Journal of Computer and Knowledge Engineering, Vol. 6, No. 2, 2023. (31-40)

Ferdowsi University of Mashhad

Journal of Computer and Knowledge Engineering

https://cke.um.ac.ir

Information and Communication Technology Association of Iran

Optimization of FlexiTP Energy-Aware Algorithm in Wireless Sensor Networks *

Research Article

Hamid Mirvaziri[1]

DOI: 10.22067/cke.2023.82926.1082

Abstract: Maximizing WSN longevity besides maintaining their efficiency and proper performance, is one of the most important challenges that researchers of this field encounter. FlexiTP, is a protocol that was designed and made for optimizing energy consumption and maximizing longevity of these kinds of networks. This study presents improved version of FlexiTP protocol using Harmony Search algorithm with the objective of optimizing energy consumption of FlexiTP protocol. The suggested method, HS-FlexiTP, is able to choose the best parent for each sensor node, using Harmony Search algorithm, based on three criteria including; distance of parent node from child node, number of the hops of the parent node and remaining energy of the parent node. Obtained results of the simulations indicate that HS-FlexiTP is able to decrease 25 percent of the consumed energy per each node throughout the various scenarios of simulation in comparison with FlexiTP protocol. In comparison with ZMAC protocol, it has much better efficiency in decreasing consumed energy as well and in comparison with both protocols, ZMAC and FlexiTP, the suggested procedure is able to maximize network longevity and optimize other efficiency criteria including average packet delay, throughput and productivity of the channel.

Keywords: FlexiTP, Harmony Search algorithm, Energy Optimization, Network Longevity, WSNs.

1. Introduction

In the recent years, wireless sensor networks have been able to bring efficiency and speed in data aggregation, wonderful analysis and decision making for people, while provides required security in unsafe environments and control or analyze various issues) for them. In wireless sensor networks, several wireless sensor nodes are used in a way that each of them, considering the mission they have, is equipped with several sensors and use to collect data. Each node sends data to the sink node after data collection and then, through various communication systems send them into the communication center to make required and urgent decision. Because of that, wireless sensor networks have numerous applications including military operations, rescue and assistance, industrial activities, controlling railways, agricultural activities and etc.

In wireless sensor networks each node has a limited computing and energy saving ability bearing in mind that it is often employed in the environment with no communication or power supply and its tiny dimension. Also, a node can remain at the network until its power supply has not been finished and when the energy of that node finishes, its undercover region will encounter failure which may have drastic consequences. One of the protocols that has been designed and implemented for optimizing energy consumption and maximizing longevity of wireless sensor networks is FlexiTP protocol, whose features and attributes has been examined in the third section. Meta-heuristic Harmony Search algorithm, whose feature has been fully explained in the fourth section of this article, is an algorithm derived from music orchestra. In this algorithm the best harmony would be chosen and played and by repeating and testing various sounds performed by artists. The objective of this article is optimizing consumed energy of wireless sensor networks through redesigning FlexiTP using Harmony Search algorithm. It's expected that this reconstruction would be able to decrease energy consumption significantly in the FlexiTP and increase longevity of the network while provides performance, reliability and scalability of the network. This article organized as follows: Previous works and researches are presented in the second section. Third section is dedicated to introducing FlexiTP protocol; the fourth section has covered Harmony Search algorithm and implementation of improved protocol is offered in the fifth section. Obtained results and comparison with other protocols are presented in the sixth section and finally seventh part is about conclusion and suggestions for future investigations.

2. Review of related works

In order to optimize energy consumption in sensor networks, many solutions and protocols are presented in MAC layer that is divided into three categories of contention based MAC protocol, contention free MAC protocol and synthetic protocol.

2.1. Contention based MAC protocols

Protocols such as [1], [2], [3] and [4] are among contention based MAC protocols that have used multiple access mechanism with (CSMA) (Carrier Sensing Multiple Access) collision detection in their structure. In SMAC (sensor MAC) [1] and T-MAC (Timeout MAC) [2] RTS/CTS (request to send/clear to send) handshaking mechanisms is used as well

* Manuscript received: 2023 March 13, Revised, 2023 July 9, Accepted, 2023 September 20.

[1]Computer Department, Faculty of Engineering, Shahid Bahonar University, Kerman, Iran, **Email**: hmirvaziri@uk.ac.ir

as CSMA mechanism to prevent contention in multi-hop communications. SMAC has alternative waking and sleeping periods with fixed length. In this protocol, nodes go to periodic sleep. This feature causes decreasing of energy consumption but on the other side, this behavior increases delay as the transmitter node has to wait for the listening period of the receiver node when the receiver node wakes up. In order to overcome the problem of using stable duty cycle in SMAC, T-MAC was suggested with dynamic duty cycle. In this protocol the period of nodes' activity and sleeping is determined based on the network traffic and it overcome former protocol problem significantly. Other protocols such as D-MAC [4], B-MAC [5] and WiseMAC [6] are contention based protocols that try to decrease SMAC duty cycle in some way respectively by offering tree structure of data aggregation and utilizing features of the channel and header sampling simultaneously. IEEE 802.15.4 [7] is a popular standard for the medium access control (MAC) scheme of low-powered, low data rate wireless sensors. Further IEEE 802.15.4 has a MAC protocol in MAC layer which defines the slotted medium access control scheme for the short-range communication devices with low data rates. MAC mechanism in IEEE 802.15.4 extends the number of Guaranteed Time Slot (GTS) and the single channel operation of IEEE 802.15.4 standard multichannel operation for data transmission. Performance analysis of the slotted CSMA/CA scheme in the IEEE 802.15.4 standard is discussed in [8]. FROG-MAC [9] as a new algorithms, introduced a new fragmentation strategy for heterogeneous traffic in WSNs that enables high-priority data packets to interrupt any unimportant ongoing transmissions. Main problems of these protocols are contention in multi hop communications and lack of guarantee to deliver packets in these types of communications which causes increasing in energy consumption ratio and decreasing in maximum of network longevity which degrade their performance.

2.2. Contention free MAC protocols

Time division multiple access (TDMA), is one of the contention free protocols in which various users can share channel bandwidth through dividing signal into various time slots. Problem of listening in leisure time and contention is solved by assigning a time frame to each node in this protocol. However, the most important problem that these protocols encounter is the way of specifying length and measurement of each frame or time slot which could influence energy consumption of the network to a great extent [10].

[13], [14] and [15] are synthetic protocols with combination of TDMA/CSMA communicational models. It was tried to use the advantages of those models and remove their defects. In [15], reduced frame protocol TDMA, has been suggested which is a synthetic model of TDMA/CSMA and each time period has been spread with a short time period of competitive mechanisms based on CSMA. In comparison with traditional TDMA that solve the problem of contention by a separate piece of time period, a potential part of these contentions was limited and remains which was resolved using CSMA protocol in a dynamic way. Two strategies are introduced; first one includes the length adjustment of TDMA frame and second one is related to decreasing the number of conflicts over time periods using an Exploration Concession Period algorithm.

ZMAC is a MAC synthetic protocol in which the power of two CSMA and TDMA protocols are combined [14]. The most important feature of this protocol is its performance under low contention situation (similar to CSMA) and it has a performance under high node density (similar to TDMA). ZMAC has two basic components. First is called neighbor detection and slot assignment, and second called local framing and synchronization. Also this protocol is resistant against dynamic changes of topology, breakage in time synchronization and breakage in assigning time slot to nodes. In the worst case it has a performance similar to CSMA. In spite of abilities that were discussed above, it is not able to have a proper performance in high node density and its performance is degraded down to the performances of contention based protocols. Also, high contention in this protocol leads increasing of node's energy, decreasing of network longevity, increasing degree of packet delay and efficiency reduction of the whole network. Consequently this protocol could not be a proper option in network with high node density. Both ZMAC and IEEE 802.15.4 are hybrid protocols which can save higher energy and supply better scalability and flexibility in comparison to their ancestors.

In the primary stage of FlexiTP protocol, each node performs data aggregation related to their neighbor in order to construct data aggregation tree and determining parent, child, and ancestors using CSMA mechanism. In the next stage a time slot is assigned to each node similar to TDMA mechanism by which it would be able to activate with its parent or child node to send/receive data [13]. In this protocol there are not only maintaining performance criteria but also ability of increasing network longevity by taking proper advantage of features related to CSMA/TDMA. Also, this protocol is able to guarantee packet delivery while removing contention in the channel. It has also a fairness mechanism to ensure fair access of channel among nodes. In order to maximize the longevity of the network in [4], [9], [11], [12] and [14] and reducing energy consumption, nodes timing techniques in [9], clustering technique in [4] [12] [14] and distributed troubleshooting technique in [11] was employed. In [13], Harmony Search algorithm based on clustering was used in order to reduce energy consumption in wireless sensor networks. IEEE 802.15.4 is a low-rate Wireless Personal Area Networks (WPAN). To maintain the synchronization of time-frames it takes coordinator which is operating in the beaconed mode. It has concept of super-frame structure uses TDMA-based period for access so even for energy conservation there is no special design method except a typical duty cycle controlling scheme [16].

There are some major design challenges in wireless sensor networks due to lack of energy and many researchers are looking for those algorithms that can optimize the use of this energy [17]. Harmony Search algorithm is used to optimize energy consumption in many applications. For example a mutated harmony search algorithm (MHSA) is used to improve the energy efficiency of an optimized routing protocol [18]. HS algorithm is also employed for charge scheduling of an energy storage system [19]. In another work a comprehensive review on the applications of HS method is inspected [20]. They evaluate researches in energy systems by using HS will be analysed. In the next sections we discuss only about contention free protocols for non-guaranteed access and then compare proposed method with them.

3. FlexiTP protocol

The main performance of FlexiTP protocol includes management in generating the routs (forming data aggregation tree), generation of nodes' timing (assigning time period), synchronization in order to reduce clock drift and local fixing and reconstructing for the network in the time of error occurrence (bearing the error). This protocol contains two main phases: First one includes primary initiation of the network that is performed thoroughly by CSMA/CA protocol and second one is data aggregation cycles that is performed by TDMA protocol. Data aggregation structure is located in the primary phase and performs in three levels which include: choosing parents, improving network communication by aggregation of the neighborhood data which eventually leads into formation of clusters and identification of components and network topology. As it was already mentioned, this stage is performed by CSMA/CA mechanism. The following stage (assigning time periods) is performed by the same protocol as well and nodes are allocate in various time periods based on their structure that eventually leads into formation of required routs for data transport. Because of using TDMA in the second stage, time synchronization is very considerable as nodes are required to wake up in a specific time and transport their data. In FlexiTP hierarchy structure is used in formation of data aggregation tree and by performing this synchronization the clock difference is minimized at each cycle. In this protocol, nodes listen to environmental activities to resolve the errors when they occur, without previous notification. This happens at disconnection time of the link or network topology alteration. The architecture of protocol is static in WSNs here. Nodes may suffer from temporary or permanent errors and new nodes may be added to the network at any moment or a node may exit from the network because of a reason such as termination of the energy or movement, but despite of this situation, nodes are placed on their previous position. In this protocol, inner group consulting mechanism is used to categorize all types of defects [5].

4. Harmony Search algorithm

Harmony search (HS) algorithm in this context uses the best chosen process by repeating numerous processes. Each process is tested and would be considered as a solution (solution vector) if it has the required harmony. In order to achieve a better and more beautiful harmony, this work is repeated and in case of success, previous work is replaced with new one. Obtained results will be compared with the fitness function to achieve a better solution in HS algorithm. In order to achieve the best solutions, Harmony Memory (HM) is used. This memory is implemented in the form of a matrix and each row is indicative of a solution in it. Number of columns in that matrix, indicates the number of possible solutions and last column is used for computing and saving degree of fitness function of each row. Number of rows in the matrix is called Harmony Memory Size (HMS) and measurement of the matrix will be equal to HMS*(N+1). In HS algorithm choosing value of variables is through using one of these three procedures including employment of existing variables in the memory (considering Harmony Memory or HMC), generating minor alteration in the value of the variables and applying them (Pitch Adjustment or PA) and generating a random value for variable (randomization). Every note is fixed in music; thus, values of variables in the whole memory of the harmony would be alike as well. Probability of choosing a variable from the Harmony Memory is between 0 and 1 and known as Harmony Memory Considering Rate (HMCR). In case that this value is close to 1, desirable solutions would not be gained and if it is close to 0, convergence would be slow down as it should try numerous solutions. Consequently, the value of this probability can be a number between 0.7 and 0.9. This procedure guarantee solutions close to the optimized one, are always kept in the Harmony Memory and they could be more optimized by adjusting the pitch or applying minor alterations in the future usages. It is possible to apply some changes in HS variables after choosing existing variables in the memory. The objective of these minor changes would be optimizing of local solutions. Value alteration of PA occurs with the probability of Pitch Adjustment Rate (PAR) and it has a value between 0 and 1. This value should be chosen carefully i.e. algorithm have to try more local solutions in low values which would slow down the whole complex. For high values, several solutions remain unexamined so the solution is mostly random. This value is often chosen from 0.1 to 0.5. Randomization in HS Algorithm means choosing random values for variables and causes more variation in the solutions. The difference between pitch setting procedures and randomization is that PA tries to find the optimized local solutions by limiting the search area while randomization takes the algorithm performance toward overall searches and finding overall optimized solutions by expanding the search area.

5. Proposed Method

In FlexiTP algorithm, generating of data aggregation tree is performed only once and that would be in primary initialization phase of the network. Also, considering the fact that this protocol is utilized assigning time slots for sleeping and waking periods of the nodes, and each node knows its parents, ancestor and children and their sleeping and waking periods are adjusted together, flat routing algorithm is practically used. In the other word if a node is a few hops far from the sink node and attempt to transmit data to it, this data is delivered to the destination node through the same time slots and in forwarding data mode by its parent and ancestor. On the other hand, the main usage of the HS algorithm is in multi hop routings among wireless sensor nods; thus HS algorithm can only be used to generate optimal data aggregation tree at the beginning time when this protocol starts. Therefore the best middle nodes (ancestor and parent/ parents) are chosen for the node which is a few steps far from the sink node. When the structure of the data aggregation tree is shaped by this algorithm, the protocol enters its next phase which is assigning time slot into the nodes. As a result, it would be assured that the best structure of the data aggregation tree is dedicated to the protocol to continue. In order to achieve this, the suggested method is implemented in three stages and accuracy in the data aggregation is evaluated at the evaluation stage.

In the first stage all of the existing nodes in the network identify the nodes which are located in their direct radio range by using mass effect and propagation of its data (the remaining energy, positional data and the number of the pitches in relation to the sink node) and save them in their neighbors' table.

In the second stage all nodes know their neighbors, along with the number of their hops to the sink node. They also have gained their distance to the neighbor nodes. In this case they proceed to fill the Harmony Memory and then choose the best node as their parent based on determined fitness function.

In the third stage the structure of the data aggregation tree is generated and dedicated to the second phase of the protocol which is assigning the time slots into the nodes. In this situation, the nodes receive data of time slots in a state that they have chosen the best parent in terms of distance, energy consumption and the number of hops to sink node according to the fitness function defined for them. In the following details of each stage have been explained.

6.1. Identifying the neighbor nodes

In the beginning, the sink node produces a packet contains: identification of a node, its remaining energy and distance to the sink node and then propagates it in the network pervasively.

Those nodes that are located in the direct communicational zone of the sink node receive this message and save it in their direct neighbors table.

After receiving this message, the neighbor nodes specify their status and distance from the sink node. This is happened by adding one hop to the received distance from transmitter node and then responding to the node that has sent the message in order to make the transmitter node able to identify its neighbor nodes and register them in its neighbors table.

It's worth mentioning that determining status and distance to the sink node is only performed once so a node evaluate its status at first by the time of receiving the message and then in case the node's status is initialized, it uses that value and otherwise, adds one hop to the field of received distance from transmitted node and propagate it as its status.

The direct and first surface nodes of the sink node propagate their data pervasively similar to the previous stage. The neighbor nodes of transmitter node receive transmitted data and save it in their neighbors' node table.

The receiver node first looks at its neighbors' table during registration of transmitted node's data. In case that data of this node is in the table, it updates them and otherwise, it registers new data in its neighbors table. Algorithm 1 illustrates Pseudo-code of the above stages. When neighbor's aggregation data phase is finished, phase of generating data aggregation tree structure is started by HS algorithm.

Step1. aggregating neighbors information nodes

```
Start
Initial My Status packet (my id ,remaining energy ,hop to sink ,
distance to base station , my position )
Generate My Status packet
Broadcast My Status packet
End
```

a. Base Station

```
If (received NewPacket )
{
Read NewPacket (Node ID ,Remain Energy ,hop to sink, D2S
and Position of sender node )
    If (node id of NewPacket Not exist in my  Neighbor Tables
)
     {
          Add sender node to my  Neighbor Tables
          If (My Status not initialized )
                   Initial  My Status packet (my id , Remain
Energy , hop to sink of sender node +1 , D2S and my Position)
          Broadcast My Status packet
      }
     Else
          Ignore received packet
 }
```

b. Receiver nodes

Algorithm 1. Neighbor's Data aggregation to a. basic station b. transmitter groups

6.2. Generating of data aggregation tree by Harmony Search algorithm

In this stage, each node has the data related to its all neighbors. In order to implement the HS algorithm, Harmony Memory matrix is used with size of HMS * (n+1) in which HMS (Harmony Memory Size) indicates the number of rows and solutions and n indicates maximum of the route length between source and destination and could be equal to all of the existing nodes in the network in its maximized status. n is chosen to be 2 in this sample because the objective of choosing the best parent from the neighbors of a node is by using HS algorithm. For computing the fitness of each row, fitness function is used. In order to implement HS algorithm, it is required to fill the memory of the harmony randomly based on the condition that orbit have not been shaped in each row or solution. If there are only two nodes in the solution then the orbit will never been shaped. Also, HMS would be equal to the number of the neighbors of a node in its maximum state. This value is obtained even less after optimization by the algorithm. In this article HSA has been used for choosing the best parent for every existing node in the network. In this state, each node has access to data related to its neighbors so the number of rows in the Harmony Memory is filled randomly and the value of each obtained solution is computed based on the following fitness function in equation (1).

$$fitness\ function = \frac{E_R}{D}/h \qquad (1)$$

Here, ER indicates remaining energy of the node which is considered as the parent node. D is indicator of the distance of two nodes from each other and h is indicator of the number of hops between the candidates of parent with the sink node. The main objective of choosing this fitness function is because of the following properties: 1-candidate node would have the least distance with the chosen parent 2-parent node would have a proper remaining energy and 3-candidate node would have the minimum number of hops with the sink node for becoming a parent. These three features are able to optimize the consumed energy to a great extent. In this fitness function not only proper distribution of the consumed energy but also the distance between two neighbor nodes are considered. The first one increases longevity of the network and the less distance between two nodes; the less energy is consumed to reinforce the signal. In addition to the mentioned points, distance of neighbor node has been considered in terms of the number of hops to the sink node which can save energy by eliminating additional and futile forwards by the middle nodes so increase network longevity. Consequently, the bigger the degrees of the fitness function; the more valuable it gets. In order to implement Harmony Memory, each node is filled randomly and based on its neighbor table so the maximum number of rows in the Harmony Memory matrix, can be equal to the number of the neighbors of that node which was demonstrated before by HMS. This matrix would have three columns. The first column contains the source node, the second column is one of the neighbors of the node which has been chosen randomly and the third one is computed degree of the fitness function for each solution.

A. Harmony Search algorithm Optimization

Rows of Harmony Search matrix are filled randomly and each of them is considered as a solution or a vector and fitness function should be computed for each one so if these solutions are not being optimized, the algorithm will work slowly as it have to examine solutions that are not optimized and therefore, in order to optimize functionality of the algorithm, neighbors nodes and the node that is in the state of choosing parent and have equal hops (distance from the sink node) are eliminated from the solution set.

As a result, only those nodes will remain in the Harmony Memory that is closer to the sink node in comparison to the node itself, this could eliminate the solutions which are not optimized and allocate a faster convergence to the algorithm. After the end of this period, each of the nodes has gained the best position in the structure of data aggregation tree, so, in the third stage of the time slots assignment mechanism, FlexiTP protocol is used to determine the activation and sleeping time of nodes. Pseudo-code in Algorithm 2 demonstrates this stage.

Step 2. data aggregation tree using HSA per nodes

```
Parent=-1
HMS=Length of Neighbor Tables
N=2
HS[HMS][N+1]
For (i=0; i<HMS;i++)
{
If (my hop to sink > hop to sink Neighbor Tables[i]
Compute fitness function (parent candidate)
If fitness function(parent candidate > current parent)
   Parent = node id  Neighbor Tables[i]
}
Set best parent id
```

Algorithm 2. Optimizing the performance of the HS algorithm and choosing the best parent for each node

6.3. Implementation of the proposed algorithm

In order to implement the proposed algorithm some changes are done in the base code of FlexiTP and HS algorithm has been added to that code in NS2 simulator. The end results are based on the results of 20 various network topologies each them has owned about 100 nodes and are distributed in 300 square meters area.

In the performed simulations the status of the base station has been fixed on the central spot of the map and the parameters of the simulation have been based on Mica2Mote hardware. Table 1 indicates the parameters of simulation used in the simulation. Also, the gap length of the data aggregation FlexiTP and MFS has been chosen 26 milliseconds. 23.3 milliseconds of that time is for transporting the packet and 2.45 milliseconds for the status of the radio of the node and transition from sleeping to idle state and 0.25 milliseconds is for the transition of the nodes from the idle to sleeping state [5]. The radio range of the existing nodes in the network is 60 meters and the used traffic is CBR (Constant Bit Rate) with the packet production rate of 5 in every second. Also, the whole time span of simulation was 1000 seconds. Choosing this duration make it possible for required outputs to perform optimization and functionality comparisons between proposed and other protocols in a reasonable time.

Table 1. Simulation parameters of FlexiTP in NS2 [5]

Default value	Simulation parameters
19.2 Kbps	bandwidth
56 byte (36 byte for payload and 20 byte for header)	Packet size
60 meter	Communicational zone (radio range of sensor nodes)
63 microwatt	Power consumption in transportation status
30 microwatt	Power consumption in receiving status
30 microwatt	Power consumption in idle status
0.003 microwatt	Power consumption in sleeping state
30 microwatt	Power consumption for transition of sleeping to idle state and vice versa
2.45 microsecond	Transition point
27 microseconds	The size of the FlexiTP gap
100 microseconds	Period of FlexiTP FTS
54000 joule	Primary energy of the node
1000 seconds	Simulation time

7. Obtained results and Evaluation

In this section we discuss about the results obtained from simulation in NS2. We also evaluate proposed algorithm with other protocols and compare them by known criterion.

7.1. Installation of time span and initialization of the network

Figure 1 indicates performance comparison of HS-FlexiTP and FlexiTP protocols in the installation time span and initialization of the network. As it is indicated in this figure, the suggested method is able to have a better performance in the installation time span and initialization in comparison with FlexiTP protocol and improve this time up to 5 percent.

In any case in the proposed algorithm, neighbor's nodes data are saved in the table of their neighbors in the beginning time of data aggregation of the neighbor's period and computing features such as the distance of the neighbor node from the main node and computing the degree of their fitness function will be occurred in the node itself. This process decreases network traffic and the number of the exchanging packets between existing nodes in the network so this period will be finished in a less time span.

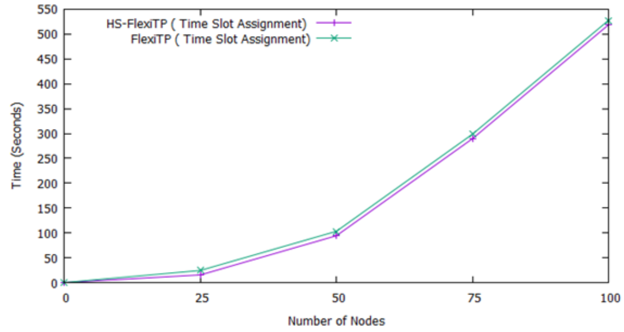

Figure 1. Network installation and initialization time span in FlexiTP and HS-FlexiTP protocols

7.2. Assigning time slot to the nodes

After installation and initialization of the network, the nodes which have been able to receive the neighbors data aggregation messages from the other nodes at the first stage, are positioned in the tree structure and specific time slots is assigned to them in order to enable them to transmit the aggregated data to the parent nodes and eventually to the base station based on these gaps. Figure 2, indicates a comparison between HS-FlexiTP and FlexiTP protocol in assigning time slot to the nodes.

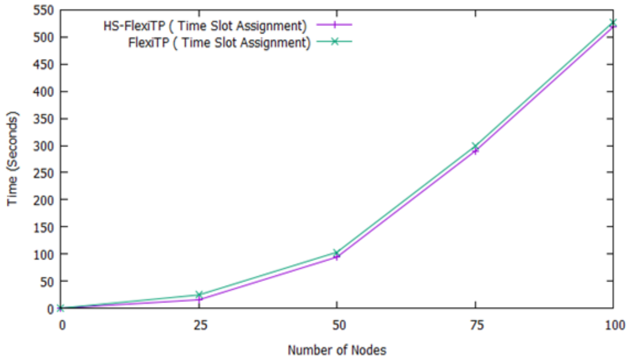

Figure 2. Assigning time slos to the nodes in FlexiTP and HS-FlexiTP protocols

It is obvious in Figure 2 that suggested method is able to reduce the time span of time slots assigned to the existing nodes in the network up to 3.2 percent. Reduction of this time in the two mentioned phases leads to reduce energy consumption for each node and eventually leads to optimize consumed energy and increase network longevity while maintain its efficiency. One of the reasons that the suggested procedure has been able to reduce the duration of time slot assignment, is choosing appropriate parents for each node through computing fitness function of the neighbor nodes and choosing the best node as the parent node of each node.

Of course, optimization of the suggested method in the installation and initialization phase of the network is performed in order to eliminate the neighbor nodes, whose number of hops to the sink node is more than the node which is in the states of choosing the parent itself. This fact leads to choose the node as the parent node that firstly, has the least hops to the sink node and secondly, the number of its hops is less than the node itself and thirdly, the distance between the parent node and the current node has the minimum value. These points cause to reduce the distance that the packets move between the nodes, and as a result, total energy consume less than before.

7.3. Energy consumption Criteria

In order to evaluate the performance and efficiency of the suggested method in energy consumption and comparing it with FlexiTP and ZMAC protocols, three criteria has been considered: average degree of consumed energy for each node, average degree of consumed energy for each packet and maximum network longevity [5]. As the suggested method is able to reduce the required time in the installation hops and initialization of the network and time slot assignment in comparison with FlexiTP, it is expected that the suggested method has a better performance in the degree of energy consumption. FlexiTP protocol has the capability of using or not using time slots assigned to the nodes by the other nodes. Both features have been considered in the simulations. Figures 3 and 4 show the average consumed energy in activation and deactivation states of capability of reusing time slots for the proposed method, FlexiTP and ZMAC respectively. It is worth mentioning that this capability is not defined in ZMAC.

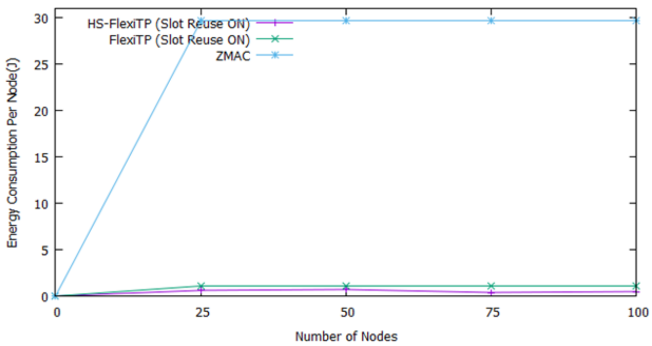

Figure 3. The degree of the consumed energy for each node with the capability of reusing time slots in HS-FlexiTP, FlexiTP and ZMAC protocol

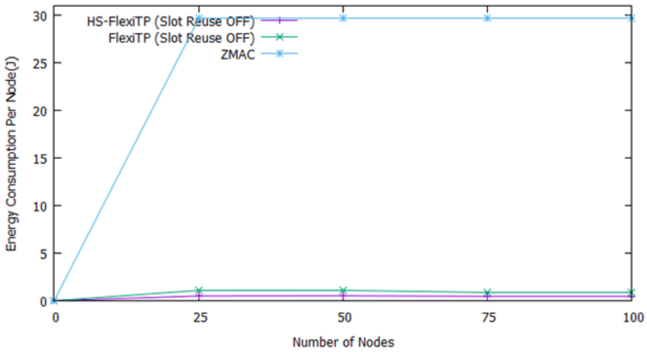

Figure 4. Consumed energy for each node without the capability of reusing time slots in HS-FlexiTP, FlexiTP and ZMAC protocols

As it is clear, the proposed method can have relatively reduced consumed energy for different scenarios of simulations with different node density, in activation and deactivation of capability of reusing time slots up to 26.3 and 24.9 percent respectively. Performance of the suggested method is significant. It is able to reduce the energy consumption up to 98 percent in comparison with ZMAC protocol. In the activation and deactivation of capability of reusing time slots, FlexiTP is able to optimize the degree of energy consumption about 97.4 and 97.8 respectively in comparison with ZMAC protocol. FlexiTP protocol consumes 2.51 (0.746 joule) and 2.18 (0.649 joule) percent of the whole energy that ZMAC protocol consumes in activation and deactivation of capability of reusing time slots states respectively with the similar simulation parameters. This was predictable, as the performance of this synthetic protocol in the busy and crowded networks is being degraded to a contention based protocol. In such status, nodes compete with each other in order to obtain the channel and transmit their data which increases the degree of contention in the channel excessively and leads to increase the energy consumption and reduces the network longevity. In addition to this, average packet delay increases because of the contentions and competitions happening in the channel. On the other side, FlexiTP protocol has excessively reduced the probability of contention in this channel by assigning the accurate time slots specified to each node and their waking up according to this timing. Therefore nodes have no competition for gaining the channel and considering the timing that has been allocated to them. They activate and deliver their data to their parent nodes and go to sleep again and wait for the next period of transmission. The proposed method has consumed 1.85% (0.55 joule) and 1.58% (0.487 joule) of the whole consumed energy of ZMAC in activation and deactivation of capability of reusing time slots respectively. Consequently it is able to optimize the degree of energy consumption in those states up to 98.1 and 98.4 respectively in comparison with ZMAC protocol. Obtained energy of each node indicates the performance of proposed method in optimization of energy consumption in comparison with the other protocols. In fact, optimization of energy consumption is due to its efficiency and appropriate performance in two installation and initialization and time slot assignment phases.

One of the most important features exist in FlexiTP protocol is guarantying of the packet delivery through assigning time slots to the nodes. In fact, this protocol is able to eliminate contention in the channel, while making fairness between the nodes to access the network using this mechanism. In comparison with Flexi-TP, the mechanism of proposed method just differs in the generating of data aggregation tree therefore it is expected that they wouldn't be different much in this criterion. However, there is completely different story in ZMAC protocol. The degree of contention in the channel is excessively high while applying ZMAC protocol at networks with heavy traffic. Occurring contention in the channel, in addition to have negative effects on the degree of energy consumption have negative effect on the network efficiency and increase the delay for packet delivery. Obtained results indicate that ZMAC protocol has the highest energy consumption for each node. The difference between FlexiTP protocol and the suggested one is not significant in this criterion but the performance of the suggested one is better than the mentioned protocol based on this criterion. Obtained results indicate that the suggested method is able to increase the network longevity in comparison with FlexiTP and ZMAC protocol. Possibility of contention in ZMAC has excessively increased the degree of energy consumption of the sensor nodes in this protocol. This feature increases the delay of the packets in this protocol as well.

Figures 5 and 6 indicate the network longevity in activation and deactivation of reusing time slots in previous protocols. Network longevity is increasing up to when nodes are equal to 25 but after that there is a decline when nodes are 50 and it will increase again. It is clear that capability of reusing time slot assignment made a more sharply decline when the number of nodes are increasing up to 50. The main reason of such variation is reaching to a local optimum value of nodes. Obviously reusing time slot assignment make network to have more longevity in general. For the rest of figures the optimal value is 25 nodes for activation of reusing time slot assignment and this value is 50 for deactivation of reusing time slot assignment. Obviously reusing time slot assignment make network to have more longevity in general. As it is obvious from these figures, the proposed method is able to optimize the network longevity in comparison with FlexiTP protocol. Also, the presented longevity of the network by the suggested one is significant in comparison with ZMAC protocol.

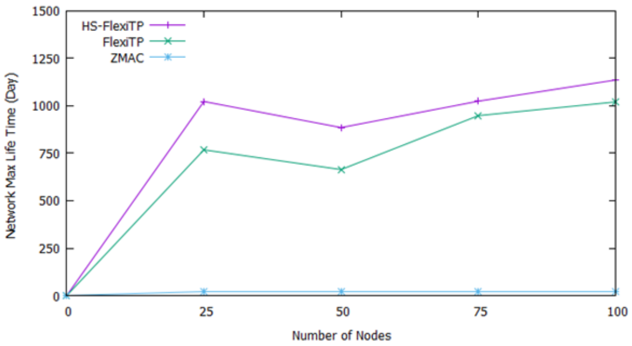

Figure 5. The longevity of the network with the capability of reusing time slot assignment in FlexiTP, HS-FlexiTP and ZMAC

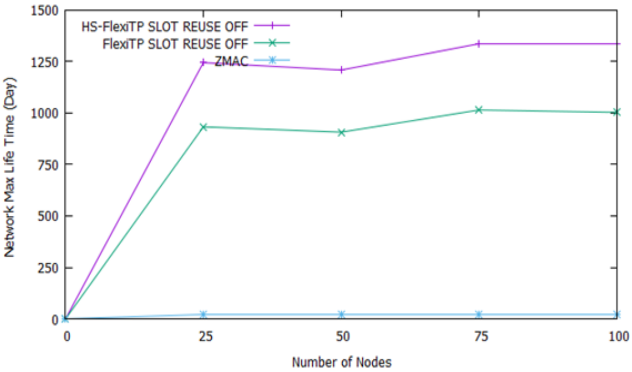

Figure 6. Maximum of the longevity of the network without the capability of reusing time slot assignment in FlexiTP, HS-FlexiTP and ZMAC

7.4. The criteria of efficiency evaluation

In order to evaluate the performance and efficiency of our method and compare it with FlexiTP and ZMAC protocols, four criteria are considered. These criteria are average throughput, percentage of channel efficiency, average packet delay and fairness in nodes accessing to the communicational channel. [5]. In FlexiTP time slots are assigned to each node with equal length. This make it possible for the aggregated data to be transmitted based on the determined timing so fairness is guaranteed [5]. Therefore, this criterion is guaranteed in the suggested method as it is derived from this protocol.

Simulation results indicate that when the capability of reusing assigned time slots is deactivated, network throughput is relatively more than when it is activated. Also, the number of received packets in deactivation of capability of reusing time slots is more than its activated status as well. Theoretically, a slot which is assigned to a node at the network can be reused by the other nodes which are a few steps far from that node. Albeit, this will not guarantee the channel being without contention, as the results of the simulation indicate that the throughput of the network is relatively higher when there is no possibility of reusing time slots than when this possibility exists. In [5], the reason of this is said to be contention or irregularity in radio channel. In ZMAC protocol there is not a feature called capability of reusing or not reusing time slots, and this feature has not been defined in the body of this protocol. Simulations results indicate that due to numerous contentions in high node densities, ZMAC protocol has the worst performance among the three mentioned protocols in the field of average packet delay, channel efficiency and throughput. According to the predictions, in scenarios with high nodes density, the number of the packets that are delivered to the base station in the suggested method in activation of the capability of reusing time slots assignment is more in comparison with the main protocol. This happened due to decreasing of packet delay through choosing parent nodes with less distance in the proposed method. Anyway, the degree of the delivered packets has been equal in the time of deactivation of the capability of reusing time slots assignment, as in this status, the probability of contention in channel, has been zero. The degree of the packet delay of the suggested procedure, in both activation and deactivation of reusing time slots has been improved. Also, based on predictions, the degree of the throughput and efficiency of the channel is equal for both protocols in both activated or deactivated status of reusing time slots assignment. Although, in scenarios with high node density and active reusing time slots assignment, considering high contention rate and radio interactions and also high packet delay in FlexiTP protocol, based on the expectations, the suggested method has a better performance in throughput. In figures 7 to 12, there is a performance comparison of the suggested method with ZMAC and FlexiTP protocols in criteria such as average packet delay, average throughput and average channel efficiency for both being activation and deactivation of the capability of reusing time slot assigned to the existing nodes at the network. As it is mentioned before, the optimal value is 25 nodes for activation of reusing assigned time slot and this value is 50 for deactivation of reusing assigned time slot. For example, in figure 12, throughput is maximum when the number of nodes are 25 without reusing assigned time slot for Flexi-TP and the proposed method while it is maximized in figure 11 with reusing assigned time slot for the same protocols.

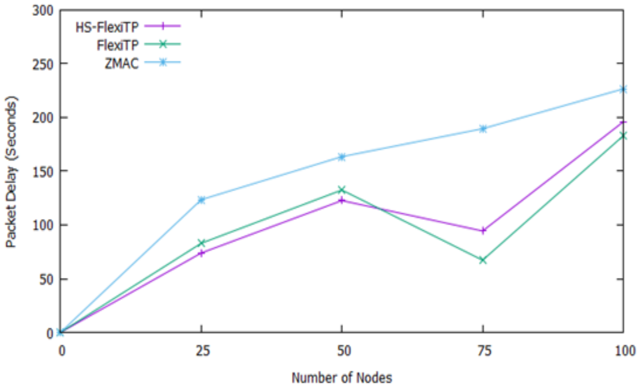

Figure 7. The degree of the packet delay with the capability of reusing assigned time slots for ZMAC, FlexiTP and HS-FlexiTP protocols

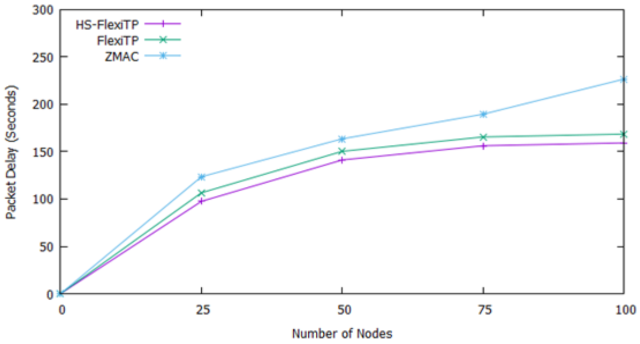

Figure 8. The degree of packet delay without the capability of reusing assigned time slots for ZMAC, FlexiTP and HS-FlexiTP protocols

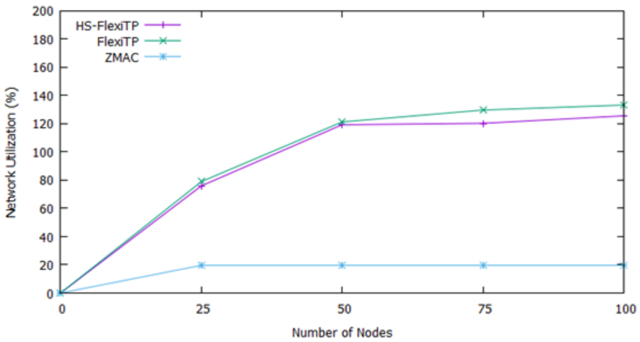

Figure 9. Efficiency percentage of the network with the capability of reusing assigned time slots for ZMAC, FlexiTP and HS.FlexiTP protocols

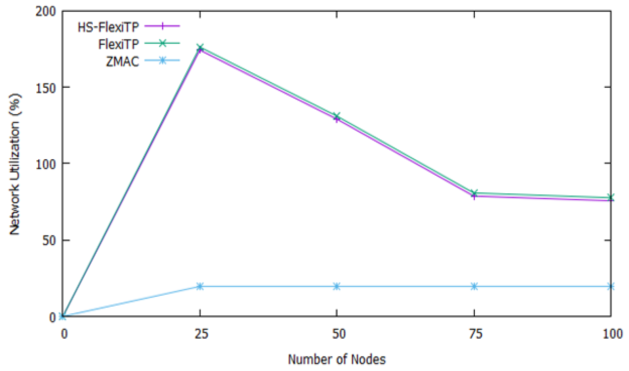

Figure 10. The percentage of the network efficiency without the capability of reusing assigned time slot for ZMAC, FlexiTP and HS.FlexiTP

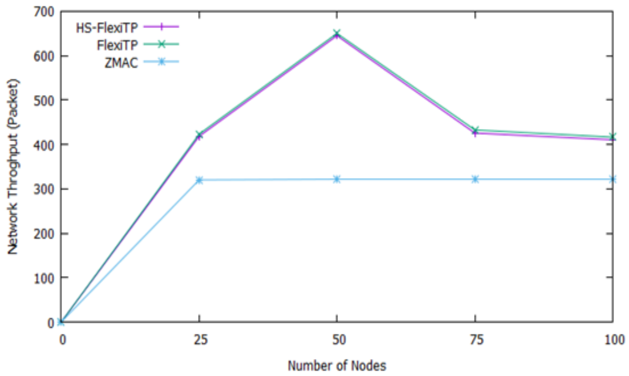

Figure 11. Average network throughput with the capability of reusing assigned time slots for ZMAC, FlexiTP and HS.FlexiTP protocols

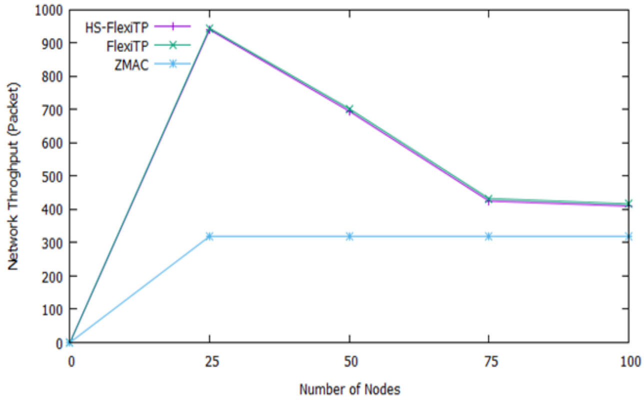

Figure 12. Average network throughput without the capability of reusing the assigned time slots for ZMAC, FlexiTP and HS.FlexiTP protocols

8. Discussion

In this study some important parameters such as distance, hops and energy are considered to evaluate proposed method with relevance works in this field. Some other parameters are measured for comparison such as average packet delay, throughput, residual energy of the node and its parents and productivity of the channel. Also average throughput, percentage of channel efficiency and fairness in nodes accessing to the communicational channel are considered in this evaluation. Longevity of the network is shown in Figure 5 and 6. Improvement of the packet delay of suggested procedure, in both activation and deactivation of reusing time slots is shown in Figure 7 and 8 respectively. Figure 9 and 10 show the efficiency of suggested method in above cases which is computed based on the average degree of consumed energy for each node, the average degree of consumed energy for each packet and the maximum of the network longevity. Throughput Improvement of suggested method is shown in Figure 11 and 12 in both activation and deactivation of reusing time slots respectively. Obtained results indicate that the suggested method is able to increase the network longevity in comparison with FlexiTP and ZMAC protocol. Also suggested method have a better performance in throughput. By comparing the results of simulations, HS.FlexiTP reduces installation time span, initialization, and assigning time slot and energy consumption for each node and increase longevity of the network by choosing the best parent node for existing nodes in the network.

9. Conclusion and future works

In this research Harmony Search algorithm has been applied in FlexiTP protocol in a way that for each node, the parent would be computed according to the degree of the fitness function based on the distance, the remaining energy of the node and the number of hops of the neighbor nodes. Applying this procedure cause the reduction in the time span of installation and initialization, time slot assignment and energy consumption for each node and increasing the longevity of the network while maintaining efficiency parameters in comparison with FlexiTP protocol. In order to perform and depict the results of the suggested method and comparing it with FlexiTP and ZMAC protocol, simulation is performed in NS2 software. Generally by comparing the results of simulations for two FlexiTP and ZMAC protocols and the suggested one, HS.FlexiTP cause reduction in the installation time span and initialization, assignment of time slot and energy consumption for each node and increasing longevity of the network by choosing the best parent node for any node exist in the network.

The performance of the HS algorithm in FlexiTP protocol clearly indicated that this protocol can be used for modification of the protocols which use the structure of the data aggregation tree. Consequently, the objectives of the future research could be redesigning the protocols which have used hierarchy procedures and data aggregation tree structure in order to make it possible to see the obtained results after implementation of the algorithm in optimization of their energy consumption.

conflicts of interest: The author declares that he has no conflict of interest.

9. References

[1] Ye, W., Heidemann, J., Estrin, D., "An energy-efficient MAC protocol for wireless sensor Networks", *in: 21th Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM),* Vol. 3, pp. 1567–1576, 2002.

[2] Van Dam, T., Lengendoen, K., "An adaptive energy efficient MAC protocol for wireless sensor networks", *in: 1st ACM Conference on Embedded Networked Sensor Systems*, pp. 171–180, 2003.

[3] Polastre, J., Hill, J., Culler, D., "Versatile low power media access for wireless sensor networks", *in: Proc. of the Second ACM Conference on Embedded Networked Sensor Systems*, pp. 95–107, 2004.

[4] Kumar, S. S., Kumar, M. N., Sheeba, V. S., and Kashwan, K. R., "Power Efficient Dynamic MAC Protocol (D-MAC) for Wireless Sensor Network *Journal of Information & Computational Science*, Vol. 9, No. 7, pp. 1795–1805, 2012.

[5] Lee, W. L., Datta, A., Cardell-Oliver, R., "Flexitp: A Flexible-Schedule-Based TDMA Protocol For Fault-Tolerant And Energy-Efficient Wireless Sensor Networks", *IEEE Transactions On Parallel And Distributed Systems,* Vol. 19, No. 6, 2008.

[6] El-Hoiydi, A., and Decotignie, J. D., "WiseMAC: An Ultra-Low Power MAC Protocol for Multi-HopWireless Sensor Networks", In Proceedings of the first Springer Verlag International Workshop on Algorithmic Aspects of Wireless Sensor Networks (ALGOSENSORS’04), July 2004.

[7] IEEE Standard. 802.15.4-2011: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personal Area Networks (LR-WPANs); IEEE Standard: New York, NY, USA, 2011.

[8] Park, P., Marco, P. D., Soldati, P., Fischione, C., Johansson, K. H., "A Generalized Markov Chain Model for Effective Analysis of Slotted IEEE802.15.4", *In Proceedings of the IEEE 6th International Conference on Mobile Adhoc and Sensor Systems, Macau, China,* 12–15 October; pp. 130–139, 2009.

[9] Khan, A. A., Ghani, S., Siddiqui, S. A., "Preemptive Priority-Based Data Fragmentation Scheme for Heterogeneous Traffic in Wireless Sensor Networks", Sensors 2018, Vol. 18, No. 4473, 2018.

[10] Rajendran, V., Obraczka, K., and Garcia-Luna-Aceves, J. J., "Energy-Efficient Collision-Free Medium Access Control for Wireless Sensor Networks", Proc. First ACM Int’l Conf. Embedded Networked Sensor Systems (SenSys ’03), Mar. 2003.

[11] Mengjie, Y., Mokhtar, H., and Merabti, M., "Fault management in wireless sensor networks", *IEEE Wireless Communications*, Vol. 14, pp. 13–19, 2007.

[12] Alagoz, I. B. F., "Energy Efficient Delay Sensitive Fault Tolerant Wireless Sensor Network for Military Monitoring", *International Journal of Distributed Sensor Networks*, Vol. 5 pp. 729–747, 2009.

[13] Dhawan, A., Parks, M., "Fault-tolerant Coverage in Dense Wireless Sensor Networks", *2nd International Conference on Sensor Networks (SENSORNETS),* Barcelona, Spain, Febraury, 2013.

[14] Rhee, I., Warrier, A., Aia, M., Min, J., and Sichitiu, M. L., "Z-MAC: Hybrid MAC for Wireless Sensor Networks", IEEE/ACM Transactions on Networking, Vol. 16, No. 3, June 2008.

[15] Jovanovic, M. D., Goran, L. J., jordjevic, D., "Reduced-Frame TDMA Protocols for Wireless Sensor Networks", *International Journal of Communication Systems,* Vol. 27, No, 10, pp 1857–1873, 2014.

[16] Ramya, R., Saravanakumar, S., and Ravi, S., "MAC Protocols for Wireless Sensor Networks", *Indian Journal of Science and Technology,* Vol. 8 No. 34, DOI: 10.17485/ijst/2015/v8i34/72318, December, 2015.

[17] Hoseini, R., Mirvaziri, H., "A New Clustering-Based Approach for Target Tracking to Optimize Energy Consumption in Wireless Sensor Networks", *Wireless Personal Communications*, Vol. 111, pp. 729–751, 2020.

[18] Poonguzhali, P. K., Ananthamoorthy, N. P., "Design of Mutated Harmony Search Algorithm for Data Dissemination in Wireless Sensor Network Wireless Personal Communications 111", pp.729–751, 2020.

[19] Geem, Z. W., Yoon, Y., "Harmony search optimization of renewable energy charging with energy storage system International Journal of Electrical Power & Energy Systems, Vol. 86, pp. 120-126, 2017.

[20] Nazari-Heris, M., Mohammadi-Ivatloo, B., Asadi, S., and Woo Geem, S., "A comprehensive review on the applications of HS method to energy systems", *Journal of Experimental & Theoretical Artificial Intelligence*, Vol. 31, No. 5, pp. 723-749, 2019.