Section A-Research paper
ISSN 2063-5346

ENERGY EFFICIENCY USING LoRaWAN PROTOCOL IN INDUSTRIAL IOT

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Abstract

Wireless IoT sensor networks (WSNs) are a new type of wireless communication technology that provides uninterrupted communication beyond geographical barriers. In the LORAWAN, data transmission is the main source of energy consumption, 6nd it is the major issue that degrades the network performance significantly. Cluster-based routing is one of the approaches in the area of efficient use of energy, which is an important issue in the energy efficient routing protocol. Our proposed system, Energy Efficient Sleep-scheduling for Cluster Based Aggregation (EESCBA) technique for a Low-Response Area Network (LORWAN) through strategic selection of the CH, RED FOX node and the shortest path from the source node to the sink. The proposed WO protocol is based on a cluster-based clustering protocol, where clusters are formed using the Clustering Managers (CMs), the CHs and REDFOX nodes and the routing path is determined. WO achieves higher residual energy, higher lifetime, higher packet delivery ratio, higher energy efficiency and lower end-to-end delay compared to ARPEES and WCH protocols under varying number of rounds. The performance metrics such as delay, packet drop, and average residual energy are evaluated and compared with those of EECS.

Keywords: LoRaWAN, EESCBA, Clustering, REDFOX

INTRODUCTION

Recent advances in the Internet have revolutionized the world, influencing each aspect of human life, by providing uninterrupted communication beyond geographical barriers. This has facilitated accessing remote and isolated environments for various applications. When searching for solutions in wireless technologies LORAWANs are the viable option. The LORAWAN consists of a large number of spatially distributed small lightweight IoT sensor nodes to monitor various environmental or physical conditions, such as temperature,

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sound, humidity, vibration and pressure. The typical LORAWAN consists of two major components, namely, the IoT sensor nodes and the sink. Basically, the IoT sensor node's task is to sense the required information and route it to the central node called the sink. Wireless IoT sensor nodes are battery powered devices, and it is very difficult to charge the IoT sensor node's battery regularly. IoT sensor nodes are mainly deployed in an aggressive or impractical environmental condition, and their functions such as sensing, computation and communication consume high energy of the IoT sensor nodes, especially data transmission which is the main source of energy consumption. Various researchers have attempted to minimize the energy consumption and maximize the network's lifetime for the LORAWAN using cluster-based routing techniques.

LORAWAN ARCHITECTURE

An IoT sensor is a transducer, which converts physical signals into electrical signals. A IoT sensor node, also called a mote, performs various functions, such as sensing, processing, gathering information and communication. The hardware architecture of an IoT sensor mote and the various functional subunits are shown in Figure 1. An IoT sensor node includes basic components like the sensing unit, processing unit, communication unit and battery power unit (Tilak et al. 2002).

A sensing unit consists of three parts, the IoT sensors, analog-to-digital converter (ADC) and digital-to-analog converter (DAC). IoT sensors sense the physical environment and convert the sensed information into electrical signals, and convert the analog electrical signals into digital signals and then feed the processing unit. A processing unit consists of a processor or a controller and a memory unit for data processing and storage purposes. Information received from the IoT sensor unit is passed on to the processor or the controller, and the processing depends on various algorithms. A communication unit, also called the transceiver unit, performs data transmission and reception. DAC is used to convert the digital signal into analog signal.

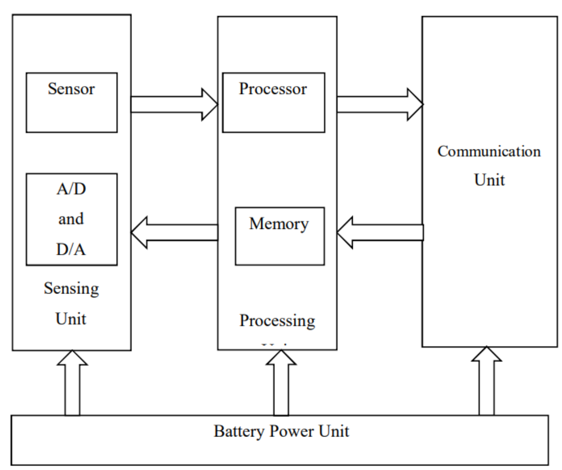

Figure 1. Hardware Architecture of a IoT sensor Mote

The transceiver unit consists of the modulator,

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demodulator, amplifier, filter, mixer and so on, to achieve efficient communication. A battery power unit consists of a battery through which all units get their energy. An IoT sensor node is powered using stored energy or other sources of energy.

2. RELATED WORK

LORAWANs operate in human-inaccessible terrains. The information from the IoT sensor nodes should be routed efficiently and the energy saving measures are required. The aim of cluster-based routing in LORAWANs is to minimize the energy consumption and maximize the network's lifetime. This chapter discusses in detail the research work carried out by various authors for the efficient cluster-based routing in LORAWAN. The CHs, RED FOX nodes and routing path selection in cluster-based approaches available in the literature survey can be classified into three categories as follows:

i. Clustering and gateway selection approach

ii. A method for choosing gateway nodes and routing paths

iii. A mobile routing and data collection strategy based on sinks

CLUSTERING AND GATEWAY SELECTION APPROACH

Routing protocols in cluster-based LORAWANs depend on clustering and the CH selection. Hence, it is the basic and the most important service that helps in finding the efficient routing path to reach the sink. A survey on the CH selection for cluster-based LORAWANs is discussed below. Clustering mechanism is a key to achieve energy efficiency in LORAWAN. Heinzelman et al. (2000) have proposed the basic clustering protocol for LORAWAN called LEACH (Low Energy Adaptive Clustering Hierarchy). It is the most popular energy efficient clustering protocol which deals with distributed cluster formation. The main objective of this scheme is to achieve energy efficiency by minimizing the energy consumption, and to ensure even distribution of the load to all the IoT sensor nodes. LEACH protocol function is broken up into rounds. Each round contains two phases, namely, the setup phase and the steady state phase. In the setup phase, the nodes are deployed, the clusters are formed and the gateways are selected. The gateway selection is based on the predetermined value p (the desired percentage of gateways in the LORAWAN). In this phase, each node could be a gateway or a cluster member. All the wireless IoT sensor nodes select a random number p between 0 and 1. The node with a random number less than the desired threshold value T(n) becomes the gateway for that specific round. The threshold value is determined using the percentage of a particular node for becoming a gateway in the current round and the set of other nodes that have not been selected as gateways in the last (1/p) rounds. In the steady state phase, the data is gathered and communicated between the source node and the sink. During the steady state phase all the IoT sensor nodes initiate sensing and transmit the data to the cluster head.

ROUTING PATH SELECTION APPROACH AND GATEWAY NODE

In multi-hop communication, the sensed data needs to be routed over a long distance to reach the sink which reduces the strength of the information and consumes more energy. Hence the RED FOX nodes are required to send the information efficiently to the sink using multiple hops. The routing path selection is an important factor for achieving energy consumption in LORAWAN, since the link or path failure causes a large number of packet drops in the network. Hence the dynamic path selection is required for the achievement of a high packet delivery ratio. The following section analyzes the various reviews based on RED FOX node selection and dynamic routing path selection. Wang & Chen et al. (2013) have proposed a Link-Aware Clustering Mechanism (LCM) to achieve energy efficient routing for cluster-based LORAWAN. In this protocol, energy efficiency is achieved through a proper selection of gateway and gateway with the help of Predictable Transmission Count (PTX). This scheme achieves reliability and energy efficiency, but the CH selection criteria considers the residual energy of the node and distance of the node which is not enough for the selection of the best gateway or gateway node in LORAWAN. A Passive Clustering (PC) scheme for LORAWAN has been developed by Kwon & Gerla (2002). This mechanism describes all the nodes in the network with their own state. The receiver node changes its state depending on the sender node state and all the nodes update the new state to their neighbors, with the knowledge of the current cluster state. This passive clustering technique has reduced additional load by reducing the control packets in the network. This passive clustering uses the random CH selection procedure to reduce the battery power very quickly making the CH selection and the routing scheme inefficient.

Tarhani et al. (2014) have proposed SEECH (Scalable Energy Efficient Clustering Hierarchy). This protocol is subdivided into two phases, start phase and steady-state phase. In the start phase, the distance of each node from the sink and the number of neighbors in a

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particular radius are calculated. The highest distance node is selected as the CH. This scheme also made analyzes of the gateway node selection scheme which has distance as its criterion. In the steady-state phase, data is gathered from the nodes and communicated to the sink using a selected topology, CH and RED FOX node, based on the distance criteria alone which leads to an inefficient CH selection. Abbasi & Younis (2007) have given a survey on clustering algorithms for LORAWAN which analyzes the various clustering algorithms needed for clustering, highlights the clustering objectives, features and clustering complexity.

MOBILE SINK-BASED ROUTING AND DATA GATHERING APPROACH

In mobile sink-based LORAWANs, the position of the mobile sink is always in an ad-hoc manner, making the routing and data gathering more challenging. Hence the following section presents a survey of the mobile sink-based LORAWANs. Zahhad et al. (2015) have proposed (MSIEEP) Mobile Sink based adaptive Immune Energy-Efficient Clustering Protocol which avoids the energy hole problem by minimizing the total dissipating energy in communication. The above scheme uses AIA (Adaptive Immune Algorithm) in order to reduce the communication overhead control packets in the network and optimize the required number of CH in the network. AIA identifies the location of the CH and also the mobile sink which leads to the reduced energy consumption while communicating between the CH and mobile sink. Rani et al. (2016) presented a BDEG (Big Data Efficient Gathering Algorithm) for real time data gathering using RSSI (Received Signal Strength Indicator) data communication methodology. The static approach is followed, for determining the clusters. The CH and the. Takaishi et al. (2014) have proposed a methodology which describes the sink mobility utilization to assist data gathering in a densely distributed LORAWAN. This scheme describes the modified maximization technique and the cluster optimization for reducing energy consumption. This algorithm groups the nodes based on their communicating ability. To gather the data from all the IoT sensor nodes in the network, the number of clusters must be high in the network, this is achieved through the connectivity value of the node which is based on the IoT sensor node’s location. This scheme deals mainly with clusters of an optimal number.

PROBLEM STATEMENT

The special and unique characteristics of a LORAWAN are that it is infrastructure-less, and self-organized with limited energy sources, memory and bandwidth. Most of the LORAWANs have real time applications with deadlines. The challenges facing LORAWAN are briefly stated below.

i. Energy Efficiency: The LORAWAN requires high energy efficiency, the IoT sensor nodes are powered by limited batteries, and the main causes of battery drainage include, continuous sensing, data gathering, processing, buffering, transmission and reception of data. More energy is consumed by these functions, which is a major challenge in the LORAWAN.

ii. Deployment: LORAWAN nodes are deployed in two categories on the basis of the IoT sensor node movement, namely, the deterministic node deployment and random node deployment methods. The deterministic node deployment method is used mostly when the deployment region and the requirements are known earlier and the location of the IoT sensor nodes remains static. In the random node deployment method, the IoT sensor nodes are spread randomly forming an ad-hoc infrastructure. The random node deployment method is used mostly for real time applications in critical environments without any prior information about the deployment region, environment requirement and communicable range.

iii. Topology: The wireless IoT sensors are deployed mostly randomly. They are required for the achievement of high network reliability, network coverage, network connectivity and energy efficiency. Hence, the network topology requires an efficient design.

iv. IoT sensor Localization: IoT sensor localization is a vital issue for LORAWAN management and functions. In most of the real time applications, the wireless IoT sensors are deployed randomly without any infrastructure. The determination of the location of the IoT sensors in real time applications is another important challenge.

2. METHODOLOGY

A LORAWAN is a self-configurable collection of specialised, spatially scattered IoT sensors that can sense, process, and talk to one another using radio signals. For monitoring and measuring physical conditions including temperature, sound, pollution levels, humidity, wind speed, and other factors, it can be used in a variety of situations. The data collected from various IoT sensor nodes is sent to a sink to reduce their energy consumption, which is the main problem with the LORAWAN and dramatically lowers network performance. One strategy for the efficient use of energy in LORAWANs is cluster-based routing. The CH selection processes used in cluster-based routing are typically based on the node's residual energy or random selection. But this is an inefficient methodology since some nodes contain

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high energy but the distance from the node to the base station is high, which results in early depletion of energy. In the random selection procedure, the node that contains minimum energy which is selected as the CH quickly drains the energy level, thereby reducing the lifetime of the network. The closest node to the washbasin is typically chosen as the RED FOX node in the RED FOX node selection process. However, that node receives more messages than other nodes, which reduces their energy and makes them more susceptible to errors in LORAWANs.As a result, choosing the RED FOX node is crucial and must be done carefully. As a result, choosing between CH and RED FOX nodes is crucial for the LORAWAN's energy-efficient cluster-based routing protocol. By carefully choosing the CH, RED FOX node, and the shortest route between the source node and the sink, the WO protocol for LORAWAN is proposed in this chapter.

Energy-efficiency in the WO protocol is attained by carefully choosing the CH and RED FOX nodes along the shortest route from the source node to the sink. To accomplish an efficient routing, WO comprises of two steps, the setup phase and the steady-state phase. CM, CH, and RED FOX nodes are used to build clusters during setup, and the shortest routing path is then identified. Data is gathered from the CMs and sent to the sink via the CH and RED FOX nodes during the steady-state phase. In WO protocol, energy-efficiency is achieved through efficient selection of the CH and the RED FOX nodes along the shortest path from the source node to the sink. WO consists of two phases, namely, the setup phase and the steady-state phase to enable achievement of an efficient routing. In the setup phase, clusters are formed using the CMs, the CHs and RED FOX nodes and the shortest routing path is determined. In the steady-state phase, data is collected from the CMs and routed to the sink through the CH and RED FOX nodes. The protocol assumes all the IoT sensor nodes and the sink as stationary, with the sink located far away from the sensing field, all the IoT sensor nodes' energy levels are equal and they have an unique ID. All the IoT sensor nodes are equipped with the GPS device to measure their own geographical position, the IoT sensor nodes are capable of performing in the inactive mode and the sleeping mode. All the IoT sensor nodes have the same fixed energy and rate, and each round consists of a complete cycle for forming clusters, selecting the CH, and the RED FOX node and sending the data to the sink. The block diagram of WO protocol is shown in Figure 3. The various stages of WO protocol, such as CH selection, algorithm for CH selection, RED FOX node selection, algorithm for RED FOX node selection, cluster formation, WO message formats, operation of WO protocol, and intra-cluster and inter-cluster routing are discussed in the following sections.

Gateway Selection Mechanism

In cluster-based routing, the CH, which serves as the cluster's backbone, carries out all necessary network operations, including cluster formation, CM insertion, CM deletion, and communication.

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As a result, the CH needs to be chosen carefully. In the WO protocol, CH selection parameters have been used in the CH selection process, such as the residual energy of the node and the angle and distance between the node and the sink. IoT sensor nodes totaling n are dispersed throughout the network area. For each round, the source node is taken into account as the tentative CH (TCH). A CH selection algorithm is used by all IoT sensor nodes to choose the CHs. Take node j, for instance, as the CH. Following that, Node J calculates CHn to determine its change for being a CH

Algorithm for CH Selection

All of the IoT sensor nodes nearby are sent the CH advertisement message CHn (j) by the CH. After receiving the message, the nodes respond with a join message (JOIN_MSG) to that specific CH. The CH accepts the nodes as CMs for that specific CH after receiving the join message from the IoT sensor nodes in the network successfully. The reply message (REP_MSG) is sent to all CMs by the CH. The perceived information is sent to the appropriate CH by each CM. The CH determines the quickest route to the sink and uses single-hop or multi-hop routing across the RED FOX nodes to send all the collected data there.

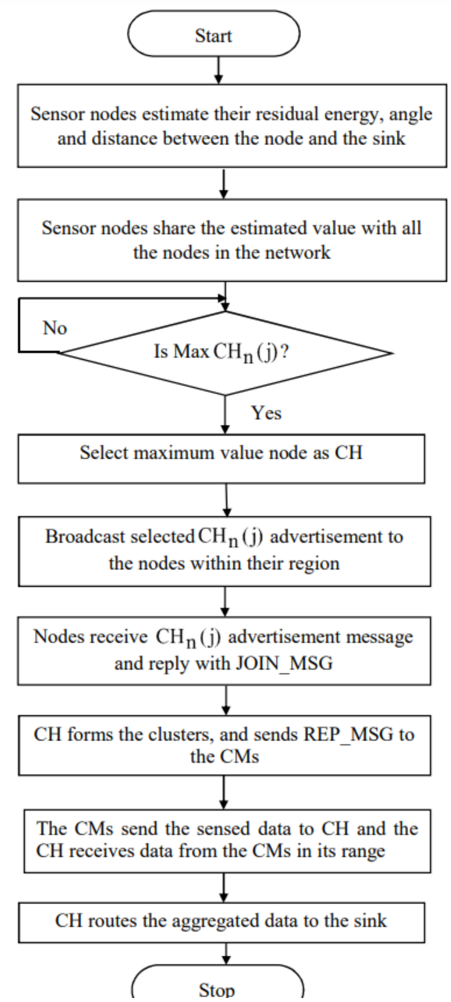

Figure2. Proposed Algorithm Flow Diagram

The various steps involved in the CH selection process are described below.

Step 1: Networks are created when all IoT sensor nodes are randomly placed in the designated area.

The source node is initially chosen as the tentative CH (TCH).

Step 3: To choose the CHs, each IoT sensor node calculates its residual energy, angle, and distance from the sink.

Step 4: In the network for that specific location, the node with the highest value becomes the CH.

Step 5: The chosen CH notifies all of the IoT sensor nodes in the network in the region of the CH advertisement message.

Step 9: The CH notifies all the CMs of the reply message (REP_MSG).

Step 10: In response to the chosen CH, the CM sends the detected information to the CH.

Step 11: Using the shortest path, the CH gathers all the data and transfers it to the sink.

efficient routing methodology of WO protocol has been proposed. Energy efficient routing is achieved with the help of an efficient selection of the CH, RED FOX node and the shortest path, by strategically selecting parameters, such as residual energy, angle and distance between the node and the sink. The simulation results of WO protocol are implemented using NS2. WO achieves higher residual energy, higher lifetime, higher packet delivery ratio, higher energy efficiency and lower end-to-end delay compared to ARPEES and SEECH protocols. WO protocol is also suitable for all environments. However, the proposed WO does not provide a solution for link or path failure. In case of any link failure, WO protocol needs to search the alternative path again, which leads to incWOe the end-to-end delay in the network.

Cluster Formation

In WO, CHs and RED FOX nodes are selected efficiently, all the CHs introduce themselves to the network using a CHn (j) message. IoT sensor node chooses the nearest CH depending on the strength of the CHn (j) signal. Subsequently, it informs the CH about its choice by transmitting a JOIN_MSG message, which contains the IoT sensor node ID and gateway ID. All the CHs count the CMs according to the JOIN_MSG messages and use the TDMA scheduling scheme to communicate the information without congestion in the network. The CHs transmit the number of TDMA time slots to all the CMs for data transmission and reception. The steady-state phase selected CHs starts gathering the information from the CMs using intra-cluster communication and the CHs transmit the gathered information to the sink directly, and for long distance communication the CHs transmit the gathered information through RED FOX nodes using inter-cluster communication.

PERFORMANCE EVALUATIONS

In this section, the performance of WO protocol is studied in terms of residual energy, lifetime, packet delivery ratio, energy efficiency and end-to-end delay. WO is implemented by using Matlab. The performance of WO is compared with that of ARPEES (Adaptive Routing Protocol with Energy efficiency and Event clustering for Wireless IoT sensor Networks) and WCH (Whale Clustering Hierarchy) protocols under varying number of rounds. Hundred nodes are randomly distributed in a 100 m x 100 m area. The initial energy is kept at 2 joules. The simulation parameters used to implement WO protocol are listed in Table 1.

Table.1 Simulation parameters of Proposed protocol

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Parameters	Value
Number of nodes	100
Network size	100 m x 100 m
Communication range	80 m
Application Type	Event driven
Initial energy	2 J
Simulation Time	20 sec
Packet Size	512 bytes
Antenna	Omni Directional Antenna

The various metrics used to study the performance of WO protocol are defined as follows.

Residual Energy: It is the mean value of the remaining energy of all the alive IoT sensor nodes when simulation ends.

(ii) Lifetime: It is the ratio of the number of alive nodes to the number of rounds.

(iii) Energy Efficiency: It is the ratio of the total number of data delivered by the node to the total energy consumed by the node.

(iv) Packet Delivery Ratio: It is the ratio of the total number of data packets received by the sink to the total number of data packets sent by the source node at a specific time period.

(v) End-to-end delay: The time required for a data packet to be transmitted across the IoT sensor network from the source node to the sink.

RESULTS AND DISCUSSIONS

SIMULATION RESULTS

TheNetworkSimulator(NS-2)is used to simulate the proposed technique

Simulation Model and Parameters The proposed Energy Efficient Sleep-scheduling for Cluster Based Aggregation (EESCBA) technique is compared with the Energy Efficient Centralized Scheduler (EECS) (YanweiWuetal.,2010). The performance metrics delay,packet delivery ratio,packet drop and average residual energy are evaluated.

The following table 1 shows the simulation settings and parameters which are summarized as

Table1 Simulation Settings

No. of Nodes	25,50,75 and 100
Area Size	500 X 500
Mac	IEEE 802.11
Transmission Range	250m
Simulation Time	20 sec
Traffic Source	CBR
Packet Size	512
Initial Energy	10.3J
Receiving Power	0.395
Transmission Power	0.660
Rate	250Kb

Results

The number of nodes is varied from 25 to 100 and the result sarede picted .

Nodes	Delay		Delivery Ratio		Drop		Energy	
	RED FOX OPTIMIZATION	EXISTING SYSTEM	RED FOX OPTIMIZATION	EXISTING SYSTEM	RED FOX OPTIMIZATION	EXISTING SYSTEM	RED FOX OPTIMIZATION	EXISTING SYSTEM
25	12.17904	15.78065	0.363543	0.273117	3060	16956	17.96725	15.0685
50	10.91647	13.83152	0.547511	0.355303	3648	18200	12.8849	11.37878
75	9.987776	15.43793	0.721023	0.337649	3731	24111	13.63771	11.64326
100	9.806292	16.37729	0.742277	0.433514	3820	20786	13.26564	11.10741

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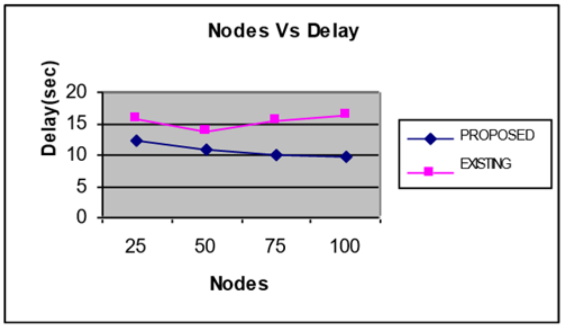

Figure3 ComparisonbasedonNodesVsDelay

Figure3 shows the results of delay for RED FOX OPTIMIZATION and EECS techniques,when the number of nodes is increased.As we can see from the figure,the delay starts to increase from 50 nodes for both the techniques.However, since RED FOX OPTIMIZATION involves TDMA scheduling and effective cluster routing,the delay is 29% less,when compared to EECS.

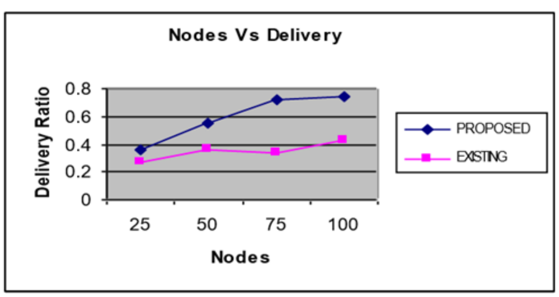

figure 4 Comparison based on Nodes Vs Delivery Ratio

Figure4 shows the results of packet delivery ratio for RED FOX OPTIMIZATION and EECS techniques, when the number of nodes is increased.As we can see from the figure,the delivery ratio increases from 0.36 to 3.74 forRED FOX OPTIMIZATION and 0.27 to 0.43 for EECS. However,since RED FOX OPTIMIZATION involves efficient clustering and collision free scheduling,it attains 38% higher delivery ratio when compared to EECS.

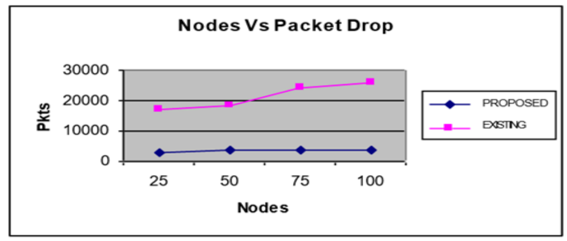

Figure5 Comparison based on Nodes Vs Packet Drop

Figure5. Shows the results of packet drop occurred for RED FOX OPTIMIZATION and EECS techniques,when the number of nodes is increased.As we can see from the figure, the packet drop increases from 16955 to 25786 for EECS and it remains almost constant RED FOX OPTIMIZATION.Since RED FOX OPTIMIZATION involves efficient clustering and collision free scheduling the packet drop is reduced by 82% when compared to EECS

Figure6 Comparison based on Nodes Vs Residual Energy

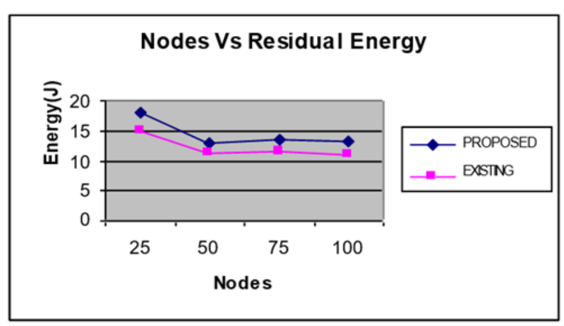

Figure.6 shows the results of average residual energy for RED FOX OPTIMIZATION and EECS techniques,when the number of nodes is increased .As we can see from the figure,the residual energy decreases from 17 joules to 13 joules for RED FOX OPTIMIZATION and 15 joules to 11joules for EECS. Since RED FOX OPTIMIZATION applies compressed data aggregation along with energy efficient sleep scheduling ,the residual energy is higher by 11% when compared to EECS.

Table6 presents the percentAge wise improvement RED FOX OPTIMIZATION over EECS for varying the number of nodes.

Nodes	Delay (%)	Delivery Ratio (%)	Drop (%)	Energy (%)
25	22.82299	24.87354	81.95329	16.13355
50	21.07537	35.10578	68.96703	11.68905
75	35.30367	53.17084	89.91747	14.62451
100	40.12261	41.59674	81.62225	14.20806

CONCLUSION AND FUTURE WORK

Through effective selection of CHs, RED FOX nodes, and the shortest routing path in the LORAWAN, this research has developed the WO protocol to reduce energy consumption and maximise the lifetime of the network. Using factors including the node's residual energy, angle, and distance from the sink, the CH and RED FOX nodes have been strategically chosen for this protocol. For effective information routing from the source node to the sink, WO employs two phases, namely the setup phase and the steady-state phase. Setting up takes placeThe CMs are used to form the clusters, which have higher lifetimes than ARPEES and SEECH protocols, packet delivery ratios that are 12.7% and 7.7% higher than those of those protocols, energy efficiency that is 13.8% and 7.1% higher than those of those protocols, and end-to-end delay that is 13.4% and 7.1% lower than those of those protocols, respectively.

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