Efficient Energy Resource Selection in Home Area Sensor Networks using Non Swarm Intelligence Based Discrete Venus Flytrap Search Optimization Algorithm

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Research Article

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Posted Date: March 24th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-230204/v1

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Abstract

This research work examines the foraging behavior of the Carnivorous plant called Venus flytrap. These plants derive their nutrients from trapping and consuming insects and another arthropod. Unlike swarm behavior, they forage independently and autonomously. Based on this, a new non-swarm intelligence algorithm called Discrete Venus Fly-Trap Search Algorithm (DVFS) is proposed for energy resource selection for sensor nodes in the Home Area Sensor Network (HASN). Discrete Venus Fly-Trap Search Algorithm is a population-based, non-swarm intelligence search algorithm that copycats the foraging behaviors of Venus Fly-Trap Plant.

The search performance of DVFS algorithm is studied by simulating in Wireless Sensor Network Toolbox in Matlab2016. The results expose that the proposed algorithm can identify optimal energy resource selection from the energy source station to provide the power supply to the nodes in HASN for the network lifespan increment.

Keywords: Home Area Sensor Network, Discrete Venus Fly-Trap Search Algorithm, Energy Resource Selection, Non-Swarm Intelligence, Carnivorous Plant, Venus Fly-Trap

1. Introduction

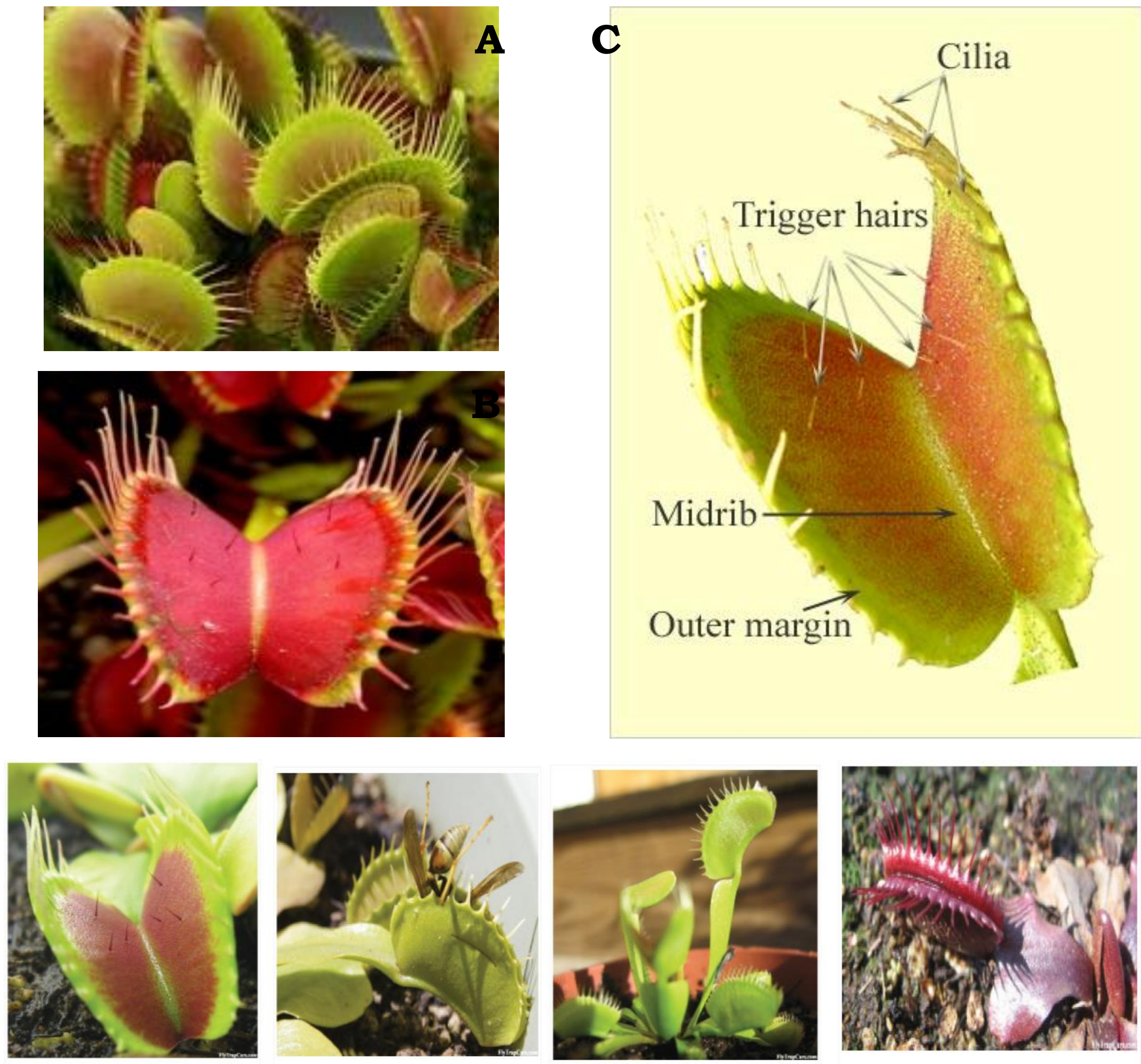
For the past two decades, many meta-heuristic optimization algorithms are proposed to solve problems in different fields. Nowadays, these algorithms are quite popular methods because of their good computation power and easy conversion to the real problem. Meta-heuristic methods are very general which can be adapted easily to any type of problems with a single objective or multi-objective.

A recent study indicates that plants also exhibit intelligent behaviors, which can be modeled mathematically for the system model and objective function. For example, foraging behavior of Venus flytrap, a carnivorous plant can be modeled as an optimal search algorithm for identifying the optimal solution under specified constraints.

Swarm Intelligence based Search algorithms inspired by social insects, fish, bird flocking, honey bees, etc., mimic direct or indirect communication among individuals, especially information regarding promising search space for their foraging. But, many species search for food independently and autonomously rather than cooperatively. Such species also have food search stratagems to maintain the species, which is known as Non-Swarm Intelligence.

Discrete Venus Fly-Trap Search Algorithm (DVFS) is modeled based on the foraging behavior of Venus Fly-Trap plant. The botanical name of Venus flytrap is Dionaea Muscipula is shown in following figure 1. The great scientist Darwin quoted this plant as “one of the most wonderful in the world”. This algorithm is devised on the rapid closure action of its traps (also called as leaves). This trap closure is due to the stimulation of the trigger hairs that present in the two lobes of the leaf by the movements of prey (small insects, small animals, raindrop, fast blowing wind, etc.). This traps in this plant search for their food independently and autonomously without any information exchange among them [15].

Energy Resource Selection (ERS) is techniques that can find an optimal energy source selection for a home appliance through wireless power transfer to calculate the overall network energy consumption. In this paper, Discrete Venus Fly-Trap Search Algorithm (DVFS) is the new optimal search algorithm devised the first time for selecting energy sources [8]. The remaining part of the paper is organized as follows. Section 2 presents the state-of the-art of energy efficient sensor network models using optimization algorithms. Section 3 describes the methods and materials needed for the proposed work. The detail description of the proposed work is in section 4. The summary and possible future enhancement is in Section 5.



(1)Initial phase (2) Prey Capture (3) Start tighten (4) Sealing phase

Figure 1. Different Stages of Venus Fly-Trap

2. Review Literature

Table 1 describes the detailed assessment of the state-of-the-art in energy-efficient model techniques for sensor network and the issues in the existing research work related to node energy saving.

Table 1. Smart Home Area Sensor Network Model Analysis

AUTHOR NAME	TITLE MODEL	OUTCOME	REMARK
Ayesha Hafeez, Nourhan H. Kandil, Ban Al-Omar, T. Landolsi, and A. R. Al-Ali, 2014 [3]	This paper presented the Architecture of Smart Home and Networks with grid context	Homes are equipped with devices such as smart meter, in-home displays, storage, & smart appliances. In the uplink & downlink process is utilized by on-demand response, advanced metering setup, spread energy source generation & storage	PLC has been utilized in smart home appliances some device controls to pre-adjustable
Aravind Kailas, Valentina Cecchi, Arindam Mukherjee, 2013 [2]	It mentioned the Smart Energy Management and Architecture to home area networks	Used the SG to initiative hundreds of companies to energy managed system. This effort is design new standards, protocols, optimization methods that efficiently utilize supply resources to minimize cost	To maintain the smart grid is not easy and only educates consumers available for using the devices.
Abdulfattah Noorwali, Raveendra Rao, and Abdallah Shami, 2016 [1]	In the paper tell theoretical derivation on bounds of the delay analysis in 802.11 protocols with HAN	Devices communicate the TDMA, FDMA, CDMA and the multi-access done by upper & lower bounds on the delay which is SNR, interference range, number of devices and channel.	To analyze the complexity associated with line up delay of traffic in the HAN of smart grids not considered
Vukasin Nuhijevic, Sasa Vukosavljev, Boris Radin, Nikola Teslic, Mirko Vucelja, 2011 [18]	This paper describe the Intelligent system belong to power saving via control triggering by sensor and events	An intelligent HAN control the appliances, energy controller triggered by sensors and events so only energy to be saved.	Energy controller control with many interfaces, device manager, event controller that only occur interference.
SL Clements MD Hadley TE Carroll, 2011 [17]	The paper told wired (802.3, PLC)& wireless (802.11n, Zig-bee) Smart Grids	This HAN process, control the Utility Managed Smart Devices and Consumer Managed Smart Devices	HAN Operates the crowded ISM bands & Still at risk to forged management frame attacks
Kamrul Islam, Weiming Shen,	This paper displays the home management	The sensor networks solves the Eavesdropping, DoS, Node	Not clear demand deployment

Xianbin Wang, 2012 [11]	process, flow of work, interference, place & movement of appliances	Compromise, Sinkhole & Wormhole Attacks, Physical Attack and Detection & Prevention problem	environment in applications and Sensor effectively minimally solve the security and privacy
Ms.Jayshri V.Ekshinge Santosh S. Sonavane, 2014 [13]	Paper shows the smart control to make HAN more intelligent and energy efficiency with power saves	Zigbee monitor, collects information to pass & process over microcontroller, it controls the appliance on demands	This system not mentioned environment of a sensor and dynamic controls of the HAN
Ming Xu, Longhua Ma, Feng Xia, Tengkai Yuan, Jixin Qian, Meng Shao, 2010 [12]	Paper focused on wireless sensor & Zig-bee with coordinator based GPRS connections	Zigbee technology with GPRS using multi-hop communication-based Dijkstra algorithm presented	Used coordinator based HAN and topology not defined.
Ekhlas K. Hamza Heba H. Alhayani, 2018 [5]	Its analyzing energy reduce & balance of the Sensor & increase Network lifetime	Work to focus on hop counting for single-hop in LEACH and Multi-hop in MODLEACH	One to another hop link may be drop
Debraj Basu, Giovanni Moretti, Gourab Sen Gupta, Stephen Marsland, 2013 [4]	This Paper used for iMonnit application to select Sensors, Deploy and Monitor the whole Home	Hub communicates to the iMonnit server via the internet with the help of ISP. Sensors provide meticulous, tedious, significant data to apply machine learning	Lacking the timestamps of activities
Hemant Ghayvat, SubhasMukhopadhyay, Xiang Gui, Nagender Suryadevara, 2015 [10]	This paper shows based on analysis of ISM band interference, attenuation issues	System made by heterogeneous sensors with zigbee based Digi Xbee serious 2 for HAN to avoid interference, attenuation	Heterogeneous sensor data acquisition not specify network environment, topology

Limitation

Currently, the varieties of sensor network application use tiny sensor motes, which is limited battery capacity. This is one of the most important energy constraints for the increase of network lifespan. Energy Harvesting is an alternative way for giving external energy resources like solar, wind energy, vibrational, private sector…etc. The drawback of this energy harvesting solution is high uncertainty, which shows frequent irregular behavior (time varies the amount of solar radiation, weather condition.). So, recent technology develops the wireless energy transfer in perspective of more consistent and deterministic energy resource in wireless sensor network which can also be adopted for HASN. Recent trends focus charging the wireless sensor motes as per benchmark scheduling in network time.

This research work proposes a novel on-demand wireless charging scheme for HASN using DVFS algorithm, which finds the optimal power using on-demand energy-efficient strategy. Following challenges are, discover and give the solution.

- To avoid node failure by maintaining the service queue buffer to store the charging the request received
- To find optimal ESS using on-demand wireless charging scheme using DVFS algorithm for HASN
- Scalability of node charging request is possible by using service queue buffer

Moreover, 70-80% of sensor energy utilized for network communication processes in the HASN. When the sensor runs out for their residual energy, external energy source plays a vital role to supply energy to the sensor node. Hence, this work proposes the optimal energy source selection for HASN.

3. Methods and Materials

3.1 HASN Architecture

A home area sensor network (HASN) is a network of numerous smart home devices. These smart home devices are monitored and controlled by in-house control called Utility Gateway (UG) for network communication. Mainly, it is used to gather sensor information from a variety of home devices/appliances and deliver control information to these devices for efficient consumption of energy through Utility Gateway. The HASN has the option to turn home devices off and on conveniently for energy efficiency (e.g. automatic air conditioners on/off). Typically, HASN covers areas up to 1000 square feet and to support from 1 to 1000 kbps.

HASN [16] is composed of a smart meter, many smart devices, other connected devices & alternate private energy sources that are involved for communications. Figure 2 depicts the HASN architecture taken for the study.

Smart Meter (SM) is the main controller with a wireless transceiver. It can synthesize and analyze the information received from all Intelligent Motes (IMs); send back data to distributed IMs, information it sends a response to the user terminal and the control signal to the utility gateway. Each node or home appliance is connected with an IM. The IM collects information from its appliance and forwards it to the smart meter.

Intelligent Mote (IM) integrated into the utility gateway, wireless transmitters and attached with a variety of home sensors/devices. They are used to collect environment information, transmit sensing and control data.

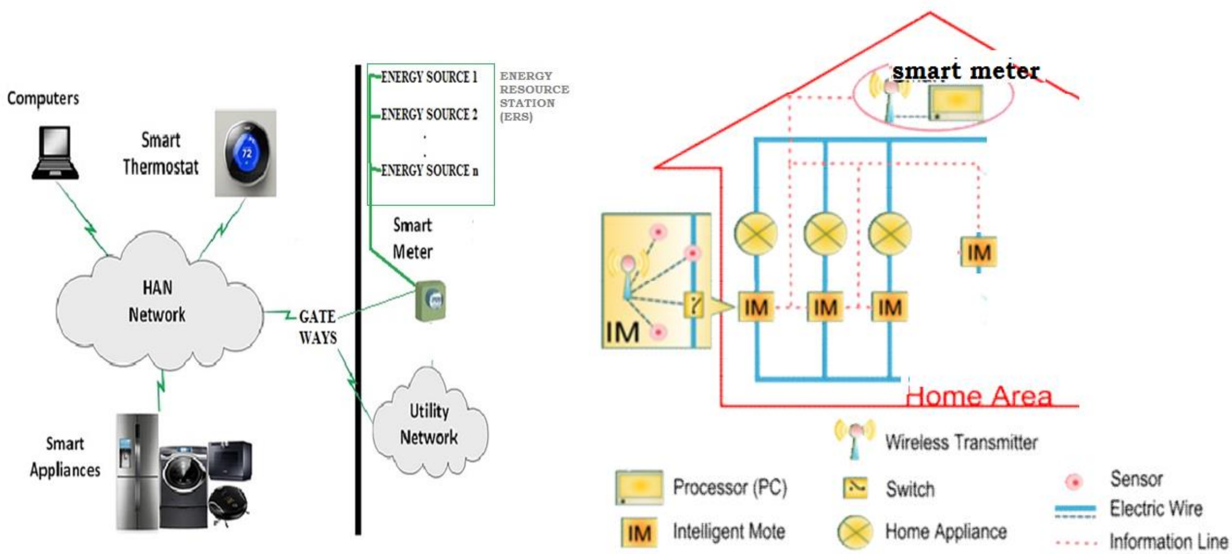


Figure 2. Design of HASN Architecture

Each IM can make an automatic response in consideration of the energy characteristics of its connected home device. That is it sends the communication Energy request (Ereq) to the smart meter via utility gateway for active node participation in HASN.

3.2 Network Model

Suppose there area N nodes with intelligent mote, m gateway and smart meter are connected to the k energy source. Eo is the initial energy of nodes which is randomly distributed in the area on A. Nodes in HASN satisfy the following conditions:

a. The initial energy of all nodes is the same for the network area A.

b. Nodes are equipped with un-replace-able or un-rechargeable batteries.
c. Each node works independently & autonomously.

3.3 Energy Resource Selection (ERS) in Energy Source Station (ESS)

Given Utility network G= (N,E) with communication data X= { $X_1, X_2, \ldots, X_n$), reserved energy level Residual energy
(t) = {$e_1(t), e_2(t), \ldots, e_n(t)$} at time 't' and given threshold (N_e).

ERS aims to

a. Select the energy source with maximum energy balance for communication
b. Find energy source on-demand by Intelligent Mote which intimate through smart meter maximize the node lifespan

3.4 Objective Function

The goal is to maximize the fitness function in order to achieve the maximum lifetime of the nodes in the HASN by extending the battery power of the node via external energy source in ESS.

Energy Expend Cost (ES_i) = $\sum \{(T_{tx} * E_{tx}, T_{rec} * E_{rec}, T_{idle} * E_{idle})\}$ (1)

Where,

Energy Balance Cost (EBC (ES_i)) = Renergy (ES_i) - Energy Expend Cost (ES_i) (2)

$$\text{Fitness Function } F = \text{Max} \quad \text{EBC} \begin{cases} (\text{ES}), & \text{if } (\text{EBC (ES)}) > N_e \\ 0, & \text{otherwise} \end{cases} \qquad (3)$$

Where,

ESi - i^{th} Energy Source

T_{tx} – Time is taken for Tx

T_{rec} -Time is taken for Rec

T_{idle} – Time is taken for idle

E_{tx} – Energy consumption for Tx

E_{rec} - Energy consumption for Rec

E_{idle} – Energy consumption for idle

N_e - Node on-demand energy

4. Discrete Venus Fly-Trap Search (DVFS) Algorithm

In DVFS, the rapid closure behavior of the Venus Flytrap leaves (trap) to capture the prey is mimicked. The number of traps is decided based on the problem objective. Each trap represents one energy resource. It is represented as binary strings of length n, where n is the number of resource nodes in HASN.

The presence of each node in a particular trap (Energy Resource) is depicted using this binary string. The trap parameters like trigger time (t), action potential (u_t), the charge accumulated (C), flytrap status ($\delta(f(t))$), object status ($s(C)$) are initialized at the beginning of the algorithm. The trapping process is performed until the optimal solution is attained.

Initially, the trap is kept open, seeking prey. The Energy resource nodes are randomly chosen initially. When the prey has arrived, the trigger hair is stimulated first at t=0, the second stimulation is performed at t<T (T= 30s) then the flytrap parameter values are updated.

The fitness of the flytrap is defined as the energy balance cost of energy resource calculated using equation 4.

Energy Balance Cost (EBC(ES_i))= Renergy(ES_i) - Energy Expend Cost (ES_i) (4)

where **ES_i** - i^{th} energy source **Renergy**(,) – Initial energy of the **ES_i**

Energy Expend Cost (**EBC**)- Total Energy expenditure incur in ES_i

The objective function is to maximize the node lifetime by selecting the energy resource with maximum energy balance. At each iteration of the EBC is evaluated; the maximum energy balance source is selected. So the fitness of the energy resource node (prey) is necessary to decide the object (prey) capture. The flytrap will be sealed. If the trap is closed as well as the object is trapped otherwise the flytrap will be reopened for the next capture. The sealed trap will not be undergone to next iteration until better flytrap than the sealed trap has arrived. The process of capturing the prey will be performed until the maximum snaps of the flytraps. After max_snap iterations, the best flytrap is returned which is the required optimal energy source for communication.

Algorithm:

//Initial phase

Fitness function f (ESS), ES = (es_1, ..., es_d) S

//Energy sources

Initial stage population of

flytraps es_i (i = 1, 2, ..., n)

//flytraps- sources

While iter< = S

For i=1 : n all n flytraps //trapping phase

At t=0, //first stimulation

Evaluate Action Potential u_t of flytrap i

Accumulate Charge C of flytrap i is determined by $f_{(es_i)}$

At t=rand() //second stimulation

if t<=T then

Action potential (u_t) updation, C of flytrap i

evaluate the Status of Object

end if

end for

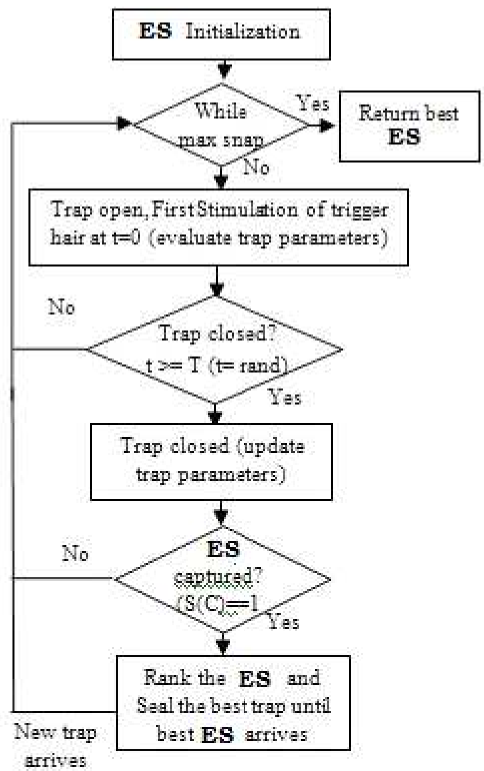
Put rank on flytraps and catch the current best

//sealing phase

seal the best flytrap until another best flytrap arrives

end while

Post process results and visualization



Flow of the Energy resource Selection in DVFS Algorithm

Parameter Setup

In this plant, the action potential [14] essential for the closure of the leaf. The potential generated is dissipated at a specific rate and reaches to zero. It's jumped to 0.15 V at 0.001 s and simultaneously dissipated to zero after 0.003s. The action potential u_t required for how much the energy takes and it is defined by the exponential function is given in equation 6 (C).

$$u_t = \begin{cases} 0.15e^{-2000\,t}, & t \geq 0 \\ 0, & t < 0 \end{cases} \tag{5}$$

Where, t - the trigger time at which the trigger hairs are stimulated,

t<0 – represent before the first stimulation,
t=0 – intimate for the first stimulation,
t>0 – means the second stimulation.

The two successive stimulations times may be less than 30 seconds in demand to start the flytraps are going to the closure stage. There is no action potential available for before first stimulation of the flytrap. The charge accumulation [14] can process to the stepwise growth of a bio-active substance, subsequent channel activation by the action potential. The charge accumulation will be described by a linear dynamic system is given in the equation 7(δ(ft)).

$$\mathrm{C} = -\mathrm{k_c C} + \mathrm{k_a u_t} \tag{6}$$

Where is C the charge accumulated by the lobes for trap shutter, k_c is network channel rate of dissipation of charge between the first two stimulations and C reaches to zero after 30 seconds, k_a is channel rate of charge accumulation. So, it's implicit the second stimulation will be occurred within 30 seconds to attain the maximum charge of 14μC to shut the flytrap. In these computational of the flytraps actions, the charge accumulation is calculated based on the fitness function f (ES) given in equation (2).

The next parameter is evaluating the status of the flytrap, used to know the present flytrap status of the plant. The flytrap status may be either 0 or 1 or 2 (open or close or seal.) is estimated using the equation u_t.

$$\delta(\mathrm{ft}) = \begin{cases} 2, & S(\mathrm{C}) = 1, \delta(\mathrm{ft}) = 1 \\ 1, & 0 \leq \mathrm{t} \leq \mathrm{T} \\ 0, & \text{otherwise} \end{cases} \tag{7}$$

Initially, the flytraps in the opened state (0). If the prey (object) triggering, the trap is closure then the trap will be in a closed state (1). The first stimulation of the time point zero is taken, the second stimulation time is representing t. The time threshold T takes two stimulations periods (say 30 seconds) [7]. All the closed stage of the traps won't be sealed. Only the best fitness of the flytrap will be located in the sealed stages. The reopening of the sealed flytraps takes when the fittest flytrap will be achieved.

Energy Source Station (ESS)

Energy source station is plenty of energy sources available in a station or certain area, and it's connected with Smart Meter (SM), used for charging the energy consumed nodes/sensors/end devices/home appliance devices. Many researchers have done a lot of research works to find two types of charging methods and they are

- Periodical charging scheme
- On-demand charging scheme

Due to the uncertainty of network environmental changes, the periodical charging scheme is not suitable for the complex network environment change. Generally, the on-demand charging scheme is appropriate for the complex and changeable environments, in which, and the nodes send charging requests to the SM when the residual energy is more minimum than the predefined energy threshold (N_e), and the SM will charge the sensors/nodes through Wireless Power Technology (WPT) from the sources in ESS as per charge request received [9].

SM maintains the service queue buffer to store all the energy charging requests and will serve the request according to the Adopted On-demand Charging Strategy (AOCS). This AOCS ranks the sensor/node with energy requests based on their amount of the residual energy. The priority is given to the sensor/node, which has low residual energy. At this point, to serve a request, an optimal energy source is selected for sensors/node and fills its energy supply via WPT. SM may be used to charge the power of multi nodes in the network simultaneously, based on multiple charging requests received from the charging coverage area. To avoid the battery depletion in sensors/nodes a more flexible and high efficient method called energy source selection using DVFS is proposed in this work to serve the charge request of the sensors/nodes. On the whole, it prevents node failures and increases the network lifespan.

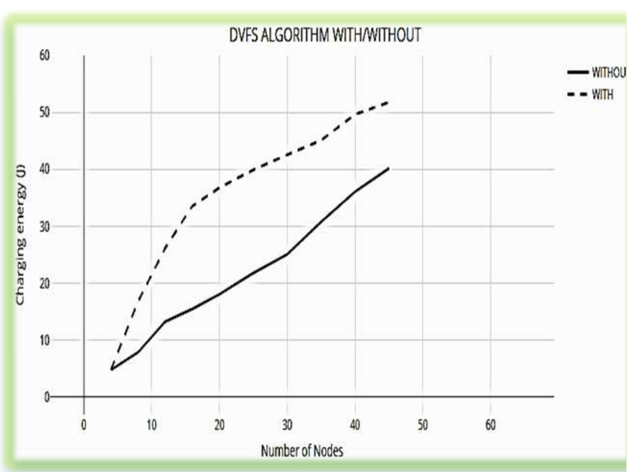
4.1 Results and Discussion

The HASN simulation done by using Network Simulator Tool (NS 2.35). It's a Tool control Language and easy to generate different type of network area environment, network size, packet size/length, can create single/multiple/grid-based nodes, various topologies, interfaces, TCP/UDP to sink, CBR & FTP connection. The available protocols are AODV, AOMDV, DSDV, DSR, TORA, and one can create own protocol is also possible in ns2 tool.

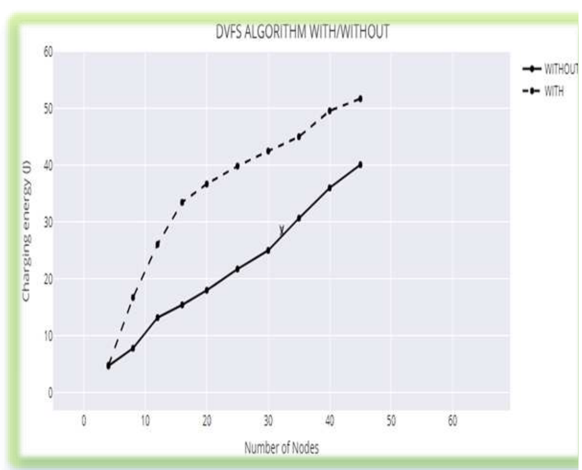
Table 2. Parameter Setting for Proposed Work

Parameter	Value
Number of Nodes	10-60
Area Size	1000*1000
Packet length	500
Connection	CBR,FTP
Simulation time	300ms
Packet size	CBR Packet size 50, Interval 1.0
Topology	Star of stars / Star of bus
Initial Energy	100.00 J
Transmission power (TX)	2.30 J
Receiving power (REC)	1.56 J
Idle power	0.54 J
Sleep power	0.59 J

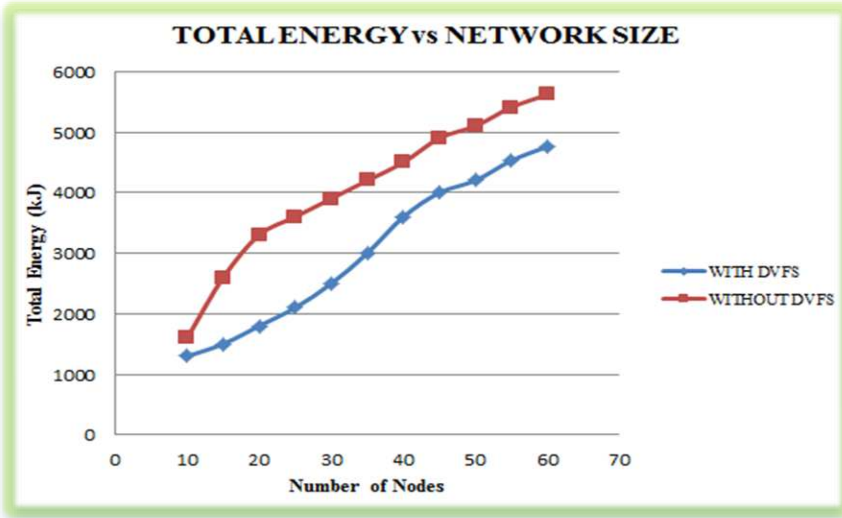
Table 2 shows the parameter setup for the home area sensor network taken for study in this work. Table 3 displays the performance of the proposed DVFS algorithm for Energy Source Selection (ESS) problem.



A. Charging Energy vs Overall node



B. Charging Energy vs Individual Node



C. Total energy vs Network size

Figure 3. Energy charging to the nodes, Total energy vs network size

Figure 3 displays the energy source station (ESS) charging the HASN nodes and variant of overall charging, individual node charging via SM decision-making approach for the energy source selection.

Table 3. Parameter Performance of HASN

QoS PARAMETERS	NUMBER OF NODES	DVFS ALGORITHM	
		WITHOUT	WITH
PACKET DELIVERY RATIO **PDR (%) =** N_R / N_S × 100 N_R = Number of packet received by a controller from sensor / end device. N_S = Number of the packet sent by the sensor / end device	10	89 %	95 %
	20	83 %	92 %
	30	78 %	90 %
	40	74 %	89 %
	50	69 %	89 %
	60	65 %	86 %
THROUGHPUT **Throughput (Kbps)** = Number of Bit Successfully Received by Destination / 1000	10	80 %	85 %
	20	77 %	81 %
	30	72 %	78 %
	40	68 %	74 %
	50	63 %	74 %
	60	61 %	70 %
	10	19 %	27 %

ENERGY CONSUMPTION **Energy Expend Cost** $=\sum \{(T_{tx} * E_{tx}, T_{rec} * E_{rec}, T_{idle} * E_{idle})\}$	20	22 %	31 %
	30	28 %	35 %
	40	30 %	39 %
	50	36 %	42 %
	60	39 %	45 %
PACKET LOSS RATIO **Packet Loss Ratio (Packet)** = Number of packet sent – Number of packet received / sent * 100	10	11 %	5 %
	20	17 %	9 %
	30	22 %	10 %
	40	26 %	11 %
	50	31 %	11 %
	60	35 %	14 %

The performance of this work is analyzed using the relevant QoS parameter such as Packet Delivery Ratio, Throughput, Energy Consumption, Packet loss ratio. The number of nodes in the HASN is varied from 10 to 60 in the increment of 10.

PDR percentage is higher for ESS with DVFS than the normal problem. This is because of when a sensor/node with low residual energy is charged with an external energy source through WPT. Therefore, the availability of a sensor/node is increased for communication in which turn increase the PDR and Throughput. Packet Loss Ratio of the proposed work is lesser which means that almost all the nodes in the HASN are the inactive state for the network communication.

The energy consumption of the proposed work is a little bit higher which is evident from table 3. This is due to less number of nodes are in the inactive state. The nodes in the in-active state do not participate in the communication. Due to this, the standard algorithm has less energy consumption than ESS with DVFS algorithm.

Figure 4 shows the packet delivery ratio of home area sensor networks with/without applying the Discrete Venus Fly-Trap Search Algorithm in the given NS-2 simulation environment. Figure 5 presents the Throughput of the different home appliances (nodes) in home area sensor networks.

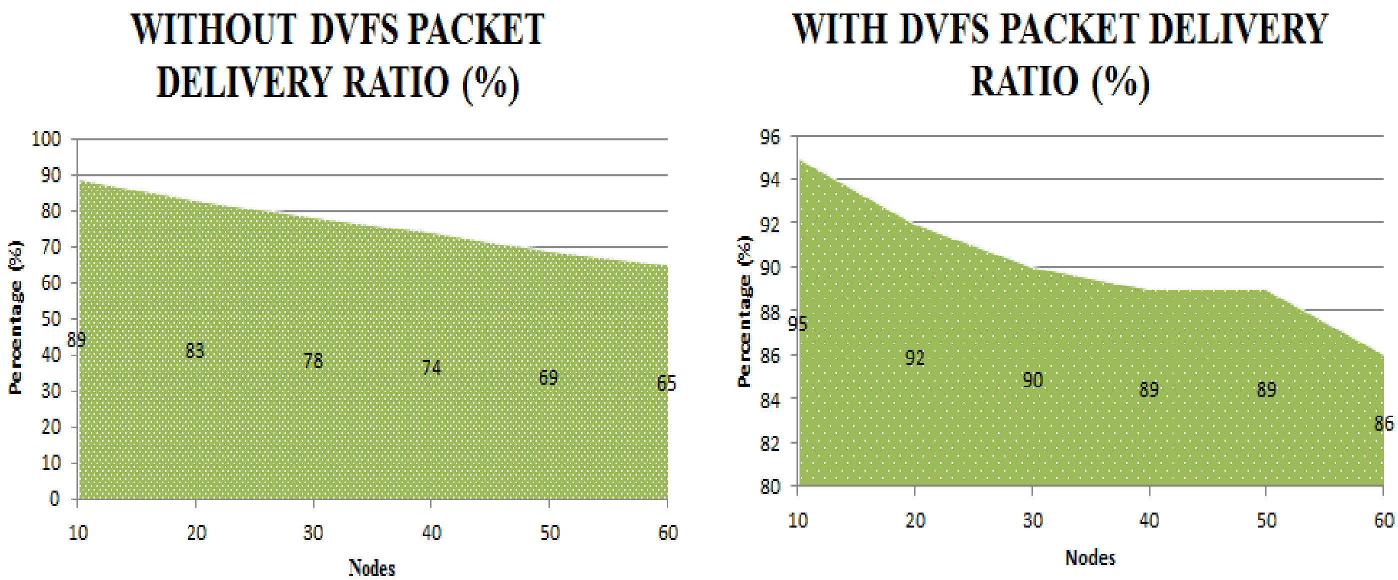


Figure 4. Packet Delivery Ratio of HASN

Table 4. Throughput in HASN

THROUGHPUT (KBPS)	
WITHOUT DVFS	WITH DVFS
443	498
429	465
414	441
402	429
382	404
369	396

Table 5. Energy Consumption in HASN

Energy Consumption (J)	
With DVFS	Without DVFS
20	14
24	19
29	22
32	27
38	31
42	34

Table 6. Packet loss ratio in HASN

Packet Loss Ratio (packets)	
WITHOUT DVFS	WITH DVFS
15.33	10.29
19.89	14.1
20.31	14.02
18.99	12.23
15.61	9.54
16.32	11.03

Tables 4, 5 and 6 show the performance of the proposed work in terms of Throughput (in Kbps), Energy Consumption (in Joules) and Packet Loss Ratio (in Packets/μ sec). From the above tables, it has been observed that the proposed DVFS algorithm has the capability to identify the optimal energy source for the single/multi sensor(s)/node(s) in the HASN efficiently in order to increase network lifespan.

Figure 6, 7 graphical representations of table 4, 5, 6 in different home appliances using energy-consumption & Packet loss ratio of home area sensor networks with/ without applies the Discrete Venus Fly-Trap Search Algorithm.

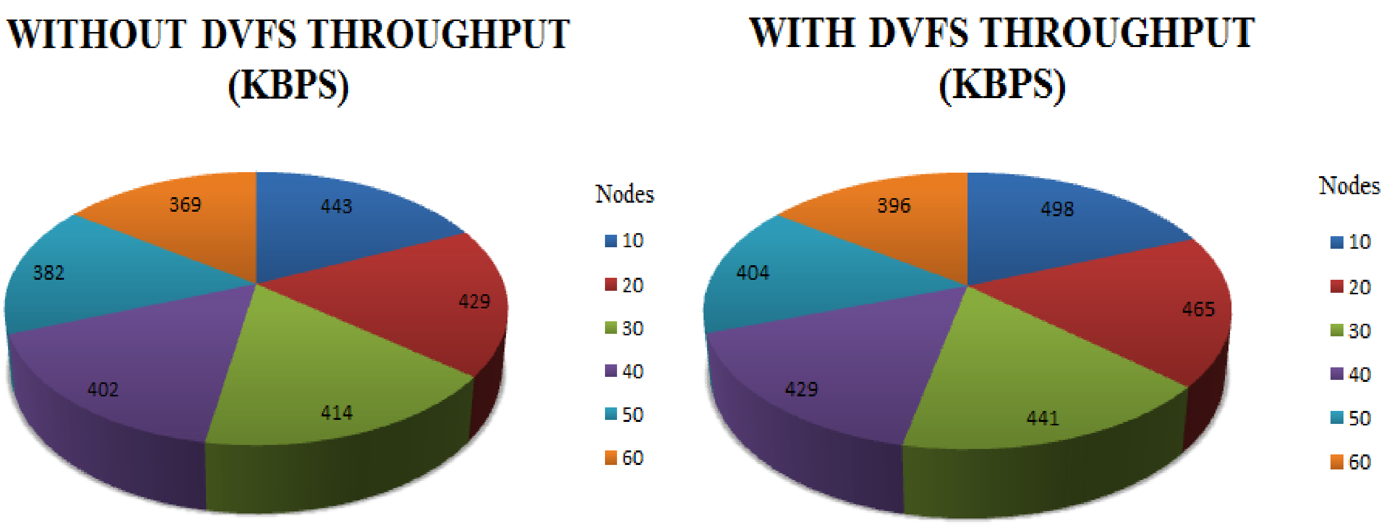


Figure 5. Throughput of HASN

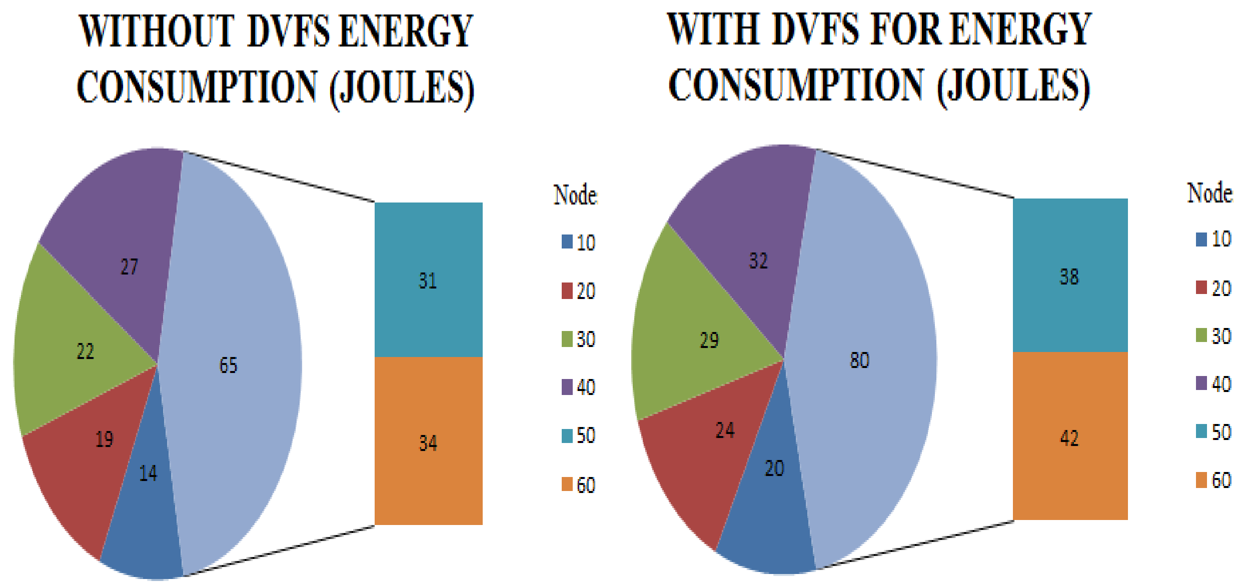


Figure 6. Energy Consumption of HASN

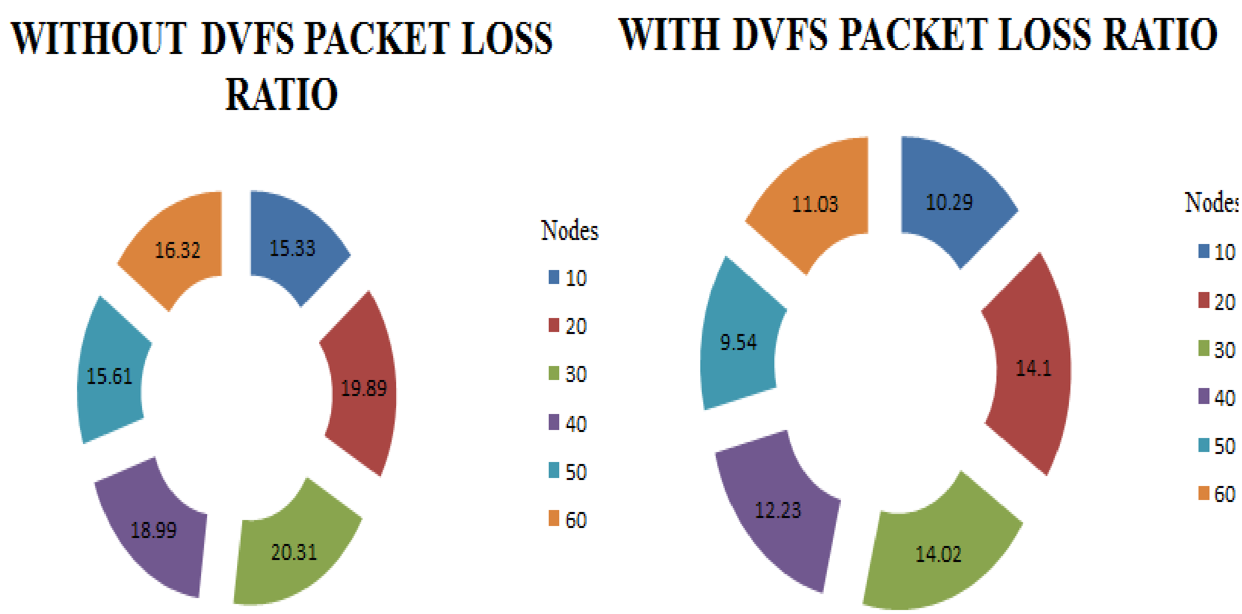


Figure 7. Packet Loss Ratio of HASN

5. Conclusion

There are many successful searches, optimization algorithms and techniques in the literature for energy-efficient sensor network model. But still, design, development, and implementation of new techniques are a key for improvement in the scientific. Even the benchmark algorithm cannot give the best results for all of the problems. Moreover, all existing search or optimization algorithm cannot give the best result for all real-world problems of a different nature. That is reasons new DVFS algorithms have been proposed for energy source selection for HASN. The results showed that the optimal selection of the energy source has been done to provide the power supply to the nodes in HASN for the increased network lifespan.

Acknowledgement

The first author gratefully acknowledges financial support from **UGC-RGNF** (Rajiv Gandhi National Fellowship) and its award letter-number UGC No: F1-17.1/2014-15/RGNF-2014-15-SC-TAM-85083 (SA-III/Website) Dated: 26 Feb 2015.

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Figures

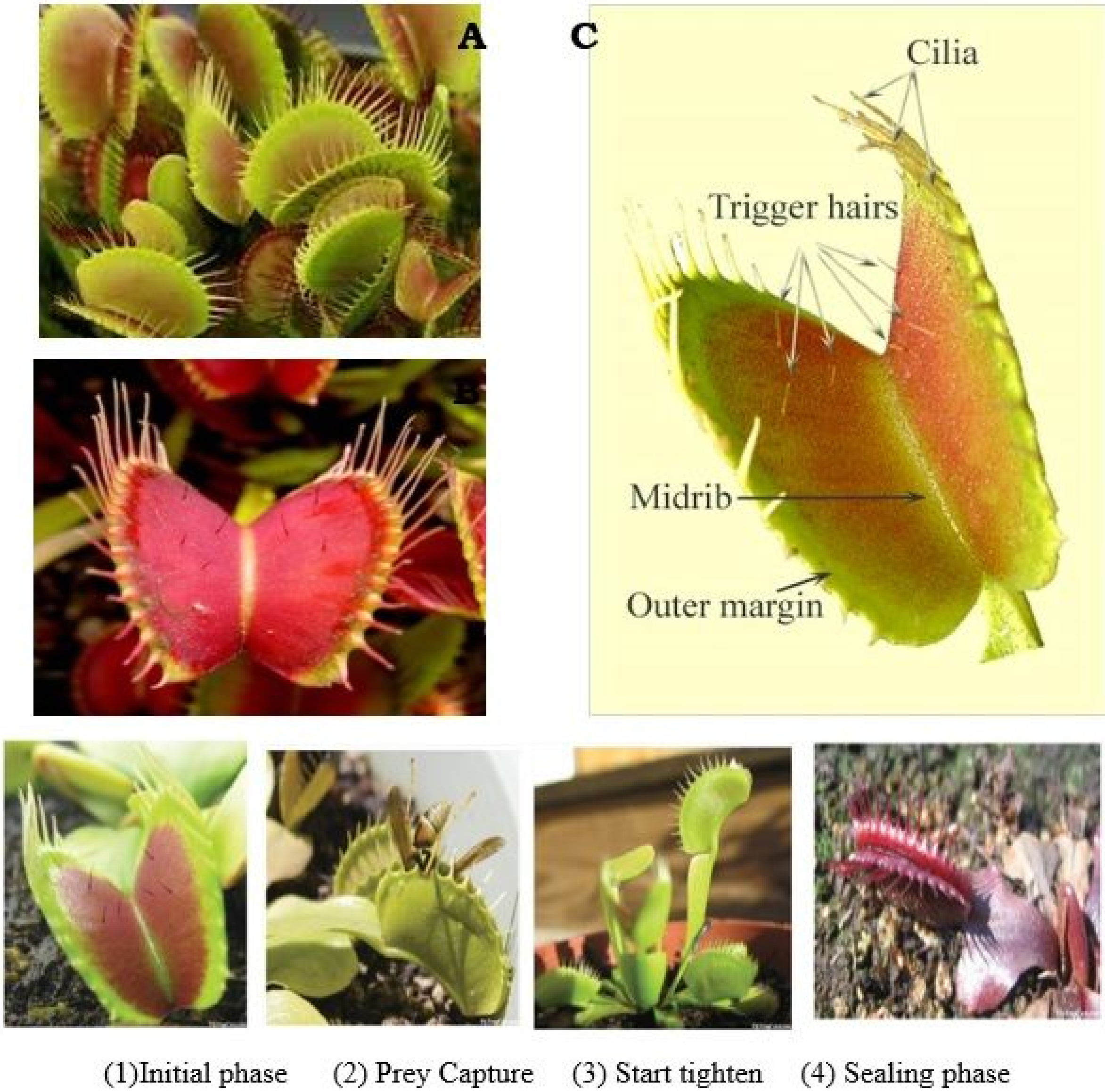


Figure 1

Different Stages of Venus Fly-Trap

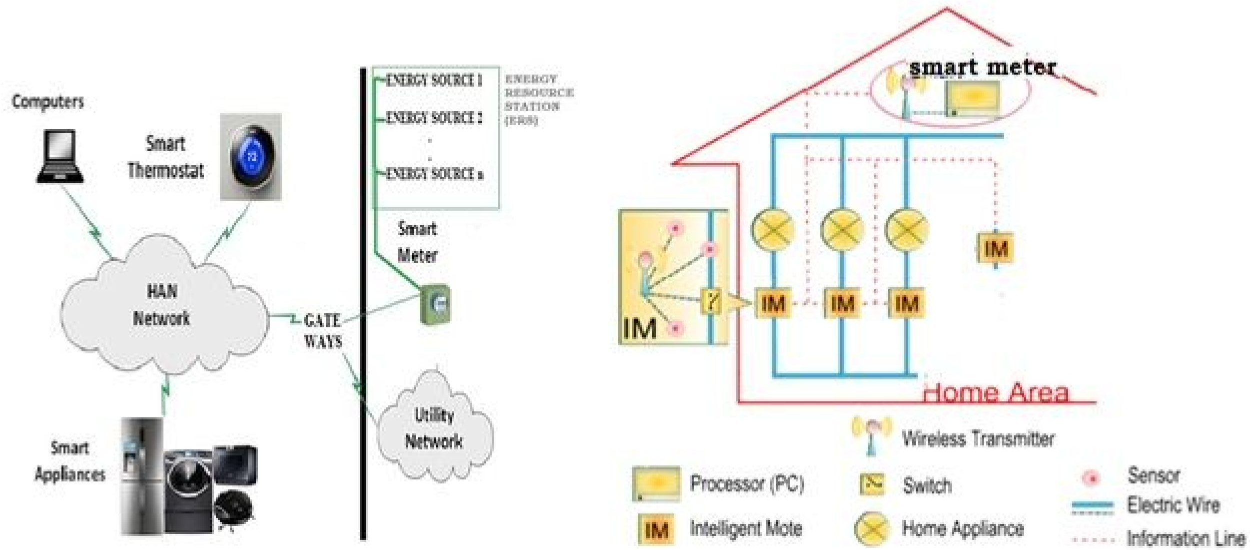
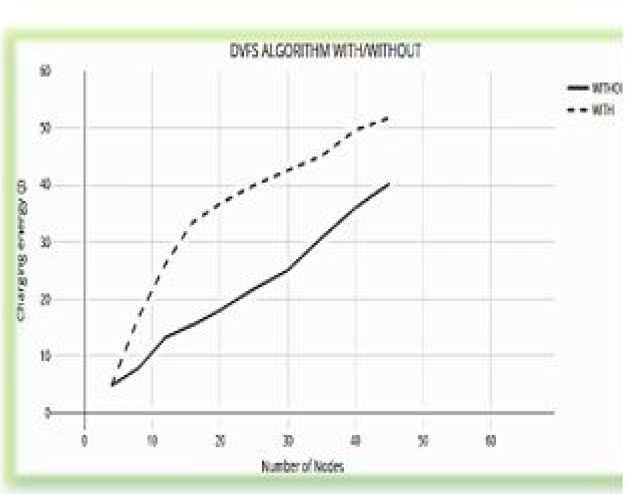
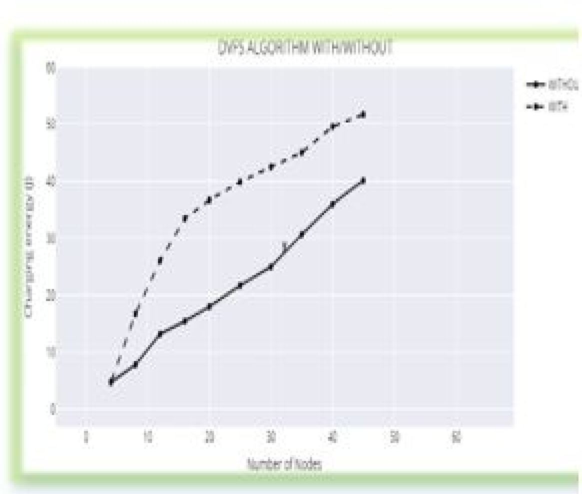


Figure 2

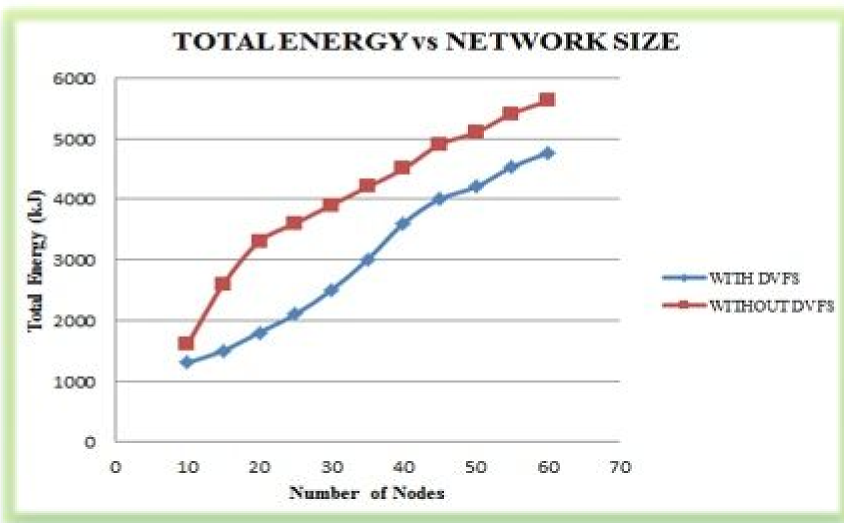
Design of HASN Architecture



A. Charging Energy vs Overall node



B. Charging Energy vs Individual Node



C. Total energy vs Network size

Figure 3

Energy charging to the nodes, Total energy vs network size

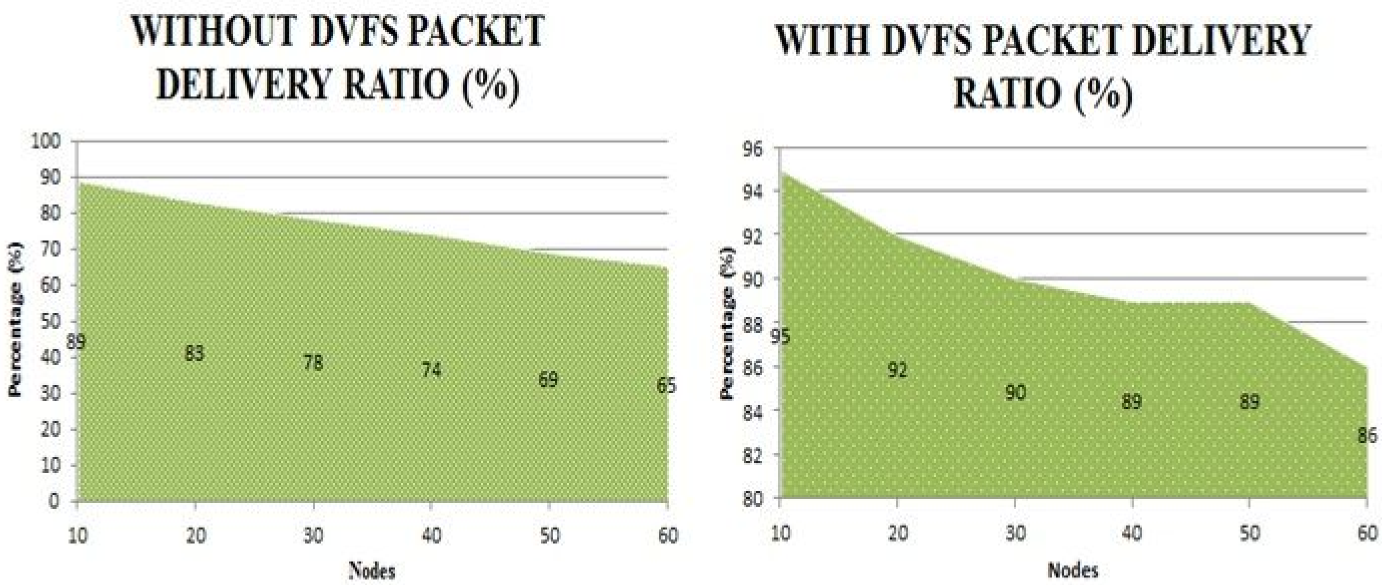


Figure 4

Packet Delivery Ratio of HASN

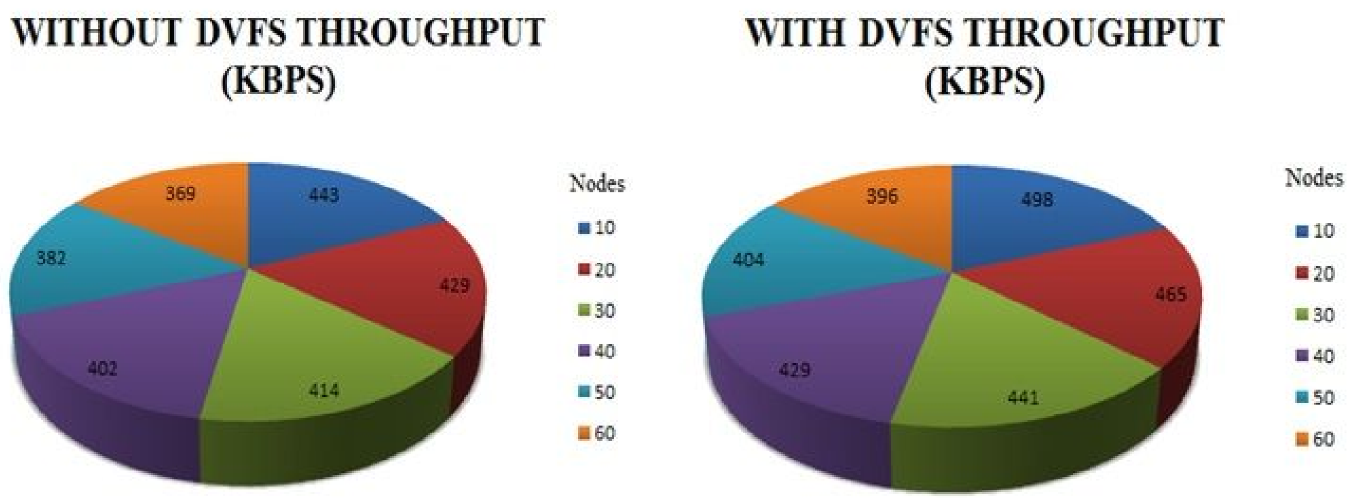


Figure 5

Throughput of HASN

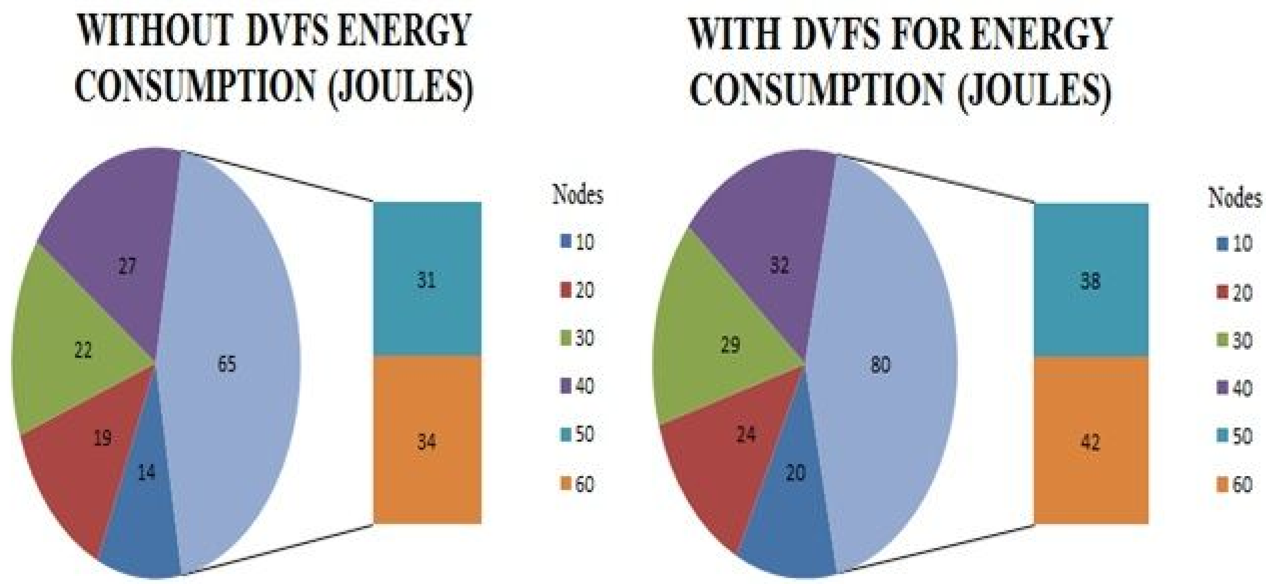


Figure 6

Energy Consumption of HASN

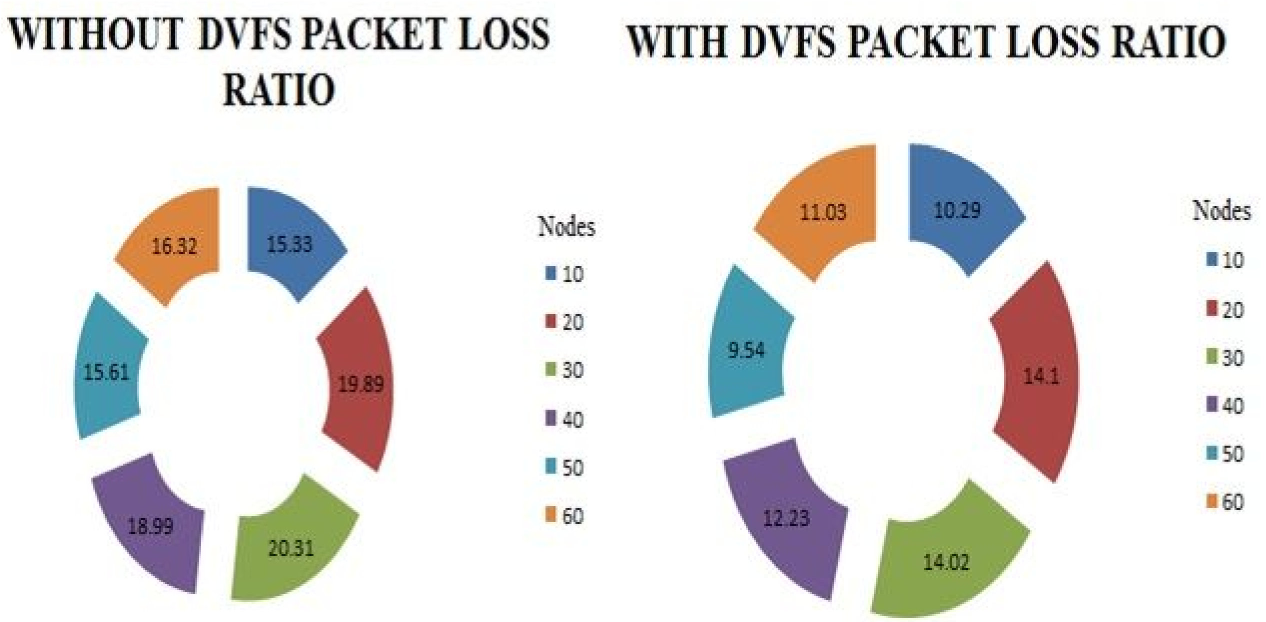


Figure 7

Packet Loss Ratio of HASN