Energy-efficient data-aggregation for optimizing quality of service using mobile agents in wireless sensor network

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ABSTRACT

Quality of service (QoS) is essential for carrying out data transmission using resource-constrained sensor nodes in wireless sensor network (WSN). The introduction of mobile agent-based data aggregation is reported to offer energy efficiency; however, it has limitations, especially using a single mobile agent, where QoS optimization is not feasible. A review of existing studies showcases some dedicated attempts to use a mobile agent-based approach and address QoS enhancements. However, they were never combined studied. Therefore, this paper introduces a unique concept of retaining maximum QoS performance during data aggregation using a single mobile agent. The model introduces a unique communication framework, transmission provisioning using exceptional routine management, and simplified energy modeling. The proposed model has aimed for a lower delay and faster data aggregation speed with lower consumption of transmittance energy. The implementation and assessment of the model are carried out considering the challenging environment of WSN with multiple scales of data priority. The proposed model also contributes to evolving out with simplified communication vectors in a highly decentralized method. MATLAB's simulation outcome shows that the proposed system offers better delay performance, optimal energy management, and faster response time than existing schemes.

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1. INTRODUCTION

Wireless sensor network (WSN) has contributed for the past two decades to facilitating environmental sensing of physical attributes [1]. At present, various applications make use of cost-effective sensors in carrying out different ranges of operation viz, environmental monitoring, habitat monitoring, healthcare, oilfields, climatic condition monitoring, industrial monitoring, and many more, to name [2]. A sensor node is a small embedded device capable of sensing data, processing it, and forwarding it to the next destined node. However, it does this job by adhering to a structuring principle called clustering [3]. Various clustering algorithms mainly target energy efficiency [4].

The definite group is formed during clustering, consisting of member nodes that sense the data and forward it to the cluster head. In this process, the cluster head consumed maximum energy to transmit data, thereby safeguarding the excessive energy consumption from other member nodes. A cluster head carries out two essential operations, i.e., data fusion and data aggregation [5]. Data fusion is carried out to ensure the collection of unique data from member nodes while data aggregation pertains to forwarding the fused data to the base station or sink. The complete operation of clustering is also associated with the use of various ranges of routing protocols. Existing studies exhibit three significant categories of routing protocol in WSN, i.e., geographical protocol, flat protocol, and hierarchical protocol [6]. Apart from this, there is another concept where WSN uses the mobile agent to offer a balance between throughput and resource efficiency. The idea of mobile agents is utilized for mobile computing for effective management and control of the network. Apart from this, the complete data delivery process to sink solely depends upon the mobile agent, who also brings various security concerns [7]. However, the biggest problem is to optimize data aggregation's performance using a single mobile agent to meet specific quality of service demands. Therefore, the proposed system presents a unique concept that implements transmission provision in WSN to increase maximum path establishment among the sensors. This fact will significantly affect itinerary planning, where a mobile agent can obtain maximum data with reduced energy and faster operation. The contribution/novelty of the proposed system in contrast to the existing system are: i) a novel provisioning approach is introduced for a practical resource utilization, ii) formulating dynamic routine management to study the impact of transmission of concurrent use, and iii) dynamic power demand computation for transmittance.

The present manuscript's organization is as follows: section 1 briefs the existing approaches towards using mobile agents and quality of service in WSN while investigating various techniques used, followed by highlighting the encountered unaddressed issues from existing studies as well as it also briefs about the proposed methodology. Briefing of the system design is carried out in section 2 while discussing the outcomes of the simulation study is carried out in section 3. Finally, the summary of the paper is provided in section 4.

There are various applications reported in existing approaches [7], which are associated with potential advantages for introducing them in WSN, which is one of an integral part of internet of things (IoT) [8]. The existing system has witnessed study associated with various application-specific models, e.g., sensory-based parking mechanism remotely [9], emergency evacuation system [10], Water monitoring [11], fire detection using sensor and vast area network with low power [12], microcontroller-based air quality monitoring [13]. Furthermore, various studies carried out towards securing sensors in WSN where the discussion has been carried out towards the need for further improvement in the data aggregation process [14]–[19]. Apart from this, various optimization approaches [20]–[22], as well as studies towards quality of services [23], [24], have also been presented toward improving data transmission in WSN. The existing system [25] reports incorporating the intelligence in the mobile agents in WSN to enhance its performance towards autonomy, executability, and mobility. The investigation shows that such agents offer learning capability that dynamically contributes towards path planning for controlling energy consumption. The study outcome shows that multi-agent energy consumption is lower than single-agents over the increasing number of source nodes. Study towards incorporating intelligence in multi-agents in WSN is also proven to be successful by using game theory and reinforcement learning [26]. Yao and Jia [4] also carried out a similar study's direction, where a multi-agent-based approach is used to address the jamming problem. This approach makes use of a learning scheme where an error-free path is found. Usage of agent-based solutions is also reported to help share resources in internet-of-things (IoT), as seen in Yildirim and Tatar's work [5]. Itinerary planning is another essential focus of current research work. The idea is to minimize the duration of the task by enhancing the throughput. Sasirekha and Swamynathan [27] have developed a clustering algorithm by integrating hierarchical and energy-efficient approaches with lesser dependency on clusters to improve energy efficiency.

The inclusion of a multi-mobile agent will always offer a better result in this perspective than a single mobile agent. However, deploying a single mobile agent is always a cost-effective solution compared to a multi-agent. Still, it is not suitable when deployed in monitoring areas with uncertain traffic and a large-scale sense. Few studies considered adopting a single mobile agent to accomplish enhanced quality of service performance in data aggregation of WSN. There are various temporal parameters, e.g., temporal factors involved in exchanging beacons, data packets, and change of state of sensors. Until a mobile agent does not get a highly updated feed of this information, the itinerary planning will never be optimized. For high-end larger applications, a mobile agent could also drain out its energy if the itinerary planning is ineffective and not supportive of a dynamic environment. To develop a better form of itinerary planning, it is always better to reduce the number of time instances allocated for the explicit operation to be carried out inactive and sleep mode. However, it is not feasible computationally, and hence, a better alternative solution is required to solve this problem. Therefore, there is a need for a good balance between the communication demand and computation demand while deploying mobile agents in WSN.

Novel analytical modeling is designed to offer maximum quality of service (QoS) in data aggregation performance in WSN. The proposed system constructs a primary hypothesis that a single mobile agent alone cannot perform higher QoS performance in large-scale deployment. The study's secondary idea is that developing a distributed provisioning scheme for the sensor nodes to forward data could significantly assist in optimizing the mobile agent's itinerary planning. Proposed system's architecture is classified into three main blocks, i.e., computational model, transmission provisioning, and energy model. The constraint/limitation of the proposed system is that it offers energy improvement without considering resource allocation used for security operation in WSN. To deploy it in a real-world application, the initialized values of the sensory parameters (especially associated with the communication model) will be required to be fine-tuned. Otherwise, it is replicable to all the scenarios. The communication model plays a contributory role in the proposed system as it introduces routing management unlike any conventional studies discussed above. The transmission provisioning operation is carried out over the communication model, where finally, energy modeling ensures computation of demanded energy for data aggregation complying with proposed routing management in WSN. The proposed concept's core idea is to provide higher path establishment ranges among the sensors. This will let the mobile agent collect the maximum quantity of data with lesser exploration towards the defined itinerary. This is made possible by developing a novel routine that is a defined set of instantaneous operational times for the sensor to perform data transactions. The proposed model also contributes to developing an effective scheduling policy that allows specific nodes to perform data exchange while other nodes are maintained in radio-silence mode. An elaborate discussion of the operation involved in the proposed study is discussed in the next section.

2. PROPOSED METHOD

The proposed system discusses the use of mobile agents to provide extensive QoS performance in WSN. This section elaborates on the communication model, the role of mobile agents, and energy modelling in order to provide better QoS support in large-scale WSN implementation. The communication model has two routines: primary and secondary; the primary routine uses random access, while the secondary routine uses provisioned access. The transmission for the mobile agent is carried out by the sensor nodes after a series of operations such as initial route discovery stage, allocation of general routine, and switching to dynamic states. In order to control energy consumption, the energy model has the capability to fine-tune energy demands.

2.1. Communication model

Figure 1 highlights the steps of the algorithm with steps number for communication establishment. First, the algorithm takes n (total sensors) input, which will yield p (path establishment) after processing. Second, the algorithm considers all the sensor nodes n (Line-1). Finally, the algorithm performs a random deployment of the nodes n, which leads to random positioning of the nodes, i.e. (x, y) (Line-2).Then, the study performs a pairwise distance between all the sensors to be forwarding the aggregated data to the base station. First, a specific range of higher and lower bounds of communication range is considered, followed by performing routing. For this purpose, the proposed system develops a connection matrix C_{mat} (Line-5), which should be within the limits of higher and lower communication range cost of transmission (COT) (Line-4). Then, a Euclidean distance is applied in function f_1 (x) that computes the distance between sensor node (SN) and base station (BS) (Line-3). If this distance d is found within the COT (Line-4), the proposed system updates its connection matrix C_{mat} (Line-5). Finally, the proposed method applies another function, f_2(x), for obtaining the shortest path distance between the sensor nodes and base station (Line-7). The variable XY represents a matrix which stores all the connection between the typical sensors and base station. This function f_2(x) is responsible for computing the shortest path from multiple source sensors to the numerous destination sensor. Suppose a mobile agent gets connected with sensors with a higher number of paths connected by this function f_2(x). In that case, the mobile agent will extract more information by traveling a smaller number of paths. The communication model includes a general routine for all the sensors, further classified into a primary and secondary routine.

In the primary routine, the sensors initiate data communication (transmit and receive), while the secondary routine allows the sensor to maintain radio silence. The proposed system also considers another parameter, i.e., Critical Message Priority, which is the primary to secondary routine for each sensor. It helps formulate decisions for the mobile node to schedule its itinerary planning towards reaching a specific set of sensors.

The model also considers a dedicated routine where a communication channel is established between source and destination node via a relay node. To compensate for the delay during the itinerary planning for the mobile agents, the proposed system also adopts a delay-compensation scheme where the data packet is represented concerning their significance. By adding a minimum bit (1-5 bit) flag message, the user can highlight the packet's significance. The source sensor only assigns the degree of importance of the data packet. The complete communication duration of WSN is carried out based on fixed routines.

Algorithm for Communication Establishment
Input: n (total sensors)
Output: p (path establishment)
Start
1. **For** i=1:n
2. (x, y)=rand(n)
3. d=f_1($SN_{x,y}$, $BS_{x,y}$)
4. **If** d>COT
5. update C_{mat}
6. **End**
7. [c p]=f_2(C_{mat}, xy, i)
8. **End**
End

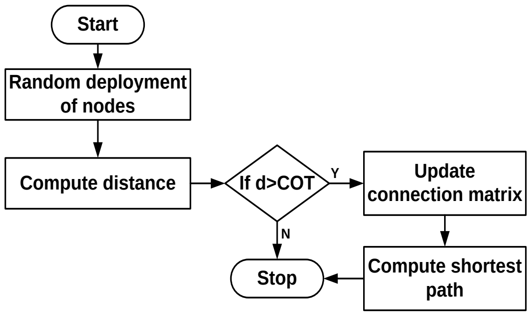

Figure 1. Algorithm and flowchart for communication establishment

2.2. Provisioning transmission for mobile agent

The provisioning of the mobile agent transmission is carried out considering series of operations by the sensor nodes.

- Initial route discovery stage: The sensor nodes broadcast the request message route request (RREQ) and wait till its timeout session. After the timeout session, the sensor selects a general routine schedule and forwards a coordinated packet (CPKT). This packet consists of information about the duration till the system initializes the next generation of routine. The schedule received is followed by the sensor using the CPKT while it obtains CPKT from a different sensor. This operation is followed up by forwarding its CPKT data of its own. If the sensor possesses the schedule, the CPKT data is still heard from different sensors with a different schedule.
- Allocation of general routine: The proposed study considers that every general routine of the sensor consists of a uniform size of the duration of coordinated packet CPKT. The study also considers a uniform size of data and radio silence duration in secondary routine. This is entirely dependent upon the critical message priority (CMP) score. The study considers the CMP selection in a specific manner where there is a higher duration of radio silence is considered to facilitate forwarding the data and conformity message (CNFM). All the sensors are permitted to carry out the data transmission over any generalized routine except the node with prioritized data. Nodes with increased prioritized data will be offered higher importance compared to medium and low priority. However, in the absence of any data packet for any instance of time, the user of the data and the general routine will get the privilege to reconfigure the priority scale. Every sensor will also compute its dedicated routine based on its available size of memory, latency, and network load.
- Switching to the dynamic states: It is now known that the proposed system calls for radio silence during the activation of the routine secondary state. In the secondary routine, the sensor initiates the sensor's logical clock with a priory configured duration as per the critical message priority considering the dedicated routine between two communicating sensors. The sensor switches its state to the primary routine by switching off its prior state of secondary routine after the timer for the secondary routine is over. In this stage (primary routine), the radio is switched on autonomously, and the sensor initiates reading the incoming stream of data from its environment. In the absence of any traffic, the sensor reads the idle mode's message. By idle mode, the sensor exchanges the control messages among themselves but does not transmit any data along with it. In the presence of any specific traffic, the sensor node opts for carrier sensing multiple accesses to receive or transmit the data. The sensor node chooses the same radio channel with multiple other concurrent sensors to carry out transmission and receiving states in the primary routine. Once the timer is expired, it instantly switches to a secondary routine. If any sensor node is unsuccessful in coordinating with another node to use the same communication channel, they switch to a secondary routine. It should be noted that complete operation is carried out considering system active time, a uniform duration for transmitting the data packet. It will mean that all the forwarding sensors must perform their transmission after a specific duration of time. This makes the data transmission model quite deterministic for the construction of the itinerary planning for mobile agents. Furthermore, the proposed system considers an input of the critical message priority CMP and the size of the general routine route. Figure 2 highlights the algorithm with respective step numbers and its process flow towards transmission provisioning. A simplified mathematical expression is used for this purpose as in (1).

$$T_{prim} = CMP * rout$$
$$T_{sec} = (1 - CMP) * rout \quad (1)$$

Expression (1) is used for computing time for primary and secondary routine, i.e., T_{prim} and T_{sec}, respectively. The algorithm considers all the sensor *n* (Line-1). The algorithm then considers computing the beacon arrival time b_{at} by applying a function f_3(x), which uses a method *g* applied over the random index R_{id} and several routines N_{rout} (Line-2). The method *g* is used for rounding the values owing to the inclusion of random numbers. The following process is to apply the similar function f_1(x) for Euclidean distance d_1 between the specific sensor node $SN_{x,y}$, and node present in next-hop n_{hop} (Line-4). The proposed system also has an explicit energy modeling motivated by Ghasempour and Gunther's work [8]. The proposed algorithm then computes the transmittance energy E_{TX}, where a function f_3(x) is used using the proposed energy model. This function f_3(x) offers the computation (2).

$$E = E_{TX} * p_{len} + E_{amp} * p_{len} * d_1^4 \text{ for } d_1>d_o$$
$$E = E_{TX} * p_{len} + E_{fs} * p_{len} * d_1^2 \text{ for } d_1<d_o \quad (2)$$

The expression (2) is inspired by the standard computation of transmittance energy from the first order radio energy model. According to this standard, the system computes transmittance energy based on two conditions of distance. If the distance d_1, which is recently computed, is more than a cut-off distance, then the first expression of (2) is used, or else it uses the second expression. The computation of total energy *E* is calculated by considering the standard value of transmittance energy E_{TX}, length of packet p_{len}, amplification energy E_{amp}, and energy used for radio antenna resource E_{fs}. Hence, this function f_3(x) is used for adjusting the transmittance energy in Line-5 of the algorithm. The next part of the algorithm considers all the number of general routine N_{rout}(Line-6).Considering all the group ngrp (Line-7), the algorithm creates a message flag Mf associated with the respective cluster-id C_{id} to identify the data's origination point (Line-8). The proposed system considers different priority scales p_{scale} of data to allocate the dynamic memory *mem* accordingly considering the message's size (Line-9). Finally, the algorithm based on memory allocated with respective priority scales initiates in the forwarding data packet (Line-10).

Algorithm for Transmission Provisioning
Input: n (number of sensors)
Output: α (data forwarding)

```
Start
1. For i=1:n
2. b_at=g(R_id, N_rout)
3.     n_hop=nan(i)
4.     d1=f1(SN_xy, n_hop)
5.     E_TX=f3(d1, p_len)
6.     For j=1: N_rout
7. For k=1: n_grp
8.           d_id=M_f(C_id)
9.           mem(C_id(p_scale)=mem(Cid(p_scale)+msg_size
10.          α→forward pkt
11.      End
12.  End
13. End
End
```

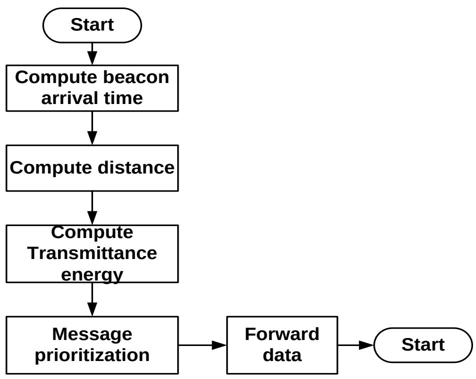

Figure 2. Algorithm and flowchart for transmission provisioning

2.3. Energy modeling

Unlike any existing energy efficiency approach, the proposed system can fine-tune energy demands to control energy consumption. According to this logic, the proposed method uses maximum energy E_{max} to broadcast route request (RREQ) and route reply (RREP) control messages. Upon receiving an RREQ message, the destination node forwards RREP with similar energy, i.e., E_{max}. The transmitting sensor computes the demanded energy E_{dem} after obtaining the RREP message based on the receiving energy level E_{RX}. The mathematical formulation of maximized energy is as (3),

$$E_{dem}=E_1 * \delta \quad (3)$$

In the expression (3), the energy variable E_1 will represent the ratio of maximized energy E_{max} to receiving energy E_{RX}. In contrast, the variable δ will represent the product of optimal signal strength and network coefficient. The proposed system computes the demanded energy E_{dem} to forward the data packet to the next node or sink. The energy level is computed for the destination node when it receives RREQ using signal strength to transmit a CNFM. The study considers that both transmit and receive sensors possess a similar range of signal attenuation to ease energy computation. It is to be noted that the proposed system permits the forwarding of a data packet between a single pair of communicating sensors corresponding to the primary routine, with all the adjacent sensors being in radio-silence mode to conserve energy.

3. METHOD

WSN network architecture is modeled as a disjoint set of graph (G,v). The proposed algorithm constructs a mathematical model to find overlapping region for scalable sensor nodes deployment in such a way that the trade-off problem of balancing energy consumption and QoS is solved. This is NP-complete problem which is solved using cross layer design approach of communication protocol considering network and physical layer parameters. Energy is optimized by balancing placement of sensors and sink node in such a way that it achieves centrality and avoids packet losses by minimizing collision with the help of effective scheduling.

4. RESULTS AND DISCUSSION

4.1. Simulation environment

The proposed logic is scripted in MATLAB considering 100-500 sensors randomly deployed in 1100x1200 m^2. The study considers all the sensors to be in a static position with the condition that each sensor should have at least three neighboring nodes to facilitate edge connectivity. The base station can be positioned at any position of the simulation area; however, it is the position in the middle of the simulation area for effective analysis. The simulation parameters are i) priority message: 20%, ii) size of message: 10 bits, iii) initial energy: 0.5 Joule, iv) length of routine 1 second, v) receiving energy: 25 nj/bits, vi) beacon arrival time: 1-10, vii) length of the data packet: 200 bytes, viii) channel capacity:10 kbps, ix) Transmittance energy: 50 nj/bits, and x) simulation time: 100 seconds.

4.2. Results accomplished

Figure 3 highlights the comparative analysis of delay as a performance parameter where it can be seen that the proposed system offers better delay performance in contrast to the existing system. The proposed method uses a concurrent transmission approach that ensures faster dissemination of the data packets. Apart from this, the proposed provisioning scheme is used for controlling the signals while performing data forwarding. The outcome is obtained by considering 5% of the prioritized traffic in the complete network. With a low rate of beacon arrival time, the data packet generation could be very high, but it does not affect the quantity of prioritized traffic. The proposed agent-based approach offers seamless data transmission to the prioritized traffic by facilitating concurrent data transmission to speed up the rate in contrast to low-prioritized traffic. Hence, delay performance is significantly controlled. The usual traffic never gets affected owing to the presence of prioritized traffic. Unfortunately, this operation is not carried out by the existing approach causing an increase in delay. This is also the reason for energy demands that is exhibited in Figure 4 for energy required per bit.

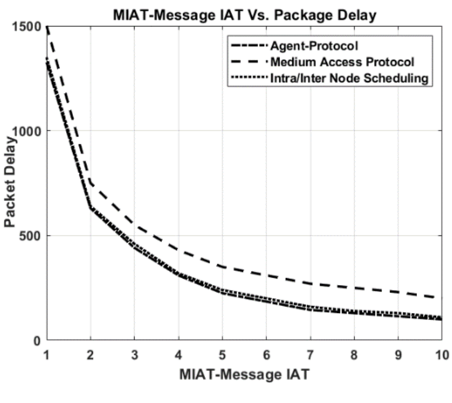

Figure 3. Delay performance

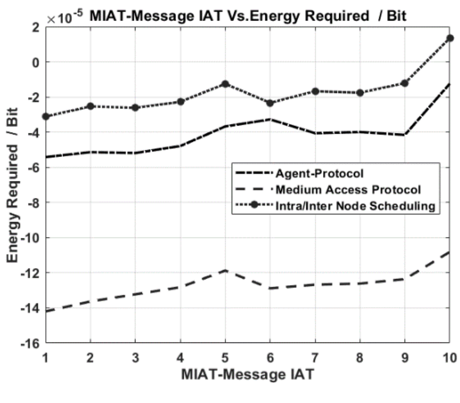

Figure 4. Energy required per bit

Figures 5 and 6 highlight the analysis of remnant energy and processing time, respectively. A closer look into the energy trends in Figure 5 shows that it is better than intra/inters scheduling. The prime justification behind this is that intra/inter-node scheduling emphasizes the clustering approach. Thus, the maximum focus is on selecting a cluster head that consumes maximum energy in the high-priority data packet. Although the medium access protocol offers good retention of energy, due to its excessive duty cycle and slot management usage, the performance is degraded compared to the proposed system. Figure 6 highlights the comparative analysis of algorithm processing time where it can be seen that the proposed agent-based protocol needs 0.5 seconds in the Core i7 processor. In comparison, intra/inter scheduling approaches consume 1 second, and medium access protocol consumes approximately 2.5 seconds. Furthermore, it should be noted that the proposed system offers a simplified provisioning approach where less emphasis is given to cluster formation and more priority is given to transmission provisioning and allocation of routines. Apart from this, the routine's content consists of primary and secondary routines that can effectively control the complete traffic management dealing with all prioritized data levels.

Hence, the proposed system does not need much algorithm processing time. On the other hand, existing approaches consume maximum iterative steps to carry out slot management and resource allocation and clustering, demanding higher processing capability and consuming time. Because of this reason, a mobile agent planning for trip itinerary consumes more time and resources, which cumulatively affect network lifetime too. Hence, the proposed system is considered to offer better QoS performance using mobile agents.

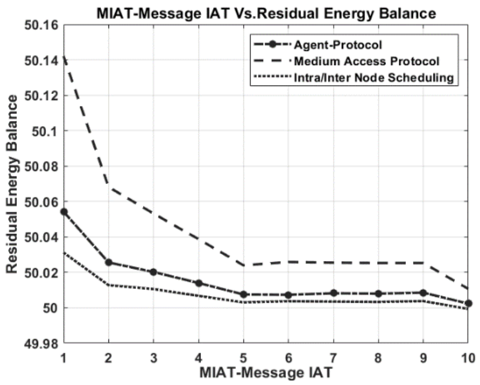

Figure 5. Analysis of residual energy

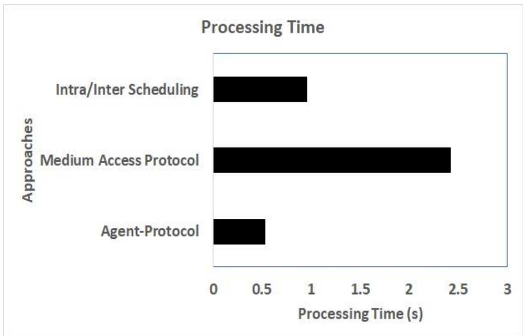

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Figure 6. Algorithm processing time

5. CONCLUSION

This paper discusses a novel energy efficiency approach in WSN where a single mobile agent is assumed. The idea of the proposed study is to optimize the energy-efficient data aggregation considering a single mobile agent. The contributions of the proposed study are as follows: i) the proposed model introduces novel provisioning of transmission to ensure a higher degree of utilization of resources, ii) the proposed system offers a scope to explore the consequences of concurrent transmission by forwarding a data packet using a dynamic routine management scheme, iii) unlike any existing system, the proposed system does not allocate static transmission power, but it computes the power which can be fine-tuned and then allocate it for transmittance purpose. The proposed system's simulation outcome showcases that the proposed agent-based protocol significantly benefits delay and energy efficiency compared to existing schemes. The future direction of studies will be further optimizing the scheduling process using a cost-effective approach. A novel analytical model could be constructed with more inclusion of constraints towards achieving energy-efficient data transmission. The idea is to achieve cost-effective scheduling using an optimized scheduling scheme. The potential findings that can be expected will reduce the algorithm processing time and more conservation of residual energy in dense traffic conditions.

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