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Geographic Routing Scheme for Resource and Communication Efficiency in the IoT Ecosystem using Swarm-Intelligence based BFO Algorithm

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Abstract

Wireless sensor networks (WSNs) are the sensor nodes that are generally interconnected and these nodes communicate wirelessly to collect the data from the environment around them. Sensor nodes are low-powered and distributed in a decentralized ADHOC manner. WSNs setup comes with some limitations such as energy constraints and the cooperative demands essential to perform multi-hop geographic routing for Internet of things (IoT) applications. Quality of Service (QoS) depends to a great extent on offering participating nodes an incentive for collaborating. The real-time applications of WSNs have potential design limitations such as energy and other QoS constraints in the context of IoT. This work formulates two different re-transmission strategies for optimized cross-layer design and also integrates the framework with a swarm intelligence technique assisted Bacteria Foraging Optimization (BFO) for efficient Cluster Head (CH) selection. The proposed work designs analytical modelling to realize the formulated concept and also simulates the computational design in a numerical computing tool. Finally, an extensive simulation is carried out using the MATLAB simulation tool. The obtained results show the effectiveness of the proposed system in terms of delay is reduced by 12%, throughput is increased to 10%, remaining energy of the network is increased to 11%, and packet delivery ratio of the proposed work in increased to 7-9% in comparison with the existing system.

Keywords: Internet of Things, Quality of Service, Swarm Intelligence, Bacteria Foraging Optimization Algorithm.

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Introduction

The collaboration of physical objects attached with the embedded devices having the capacity of sensing, processing and transmit data to the internet from a highly distributed network is called IoT. The distribution of nodes needs to be uniformly placed across the monitoring region. The typical application includes disasters like earthquake monitoring, volcano identification, vehicle monitoring, climatic change surveillance, etc. The improper design of deployment causes non-uniform power uses that leads to the challenges like error-prone links thus improper routing (R. Krishnamurthi, et al., 2019). The challenge is to control the medium access to avoid collision in the network. Therefore, in a proactive approach, the localization of information on the nodes is required in making reliable routing protocols. The geographical routing protocol uses the approach of maintaining one-hop, n-hop information that reduces the use of storage and forwarding the packet to the sink in the closest route (J. Shreyas, et al., 2020) (J. Shreyas, et al., 2019). Whereas, in the non-geographic routing approach to maintaining the proactive details of neighbour location, a flood of control messages needs to be broadcasted that consumes excessive energy and bandwidth, which leads to the issue of the weakest link problem. Thereby this reduces the network performance in terms of more packet drop, maximized delays and most importantly the network life reduction due to excessive use of energy. In IoT, the nodes decide the route depending upon the parameters such as distance, number of hops and less channelization. The IoT nodes deployment adopts ADHOC technology that uses two patterns of data transmission.

1. Single hop communication: If the destination is within the communication range.
2. Multi-hop communication: If the destination belongs to the communication range.

Therefore, the energy used is higher when the Euclidian distance is more, which also causes the unreliable link in iteration communication, whereas the energy consumption of the network increase in MAC i.e. E mod d^2, where d is a distance between transmit antenna and receiver antenna.

$E \rightarrow f$(No of hops, transmission range) Further,

$E \rightarrow E_{min}$(No of hops, transmission range, link-state)

The typical deployment of IoT differs in many folds as compared to any other wireless network. The IoT is aimed for higher scalability that poses challenges of fading effects due to attenuations of signals that brings remarkable changes into the signal to noise ratio and as a result, weak links are found frequently. Energy being the major component to route establishment for establishing green energy routing whereas the other parameters of radio and heterogeneity of links play a major role while designing an efficient routing protocol. The traffic management need to be synchronized in the random event generation along with route establishment utilizing customized priority of resources on base queue mechanism (J. Shreyas, et al., 2019) (J. Shreyas, et al., 2021).

To meet a scalability demand for a time-critical application, the methods of probabilistic queuing theory is generally used for activating optimal QoS in networks that are not adoptable directly in the scenario of IoT. Therefore, the further problem reduces to optimize the stochastic models to fit the energy-efficient or green model to address the QoS of IoT. Hence, the problem statement goes as "Designing an Energy-Efficient Model for Routing in IoT Considering the distance, hop-count, communication range, link-state, resource allocation, radio schedule, channel characteristics to provide reliability as QoS parameter for time-critical IoT application considering a Physical (PHY) and Medium Access Control-(MAC). The Evaluation parameters-considering for the effectiveness of the model is No. of hops Vs delay, Energy Efficiency, Distance Vs SNR, Path-loss"

The proposed work realizes the scope of optimization to enhance the communication performance of IoT with energy-efficient communication and attempts to apply swarm intelligence and their collective behaviour to solve distributed problem of futuristic IoT. The proposed work design and formulate numerical modelling of swarm intelligence to optimize the route establishment between IoT node to CH and from CH to Sink by mimicking the food searching behavior of Bacteria. Thereby this reduces the network performance in terms of more packet loss, maximizing delays and most importantly the network life reduction due to excessive use of energy. In IoT, the nodes decide the route deepening upon distance, number hops and the loss channelization.

A. The primary contributions of this paper are:

1. This paper proposes an energy-efficient model for routing in the IoT ecosystem.
2. In this work, an analytical geographical routing model for IoT is proposed.
3. This work proposes an optimized swarm-intelligence bio-inspired clustering paradigm based on the BFO algorithm.
4. The mapping of the BFO algorithm against IoT routing is presented.
5. The proposed work has been implemented and evaluated in the MATLAB simulation tool.

The remaining section of the paper is organized as follows. Initially, section II discusses an overview of related work which addresses all the major research work being done in this area. Then in section III problem statement of the proposed methodology is presented. Later in section IV proposed methodology and followed by research methodology has been explained Section V. Section VI discusses performance analysis and finally in section VII concluding remarks has been presented.

Background

The study of Singh, et al. (2015) has focused on a framework named data delivery for cognitive information-centric sensor networks in smart outdoor monitoring. The given cognitive information-centric sensor network shows a pattern of a wireless sensor network in which the collected sensory information is classified, and for the delivery of information from node to sink used element of cognition with good quality and it is full fill the demand of end-user. For the identification of path used Analytic Hierarchy process, and this process is based on QoI-attribute priorities set by the user. The experimental results show that the use of cognition increases the number of successful transmissions to the sink by almost 30%, while closely adapting the data delivery paths to the QoI requirements of the user.

The studies of Mir, et al. (2017) have focused on the control of collaborative topology communication in a wireless sensor network. Topology control has been extensively studied in both flat and hierarchical networks through power adjustment and clustering, respectively. While the focus of clustering is to form a connected backbone, which consists of a minimum subset of nodes, i.e., dominating set, power adjustment focuses on minimizing energy consumption. Here presented a hybrid framework called Collaborative Topology Control Protocol (CTCP), which combines dominating set-based clustering and transmission power adjustment. The presented topology control framework is capable of versatile performance in terms of transmission range/energy cost, the number of neighbors, edges and hop distance. Moreover, the topology construction process uses locally available information only with minimal communication overhead.

The works of Long, et al. (2015) have concentrated on the gathering of reliability guaranteed efficient data in WSNs. Here presented an efficient data gathering scheme that guarantees the QoS and optimizes the following network performance metrics as well as the end-to-end reliability in WSNs: 1) minimum total energy consumption; 2) minimum unit data transmitting energy consumption, and 3) maximum utilization efficiency depend as network lifetime per unit deployment. The key point of this optimization is adopting lower reliability requirements and a shorter transmission distance for nodes near the sink. Numerical simulation results demonstrate that our optimal approach improves the network lifetime by 18%, 48% and network utility by 17% and guarantees the desire reliability level.

The studies of Ehsan, et al. (2014) have focused on energy-efficient routing techniques with QoS assurances for Wireless Multimedia Sensor Networks (WMSNs). WMSNs are gaining more popularity day by day as they are envisioned to support a large number of both non-real-time and real-time multimedia applications. Here, the current state-of-the-art in energy-efficient routing techniques for WMSNs is surveyed together with the highlights of the performance issues of each strategy. Further, the classification of recent routing protocols for WM- SNs and a discussion of possible future research trends are presented.

The work of Vuran, et al. (2006) have concentrated on the cross-layer analysis of error control in WSNs. The presented analysis enables a comprehensive comparison of forwarding Error Correction (FEC) and automatic repeat request (ARQ) in WSNs. The results of our analysis reveal that for certain FEC codes, the hop length extension decreases both the energy consumption and the end-to-end latency subject to a target PER compared to ARQ. Moreover, the cases where ARQ outperforms FEC codes are indicated for various end-to-end distance and target PER values.

The study of Busse, et al. (2006) have focused on energy-efficient forwarding schemes for WSNs. Energy-efficient forwarding becomes important if resources and battery life are limited such as in Wireless Sensor Networks. Using a realistic link loss model, the proposed work derives two new forwarding schemes named Single-Link and Multi-Link Energy-Efficient Forwarding that trade-off delivery rate and energy costs best by maximizing energy efficiency. The experimental evaluations show the better performance of the proposed approach against a comprehensive framework of other forwarding strategies.

The work of Antonopoulos, et al. (2011) has concentrated on Network-Coding-Based Cooperative ARQ Medium Access Control Protocol for Wireless Sensor Networks. Here introduces a novel Medium Access Control (MAC) protocol for Automatic Repeat reQuest-based (ARQ-based) cooperative wireless sensor networks. Using network coding techniques, achieve a better network performance in terms of energy efficiency without compromising the offered QoS. The proposed solution is compared to other cooperative schemes, while analytical and simulation results are provided to evaluate our protocol.

The works of Sikora, et al. (2004) have concentrated on the Optimum Number of Hops in Linear Wireless Networks. Given a global constraint on bandwidth, the proposed work determines the number of hops that achieves a desired end-to-end rate with the least total transmission power. The experimental results show that the optimum number of hops depends on the end-to-end rate and the path-loss exponent, which is the preferred spectral efficiency in TDMA multi-hop transmission.

The studies of Hasan, et al. (2013) have focused on optimized QoS for real-time WSN using a partitioning multipath routing technique. Here presented a novel mathematical model for QoS route determination that enables a sensor to determine the optimal path for minimizing resource use while satisfying the required QoS constraints. The presented mathematical model uses the Lagrangian relaxation mixed-integer programming technique to define critical parameters and appropriate objective functions for controlling the adaptive QoS constrained route discovery process. The experimental results show that the introduced model is increased the network lifetime, and decrease the end-to-end delay.

The work of Hasan, et al. (2008) have concentrated on a multi-constrained QoS multipath routing approach for multimedia sensor networks. Here presented a mathematical model for a novel QoS routing- determination method. The presented technique enables determining the optimal path to provide appropriate shared radio satisfying the QoS for a wide range of real-time intensive media.

The works of Abouei, et al. (2011) have concentrated on Green Modulations in Energy-Constrained Wireless Sensor Networks. Here introduced an in-depth analysis of the energy efficiency of different modulation techniques using realistic models in the IEEE 802.15.4 standard to find the optimum distance-based scheme in a WSN over Rayleigh and Rician fading channels with path-loss. The implementation results show that the On-Off Keying (OOK) displays a significant energy saving compared to the optimized NC-MFSK in dense WSNs with small values of the path-loss exponent.

Problem Statement

The problem considered in the proposed work is to design and develop an efficient routing technique based on geographic routing in the IoT ecosystem to achieve communication and resource efficiency with the following objectives:

1. To reduce the average delay of the network.
2. To increase the average throughput of the network.
3. To increase the packet delivery ratio of the network.
4. To optimize the overall energy consumption of the network.

Proposed System

The modelling of green IoT considers three different prime layers associated with IoT namely perception, network and application layer. The structured implementation of the proposed module consists of a set of procedures to attain the design goal intended in the work. The implemented modules are designed and discussed concerning an analytical viewpoint where the mathematical computation is entirely performed in a numerical computing environment. The implementation of the proposed work is carried out using analytical methodology where the emphasis is to perform an optimal refinement of the routing strategies in the IoT ecosystem.

A. Core Agenda of Methodology

The prime agenda of analytical methodology is to design and develop an efficient routing technique based on geographic routing in the IoT ecosystem. To design such routing strategies, it is necessary to consider all the essential elements of the distributed routing system compliant with the protocol stack of IoT. The secondary agenda of this methodology is that it assists in mathematical modeling for effective resource utilization in the form of sensor nodes in the IoT environment. The following Fig. 1 shows an overview of the architectural block-based methodology.

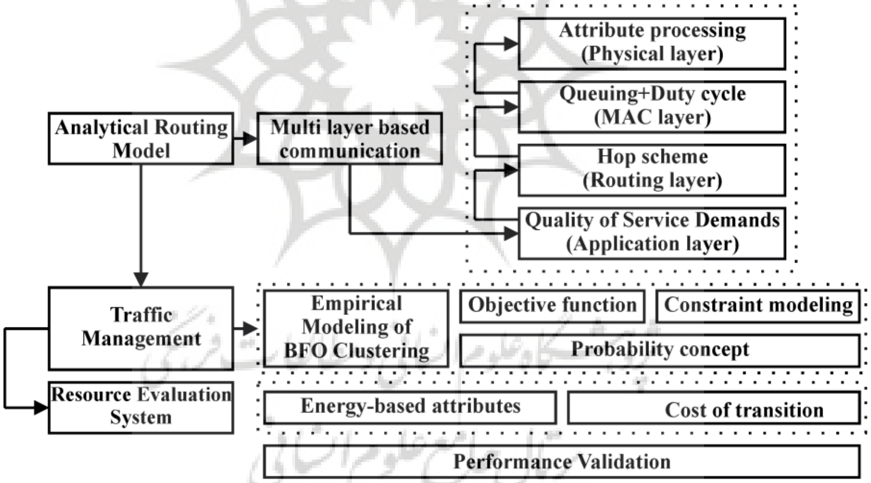

Fig. 1. Architectural block-based methodology.

B. Implementation Stages of Proposed system

The complete routing technique implementation will be carried out concerning geographic and energy efficiency considering all the possible constraints of dynamic routing conditions over peak traffic conditions in IoT. The implementation will also consider that there are fair chances of intermittent link breakage as well as uncertainty in traffic conditions caused due to unknown and unpredictable events. This use case will be considered as the core for the model validation and the complete implementation will be carried out in the following stages.

Stage-I: Developing an Analytical Routing Model In the first stage of implementation an IoT ecosystem is developed considering a 2-D topology for sensor node random deployment. The routing model will essentially consider the design allocation functions based on the multi-layers over the protocol stack of IoT. This attribute is utilized for the selection of the links using multiple/single hop and based on this attribute value, the model performs fine-tuning of the path loss exponent. This operation is carried out in the physical layer and the packet is now received in the queue system in the next upper MAC layer. A standard queuing model with identification of the successful packet transfer is now sent from the MAC layer to the routing layer, which decides to either forward these packets using a single/multihop scheme. The application layer will only consist of complying with the QoS of the network. Hence, the complete model works on a cross-layer approach.

Stage-II: Introducing Effective Traffic Management The proposed system implements a standard queuing framework (Markov) to ensure effective traffic management while performing proposed routing. A probability process is implemented over a discrete-time to develop the queuing process with a finite size of the queue. This queuing model assists the sensor to allow permission for access towards the channel for routing packets. Empirical modelling using the probability concept is carried out towards formulating steady and transmission states to define the routing behaviour mathematically. This part of the model will also use temporal factor for ensuring the slots allocated for sleep and awake schedule that indirectly contributes towards energy modelling of the sensors. Hence, necessary refinement is carried out depending upon the scale of outcomes. This stage of implementation contributes to analyzing the routing performance on the different hop configuration-based IoT ecosystems.

Stage-III: Designing Resource Evaluation System The implementation emphasizes computing the effective energy being drained towards applying the proposed cross-layered routing protocol. For this purpose, the tentative attributes are associated with transition states of the sensor, packet size, energy usage, signal-to-noise ratio, transmission rate, work-cycle, etc. The proposed system applies the formulation of energy in a way that there should be a form of energy being distributed for all the sensors with the probability of steady states of respective sensors. The energy modelling system will also compute the cost of transition of the states that have a proper inclusion of computing packet error rate for the selected hop. Apart from energy, the proposed system also emphasizes delay and throughput computation which will be done based on all possible delays associated with routing operation and switching operation also.

Stage-IV: Modeling of BFO Paradigm The proposed system focuses on the scope of optimization to enhance the communication performance of IoT with energy-efficient communication and attempts to apply swarm intelligence and their collective behaviour to solve distributed problems of futuristic IoT. The proposed system design and formulate numerical modelling of swarm intelligence to optimize the route establishment between $IoTnode \rightarrow Clusterhead$ (CH) and $fromCH \rightarrow Sink$ by mimicking the food searching behaviour of

E. coli Bacteria. The prime target of this formulated algorithm design is to select the energy-efficient CH at every round of communication which can establish a reliable link and also optimizes the communication cost in terms of delay and reliability.

Stage-V: Model Performance Validation The implementation of the proposed model is carried out in MATLAB using a simulation-based approach. Before performing model validation, the proposed system initiate simulates the scenario of the sensor network and validate it. The complete model for cross-layer based routing is validated based on the following performance parameters e.g., mean delay, energy consumption, and average throughput. The computational complexity is validated based on effective algorithm processing time which is a representation of the total time required for the proposed routing scheme to forward the data packet from source to destination effectively. The prime analysis is checked to ensure if the proposed radio propagation scheme assists in minimizing the artefacts of location information in geographic routing. The study finally performs optimization of the outcome of the proposed system concerning the packet forwarding operations.

Implementation Scenario

The core objective of the implementation scenario in the context of this proposed work performs a numerical analysis of a cross-layer design approach to enhance the performance of QoS supported routing in the area of Green IoT. The implementation structure aims to attain the design goal that includes energy-efficient optimal path formulation satisfying the QoS factors in IoT systems. The green computing model in IoT designs and conceptually develop the routing strategy for the optimal on-demand path allocation to different communication exhaustive IoT devices without compromising the QoS aspects. The following are the implementation details associated with the project development.

Eq. 1 shows how the X, Y coordinates got computed for localization of each IoT_N and compute X, Y

$$Xn(i), Y\,n(i) \leftarrow K[(l, h-l)] * \alpha \qquad (1)$$

$$Where\ K[(l,h-l)] = \sum_{i=0}^{IoTn} l + (h-l) * \alpha$$

Here $\alpha = random\ number.$

The node deployment and zone formulation are essential to choosing the transmission route using Algorithm. 1 and as shown in Fig. 2.

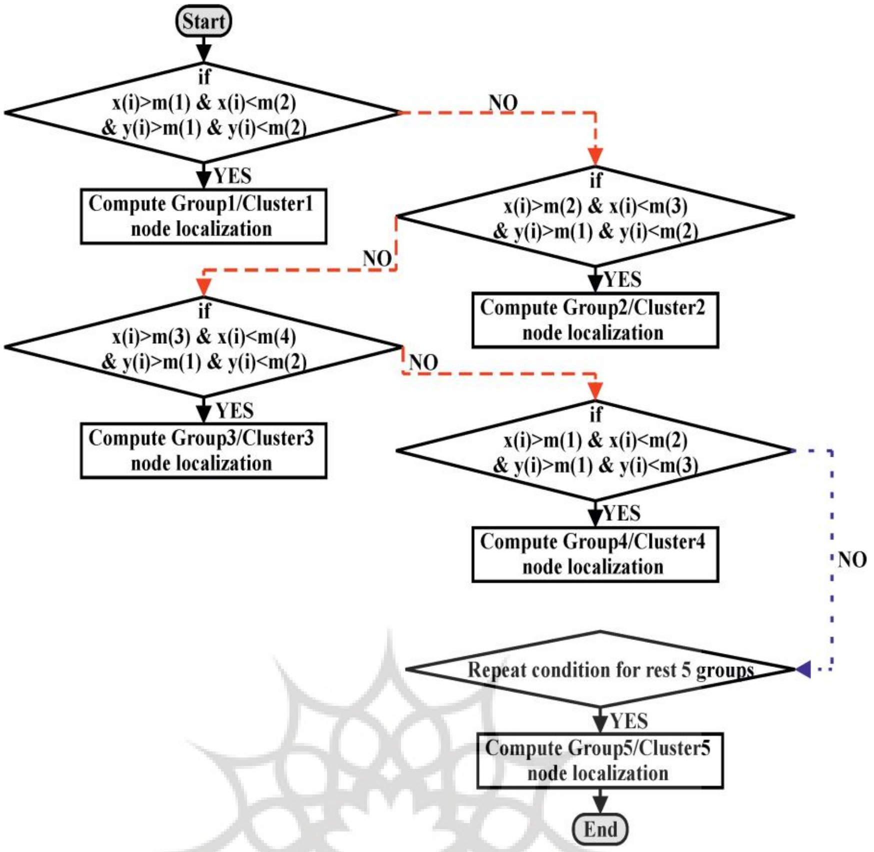

Fig. 2. Flow design for Group/zone formulation.

Algorithm 1 Process for IoT node deployment

```
procedure
    Input argument for f(x) which deploy the IoT sensor nodes.
    High-value(h), Low-value(l), mark index(m), number of nodes ($IoT_N$)
    Initialize h, l, m, $IoT_N$
    for each IoT node do
        Compute X & Y co-ordinates
        Perform location of all nodes
    end for
    Visualize the IoT node deployment
end procedure
```

The formulation of network deployment with IoT nodes as G(V) is visualized using the geographic locators. The area is divided into equal geo-located regions which have a random distribution of nodes. The node deployment starts from node 1 continuing until the limit given during the deployment computation and packet delivery and QoS validation.

C. Process for IoT gateway deployment

The IoT gateway construction consists of three zones as Zone-1, Zone-2 and Zone-3. Zone-1 consists of three different header nodes where localization of each header node is carried out by computing the following numerical expression.

$$\sum_{i=1}^{3} m(i) + \frac{m(i+1)-m(i)}{2} * m(i) + \frac{m(i+1)-m(i)}{2} \tag{2}$$

$$\sum_{i=1}^{3} m(i) + \frac{m(i+1)-m(i)}{2} * m(i+1) + \frac{m(i+1)-m(i)}{2} \tag{3}$$

$$\sum_{i=1}^{3} m(i) + \frac{m(i+1)-m(i)}{2} * m(i+2) + \frac{m(i+1)-m(i)}{2} \tag{4}$$

The next part of the computational process is to find out the header nodes:

1. For each size of geographical region.
2. Compute the coordinates for two geographical regions and save them in *COORDINATE 1*.
3. Compute the coordinates of each header IoT node and save in *COORDINATE 2*.
4. Compute DIST(*COORDINATE 1, COORDINATE)*
5. Sort the computed DIST() values and finally obtain the coordinates for each header node.

When the specified nodes are selected, the establishment of intra-gateway communication is depicted. This is where a gateway node is chosen from each zone and a path link is established to all the other neighbour gateway nodes from all the other zones. The process for intra-gateway connectivity establishment by zone n to zone n nearest neighbourhood connectivity which finally gives a graph G(N_{IoT}, $N_{Gateway}$, $E_{node-node}$, $E_{Gateway-gateway}$)

D. Analytical Formulation

The numerical modelling of the formulated concept for QoS advancing routing applies a multi-hop communication-based traffic system that mimics the scenario with Markov discrete-time M/M/1 model. The system implements 2 different core modules i) It introduces an optimized swarm-intelligence bio-inspired clustering paradigm based on the BFO algorithm. ii) Numerical modelling and Implementation scenario of an energy-aware routing with green computation in the context of IoT systems. Initially, the IoT systems are deployed with a fully connected network topological structure. After the distribution of nodes over a specific region of interest the density of nodes within that region is concerned. Therefore, the implementation scenario mimics the collaborative distributed networks of IoT that consists of a set of heterogeneous smart devices. The heterogeneous smart devices are scattered in an area of deployment for monitoring application-specific activities in the real sense.

The proposed work addresses the problems that arise in the sensor systems and their configuration as design complexity triggers higher energy consumption from the sensor node attributes. In long term scenario, the network lifetime of the system and negatively influence the wireless channel with intermittent link breakage and channel errors. Thereby designing a proper routing mechanism with energy-efficient low-cost implementation can reduce the possibilities of error-prone links and incompetent routing (M. Z. Hasan et al., 2013) (M. Z. Hasan, et al., 2017).

The prime intention of this computational design is to incorporate the energy-aware optimized delay constrained routing strategy with optimized cross-layer design by involving a) physical layer, b) MAC layer, c) routing layer and d) application layer. The numerical modelling analyses the fact that in the single-hop communication the place where the event triggers. If a sensor node A is being deployed then it usually has the longest transmission range, hence it can waste an extra amount of energy due to direct communication and re- transmission. Thereby, the prime reason for re-transmission in this scenario occurs due to the unreliable links which are needed to be fixed. Thereby this proposed work numerically optimizes the energy allocation by estimating the design of multi-hop routing with end-to-end re-transmission strategy and finally as bit-error-rate (BER). It attempts to fix the route structure with an optimized cost-oriented adaptive switching policy which ensures minimal path-loss component. The optimal forwarding of packets concerning QoS factor optimization targets to minimize the power per bit allocation along with a reliable cost-optimized link which ensures higher reliability of data transmission with lesser delay constraints.

The prime emphasis of Markov discrete-time M/M/1 is to handle the real-time traffic situation that arises under various channel conditions in the context of different triggered events under the impact of radio irregularity. The proposed work also analyses the behavior of duty-cycled MAC protocol where duty cycle refers to a well-known power management strategy in WSN that can enhance the operating life of battery-powered sensor systems with optimal resource management in reality. In MAC layer duty cycling place the node periodically into sleep mode to reduce the energy dissipation to a higher extent. The re-transmission schema of packet switching is optimized to satisfy the QoS requirements with green IoT multi-hop re-transmission and end to end re-transmission routing. Fig. 3 highlighted above clearly shows how the system performs the multi-hop data re-transmission to optimize the QoS performance with energy efficiency in green IoT.

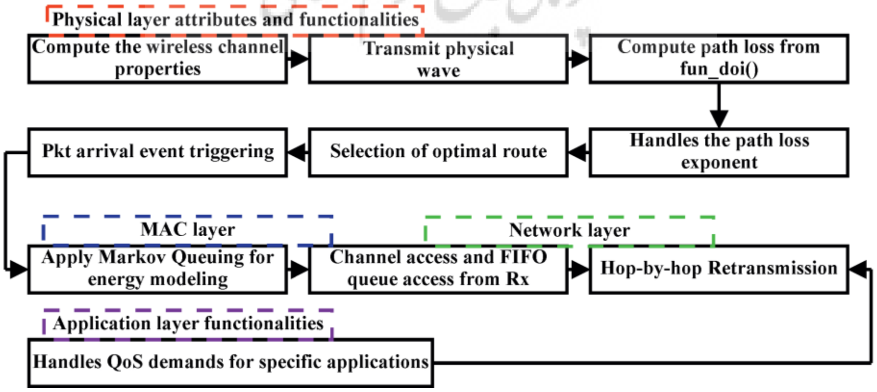

Fig. 3. Packet forwarding paradigm in hop-by-hop retransmission routing

The system considers multi-hop path loss component design by incorporating a prime functional module referred to as $\varepsilon_{doi}(x)$ which is also known as the degree of irregularity (DOI). $\varepsilon_{doi}(x)$ here depicts the signal information concerning its quality factor and also depicts its variances with incremental changes in the route path formation matrix. This function also assists the system to compute the k-coefficient module and its adjustment ensure the nearest neighbour hop formulation during the route establishment process according to the path loss component. During the completion of this stage, the packet arrival event from the next-hop neighbour notifies with $ACK_{msg[]}$. The packet navigates to the MAC layer through a formulated selected direction after adjusting the path loss exponent path-loss. If the channel allocation schema finds any bit-error existence in the packet then it directly rejects the packet and enables link layer control to correct the packet format with significant error control.

The channel access procedure here is mechanized with two different modes of re-transmission in the distributed systems like IoT. The proposed work also considered duty cycle operations of the node to enhance the channel access modelling. Here the duty cycling of IoT refers to the factor which denotes how periodically an IoT node goes to sleep mode to save the energy consumption of the overall network. The design of the protocols are further illustrated below:

1. Delay-aware reliable hop-by-hop re-transmission routing paradigm: The paradigm in this context is defined as a set of computational flows which are represented to enable the MAC layer channel. The channel allocation and management are achieved through a set of control signal attributes that involves very less resources during the transmission. This paradigm involves 4 different packets such as a request to send (req_{send}), clear to send (CLR_{send}), data packet (Pkt_{signal}) and also Acknowledgement ($Ack_{control}$). The handshaking mechanism takes place to ensure the reliable transmission of a packet in the context of IoT. In this scheme, every adjacent neighbour validates the correctness of the received data packet. And in case of encountered error, it again re-transmits the no-acknowledgement packet (NACK) to the sender node. This process arrives till the correct data packet reaches the destination and the ACK packet get initiated.

The above Algorithm. 2 clearly shows the computational steps involved to access the performance of hop-by-hop re- transmission strategy with a numerical simulation and its flow. It applies the Markov Modeling of the discrete-time stochastic process and duty cycle state operations which are subjected to energy-efficient IoT node operations.

Algorithm 2 Process for hop-by-hop retransmission Strategy

```
procedure
Input Parameters: transmitter power($T_p$), receiver
power($R_p$), idle power($I_{pow}$), Startup power($S_{pow}$),
preamble length($P_{length}$), Sender node id($S_{id}$),
receiver node id($R_{id}$)
```

```
Output: Successful operation of energy and delay
aware green IoT
Initialize→[$T_p$,$R_p$, $I_{pow}$,$S_{pow}$,$P_{length}$,$S_{id}$, $R_{id}$]
Enable function Markov Model- f1(X) : Total power
consumption of the four states
f1(X)←MarkovModel($T_p$, $R_p$, $I_{pow}$,$S_{pow}$ )
Define expected data packet arrival rate at MAC
Define the time of inter-arrival of packet arrival
Define independent probability of transmitting
data packet
Enable-Process-1:Execute the program module to
assess the steady-state probability and the transition
probabilities moving from one state to another
Enable-Process-2:Execute the program module to per
form the steady-state equations for each schedule-
driven duty-cycle node operation
Enable-Process-3: Execute the program module for
energy consumption modelling
Enable-Process-4: Execute the program module delay
modelling
Perform hop-by-hop retransmission strategy with
f2(X) : senderToRecevier()
Establish an optimized route between sender and receiver
with the multi-hop paradigm
Compute→packet delivery ratio, average delay,
throughput, fault count
Compute detection ratio =$\frac{\text{faultcount}}{\text{sizeofroute nodes}}$
end procedure
```

The numerical modelling of Markov analysis is if the total number of packets arrives at the FIFO queue of MAC is denoted with TPkt, and if a radio scheduling of node requires two different modes of states denoted with j and k. Then the probability of transition of an IoT node from j to k shown in Eq. 5.

$$\mathrm{prob}(o, j) = \forall j * I \qquad j = 0, \dots, M$$

$$\mathrm{prob}(o, M) = \forall \geq M\mathrm{prob} = \beta\forall 0 I j = 0, \dots, M$$

$$\mathrm{prob}(j, j-1) = \forall k - j + 1 * I\beta + (I - \beta * I) * \forall j - 1 * I \qquad j = 1, \dots, M-1 \tag{5}$$

Here ∀j represents the expected data packet that arrives at the state j at the MAC layer. I denote inter-arrival packet arrival and M is the length of the FIFO queue. β is the independent probability factor for transmitting the data packet. The system applies a set of power mode transition variations that lies within a space ε = [0 to M]. If the transitional probability factor is denoted with TranM (t) with m types of system packet variation then the following numerical modelling can be computed as shown in Eq. 6.

$$\mathrm{Tran}_m(t)=\mathrm{Tran}_{m-1}(t)*\beta I+\mathrm{Tranm}(t)*(1-\beta I)+O(I) \qquad (6)$$

The study also imposes energy consumption modelling for n number of hops. The total energy consumption can be numerically modelled as:

$$\mathrm{pow}(n)=2*\mathrm{Spow}+\frac{\mathrm{Plength}}{\mathrm{Tx(R)}}\big((n-1)*\mathrm{Rp}+n\mathrm{Tp}+2\mathrm{Pcircuit}+\mathrm{Ipow}+\mathrm{Pamp}+\mathrm{Psleep}\big) \qquad (7)$$

2. Delay-aware reliable end-to-end re-transmission routing paradigm: The proposed work introduces another re-transmission strategy to ensure end-to-end re- liable mode of communication by satisfying the delay constraints in the IoT environment. The system conceptualizes the proposed idea in a way where intermediate nodes do not check and validate the correctness of the data packet and directly transmit it to the sink finally the sink checks and validate the correctness of the packet. In case of any error, the sink again sends a NACK packet to notify the respective node about the failed transmission

3. Discussion on BFO algorithm for energy-optimized clustering in IoT: BFOA is a nature-inspired computational technique that is influenced by the forging behaviour of Escherichia coli(e.coli) bacteria that live in the human intestine. BFOA mimics the four fundamental processes that are **chemotaxis step, swarming, reproduction, and elimination-dispersal** step as based on a real bacterial system present in the human intestine which helps to achieve the ideal solution for the complex problem (J. Shreyas, et al., 2020). At the time of foraging behaviour of the real bacteria in the human intestine, E. coli bacterium operates the process of tumble either swim, which are two primary processes executed by a bacterium with the help of the set of tensile flagella. Flagella is made up of the protein called flagellin and is a type of thin hollow tube, like a helical hair structure which randomly attached around bacteria membrane cell, and each cell contains two to six flagella. Flagella allow the bacterium movement towards the food and to reach in contact with other bacteria. When the flagella spin in the clockwise direction or can say bacteria move in the regular direction called as bacteria swims, and when flagella spin changes to the anti-clockwise direction or when bacteria move in random direction then it called as tumble process. Swimming and tumbling both processes are the complex combination process to keep the bacterium in higher food nutrition’s areas.

Chemo taxis process

This is a fundamental process generated by the swimming and tumbling of the bacteria in search of food. The flagellated cells have a sensory system that enables them to swim towards favourable surrounding that contains attractant such as nutrients and away from the noxious environment that contains repellent signals like as harm-full products this type of sensory system called as Chemotaxis. Furthermore, when a bacterium meets with a higher nutrient surface and noxious-free surface, they continue their swim process in the way of getting higher nutrients. But when they meet with a noxious surface, then it changes the direction and moves in a random direction with the fixed small steps.

So let assume in solution space initial bacteria is an ith bacterium that is i = 1 and for each value of i,it considers as i = j +1. Where the jth parameter will consider as chemotactic steps, kth reproduction, lth is an elimination-dispersal process. Also, let us $J(i, j, k, l)$ be the fitness value with the position of the ith bacterium $\theta^{i}(j, k, l)$ from Eq. 8 here, (θ^{i} can be considered as the position of ith bacterium). So, the movement of bacterium at chemotactic process, reproductive and elimination-dispersal process can be represented in mathematical terms as:

$$\theta i(j+1,k,l) = \theta i(j,k,l) + C(i)\frac{\delta(i)}{\Delta t(i)\Delta(i)} \tag{8}$$

Where $\boldsymbol{\theta i(j+1,k,l)}$ represents a vector of bacterial movement, if J (θi(j, k, l)) be the fitness function the movement of bacteria is in swim direction then Δ remains unchanged. Otherwise, if J (θii(j + 1, k, l)) is better than J (θii(j, k, l)), then Δ is a random vector of tumbling.

Swarming process

In this process, each bacterium moves and releases a signal to attract the others bacterium to form swarms together. Bacteria have a unique sensing and decision-making technique that the bacteria use to send a signal to other bacteria, and every bacterium release an offensive substance to suggest other bacteria to keep a secure distance among each of them. The repelling effect and cell-to-cell attraction can be represented as:

$$\begin{aligned} Jcc\big(\theta, P(j,k,l)\big) \\ &= \sum_{i=1}^{S} Jcc\big(\theta, \theta i(j,k,l)\big) \\ &= \sum_{i=1}^{S}\left[-dattractexp(-wattract)\sum_{m=1}^{P}(\theta m - \theta im)^{2}\right] \\ &+ \sum_{i-1}^{S}\left[-hrepelentexp(-wrepelent)\sum_{m=1}^{P}(\theta m - \theta im)\right] \end{aligned} \tag{9}$$

Reproduction process

Here bacteria arrange themselves according to their health value or cost value in which half of the bacteria’s dies and the remaining half of bacteria are ready to survive and for reproduction. The weaker bacteria (which require more energy to sustain) dies and the remaining healthier bacteria (which need the least energy or which having low-cost value) divides each of them into two bacteria. This process maintains the bacteria population size constant. The health of bacteria is calculated by the sum of fitness that is $J^{i}_{health}\, h$

$$J^{i}_{health}\, h = \sum_{j=1}^{Nc+1} J(i, j, k, l) \tag{10}$$

Elimination and dispersion process

This process of elimination takes place after the reproduction process. Due to the occurrence of an unpredictable change in the environment all bacteria in that region are died, or they get dispersed into a new environment. The newly born bacteria occupy the location of eliminated bacteria. The highest fittest bacteria or the bacteria with minimum cost value represents the optimal solution for an objective problem. The above Algorithm. 3 shows the core computational design of the integrated BFO based energy and delay aware clustering in IoT. It also shows how efficient selection of CH can enhance reliable link formation along with optimizes energy and delay performance.

Algorithm 3 BFO Clustering strategy in IoT

```
procedure
Input Parameters: transmitter power ($T_p$), receiver
power ($R_p$), idle power ($I_{pow}$), Startup power ($S_{pow}$),
preamble length($P_{length}$), Sender node id($S_{id}$),
receiver node id ($R_{id}$)
Output: Successful operation of energy and delay
efficient clustering
Define the number of swimming steps, chemotactic steps
and reproduction steps
Number of elimination dispersal steps along with bac-
teria
Initialize→global best and local best cost
Start—BFO main loop
for 1←1 to number elimination dispersal do
    for k←1: reproduction limit does
        Evaluate chemotactic loop
        Update $J_{cc}$ and apply $J_{cc}$limites
        Update position and $J_{cc}$ mirror effect
        Apply position limits
```

```
            Evaluate personal best cost and global best cost
            Select the CH based on energy and distance
            factors
        end for
    end for
    Make best soln as the global best solution
    Repeat until the entire IoT network dies
    Evaluate the performance parameters
end procedure
```

Performance Analysis

This section analyses the performance using different parameters of QoS by examining the pragmatic scenarios of deployment of IoT in a widespread region hence evincing the geographic routing of IoT. In most single-hop and multi-hop communication cases, single-hop transmission is considered to be more efficient with respect to energy within the radio range.

Reducing the energy consumption can be assumed that it is the core issue and it can reduce the power overhead through the usage of an innovative strategy for multi-path transmissions. Here considering the hop distances and energy utilized, metrics of path loss, average packet delay, energy consumption in each node, throughput ensures green efficiency. Following are the parameters that are examined with simulated results from mathematically calculated values and by plotting them.

A. Analysis of Average delay

Fig. 4 shows that the average delay is very less in the BFOA algorithm as compared to ARGA and GPSR algorithms while Fig. 5 shows the formulated values. The delay could be happening in various stages such as when the node tends to transmit, it could have a delay depending on the packet size concerning the distance it has to travel. It could occur as an end-to-end transmission stage, where packets should deliver complete information from one cluster node to the sink. Another instance of delay is during the queuing process. Where packets have route blocked hence to avoid packet drop, the queue is maintained. All the factors are considered and plotted with data checked from three algorithms. The average delay that is observed in the BFOA transmission is 25 milliseconds.

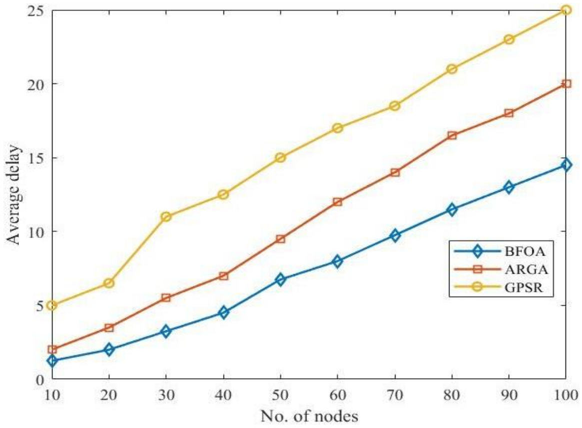

Fig. 4. Analysis of delay with respect to Route

Fig. 5. Analysis of average delay concerning node iteration

B. Analysis of Energy consumed

Fig. 6 shows the analysis of the energy consumed concerning distance covered and nodes. Each node consumes certain energy to transmit data packets and to communicate with the sink node. In the figure, the energy consumed in the proposed algorithm, BFOA is compared to the energy consumed in two algorithms ARGA and GPSR. The average energy consumed for 50 meters is about 0.015 kcal.

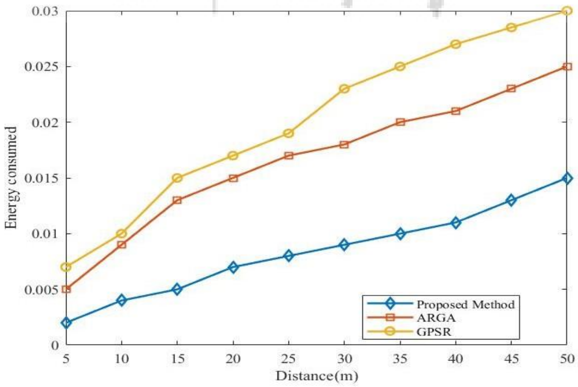

Fig. 6. Analysis of average energy consumed in the network

C. Analysis of Packet Delivery Ratio

Here, Fig. 7 shows that the packet delivery ratio is very higher in the case of both transmission strategies. It directly relates to packet drop happening in the route. No of the packets delivered is based on the energy left in the system as well as the information carried over to the sink. Hence considered this, the proposed algorithm has a benefit and has a high packet delivery ratio concerning both the strategies discussed.

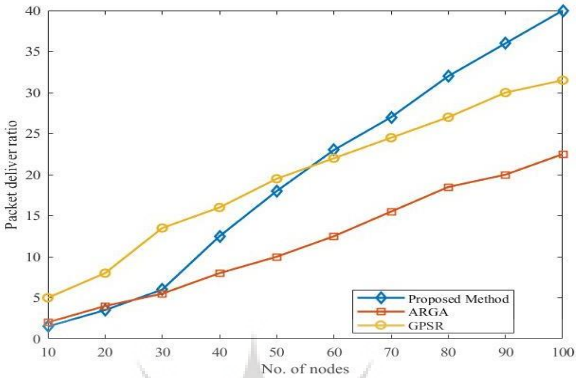

Fig. 7. Analysis of Packet Delivery Ratio

D. Analysis of Remaining energy

Fig. 8 Shows the amount of remaining energy in each IoT node. This data is obtained from the practical and mathematical formulation of various nodes and by proving base energy. During each stage of transmission, energy is utilized by all nodes for various functions like cluster head formation, cluster detection, neighbour node detection, packet transmission for various nodes and source to sink transmission. After each step, the energy utilized and energy used is calculated by checking the leftover energy before the transmission started and after it ended. An energy coefficient is written, concerning each node starting from the source node to the sink node and all the participating nodes, and sometimes the non-participating nodes as well. The non-participating nodes are mostly checked for how much energy is left out and if they can be utilized for the transaction as an intermediate node. So by the end of the transmission, depending on the nodes and left energy in the nodes, the next transmission can take place using this computed data.

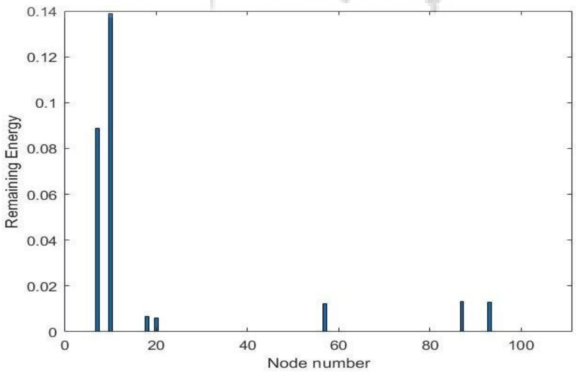

Fig. 8. Analysis of Remaining energy

E. Analysis of best cost evaluation

Fig. 9 shows that the estimation of the best cost for each iteration when the BFO algorithm is applied.

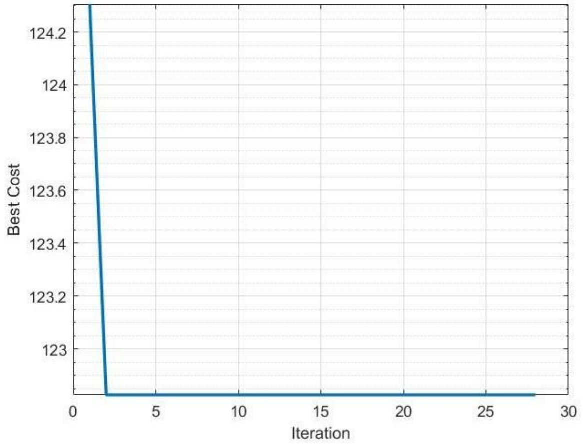

Fig. 9. Analysis of best cost evaluation

F. Analysis of Average throughput

Fig. 10 and 11 shows that the amount of throughput obtained from different route establishment using the formulated re-transmission strategies. The throughput gain is obtained from various stages such as the maximum number of packets sent without a network breakage. The algorithm makes the normalized packet size concerning distance to be travelled in turn increases throughput in the network. In end-to-end transmission, the obtained results are seen by the collection of packets in the CH is to send to the sink which selects an efficient cluster head from its energy factor which increases the throughput. The figure compares the BFOA to the other two algorithms for the throughput. The average throughput is higher in the proposed algorithm when compared to ARGA and GRSP. The throughput in BFOA is 90 to 100 kbps with respect to the number of nodes in the network.

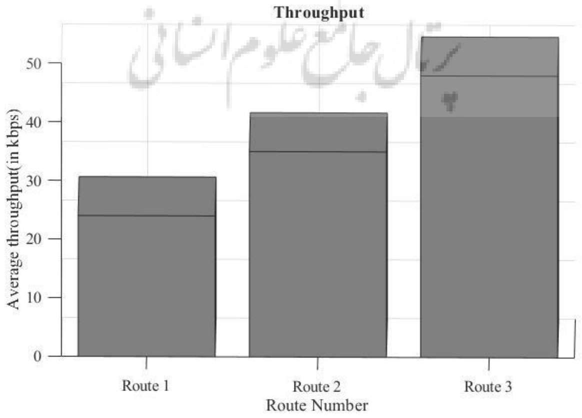

Fig. 10. Analysis of Average throughput with respect to route

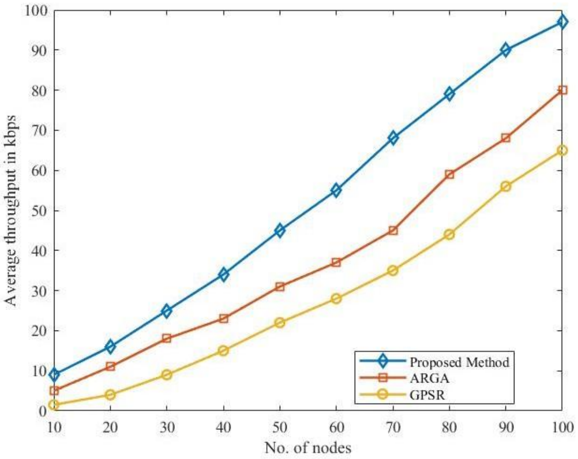

Fig. 11. Analysis of average throughput concerning node iteration

Conclusion

The IoT differs from traditional wireless networks like wireless LAN, wireless mesh networks, mobile ad-hoc networks etc as IoT forms a collaborative and highly distributed network of large scale IoT nodes with heterogeneous parameters of wireless communication standards, its energy capacity, bandwidth limitation, computational as well as storage size. The distinguishing characteristics of IoT require a multi-functional optimization for establishing a route between source and destination that should consider parameters from every layer of IoT architecture.

The weak link problem in the geographical routing is aimed to optimized by normalizing the objective function considering parameters like distance, number of hop counts, energy distribution across the zones of deployment geography, modulations, path loss, radio state from MAC layer etc. In this stage of work, a suitable routing protocol modelling is simulated in a numerical computing platform to establish the route considering the energy of zones for hop selection in the route accordingly to the event movement. An extensive simulation carried out in MATLAB simulation tool shows the effectiveness of the formulated system in terms of delay is reduced by 12%, throughput is increased to 10%, remaining energy in the network is increased to 11% and packet delivery ratio from the proposed work in increased to 7-9% when the system is compared with the existing work. The next stage of work aims to realize the objective functions for performance analysis of defined metrics. The study also attempts to numerically model a swarm intelligence-based clustering approach which targets to optimize the energy and delay constraints associated with the IoT routing paradigm

Conflict of interest

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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References

Abouei, J., Plataniotis, K. N., & Pasupathy, S. (2011). Green modulations in energy-constrained wireless sensor networks. *IET Communications*, *5*(2), 240-251.

Amiri, E., Keshavarz, H., Alizadeh, M., Zamani, M., & Khodadadi, T. (2014). Energy-efficient routing in wireless sensor networks based on fuzzy ant colony optimization. *International Journal of Distributed Sensor Networks*, *10*(7), 768936.

Antonopoulos, A., & Verikoukis, C. (2011). Network-coding-based cooperative ARQ medium access control protocol for wireless sensor networks. *International Journal of Distributed Sensor Networks*, *8*(1), 601321.

Busse, M., Haenselmann, T., & Effelsberg, W. (2006, June). Energy-efficient forwarding schemes for wireless sensor networks. In *2006 International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM'06)* (pp. 9-pp). IEEE.

Hasan, H. F. A., Ilias, A., Rahman, R. A., & Razak, M. Z. A. (2008). Service quality and student satisfaction: A case study at private higher education institutions. *International Business Research*, *1*(3), 163-175.

Hasan, M. Z., Al-Rizzo, H., & Al-Turjman, F. (2017). A survey on multipath routing protocols for QoS assurances in real-time wireless multimedia sensor networks. *IEEE Communications Surveys & Tutorials*, *19*(3), 1424-1456.

Hasan, M. Z., & Wan, T. C. (2013). Optimized quality of service for real-time wireless sensor networks using a partitioning multipath routing approach. *Journal of Computer Networks and Communications*, *2013*.

Krishnamurthi, R., & Goyal, M. (2019). Enabling Technologies for IoT: Issues, Challenges, and Opportunities. In *Handbook of Research on Cloud Computing and Big Data Applications in IoT* (pp. 243-270). IGI Global.

Long, J., Dong, M., Ota, K., Liu, A., & Hai, S. (2015). Reliability guaranteed efficient data gathering in wireless sensor networks. *IEEE Access*, *3*, 430-444.

Mir, Z. H., & Ko, Y. B. (2017). Collaborative topology control for many-to-one communications in wireless sensor networks. *IEEE Access*, *5*, 15927-15941.

Shreyas, J., & Kumar, S. D. (2019, November). A Survey on Computational Intelligence Techniques for Internet of Things. In *International Conference on Communication and Intelligent Systems* (pp. 271-282). Springer, Singapore.

Shreyas, J., Jumnal, A., Kumar, S. D., & Venugopal, K. R. (2020). Application of computational intelligence techniques for the internet of things: an extensive survey. *International Journal of Computational Intelligence Studies*, *9*(3), 234-288.

Shreyas, J., Singh, H., Bhutani, J., Pandit, S., Srinidhi, N. N., & SM, D. K. (2019, December). Congestion Aware Algorithm using Fuzzy Logic to Find an Optimal Routing Path for IoT Networks. In *2019 International Conference on Computational Intelligence and Knowledge Economy (ICCIKE)* (pp. 141-145). IEEE.

Shreyas, J., Singh, H., Tiwari, S., Srinidhi, N. N., & Kumar, S. D. (2021). CAFOR: congestion avoidance using fuzzy logic to find an optimal routing path in 6LoWPAN networks. *Journal of Reliable Intelligent Environments*, 1-16.

Sikora, M., Laneman, J. N., Haenggi, M., Costello, D. J., & Fuja, T. (2004, October). On the optimum number of hops in linear wireless networks. In *Information Theory Workshop* (pp. 165-169). IEEE.

Singh, G. T., & Al-Turjman, F. M. (2015). Learning data delivery paths in QoI-aware information-centric sensor networks. *IEEE Internet of Things Journal*, *3*(4), 572-580.

Vuran, M. C., & Akyildiz, I. F. (2006, September). Cross-layer analysis of error control in wireless sensor networks. In *2006 3rd annual IEEE communications society on sensor and ad hoc communications and networks* (Vol. 2, pp. 585-594). IEEE.

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