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Scheduling based on residual energy of sensors to extend the lifetime of network in wireless sensor network

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Abstract

The maximum amount of sensor energy is consumed during broadcasting. Hence in order to make delay with the network lifetime of a wireless sensor network (WSN), there is a need of optimum utilization of sensor energy. Scheduling in media access control (MAC) layer plays a critical role in the designing of WSN to avoid collision and conserve more energy. The Distributed energy aware MAC (DE-MAC) is one such efficient and feasible MAC protocol that addresses the energy management issues in WSN. This work proposes an extension of DE-MAC framework by allocating varying period slots to the nodes based on their residual energy level. Energy of all the nodes is exchanged at regular intervals. Accordingly, the nodes with low energy are allocated less time slots for broadcast and are made to sleep for more time. Simulation is carried out using NS2 (network simulator 2) and the efficiency and performance results are compared with DE-MAC for analysis. Improvement in performance for various parameters such as residual energy, throughput, and packet delivery ratio can be observed.

Keywords: WSN, Scheduling, Network lifetime, Sensor energy, MAC protocol

Introduction

The WSNs even sometimes called as wireless sensor and actuator networks consist of spatially distributed autonomous sensors used to monitor physical and environmental conditions, such as temperature, sound, and pressure, and to collectively pass their data through the network to other locations [1]. The development of WSN was motivated by military applications and today such networks are used in many industrial and consumer applications such as industrial process monitoring and control, machine health monitoring, and similar such processes [2]. To avoid data collision on a shared medium, several MAC protocols have been developed with scheduling playing a major role in the design of WSN [3]. In time division multiple access (TDMA)-based MAC protocol, time is divided into slots and every node is allocated time slots in a time-frame, to allow the transmissions only during the assigned time. Generally, TDMA-based MAC protocols allocate an equal number of slots to all the nodes. In any network, there exist some critical and complicated nodes with lower energy level [4]. These nodes should be recognized, given fewer broadcast opportunities, and encouraged to sleep more. This concept helps in achieving load balancing in the network conserving more energy to extend the network lifetime [5].

Energy management being a critical issue, we came across some energy-efficient TDMA MAC protocols such as power aware clustered TDMA(PACT) [6], traffic-adaptive medium access (TRAMA) [7], on-demand TDMA scheduling (ODS) [8], light weight medium access protocol (LMAC) [9], and energy-efficient and self-organized TDMA MAC protocol by wake up (TDMA-w) [10]. The DE-MAC [11] is one such energy-efficient distributed energy-aware MAC protocol that uses TDMA features for avoiding collision, idle listening, and overhearing. This protocol treats the nodes with lower energy in a different way that is identified by initializing an election process. Such nodes are called winners and are made to sleep more than their neighbors [12]. In this work, authors have proposed a technique with an extension varying time slots for broadcast and sleep based on the levels of residual energy of every node. By doing so, we conserve the energy of critical nodes and thereby making delay of the network lifetime.

The DE-MAC, critical analysis of content-based WSN, and critical analysis of schedule-based WSN have been described briefly for the understanding of reader as below.

DE-MAC

DE-MAC, the distributed energy aware MAC protocol, depends on TDMA and subsequently has the innate capacity of staying away from additional energy wastage. The primary benefits of a TDMA convention present in DE-Macintosh are the accompanying. • Bundle misfortune because of impacts is missing on the grounds that two hubs do not communicate in a similar space. Despite the fact that parcel misfortune might happen because of different reasons like obstruction, loss of sign strength, and so on, • no dispute instrument is expected for a hub to begin detecting its bundles since the spaces are pre-relegated to every hub. No additional control above parcels for dispute are required. DE-Macintosh utilizes the idea of occasional tune in and rest. A sensor hub turns off its radio and goes into a rest mode just when it is time permitting space and has nothing to send. It needs to keep the radio alert in the spaces doled out to its neighbors to get bundles from them regardless of whether the hub with current opening does not have anything to send.

Critical analysis of content-based WSN

It is predominantly made out of the media access control (MAC). The customary MAC protocol in light of the rivalry system is troublesome to address the issues of remote sensor organizations. Since content-based MAC conventions require different handshakes, there is a high gamble of information crashes, making a misuse of energy that is not helpful in remote sensor organizations. Hence, Macintosh conventions for remote sensor networks for the most part take on pre-arranged systems, for example, TDMA to safeguard node energy. MAC layer is one of the exploration areas of interest in remote sensor networks.

Critical analysis of scheduled-based WSN

The network activity is timeslot-based. Communications between any sets of nodes are painstakingly scheduled on a predefined mix of timeslot channel to keep away from impact, inactive tuning in, and overhearing issue to accomplish the energy productivity. Consequently, far reaching time synchronization is a hard necessity. In any case, it should not deliver such high above that it imperils the energy-productive activity. The convention RL-MMAC comprises of a neighbor revelation and time.

Rest of the work is organized as follows. "Existing MAC protocols" section provides a review of MAC protocols and some of the related work. "Methods" section explains the proposed energy-efficient scheduling. "Results and discussion" section provides algorithm with efficiency and performance analysis with visual representations (graphical way). Finally, conclusion of the work is presented in the "Conclusions" section.

Existing MAC protocols

Contention-based and scheduled-based protocols are the two categories of MAC protocols for WSN. In contention-based MAC protocols, there exists a common channel for all the nodes to transmit the data. With a single shared medium, probability of collision is very high and hence every node needs to listen to the channel before broadcast. The energy consumption is more as these protocols use idle listening and overhearing to avoid collisions. In scheduled-based TDMA protocols, fixed time slots are allocated to every node to access the common channel without any collisions or interference. Scalability, adaptability, and time synchronization are the limitations of TDMA protocols [12]. Further, TDMA MAC protocols can be classified as decentralized and distributed protocols. In decentralized TDMA protocols, the base station or the central coordinator allocates the time slots to all the nodes in the network. Bit-map assisted MAC (BMA) protocol, self-organized TDMA protocol (SOTP), event driven TDMA protocol (ED-TDMA), and mobility tolerant, TDMA-based protocols [3] are some of the centralized TDMA-based protocols. Unlike the centralized protocols, in distributed TDMA-based MAC protocols, there is no decentralized coordinator. Scheduling in distributed protocol takes place locally in a distributed manner by the nodes among themselves. These protocols are more energy-efficient and some of them are briefly discussed below.

Wang etal. [13] proposed a scheme where every node is made to turn on and off its radio by tuning the frequency as per the requirements to different bands. The nodes establish scheduling with different time slots maintained by the super frame to broadcast without any decentralized base station. Pie and Chien [6] use clustering and backbone methodology to save energy by rotating the role of cluster heads and gateways. Duty cycle of the nodes is used to turn off the radios. This protocol prolongs the network lifetime by conserving the energy but overhead due to clustering is seen as the limitation. Chlamtac etal. [14] presented a collision-free, energy-efficient protocol with improved performance in throughput, latency, and fairness. Neighbor protocol (NP), schedule exchange protocol (SEP), and Adaptive Election Algorithm (AEA) are the components used to reduce collision and improve sleep time to conserve energy and increase throughput.

Rajendran etal. [7] have proposed TRAMA (traffic-adaptive medium access) which reduces energy consumption using the methodology of ensuring unicast, broadcast, and multicast transmissions will have no collisions. It also allows nodes to switch to a comparatively low-power and an idle state whenever they are not engaged in transmitting or receiving. As its application in WSN-IOT (Internet of Things), Dhiman etal.

[15] presented an architecture study based on WSN-IOT applications and various approaches for their integration are stated and verified. Miller and Vaidya [8] proposed two variants of TDMA MAC protocols, the first being the busy tone on-demand scheduling (BTODS) and the second being on-demand scheduling (ODS). This protocol provides an efficient way of delivering the sensed data to sink and also reduce the energy consumption. In both the variants, nodes are allowed to identify slots without interference to the ongoing flows in their setup.

Hoesel and Havinga [9] designed energy-efficient protocol that considers the properties of physical layer. Distributed approach is used to allocate the time slots. Main aim of this approach was to reduce the number of transceivers so that the sleep time of the nodes keeps fluctuating with the amount of network traffic. Chen and Khokar [10] presented self-organized, collision-free, energy-efficient protocol with simple maintenance. Two slots are allocated to every node, one being send slot (s-slot) and another wakeup slot (w-slot). In w-slot, the channel is being sensed and in s-slot broadcasting takes place. Nodes are designed to listen and transmission while other neighboring nodes switch off their RF circuits to conserve energy.

Energy-efficient protocols

Intended for heterogeneous organizations depend on the bunching methodology [16], which is viable for adaptability and energy saving in WSNs. With exceptional benefits connected with adaptability and productive correspondence, grouping gives an effective and versatile methodology for planning and arranging enormous scope WSNs for information correspondence energy proficiency [16]. In a progressive engineering, higher energy hubs can be utilized to process and send the data while low energy hubs can be utilized to play out the detecting nearby the objective. Some of steering conventions in this gathering incorporate low energy versatile grouping ordered progression (Filter) [17], Drain C [17], Filter M [18], energy-proficient improvement heterogeneous organizations convention (EEIHN) [8], surmised dynamic programming calculation (ADP) [19], and productive bunch head determination approach for cooperative information handling (CHSCDP) [20].

Challenges in TDMA MAC protocols

GAN refers to any network that is made out of assorted interconnected CNs (WANs) and furthermore covers an unlimited geological area. It is uncertainly indistinguishable with web, which is considered as a GAN. Not at all like LANs and WANs, GANs cover a lot bigger geological region. Since GANs are utilized for supporting MTCNs across various remote LANs, one of the fundamental difficulties for any remote GAN is in moving of the client correspondences starting with one LAN then onto the next. One of the very pinnacle of well-known remote GAN classifications is a broadband (BB) remote GAN. The BB remote GAN is an overall satellite web organization (SIN) that utilizes transferrable terminals for communication.

Supposedly, there are a few challenges set by the demeanor of sensor networks [21–27], which are portion of those that are started in WSN frameworks. The sensor nodes interrelate over the remote, lossy spots without foundation. Another projecting test is the one that is connected with the compelled, usually non-inexhaustible normal asset; that is the energy premise of the sensor hubs. As detailed by Akyildiz et al. [21, 22], to partake in the total advantage of the age of the WSNs, the methodology should be planned from the very start with the point of effective observing and the board of the normal assets (energy source).

Scalability

SNs contrast in scale from certain hubs to perhaps a few numbers. Moreover, the arrangement thickness is correspondingly flexible. During the time spent social event information with high goal, the hub thickness could arrive at the degree where a hub has various neighbors in their scope of transmission. The conventions situated in SNs ought to be versatile to these degrees and ought to have the option to successfully keep up with and safeguard execution.

Culpability tolerance

SNs are vulnerable and routinely sent in unsafe climate. The disappointment in the hubs is evidently because of equipment difficulties, actual hindrance, or through overwhelming their energy source. Expectedly, the hub disappointments are a lot higher than the one for the most part thought to be in reinforced or foundation constructed WNs. The protocols situated in a SN ought to be skilled in distinguishing these disappointments in the hubs in a flash and ought to be firmly strong in taking care of a relatively tremendous amounts of the hub disappointments while keeping up with and safeguarding the total usefulness of the organization framework. This is especially applicable to the steering convention project, which guarantees that elective ways are available for diverting of the packets. Notwithstanding, different arrangement circumstances present assorted culpability resilience necessities.

Cost of creation

Because of a few organization models believe the SNs to be expendable gadgets, sensor networks might actually fight with customary data gathering techniques provided that the particular SNs could be delivered monetarily. The objective cost expected for a NS ought to ideally be extremely low in cost.

Hardware restrictions

At any rate, each NS needs to have a distinguishing part (detecting part), a handling part, a transmission part, and a power source part. In a few moments, the hubs might actually have various implicit sensors or additional gadgets like a limitation game plan that help the area mindful steering. In any case, each additional usefulness radiates with additional expense and enhances the power utilization rate and actual components of the hub. Subsequently, additional usefulness should be consistently adjusted as opposed to the expense and low-power prerequisites.

Topology of the sensor network

Despite the fact that WSNs have progressed in a few perspectives, the organizations unendingly experience a few obliged assets with regard to energy assets, computational power, stockpiling (memory), and correspondences capabilities. Among every one of these previously mentioned choking influences, energy asset is of most extreme importance, and this is affirmed by the immense amounts of calculations, techniques, and conventions that have been laid out for saving energy, and by this implies include the age of the organization. Purportedly, upkeep of the geography is one of the very pinnacle of issues that could aid the decrease of the energy utilization rates in WSNs [28].

The consumption of power

As recently expressed, the majority of the difficulties of WNSs chiefly focused on the insufficient power assets. The size of the hubs confines the extent of the wellspring of force (battery). Subsequently, in planning the both the product and equipment, there the necessities to warily consider on the issues of clever energy use. For instance, information pressure might actually decrease the amount of energy utilized for radio transmission, yet involves additional energy for the control, calculation, or/and sifting. Likewise, the energy strategy relies upon the application; where in certain applications, it very well may be reasonable to switch off a region of hubs in order to save and moderate energy though different applications need all hubs to promptly work.

Methods

The proposed energy-efficient scheduling is presented in this section. The main objective of the proposed work is to conserve the energy by making the lower energy nodes to sleep more based on fluctuations of energy levels that are identified with the exchange of energy. Let us create WSN, where N_N represents the number of nodes that are randomly deployed. At the outset, energy of nodes in the network is maximum value ($E_{\max}$) and any one of the node is randomly chosen as sink node. The steps of execution of simulation are represented in the form of flow diagram as shown in Fig. 1.

Initially every node in the network is allocated with five slots for data transmission. Nodes transmit if the data exists else go to sleep. At every fixed interval of time, there is a switching of energy value among the nodes in a self-propagated way. Average energy of all nodes is calculated and is taken as the threshold energy T_E. If S_E represents the sum of residual energies of all nodes after the exchange of energy, then threshold energy is given by

$$T_E = S_E / N_N \tag{1}$$

After every fixed interval of time, there is an exchange of energy among nodes. The residual energy of every node represented by $E[(N_N)]$ is compared with threshold energy T_E. If

$$E[(N_N)] > T_E \tag{2}$$

The broadcast time slots of the nodes are reduced to four slots and the node goes to sleep in the fifth slot. If the energy of the node $E[(N_N)]$ is

$$T_E > E[(N_N)] > T_E/2 \tag{3}$$

The broadcast time slots of the node are reduced to three slots. Similarly, if the energy of the node $E[(N_N)]$ is given by Eq. (4)

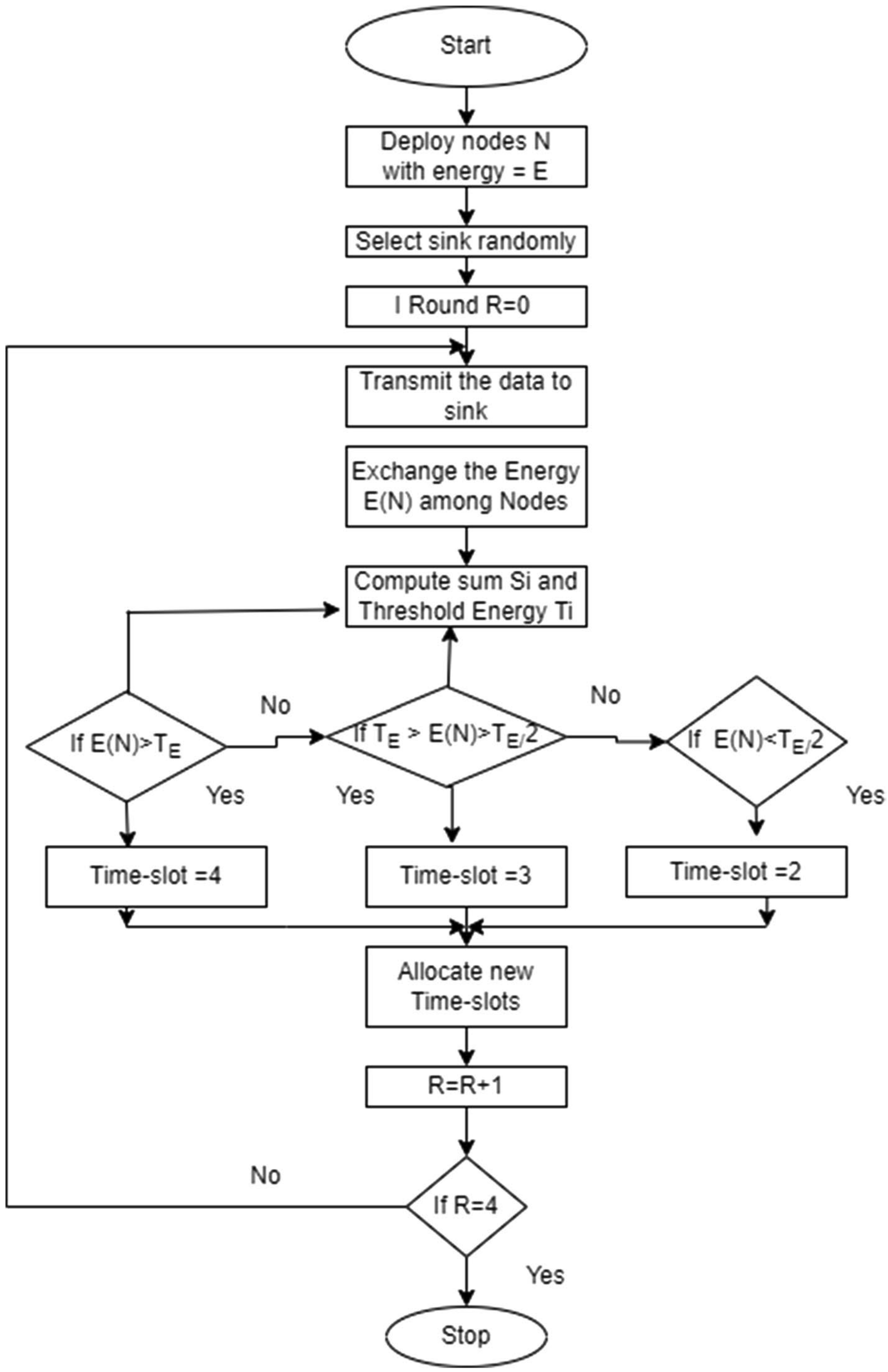

Fig. 1 Flow diagram of the proposed work

$$E[(N_N)] < T_E/2 \tag{4}$$

Then the broadcast time slots of the node are now reduced to two slots. All the nodes now transmit the data as per the new schedule and go to sleep during the remaining time slots. This makes sure the efficient utilization of energy, delaying the network lifetime, which is an essential requirement of any WSN.

The network scenario with nodes of different time slots after the exchange of energy is shown in Fig 2. It consists of a sink node wherein the data needs to be delivered. Other nodes are shown for which scheduling as per above mentioned strategy is being applied.

Results and discussion

The NS2 software has been used to investigate the proposed algorithm. This software has been executed on Intel i5 processor, 8 GB RAM, UBUNTU operating system.

This section presents different types of simulations performed and obtained results. In general, three types of simulations, namely Monte Carlo simulation, trace driven simulation, and discrete event simulation, are used, but for the WSN, trace driven and discrete event simulation are preferred. Hence, trace driven and discrete event simulation are briefly described in the following section.

Trace driven simulation

Trace-based simulation is system simulation where performance prediction is achieved by examining traces of program execution or system component access.

Discrete event simulation

Discrete event simulation [27, 28] is for the most part utilized in remote sensor organization fundamentally due to its straightforwardness in recreating different positions running on different sensor hubs. Discrete occasion reenactment records forthcoming occasions which can be reproduced by schedules. The global variables record the recreation time which empowers the scheduler for advance time expectation. Reproduction incorporates different schedules like info, result, and introductory as well as follow. The simulation gives the office of dynamic memory the executives which offices the expansion and erasure of different elements in reproduction alongside office of debugger to check the code one next to the other without interfering with the ordinary activity of reenactment.

The trace driven and discrete event simulation methods have been used for generating the results.

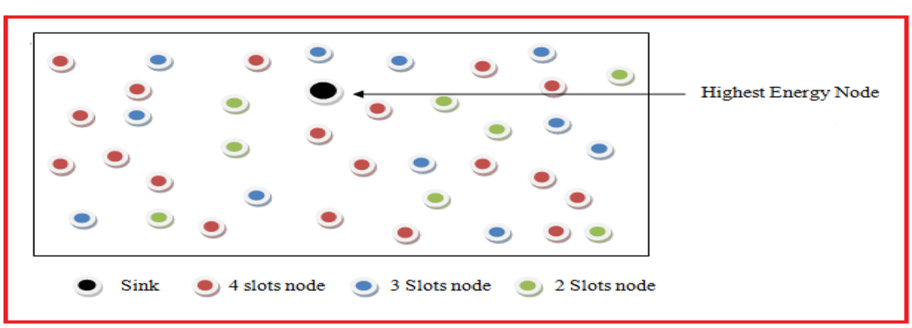

Fig. 2 Network after the exchange of energy

Simulation parameters

As heaps simulators are accessible these days for reproducing sensor network. To decide the appropriate test simulator according to client necessities is definitely not a simple request. In this way, a model [29–31] to assess and look at the test systems is required. Coming up next are some assessment parameters.

Generic simulator

Generic simulator are particularly intended for mimicking organizing regions. In this test system, the client makes code in significant level language which is altogether unique as found in genuine sensor organization. Nonexclusive level test system centers around different parts of WSN like systems administration, detecting, and information handling. These kinds of simulators are likewise utilized for assessing new correspondence conventions yet viewed as less solid because of crisscross in code which is written in simulator when contrasted with genuine sensor nodes.

Code level simulator

Code level simulators utilize a similar code in simulators as utilized in genuine sensor. The code is composed and ordered in the machine running test system which is viewed as quicker activity when contrasted with sensor node. They are operating system explicit as driver code should be supplanted when a similar code is introduced in sensor node. Code level test systems are exceptionally proficient in finding bugs as to timing and equipment design.

Firmware level simulator

Firmware simulators depend on sensor hubs copying and programming which runs in test system and is additionally a similar in the event of genuine sensor. Gives more subtleties when contrasted with conventional and code level simulator yet one next to the other, firmware level test systems are likewise exceptionally delayed in their activity concerning code execution. The basic architecture of NS2 [32] is illustrated in Fig. 3.

The main aim of our proposed work is to preserve the amount of energy available by making the nodes having comparatively lower energy to go in sleep mode for more time, based on fluctuations of energy levels that are identified with the exchange of energy. Simulation was carried out using NS2 (network simulator) with a network created with

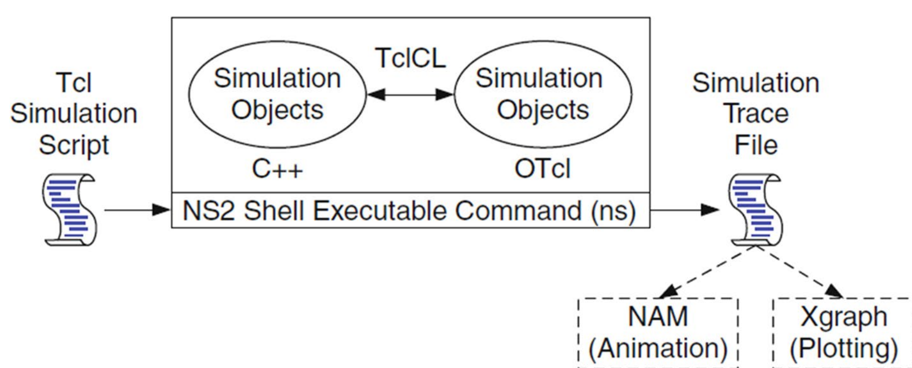

Fig. 3 Basic architecture of NS2 [32]

fifty nodes of area 100 × 100 m^2. The initial energy of the nodes is hundred joules with a simulation time of 1000 ms (millisecond) and with an exchange of energy at every fixed interval.

Computational complexity and overhead with DE-MAC

There are three normal sorts of asset heterogeneity in sensor hubs: computational heterogeneity, connect heterogeneity, and energy heterogeneity [33]. Computational heterogeneity implies that the heterogeneous hubs have more remarkable chip and more memory than typical hubs. With these strong computational assets, the heterogeneous hubs can give complex information handling and longer-term capacity highlights. Connect heterogeneity implies that the heterogeneous hubs have high-data transfer capacity and significant distance network handset than ordinary hubs. Connect heterogeneity can give more solid information transmission. Energy heterogeneity implies that the heterogeneous hubs are line controlled, or their battery is replaceable. Among the over three kinds of asset heterogeneity, the main heterogeneity is the energy heterogeneity, in light of the fact that both computational heterogeneity and connection heterogeneity will consume more energy assets. On the off chance that there is no energy heterogeneity, computational heterogeneity and connection heterogeneity will have an adverse consequence to the entire sensor organization, i.e., diminishing the organization lifetime. In remote sensor organizations, because of the boundless presence of heterogeneous asset hubs, numerous analysts have accomplished significant work examining into HWSNs. Basic energy efficiency approaches are being investigated by different researchers [34–38] and analyzed for various performance parameters [39].

Result analysis of the proposed algorithm is carried out comparing it with the DE-MAC protocol for performance metrics of energy, throughput, and packet delivery ratio. In DE-MAC, the nodes conduct a local election process based on energy of neighboring nodes. A node with the least energy is declared as winner assigning maximum slots to sleep and other nodes as losers to reduce their sleep slots by a constant factor. Our proposed work carries a similar exchange of energy among the nodes and threshold energy is calculated. Our work identifies three levels of energies and assigns varying time slots for broadcast of data in accordance with the various energy levels instead of by a constant factor as in DE-MAC. Graphs below show improvement over DE-MAC in all the three metrics average residual energy, throughput, and packet delivery ratio as shown in Figs. 4, 5, and 6, respectively.

Reduction in amount of residual energy as illustrated in Fig. 4 is obvious as and when the data sensing and forwarding takes place. Although due to proposed scheme, this rate of decrease in amount of residual energy slows down. In the graph, it can be seen that for maximum amount of initial time slots, the energy is remaining high and then at the end starts gradually decreasing. For the first 10 s of simulation time, the residual energy difference between both the protocols is lesser. After 10 s, this difference is gradually increasing. This difference, which was initially around 0.5 J, gradually is increasing to 3.8 J during 30 s simulation time, while around 50 s simulation time this difference increased to 5.25 J.

Similarly, the throughput of network as depicted in Fig. 5, where proposed scheme is applied, is comparatively higher than DE-MAC. After 20 s of simulation, the

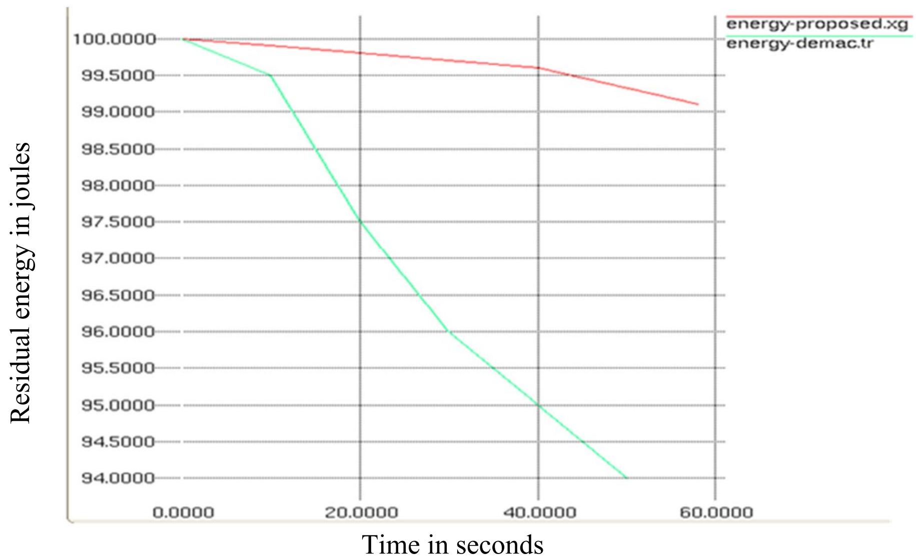

Fig. 4 Average residual energy in joules

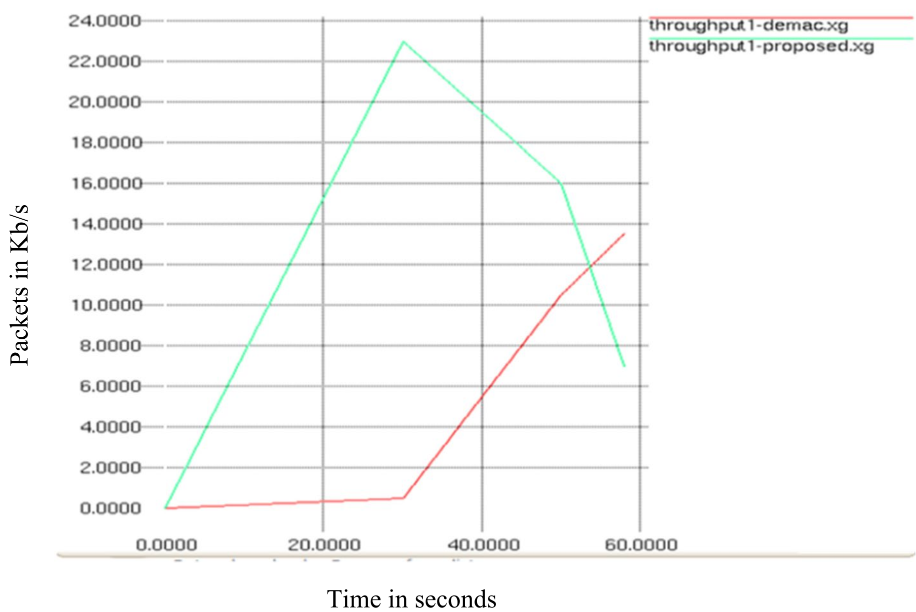

Fig. 5 Throughput in Kb/s

throughput for our proposed strategy is almost 15 Kb/s while that of DE-MAC is 0.7 Kb/s, which is much lower than the proposed work is getting. The throughput value is increasing and even though after 60% of simulation time when more number of nodes go in dead mode, throughput is decreasing, yet in almost 80% of the simulation time, the better throughput is observed.

Even the packet delivery ratio, as shown in Fig. 6, is better for proposed scheme as the overall lifetime of network is improved. The nodes remain alive for larger number of rounds which further decreases and delays the chances of packet drops.

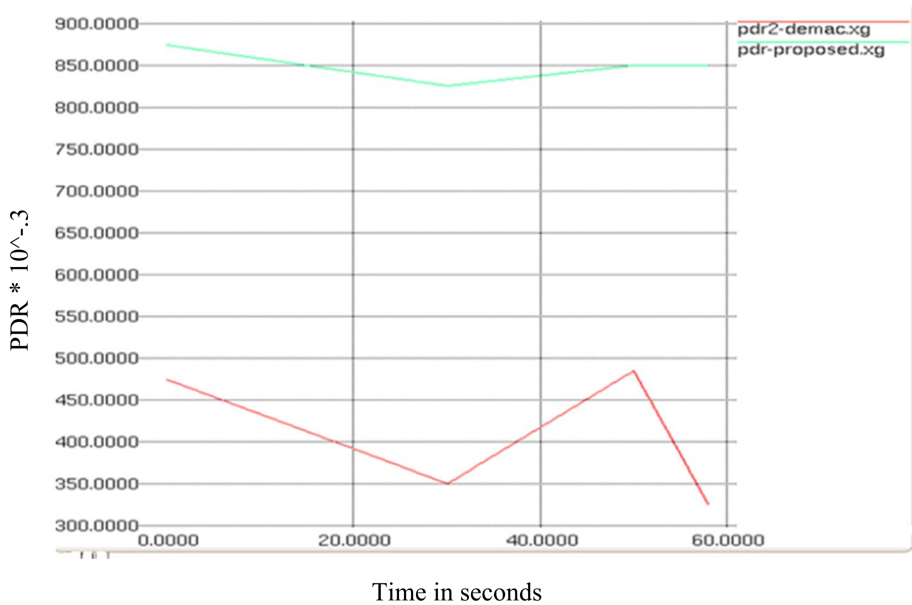

Fig. 6 Packet delivery ratio

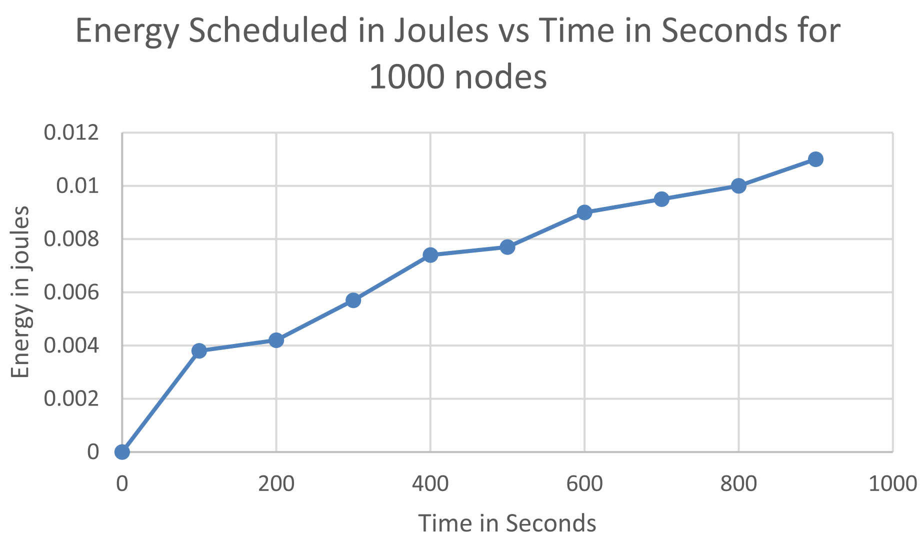

Fig. 7 Energy scheduling with 1000 nodes using DE-MAC

Figures 7 and 8 depict the energy scheduling used as a reference distribution for 1000 and 2000 nodes, respectively.

Further, Figs. 9 and 10 illustrate the residual energy distributions for 1000 and 2000 nodes, respectively.

Since maximizing the energy efficiency was the primary focus of the current study, the time slots are distributed in accordance with the residual energy of the individual nodes, as shown in Table 1 in the "Methods" section. Simulation is being performed for the validation of the proposed protocol, and for various parameters, the suggested protocol is compared with current approaches. It appears that higher energy efficiency results are achieved over the existing protocols. The distinct findings are displayed for residual

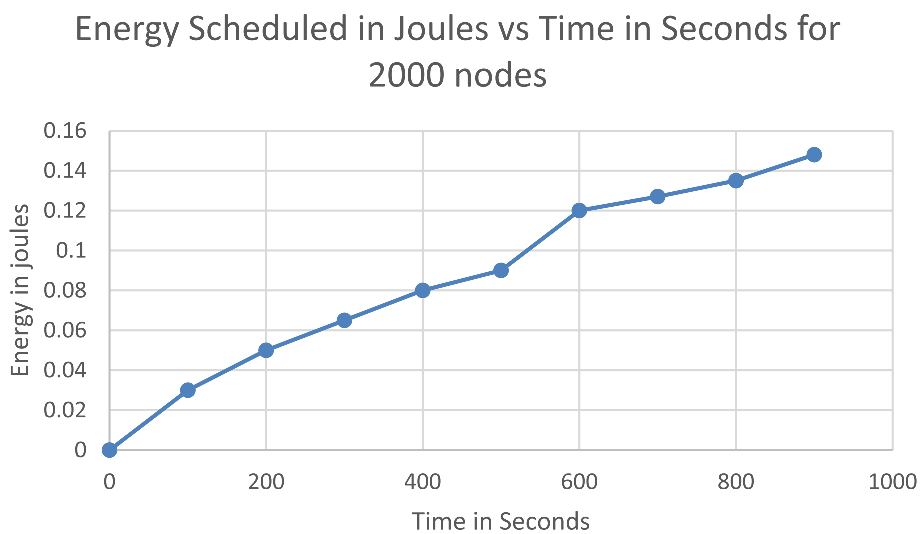

Fig. 8 Energy scheduling with 2000 nodes using DE-MAC

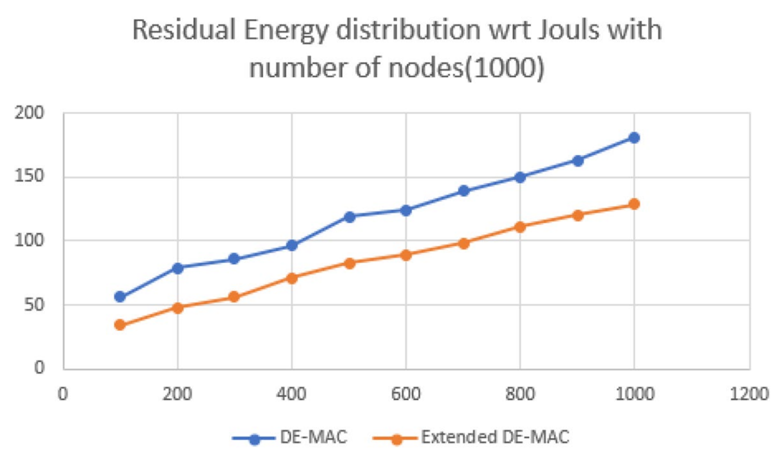

Fig. 9 Residual energy sharing between nodes with 1000 nodes

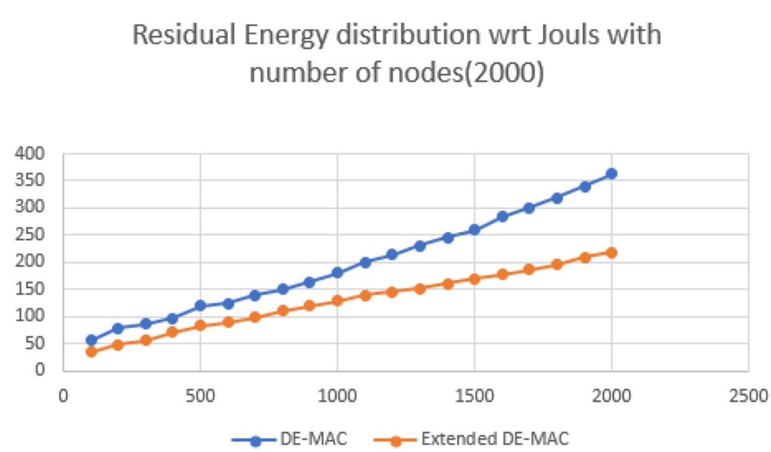

Fig. 10 Residual energy sharing between nodes with 2000 nodes

Table 1 Time slots based on energy level

Level	Energy	Time slots
I	$E[(N_N)] = E_{max}$	5
II	$E[(N_N)] > T_E$	4
III	$T_E > E[(N_N)] > T_E/2$	3
IV	$E[(N_N)] < T_E/2$	2

energy between nodes when 1000 and 2000 nodes are taken into account. An appreciable increase in energy efficiency is being achieved for the same.

Conclusions

Energy efficiency is being the highest priority in the design of WSN; this work proposes an optimum utilization of energy in sensor nodes. Critical nodes with less residual energy are forced to sleep more than their counterpart nodes. Threshold energy is calculated and accordingly three levels are figured out to allocate varying time slots for transmission of data. The simulation results are compared with DE-MAC protocol to show the improvement. Further, this work can be extended by sharing the energy data to the network layer for routing purpose with a cross layer approach.

Abbreviations

WSN	Wireless sensor network
MAC	Media access control
DE-MAC	Distributed energy aware MAC
NS2	Network simulator 2
TDMA	Time division multiple access
PACT	Power aware clustered
TRAMA	Traffic-adaptive medium access
ODS	On-demand scheduling
LMAC	Light weight medium access protocol
TDMA-w	TDMA MAC protocol by wake up
BMA	Bit-map assisted MAC
SOTP	Self-organized TDMA protocol
ED-TDMA	Event driven TDMA protocol
NP	Neighbor protocol
SEP	Schedule exchange protocol
AEA	Adaptive Election Algorithm
IOT	Internet of Things
BTODS	Busy tone on-demand scheduling
E_{max}	Maximum value of energy
N_N	Number of nodes
T_E	Threshold energy
S_E	Sum of residual energies
Fig.	Figure

Supplementary Information

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Supplementary Material 1.

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Authors' contributions

Author	Design of the work	Acquisition, analysis/ interpretation of data	Drafting/revision the manuscript
Anushri Narendra Pathak	50%	50%	50%
Arvind R. Yadav	50%	50%	50%

All authors have read and approved the manuscript.

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Declarations

Competing interests
The authors declare that they have no competing interests.

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