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Multi-Objective Optimization of Electrocardiogram Monitoring Network for Elderly Patient in Home

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Abstract

The most challenges of Wireless Body Area Network (WBAN) are energy consumption because its works using limited resource like battery and end-to-end delay because it is used to transmit real time parameters of patients' health status like Electrocardiogram (ECG). In this paper we present and discuss the modeling of a multi objective problem. The first objective is the minimization of the end to end delay; the second objective is maximization of the energy efficiency of the network depending on packets payload size. We use jMetal to test the problem using three genetic algorithms (NSGA-II, SPEA-II and OMOPSO) and we compare between them.

Keywords: *End-to-End delay, Energy efficiency, Wireless sensor network, ECG monitoring, Health monitoring.*

1 Introduction

Wireless Sensor Network (WSN) are used in different fields like monitoring of wildlife, fire detection, security monitoring and health care monitoring [1] [2]. In the recent years, healthcare in home come to help elderly patients and to solve many problems like (1) allow his/her for monitor their health status remotely without going to hospitals. (2) Solve the problem of increasing the treatments cost in health centers and hospitals. (3) Solve the problem of increasing the population [3].

Healthcare monitoring is collection of sensors that is used to measure a body health state for patients like bed sensors, ECG sensors, and hart pulse sensors. These sensors are deployed on home rooms to sense the patient health status and send these data to control center [3]. The sensor node consists of (1) radio unit which allow sensor to communicate with other device. (2) Sensor unit which sense and capture data. (3) CPU unit which is used to pre-process the data. (4) Energy resource such as battery [4].

A real time application such as healthcare application is used to monitor the continues vital signals like Electrocardiography (ECG), so there are many challenges that face it because the sensors limited in their power because it works by using battery resource and the transmitted data may be delay because the congestion by other devices on the network. In this paper, we will try to focus on two important things: (1) the minimization of the end to end delay and (2) the maximization of the energy efficiency of the network. We organized the paper as follows: section II presents related work. Section III presents background of healthcare in home. Section IV presents methodology. Section V Simulation parameters presents. VI presents Experimentation and Result. VII presents conclusions. VIII presents Open Problem.

2 Related Work

Lots of work has been done in the area of health monitoring. Next we summarize few of them.

Matthieu Le Berre et al. [5] proposed a wireless sensor network multi objective optimization. They used a set of models like (1) Coverage model to maximization the coverage area for network. (2) Network life time model to maximization the network life time. (3) Financial cost model to minimize the cost of network depends on the privies models. They test these models by using genetic algorithms (SPEA-II, NSGA-II and MOACO.). They used C++ programing language to implements theses algorithms. They tested algorithms on PC-CPU Core I5/2520M, with constants parameters like (A) 120 population size for each algorithm. (B) Probability of crossover is equal to 0.9. (C) Probability of mutation is equal 1/|s|. The results shown that NSGA-II is better than MOACO and SPEA-II algorithms.

Husna Zainol Abidin, et al. [6] proposed a wireless sensor network (WSN) objectives optimization by using biologically inspired algorithm of optimization. They compared between two algorithms single objective algorithm (Territorial Predator Scent Marking Algorithm (TPSMA)) and multi objective algorithm (Muli-objective TPSMA (MOTPSMA)) in terms of energy consumption and coverage ratio. They used these algorithms to measure coverage model to maximization the coverage area for network and energy consumption model to minimization the energy consumption as objective functions. They tested these algorithms by using Network Simulator (NS2) and MATLAB on Linux operation system. The results shown that TPSMA better than MOTPSMA in term of network coverage and MOTPSMA outperforms TPSMA in term of energy consumption.

Bt. Ab Aziz et al. [7] proposed coverage optimization for Wireless Sensor Network (WSN). They used a particle swarm optimization (PSO) algorithm to minimize coverage area. They make more than one test on this algorithm by varying topology area and number of sensor nodes, the first test contains 40 sensors deployed over topology size equal 50*50, the second test contains 20 sensors deployed over topology size equal 50*50, the third test contains 20 sensors deployed over topology size equal 30*30. They used a MATLAB program to implement the algorithm and Voronoi diagram to evaluate the solution. The experimental results shown that the proposed algorithm work well with high efficient.

Bing Peng et al. [8] proposed a network life time optimization for Wireless video sensor network (WVSN) by optimizing a set of network features such as optimizing the link rates, network coding power, video encoding power and link rates. They studied the relation between network lifetime and previous network features by making the network size static in which consists of one sink node and 9 video sensors deployed on 50*50 topological area. The results shown that when video quality decreased the network life time increased.

Wenzhong Guo, et al. [9] proposed multi objectives optimization of topology control in wireless sensor network by using minimum spanning tree included in genetic algorithm (GA) and particle swarm optimization (PSO) algorithm. They used a set of models included in the previous algorithms like energy consumption and network reliability. They tested the algorithms on MATLAB operates on PC its characteristics are (1) CPU 2.50 Intel Core 2 Duo, (2) RAM equal 2.00 Gb, (3) Windows XP operating system. The experiments results shown that PSO algorithm is efficient and better than GA algorithm.

3 Background of healthcare in home

Health care consists of different types of IEEE 802.15.4 (Zigbee) health sensors [10] [11] that fixed and distributed in patient home rooms. These sensors work to sense and to determine patient health status (vital signals) like *Electrocardiogram (ECG)*, blood pressure rate and heart rate. These vital signals are transited to hospital server by using Ethernet network to be check by a nurse or a doctor [12]. There are a large collection of medical sensors that appropriate for monitoring patients in home like ECG Sensor, Temperature Sensor and Pulse Rate Sensor [11].

Zigbee has a set of features that makes it suitable to use with physiological monitoring. We can mention is as follows [13] [14]:

1- Work on ISM band 2.4 GHz (it's free band).
2- Low complexity.
3- Low power consumption
4- Low data rate
5- It use Carrier Sense Multiple Access (CSMA)

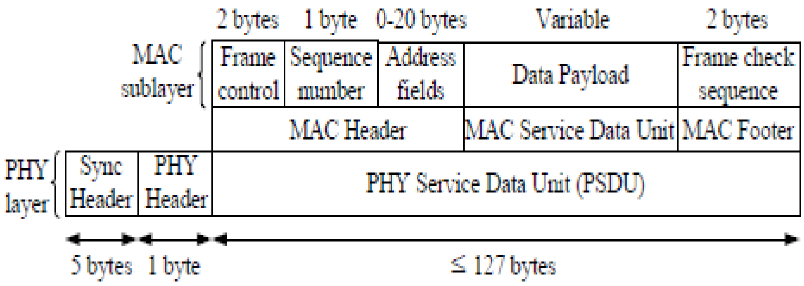

Figure 1. The IEEE 802.15.4 data frame [15]

IEEE 802.15.4\Zigbee can support star and peer to peer topologies. Zigbee defined 4 types of frame structures; contains data frame, MAC command, beacon and acknowledgment frame. Figure 1 shown the data frame structure in which used to transfer of data. By Figure 1 we can notice that the maximum MAC packet size that supported by IEEE 802.15.4\Zigbee standard equal 127 bytes and its MAC header equal 13 bytes. Thus the packet payload size is limited and equal 114 bytes [15].

4. Methodology

In this paper, we propose important models that considered the pivotal of success the health monitoring network. The first model is Energy Efficiency model and the second model is End-to-End Delay model. We handle these models to find optimal or near of optimal for the two objectives. The first objective is maximization of the energy efficiency of the network, the second objective is the minimization of the end to end delay of the data packet sent. The two models defined as follows:

A▷ Energy Efficiency Model.

Wireless sensors network are affected directly by packet size. For example if the channel condition of wireless network becomes worse, the smaller length of data packet is more eligible because larger lengths of data packets are more probable to fail when transit and the error rate become higher. It is well known that variable packet length in Wireless Sensor Network (WSN) is not appropriate to use because of the complexity [16]. So, we use the Energy Efficiency model with relation to data packet length to determine the fixed data packet length that makes model maximization. The Energy Efficiency model is defined as follows:

$$\eta = \frac{Ec \cdot \ell}{Ec \cdot (\ell + h) + Es} \cdot (1 - PER) \cdots\cdots\cdots\cdots\cdots (1)$$

Where:
Ec: energy consumption in communication.
Es: energy consumption in startup.
ℓ : Packet payload length.
h: Packet header length.

PER: packet error rate in which can be defined as follows [17]:

$$PER = 1 - (1 - BER)^{(\text{Length of packet in bits})} \ldots\ldots\ldots\ldots\ldots (2)$$

Where: BER:bit error rate.

B. Transmission Delay:

The transmission delay of packets is the time that required transmitting a data packet from sensor node to coordinator node, including transmission time of packet, back off time, turnaround time of transceiver's, T_{IFC} time and acknowledgment transmission time (T_{ACK}). Equation number (3) shows the average of transmission delay [15].

$$T_l = T_{packet} + T_{bo} + T_{TA} + T_{IFS} + T_{ACK} \cdots\cdots (3)$$

The transmission time of data packet can be measured as:

$$T_{packet} = \frac{L_{PHY} + L_{MHR} + payload + L_{MFR}}{R_{data}} \cdots\cdots (4)$$

Where LPHY is the size of physical header in byte, LMHR is the size of MAC header in byte, payload is the size of data in the packet in byte, LMFR is the size of MAC footer in byte, and Rdata is the data transmission rate. To measure the backoff periods, we must calculate the device probability (Ps) of access the channel successfully. It can be measured as:

$$P_s = \sum_{a=1}^{a=b} P_c (1 - P_c)^{(a-1)} \cdots\cdots (5)$$

Where pc is the device probability to assesses the idle channel at finish of backoff period. It can be calculate as:

$$P_c = (1 - q)^{n-1} \cdots\cdots (6)$$

Where n is the devises that operate on the network, q is the device probability to transmit at any time.

The average of backoff periods (R) can be measured as:

$$R = (1 - P_s)b + \sum_{a=1}^{a=b} aP_c (1 - P_c)^{(a-1)} \cdots\cdots (7)$$

Thus the total of backoff time (T_{bo}), is given as:

$$T_{bo} = FractionalPart[R] T_{bop} (IntegerPart[R] + 1) + \sum_{a=1}^{a=IntegerPart[R]} T_{bop}(a) \cdots\cdots (8)$$

where T_{bop} is the average backoff period, it can be measured as:

$$T_{bop}(a) = \frac{2^{macMinBE+a-1} - 1}{R_{data}} T_{boslot} \cdots\cdots (9)$$

Where macMinBE is minimum and initial value of backoff, Tboslot is the backoff time at one slot duration In which equal twenty symbol duration by using IEEE 802.15.4\Zigbee.

5 Simulation parameters

In this paper, we supposed a home health network contains of 5 sensor nodes connected as star topology and distributed in 5 rooms as follows: in living room, bed room, dining room, office room, and in bathroom. We used standard parameters to hold our work. These parameters are listed in Table 1.

Table 1. Simulation Parameters.

#	Parameter	values
0	T_S	16 μs
1	T_{boslot}	320 μs
2	T_{TA}	Zero
3	T_{SIFS}	192 μs
4	T_{LIFS}	640 μs
5	L_{PHY}	6 bytes
6	L_{MHR}	11 bytes
7	L_{MFR}	2 bytes
8	macMinBE	3
9	aMaxBE	5
10	macCSMABacko f fs	4
11	Use of ACKs	Zero
12	Payload size	From 0 to114 bytes
13	R data	250 kbps
14	n	5
15	BER	2x10 ^ - 4
16	Ec	30.5 mA
17	Es	15.5 mA

6 Experimentation and Result

Algorithm have been implemented in JAVA language, we link jMetal 4.5 of java source code with NetBeans IDE 8.0. We run the algorithm on a Core I5-3210M CPU, 4 GB RAM and Windows 7 64-bit. We use three algorithms (NSGA-II, SPEA-II and OMOPSO) to run our problem and comparing between these algorithms.

S = number of variables

The parameters of NSGA-II and SPEA-II algorithms are as follows: population size is equal to 20, the crossover probability is equal to 0.9, the mutation probability is equal to $\frac{1}{S}$ and the number of generations is equal to 250. The parameters of OMOPSO algorithm are as follows: swarm size is equal to 20, the probability is equal to $\frac{1}{S}$ and the number of generations is set to 250.

The comparison between NSGA-II, SPEA-II and OMOPSO will be done; the following table displays the minimum, maximum and average over 10 runs on each algorithm. The following graph displays an example of each algorithm run.

Table 2. Result of NSGA-II algorithm

	NSGA-II Algorithm		
	MIN	MAX	AVG
Objective 1 (Max Energy Efficiency)	0	0.85	0.45021
Objective 2 (Min Transmission Delay)	0.045087	0.046496	0.045787

Table 3. Result of SPEA-II algorithm

	SPEA-II Algorithm		
	MIN	MAX	AVG
Objective 1 (Max Energy Efficiency)	0	0.85	0.44965
Objective 2 (Min Transmission Delay)	0.045087	0.046497	0.045989

Table 4. Result of OMOPSO algorithm

	OMOPSO Algorithm		
	MIN	MAX	AVG
Objective 1 (Max Energy Efficiency)	0	0.85	0.43729
Objective 2 (Min Transmission Delay)	0.045087	0.046495	0.045809

Results show NSGA-II outperforms SPEA-II and MOACO on the resolution of our problem.

Figure 2 shows Energy efficiency by varying the packet payload size using NSGA-II genetic algorithm. We can notice by the results in **Figure2** that minimum value of energy equal 0 and the maximum value equal 0.85.

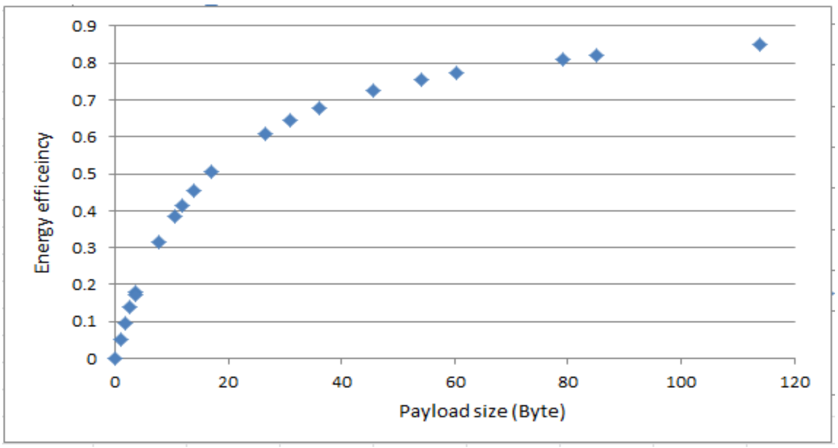

Figure 2. Energy efficiency and payload size using NSGA-II

Figure 3 shows a transmission delay by varying the packet payload size using NSGA-II genetic algorithm. We can notice by the results in **Figure3** that minimum value of transmission delay equal 0.045087 and the maximum value equal 0.046496.

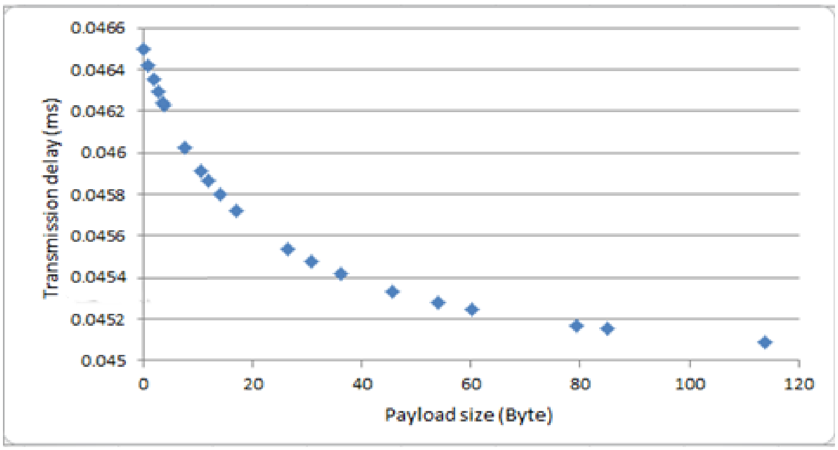

Figure 3. Effect payload size on transmission delay using NSGA-II algorithm

Figure 4 shows Energy efficiency by varying the packet payload size using SPEA-II genetic algorithm. We can notice by the results in **Figure 4** that minimum value of Energy efficiency equal 0.0 and the maximum value equal 0.85.

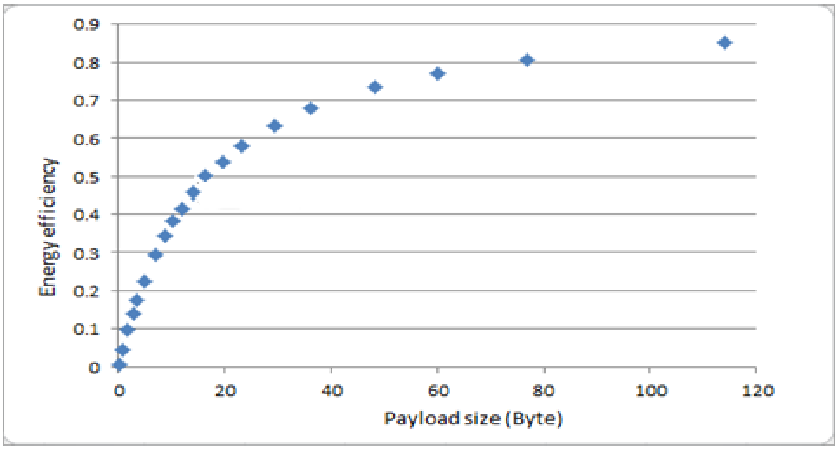

Figure 4.Energy efficiency and payload size using SPEA-II

Figure 5 shows a transmission delay by varying the packet payload size using SPEA-II genetic algorithm. We can notice by the results in **Figure 5** that minimum value of transmission delay equal 0.045087and the maximum value equal 0.046497.

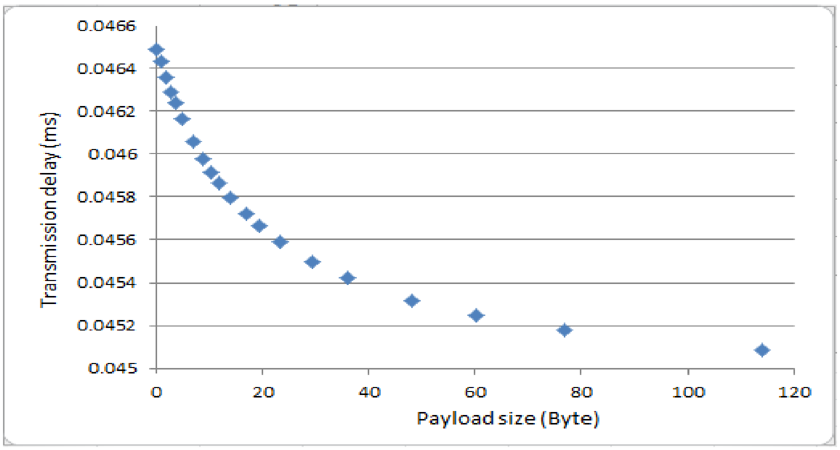

Figure 5. Effect payload size on transmission delay using SPEA-II algorithm

Figure 6 shows Energy efficiency by varying the packet payload size using OMOPSO genetic algorithm. We can notice by the results in **Figure 6** that minimum value of Energy efficiency equal 0.0and the maximum value equal 0.85.

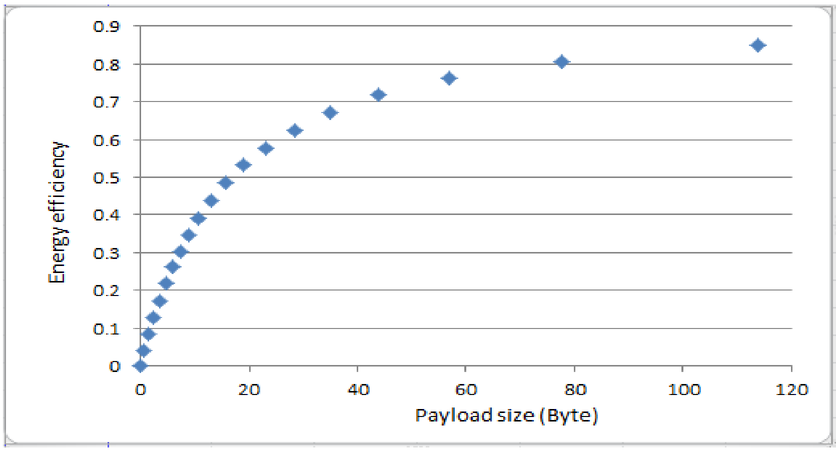

Figure 6. Energy efficiency and payload size using OMOPSO

Figure 7 shows a transmission delay by varying the packet payload size using OMOPSO genetic algorithm. We can notice by the results in **Figure 7** that minimum value of transmission delay equal 0.045087and the maximum value equal 0.046495.

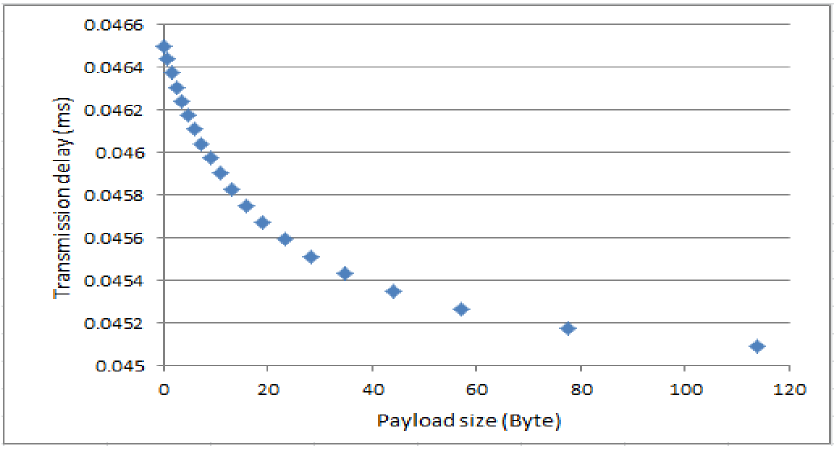

Figure 7. Effect payload size on transmission delay using OMOPSO algorithm

7 Conclusion

In this paper we tried to solve a multi-objective problem; the first objective is the minimization of the end to end delay; the second objective is maximization of the energy efficiency of the network depending on packets payload size. Using jMetal our problem implemented and tested by using three genetic algorithms (NSGA-II, SPEA and OMOPSO). The experimental results shown that the NSGA-II algorithm outperforms other algorithms on the resolution of our problems.

8 Open Problem

Health care system is an important E-Health application. Health care system at home has created to alleviate the treatment cost of patients with special cases such as elderly patients, Alzheimer's patients and patients' seats. There are many health sensors that are used to transmit patients' vital signs to control station such as heart rate sensors, Electrocardiogram sensors, and blood pursuer sensor. This system faces many problems some of them:

1. End to end delay because it is used to transmit real time parameters of patients' health status like Electrocardiogram (ECG).

2. Energy efficiency because its' operates using limited resource like battery.

In future will be to:

- Defending other health care system problems such as health sensors coverage, financial cost model to minimize the cost of network.
- Using other GA algorithms to solve the problem.
- Using different types of network topologies.

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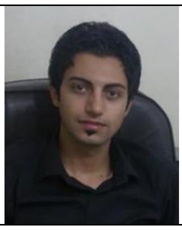

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