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# Optimizing the ZigBee Networks Lifetime with a Grey Wolf Algorithm

[1]N.R. Solomon Jebaraj and [2]H.R. Keshavan
[1]Dayananda Sagar Academy of Technology and Management, Udayapura, 560082 Bangalore, India
[2]Jain University, Kanakapura Main Road, 562112 Bangalore, India

**Abstract:** The modern industrial automation requires effective and flexible communication protocol such as standard IEEE 802.15.4 ZigBee protocol. It specifies physical and media access control layers to ensure guarantee delivery and to achieve low power. The internal topology of this protocol consists of sensors devices, cluster coordinator and Personal Area Network (PAN) coordinator. While processing the data, the PAN coordinator transmits the Beacon frame to its cluster coordinators and the sensor nodes receivesthe Beacon frames from cluster coordinates periodically. During this process collision occurs, it results in poor performance. To enhance the efficiency of network, this research applied a metaheuristics algorithm named Grey wolf optimizer is selected for scheduling problem to coordinate the transmission. In Wireless Personal Area Network (WPAN), the cost and power are the two fundamental factors considered in IEEE standard 802.15.4 while applying the protocol to different applications, it need more power to operate and offer more bandwidth. In sensor networks, the reliability and security are depending upon the factors such as network lifetime and battery operations. Hence, the proposed scheduling algorithm is analyzed and compared with genetic algorithm to evaluate the performance of IEEE 802.15.4.

**Key words:** IEEE 802.15.4/ZigBee, personal area network, Genetic algorithm, Grey Wolf algorithm, operations, periodically

## INTRODUCTION

In recent advancements, the limited battery consumption requirement is a main objective of many researches. While designing a portable device or network it is necessary to operate with minimum battery level because battery size and its capacity is directly proportional to each other, this may leads in complex network. This study describes about the IEEE 802.15.4 standard protocol and its operations.

IEEE 802.15.4 standard protocol defines the physical layer and Medium Access Control (MAC) sub-layer specifications for low-data-rate wireless connectivity which is shown in Fig. 1. In low rate sensor area network some traditional communication methods such as Bluetooth are not suitable for multi node operation. Hence, IEEE standard protocols are selected because of its low complexity, ultralow power consumption and low data rate. It is relatively short radio communication range, easy installation and low cost. Some of the applications of IEEE 802.15.4 based networks are consumer products, home automation/security, vehicle monitoring, agriculture and healthcare. A part from these applications, the IEEE 802.15.4 to be used in a networking solution with required data rate must be low (≤250 kbps) and the maximum range

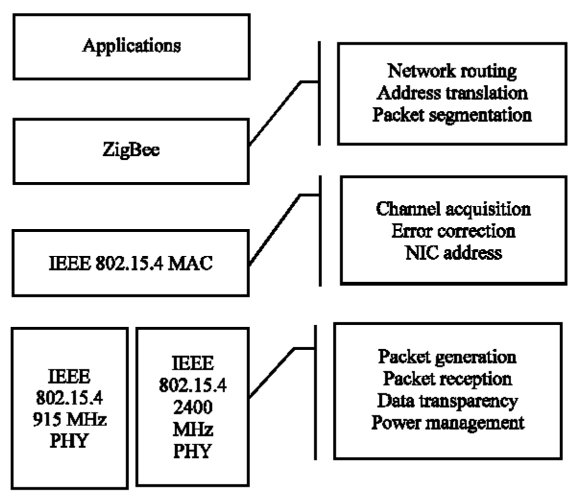


Fig. 1: IEEE 802.15.4 architecture

for communicating devices must be short. Normally, IEEE 802.15.4 allows two channel-access methods such as Beacon-Enabled and Non-Beacon-Enabled Mode. As per Wang *et al*. (2015) in Beacon-Enabled Mode, the coordinator transfers the Beacon frames periodically to all other end devices in the network within a transmission range. Hence, the end devices are synchronized by these

**Corresponding Author:** N.R. Solomon Jebaraj, Dayananda Sagar Academy of Technology and Management, Udayapura, 560082 Bangalore, India

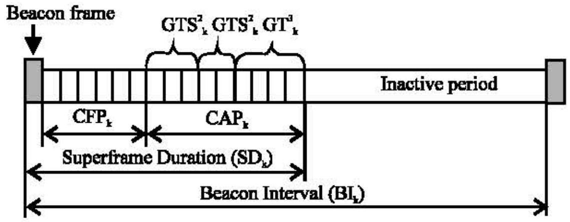


Fig. 2: Frame format to represent Beacon interval

Beacon frames. But in Non-Beacon-Enabled Mode, the medium access is only based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA).

The Beacon Interval (BI) is defined as it is a time interval between two Beacon frames and it is divided into an active period and an optional inactive period. In inactive period, nodes are kept in sleep mode to safeguard their energy. The length of the active period is Superframe Duration (SDk) and contains 16 equal length time slots as shown in Fig. 2. The total active period comprises Contention Access Period (CAP) and Contention Free Period (CFP). The CFP is managed by the coordinator, it is used for low latency applications and contains at most seven Guaranteed Time Slots as (GTSs). In order to specify the Beacon Interval (BI) and Superframe Duration (SD), Beacon Order (BO) and Superframe Order (SO) values are defined in the superframe specification by the coordinator, it follows the constraint as:

$$\left.\begin{array}{l} BI = aBaseSuperframeDuratin \cdot 2^{B0} \\ SD = aBaseSuperframeDuration \cdot 2^{S0} \end{array}\right\} \quad (1)$$
$$\text{for } 0 \le S0 \le B0 \le 15$$

In some targeting applications, the IEEE 802.15.4 is selected as standard protocol due to its effectiveness in on-going real time data flow. Mostly, it is selected because it provides energy efficient and improve the network lifetime. For real time guarantee the protocol's Beacon mode is synchronized with the duty cycles and time slots to provide collision free transmissions. To avoid the collision problem, it is necessary to configure the power utilization in terms of scheduling of clusters.

In addition to the collision and lifetime problems, this research focused on spatial reuse problems which occurs at the condition "occurrence of collision due to multi node transmission at simultaneously". Hence, for optimization and function evaluation the research is extended to apply the Grey Wolf optimizer algorithm and compare the specifications with Genetic algorithms.

**Literature review:** In recent years, the wireless technology has huge development and at the same time the general complexity problems such as security issues, cost issues, dependability and speed issues are the key problems. These factors depends upon the internal factors of network system design. In this study, the traditional methods are presented that are related to this research.

Ahmed *et al.* (2016) compared a performance evaluation between IEEE 802.11 and IEEE 802.15 ZigBee Medium Access Control (MAC) protocol. They have analyzed the mobility of Reference Point Group Mobility Model (RPGM), Random Way Point Mobility Model, Freeway Mobility Model and City Section Mobility Model. For simulation, Network Simulator (NS-2) is used, the simulation made with a specification of 25 mobile nodes and 10-80 sec with total simulation time of 100 sec. They have made various performance metrics like throughput, end to end delay and packet delivery ratio and data loss.

Khanafer *et al.* (2014) made a survey about Beacon-Enabled IEEE 802.15.4 MAC protocols to improve a diverse field of applications. They have described some solutions to resolve the coexistence problems and highlighted their strengths and weaknesses. The book representing the performance analysis of the IEEE 802.15.4 MAC layer with its applications are mentioned by Palattella *et al.* (2014). In a multi-hop fashion, the position of the PAN coordinator has several performance impact, hence, it affects the network energy for both topology formation and data routing. So, it is necessary to develop the efficient self-configuring, self-managing and self-regulating protocols for the election of the node. The node coordinating and managing the IEEE 802.15.4/ZigBee wireless sensor network is still an open research issue. Hence, Cuomo *et al.* (2013) proposed a standard-compliant procedure named as PAN coordinator Election (PANEL) to self-configure IEEE 802.15.4/ZigBee by electing a suitable PAN coordinator in a distributed way.

Wen *et al.* (2014) considered five major factors that affect the energy consumption of a sensor node. They made a rigorous integer nonlinear programming for IEEE 802.15.4-based sensor networks with dynamic transmission range which is corresponding to the physical layer, duty cycle scheduling in MAC layer, cluster-based routing in network layer and data aggregation in application layer. To address and solve these issues, two cluster construction algorithms are used such as Average Energy Consumption (AEC) and Maximum Number of Source Nodes (MNS). Finally, a Cluster-based Data Aggregation Routing (CDAR) was made to include duty cycle scheduling and a dynamic transmission range scheme were proposed. Their result were made with minimum tradeoffs and avoiding the duplication in transmissions. In addition to that the

Table 1: Survey on various algorithm applied for IEEE 802.15.4 wireless networks

| Citations | Methodology | Contribution | Advantages |
|---|---|---|---|
| Toscano and Bello (2012) | Multichannel superframe scheduling for IEEE 802.15.4 | To avoid Beacon collisions in cluster-tree networks<br>To avoid loss of synchronization between nodes and their coordinator | Scheduling the superframes over different radio channels by keeping cluster connectivity |
| Yoo *et al*. (2010) | Distance-constrained real-time offline message-scheduling algorithm | It generates Beacon order, superframe order and guaranteed-time-slot information<br>It allocates each periodic real-time message to superframe slots for a given message set | IEEE 802.15.4-compliant transceiver CC2420 and ATmega128L is implemented and verified feasibility of the guaranteed time service |
| Palattella *et al*. (2012) | Traffic Aware Scheduling Algorithm (TASA) | Presented an innovative approach to support emerging industrial applications<br>It is applied for low latency at low duty cycle and power consumption | It is highly reliable low-power MAC protocol |
| Zhan *et al*. (2016) | Guaranteed time slots Size Adaptation Algorithm (GSAA) | The Beacon frame, command frame and packet frame format have been modified to save more GTS resources and more end devices in one superframe | More end devices will satisfy the time constraints of time sensitive applications with a deadline |
| Saleh (2015) | Enhancement of the IEEE 802.15.4 standard by energy efficient cluster scheduling | An adaptive data rate control for clustered architecture is proposed<br>To regulate its data rate adaptively using the feedback message | Scalability is achieved by using Particle Swarm Optimization (PSO) to modify encoding |

proposed algorithms balance the trade-off between the aggregated data and interference. Ding and Hang (2013) made a new traffic scheduling algorithm for real-time (Industrial applications) data transmission through Guaranteed Time Slots (GTSs). It concentrates on time-critical industrial periodic messages and determines the values of network and node parameters for GTS. Based on the network traffic conditions it provide guarantee requirement in terms of 10-100 msec. It improved both real time requirements and improves the scalability and energy efficient of network. The Collision Free Multichannel Superframe Scheduling (CFSS) has proposed by Jin *et al.* (2014) for IEEE 802.15.4 cluster-tree networks. They concentrated in Beacon collisions, initially they formulated this collision as Satisfiability Modulo Theories (SMT) specification. Then the proposed method CFSS is compared with MSS made by Toscano and Bello (2012).

Chen *et al*. (2015) presented an area packet scheduler to mitigate coexistence issues in a Wireless Personal Area Network (WPAN) based heterogeneous network. The problem that is identified by them is while deploying the energy constrained devices such as IEEE 802.15.4 and IEEE 802.11x in IoT (Internet of Things) applications, it introduces coexistence issues such as intra-and inter cluster interference. Hence, to overcome this problem they proposed a novel area packet scheduler that allows co-located 802.15.4 and 802.11 devices to share the transmission channel and coexist with interference (Table 1).

**Problem statement:** The energy conservation is one of the main challenge in IEEE 802.15.4 nodes the lifetime of nods is directly depends upon the energy consumption. The prevailing literatures are not supposed to provide a solution to both power efficient and co-channel interference. In some cases, the delay and reliability is addressed separately. From the survey it is analyzed that various methods are used for scheduling. Since, the problem is exists in any one of the form such as by reframing the scheduling it lacks in flexibility in another case if number of nodes or devices interfaced with single standard protocol, it results in interference. Likewise, delay is the major factor due to the fixed number of formats while deploying the nodes in randomly the coverage problem also exists due to lagging in distance. In default 802.15.4 standard there is only one type of Guaranteed Time Slots (GTS). If an end device requests GTS then the coordinator checks whether it has GTS resource or not. If it has resource then, it allocates the requested size of GTSs to the corresponding end device. In rare cases, the end device only has a small data packet to send that may result in under-utilization of Contention Free Period (CFP). In order to overcome these issues it is necessary to construct cluster-tree and propose a new scheduling algorithm that overcome both energy and bandwidth utilization issues.

## MATERIALS AND METHODS

**Genetic algorithm applied for optimization problem:** Kim *et al.* (2015) proposed a holistic optimization framework with spatial reuse of RF resource. Its main objective is to maximize the lifetime of network. The formulation of avgPW($N_i$), the network life time is limited in the node that consumes more power. They made an objective to minimize the maximum avgPW($N_i$) for all i = 1, 2, 3, ..., m, it is given by:

$$\text{Minimize } \max_{1\le i\le m} \text{avgPW}(N_i) \qquad (2)$$

In order to solve the min max problem, the valid tree construction, end-to-end deadline guarantee and valid duty cycle scheduling is to be considered. To manage the high complexity of optimization problem shown in Algorithm 1, Genetic algorithm is considered. Initially, the chromosome is represented with fitness function. Chromosome string represents the possible solution for optimization problem. It is shown in the Algorithm 2 and 3 it is a complete set of all parameters of cluster tree construction. Then the fitness function is evaluated with a quality of each solution.

**Algorithm 1; Formulation of the constratints for optimization:**

Step 1: Valid tree Construction represents in $\omega_{ij}$s, $1\le i\le m, 1\le j\le m$ to represent a valid tree

Step 2: Each node has a parent node $N_i$ and formulated as:

$\sum^{m}_{j\text{-}1} w_{ji} \le 1, \forall_i \in \{1, 2, ..., m\}$

Step 3: Add up all the child nodes for all nodes, it should be always m-1, it is formulated as:

$$\sum_{i-1}^{m}\sum_{j-1}^{m}\omega_{ij} = m\text{-}1$$

Step 4: represent the obvious constant as, $\omega_{ii} = 0, \forall_i \in \{1, 2, ..., m\}$

Step 5: Valid power configuration for packets to transmitted packets

$$RF(PW_i) \ge RF_{recv}^{min} + 10_\gamma \log_{10}(\max_1 \le j \le m(\omega_{ij}+\omega_{ji}).d_{ij}) + C, \forall_i \in \{1, 2, ..., m\}$$

Step 6: Valid duty cycle scheduling by Cheikhrouhou *et al*. (2010) algorithm works for the example set of $(BI_k, SD_k)$s for six clusters, i.e.:

$$\{cluster_1\ (16, 4),\ cluster_2\ (8, 1),\ cluster_3\ (16, 2),\ cluster_4\ (32, 1),\ cluster_5\ (32, 4),\ cluster_6\ (16, 2)\}$$

Step 7: Determine the end-to-end deadline guarantee

**Algorithm 2; Algrithm for Genetic algorithm:**

1. Start: Generate random population of n chromosomes strings
2. Evaluate the fitness f(x) of each chromosome x in the entire solution space
3. Create a new population by repeating following steps until the new population is complete
4. Select two parent chromosomes (strings) from a population according to their fitness (the better fitness, the bigger chance to be selected)
5. With a crossover probability cross over the parents to form a new offspring (children). If no crossover was performed, offspring is an exact copy of parents. (tree Construction, power configuration)
6. With a mutation probability mutate new offspring at each locus (GTS)
7. Place new offspring in a new population (valid tree construction)
8. Use new generated population for a further run of algorithm
9. If the end condition is satisfied, stop and return the best solution incurrent population
10. Go to step 2

The reproduction selects the two chromosomes and combines them with a characteristics of strings. In normal this implementation the Genetic algorithm uses weighted roulette wheel method to select the chromosome strings with better fitness. The mutation process is considered with a random perturbation to reproduce the strings. The value which is chosen randomly out of $\omega_{ij}$s, $PW_i$s, $Bl_k$s, $Sd_k$s and $GTS^i_k$s and modify these process with a randomly generated value.

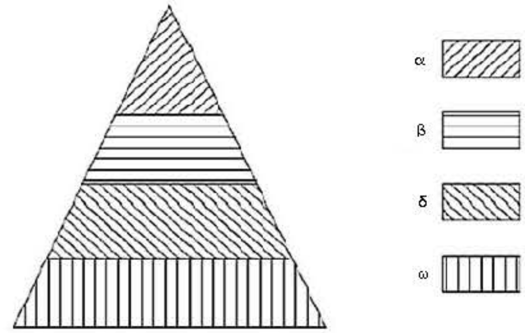


Fig. 3: Social hierarchy of Grey Wolf

Algorithm for the proposed Grey Wolf Optimizer based Super Frame Duration Scheduling Algorithm (GWO-SFDSA)

This mechanism is proposed by Mirjalili. Grey wolf optimizer plays a crucial role in maintaining the health of their ecosystems hence it is called as alpha predator because they are at the top of the food chain. Grey Wolves always live in a group in which 5-12 member's per group (Algorithm 3):

**Algorithm 3; Algorithm for proposed Grey Wolf based scheduling:**

Step 1: Initialize the Beacon frame grey wolf population $x_i$ (i = 1, 2, ..., n) including the pending data

Step 2: Initialize α, A and C and exchange the real time data in CFP period

Step 3: Calculate the fitness of each search agent (coordinate the data):

Xα = The best search agent
Xβ = The second best search agent
Xδ = The third best search agent

Step 4: While (t<Max number of iterations)
For each search agent (value) update the position of the current search agent (check the real time data position)

Step 5: Update α, A and C Calculate the fitness value for all search and start CAP

Step 6: Update $X_\alpha$, $X_\beta$, $X_\delta$, make t = t+1

The very strict social dominant hierarchy is represented in Fig. 3. The social hierarchy consists of four levels such as Alpha (α), Beta (β), Delta (δ) and Omega (ω). Here, the alpha plays a major role in order to control the members. These alpha wolves are the leaders of pack

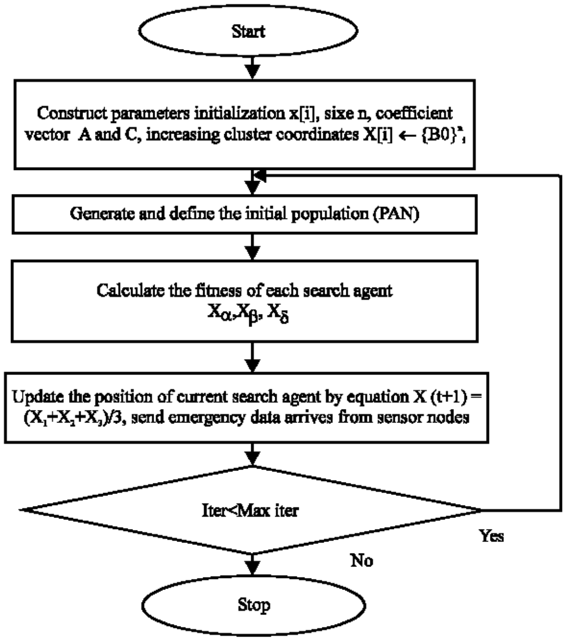


Fig. 4: Flow chart representation of proposed Grey Wolf based scheduling algorithm

combination of both male and female. It care take about making decisions about hunting, time to travel, sleeping location and so on.

In GWO algorithm, the hunting is guided by α, β and δ. The ω solutions follow these three wolves. During hunting, the grey wolves encircle prey. The mathematical model of the encircling behavior is as:

$$D = \left|C.X_p(t)\text{-}A.X(t)\right|$$

$$X(t+1) = X_p(t)\text{-}A.D$$

Where:

| | | |
|---|---|---|
| 't' | = | The current iteration |
| A and C | = | The coefficient vectors |
| $X_p$ | = | The position vector of the prey |
| X | = | The position vector of a Grey Wolf |

Let A be the random value in interval [-2a, 2a], over the course of iterations 'a' is decreased from 2-0. If |A|<1, then the wolves attack towards the prey which represents an exploitation process. Where components are linearly decreased from 2-0 over the course of iterations and r1, r2 are random vectors in [0, 1]. The vectors A and C are calculated as follows: $A = 2a.r_1.a$ and $C = 2.\ r_2$. If |A|>1, the wolves are forced to diverge from the prey to find a fitter prey.

The flow chart representation of proposed scheduling algorithm is shown in Fig. 4, instead of grey population the Beacon frame is initiated and increasing the cluster coordinates as, $X[i] \leftarrow \{B0\}^n_i$. Then generate and define the initial population of personal are network. Then calculate the each nodes search agents with respect to the search agents. Finally, the fitness value is calculated to find the effective node. The proposed approach is used to resolve the problems and the constraints with a new super frame format for fast access to channel. It also reduce the delay because of prey scheduling and hunting behavior. The end to end delay is reduced with a very low duty cycle by transferring the real time data. It is defined for the format IEEE 802.15.4, the Beacon frame is sent at the beginning of super frame and contains the information about super frames. This scheme provides a real time data access. The waiting time is eliminated due to the end of Contention Access Period (CAP) to send the data. Hence, the node performance is improved with total content access.

## RESULTS AND DISCUSSION

The performance evaluation for Genetic algorithm and grey wolf based scheduling algorithm is implemented in Network Simulator (NS-2). It evaluate the performance of frame format in IEEE 802.15.5 standard. The performance comparison is shown in Table 2 which made for genetic and grey wolf based approach on an IEEE 802.15.4 based cluster tree consists of 75 sensor nodes that are one hop away from a PAN coordinator (sink node). The area is about 200×200 with a transmission range of 14 m and its simulation time 400 sec.

The initial energy is considered as 10 J. To make an effective comparison the performance metrics such as end to end delay, throughput, packet delivery ratio, energy utilization factor are used to evaluate the performance of the proposed approach with traditional genetic algorithm. From Fig. 5, the proposed Grey Wolf optimization based algorithm attains 0.69% packet delivery ratio for 20 transmissions in the network while Genetic algorithm based scheduling attains 0.62% packet delivery ratio for 20 transmissions in the network while Genetic algorithm based scheduling attains 0.62% packet delivery ratio. Next analysis is based on delay with respect to the transmission nodes, the delay will increase when the number of transmission increases in the network. Figure 6 illustrates the end-to-end delay of real-timetasks over a number of time periods. The delay is a combination of Queuing Delay (QD), Processing Delay (PD) and Propagation Delay (PGD), it is represented as D = QD+PD+PGD.

The Energy Utilization Factor (EUF) is measured and shown in Fig. 7, it is the ratio of total Energy Utilized (EU)

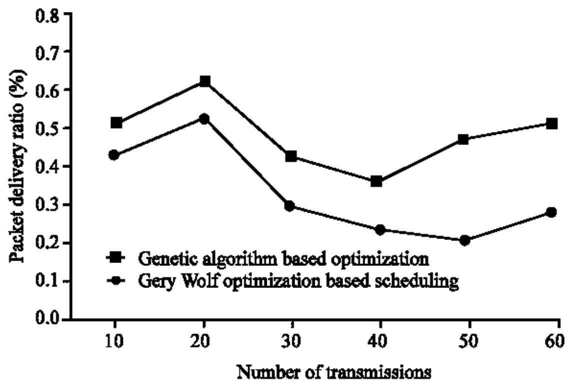


Fig. 5: Packet delivery ratio with respect to number of transmissions

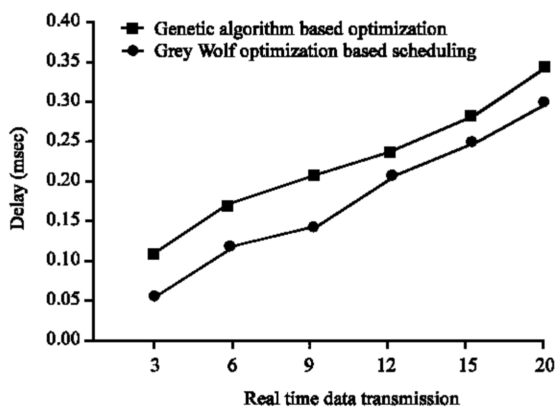


Fig. 6: Delay with respect to real time data transmissions

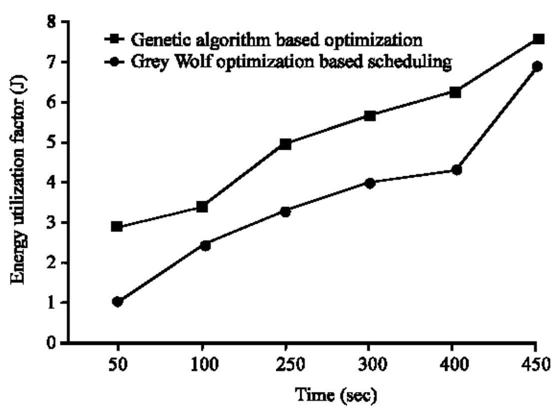


Fig. 7: Energy utilization factor with respect to time

during the whole lifetime to the Total Energy (TE) provided to the network at the time of deployment. It is represented as: EUF = EU/TE×100. For proposed algorithm the maximum energy utilization is 6.9 J. with respect to the transmission time. Figure 8 shows that, it is concluded that the proposed scheduling algorithm is suitable for implementing IEEE 8902.15.4 in real time

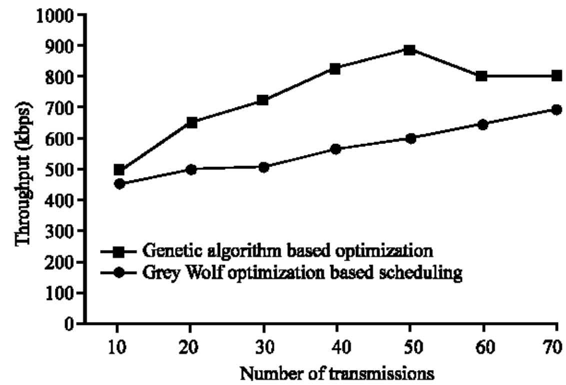


Fig. 8: Throughput with respect to number of transmissions

Table 2: Simulation parameters

| Parameters | Values |
|---|---|
| Area | 200×200 |
| Physical and MAC Model | IEEE 802.15.4 |
| Number of nodes | 75 |
| Transmission range | 14 m |
| Simulation time | 450 sec |
| Channel frequency | 2.4 GHz |
| Traffic type | CBR |
| Initial energy | 10 J |
| Transmission speed | 250 kbps |

applications because its throughput is high for the data rate, it is based upon when a network receives or send the data packet to the PAN.

## CONCLUSION

The industrial applications are increasing in demand with real time data implementation, to manage and interface the applications effectively with IEEE 802.15.4 protocol, the proposed scheduling algorithm is defined. Several traditional research concentrates only with minimum objectives to increase utilization and reduce the bandwidth. Since, energy utilization, delay, delivery ratio and the total throughput of the network is depends upon the super frame. These factors are improved based on the collision free transmission, hence, Beacon mode is synchronized with the duty cycles and time slots to provide collision free transmissions. The collision problem is avoided by Grey Wolf based scheduling with a minimum power utilization.

## RECOMMENDATION

The future, proposed research is planned to implement in real sensors for real time environment usage. In another aspect this work may extend to for multi hop clustering in multi hop network.

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