgment mechanisms in WSNs. Different values obtained from experiment is depicted in Table 3 and it compared with standard sensor network protocols like TPGF, LINK Aware, tiny cluster-based self-organization algorithm, tiny hop-based routing protocol.

Table 2. Comparison of average delay vs. PPS with different protocols

PPS	Delay (%) in CSA-MGR vs Priority DIS							
	TPGF		LINK Aware		TinyCSA		Tiny Hop	
	CSA-MGR	Priority DIS	CSA-MGR	Priority DIS	CSA-MGR	Priority DIS	CSA-MGR	Priority DIS
10	20	13	22	21	23	25	110	112
21	32	26	23	23	24	21	105	108
22	33	23	24	24	25	27	110	110
24	29	28	25	26	26	25	115	113
18	25	19	27	23	28	24	125	111
19	26	21	28	21	29	29	130	106
20	27	25	29	21	34	32	135	105

*PPS-Packets Per Second

Table 3. Packet delivery ratio vs PPS

	PDR (%) in CSA-MGR vs Priority DIS							
	TPGF		LINK Aware		TinyCSA		Tinyhop	
PPS	CSA-MGR	Priority DIS	CSA-MGR	Priority DIS	CSA-MGR	Priority DIS	CSA-MGR	Priority DIS
10	25	35	45	52	64	78	78	88
15	17	27	44	51	69	85	76	87
20	15	19	32	50.41	66	84.12	74	86
25	8	16	30	50	60	78	66	78
30	9	12	27	48	55	73	60	72
35	10	11	23	45	52	68	56	68
40	5	10	21	40	45	64	52	65
45	4	9	19	38	36	59	45	59
50	5	8	12	35	27	54	37	56

Regardless of the PPS number, TinyHop consistently exhibits higher latency compared to other protocols, which is noteworthy. This difference is attributed to the design of the TinyHop protocol. While it operates similarly to the ad-hoc on-demand distance vector (AODV) protocol, it incorporates a separate acknowledgement process for every control and information packet. However, enabling acknowledgements for information packets could extend the waiting time due to potential collisions or channel utilization issues, especially at higher PPS rates. Figure 4 illustrates the average delay vs. PPS, showing that the proposed protocol significantly reduces latency. On the other hand, existing protocols exhibit similar delay performance. Table 3 compares the PDR vs. PPS across different protocols, demonstrating the superior performance of TinyCSA [25], [26]. The average PDR changes for an increasing number of PPS (starting at 10 and going up to 50). PDR declines at TPGF and values decrease from 35 per cent to 8 per cent as PPS increases. In contrast, LINK Aware shows a relatively stable PDR of around 50%, while CSA demonstrates a gradual decrease from 78% to 54%. Tiny Hop exhibits the highest PDR, starting at 88% and decreasing to 56% as PPS increases. This analysis suggests that TPGF may struggle to maintain packet delivery rates as PPS increases, while LINK Aware and CSA offer more consistent performance, and Tiny Hop consistently achieves higher PDRs across the range of PPS values.

Figure 5 shows the PDR for various protocols against the PPS parameter, highlighting the superior performance of TinyCS. The observed trend shows that the PDR generally decreases as the PPS parameter increases. Remarkably, TinyCSA achieves better PDR compared to the other protocols, which is expected as the paths constructed for both sources in TinyCSA avoid the carrier sense effect. The LINK-Aware protocol also demonstrates relatively good PDR performance, as the path construction process considers link reliability. However, the TPGF protocol exhibits lower PDR because of its greedy forwarding approach. Another characteristic observed is that during the path construction process, it always chooses the one closest to the sink. Lastly, the Tiny-Hop protocol shows the least PDR result, which can be attributed to the challenges related to acknowledgements and potential retransmissions.

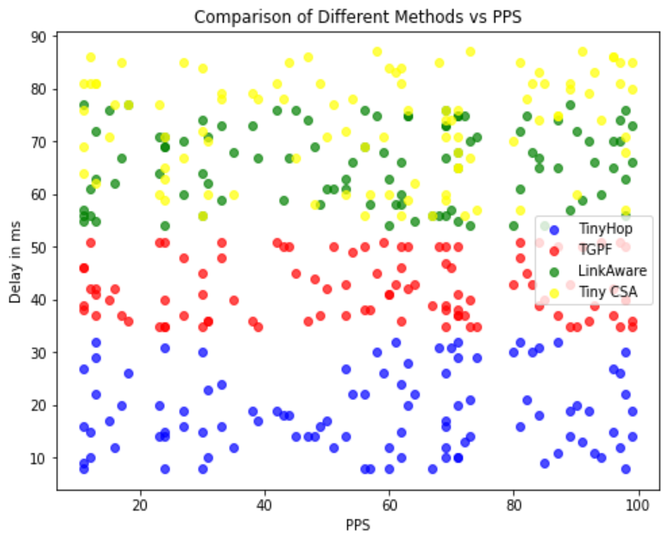

Figure 4. Average delay vs PPS

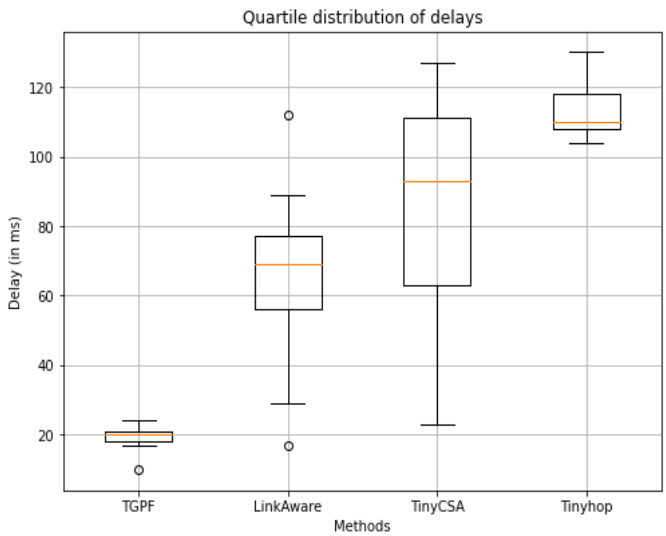

Figure 5. Number of PPS vs PDR

4.2. Discussion

This research discusses performance optimization for precision agriculture using four WSN protocols, namely TinyCSA, Link-aware, TPGF, and Tiny-Hop. The priority-based protocol of TinyCSA provides a better packet delivery ratio (PDR) without carrier sense issues, and hence, the network is highly reliable. The performance was also well-balanced with reliability due to the link awareness of the Link-aware protocol. However, the performance of TPGF was not that good in dense networks, while Tiny-Hop faced problems with acknowledgment. The results show protocols such as TinyCSA, based on priority protocols, greatly improve communication efficiency.

- TinyCSA: Achieved better PDR by constructing paths that avoid the carrier sense effect, enhancing overall network performance. This finding aligns with the hypothesis that priority-based protocols can improve network reliability.
- Link-aware protocol: Balanced between path reliability and performance, which supports the objective of achieving efficient and reliable communication.
- TPGF protocol: Struggled with lower PDR due to its path selection strategy, indicating the limitations of greedy forwarding in dense network scenarios.
- Tiny-Hop protocol: Faced challenges with acknowledgments, leading to reduced PDR, highlighting the importance of efficient acknowledgment mechanisms.

The results from TinyCSA indicate that priority-based protocols are highly effective in optimizing WSN performance, particularly in scenarios requiring high data integrity and low latency. The superior performance of TinyCSA in terms of PDR suggests that priority-based protocols can significantly improve network reliability, aligning with the study's objective of enhancing communication efficiency in WSNs. Compared to previous studies, TinyCSA's ability to avoid the carrier sense effect marks a notable improvement. However, the study's reliance on simulations limits the generalizability of these findings. Unexpected results in the TPGF protocol indicate potential issues with greedy forwarding in dense networks, warranting further investigation. This research work is aimed at developing an efficient WSN architecture for better water utilization in precision agriculture. The findings underscore the importance of priority-based protocols, but future research should test these protocols in real-world agricultural settings and consider additional QoS parameters. Unanswered questions include the protocols' performance under varying environmental conditions and their applicability to other WSN applications.

5. CONCLUSIONS AND FUTURE WORK

In this work, a WSAN-based architectural model for drip irrigation system is proposed. This model includes sensors to measure pressure, temperature, and soil moisture to track irrigation operations, including instances of system failure. We achieved high QoS performance when compared with the CSA-MGR protocol and considering two traffic levels. Our method performs better than the existing protocols in the terminology of latency and PDR for priority traffic, as shown by extensive simulations using the TOSSIM simulator. We also performed tests in a real test environment, confirming appreciable advancements over current techniques. We intend to concentrate our future work on actual agricultural lands with added QoS parameters.

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