Intelligent Software Defined Energy Management System for IoT networks

Salma El-Shaarawi
Department of Network, Faculty of computer Science
Ahram Canadian University
Cairo, Egypt
Salma.elshaarawi@acu.edu.eg

Samy Ghoniemy
Faculty of Informatics and Computer Science
The British University in Egypt
Cairo, Egypt
Samy.ghoniemy@bue.edu.eg

***Abstract*— Recently, ubiquitous computing gained huge advances after internet of things (IoT) has become an essential ecosystem. The combination of high energy consumption and difficulty in timely energy generation, substitution and redistribution present real challenges currently. This paper presents an energy management solution consisting of a combination of a networked energy harvesters, real-time energy consumption monitoring, and energy storage with an intelligent distribution system. The proposed solution is based on the use of a redundant battery that is always kept at a standby energy level and recharged directly from a harvester or a centralized energy storage. The management of consumption and recharging is based on the push-pull hysteresis theory concepts. The proposed system features timely monitor, tracking and controlling power consumption in both the sensor and harvest networks during the entire operation from switching ON, sensing, processing, and communication. The entire system is modeled and simulated using OMNET++ according to different wireless sensor networks technologies. It was confirmed via performing a variety of simulation experiments that the proposed solution remarkably enhanced overall system as well as device power consumption. Moreover, it showed advancement in synchronization, energy management and distribution process, adaptation of communication protocols, controllability, and lifetime accordingly.**

Keywords- Energy harvesting, Energy management, Internet of Things, Sensor Network.

I. INTRODUCTION

With the evolution of communication technologies, the new generation of wireless networks aims to create an integration between all technologies that go beyond the concept of the internet of things (IoT) to ubiquitous networking where all devices can adapt seamlessly to communicate without any concerns regarding the technologies utilized. Most of the devices engaged in the IoT or ubiquitous networking are low-power devices that require monitoring and control in order to optimize power consumption, thus overcoming limited power constraint. Energy harvesters contribute to solving the problem of power consumption in low power devices. Energy controllers play a crucial role in the sensor network energy to maintain balance between sensor nodes in consumption and updating the route in case of failure of any node. The synchronization process of all network devices is one of the central station devices responsibilities. This is to keep the data load balanced between the sensors and controlled by the central station based on the energy level advertised by the node. In addition to improving the performance of the network, minimizing cost as well as optimizing energy use. Therefore, several challenges have been detected regarding communication research. [1]

In ubiquitous networking, there are different technologies such as Wi-Fi that are commonly used due to the diversity of standards that allow the sensor networks to deal with different environments and requirements. Furthermore, ZigBee is another technology utilized, it is based on IEEE 802.15.4 standard model and supports Low-Rate Wireless Networks where short-range operation, low data rate, energy efficiency, and low cost are deployed.

Tracking and analyzing the performance of networks is actually a high cost, as most networks include hundreds of nodes with different technologies and protocols. Using simulation networks tool became a brilliant and suitable solution to track and analyze performance. Many simulations appeared in the past years, such as NS2, NS3, OPNET and OMNET++. There are many different simulators, nonetheless, OMNET++ comes at the top of the recommended simulation environment because it is an open source, component-based simulator, a friendly GUI and an embeddable simulation kernel.

This paper proposes a system model to optimize and enhance energy consumption in IoT networks. In order to improve power consumption over time and harvest cycle in the IoT sensor network. The remainder of the paper is organized as follows: related work is represented in Section II and in Section III introduces the proposed model. Section IV, discusses the simulation setup while Section V deals with the discussion of results, and finally Section VI concludes all the work performed to achieve the optimization.

II. RELATED WORK

Ubiquitous networks face multiple challenges at different levels to meet the required efficiency and performance, for instance; handover and seamless communication between technologies and reliability, which are major challenges to ensure that all messages from the nodes reach the controllers or the gateway correctly in the shortest time and path with the minimum power consumption. Ubiquitous networking aims to objectify all things around to make things connected and controlled.

Ubiquitous networking contains many types of smart networks such as Personal Area Network (PAN). It works by injecting or attaching tiny sensor devices into the human body and monitoring all changes as well as updates. All this illustrates the importance and extensive role of the wireless sensors in life. sensor node contains its network stack as shown in Fig.1.

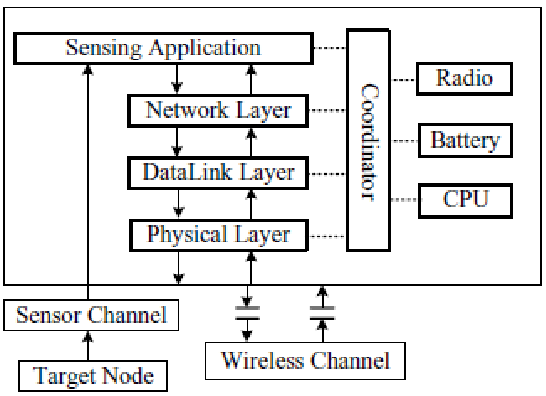

Fig.1 Sensor Node Representation in a Network.

The most commonly used nowadays are IEEE802.11 and IEEE802.15.4 since they support the low power devices required in IoT.

Wi-Fi represents the IEEE 802.11 standard designed to provide an internet connection to users at broadband speed. It may operate in a structure mode through an access point (AP) or AdHoc mode. It starts working by scanning the available channels to check the availability of adding more nodes to the network.

Zigbee comes from the IEEE 802.15.4 standard model, and is designed to support Low-Rate Wireless Networks where short-range operation, low data rate, energy efficiency, and low cost, operating at 2.4GHz ISM band and defining 16 channels. It consists of the physical layer and MAC address. Respectively, the first layer implements the main functions and specifications, whereas the second layer is responsible for the data transfer and management modes [2][3].

IPv6 is promising for IoT networks, increasing (MTU) from 576 to 1280 bytes. It covers an address space of 2128 and 3.4*1038 unique addresses. This should be enough for Internet to scale even with the rabid spread of the Internet of Things. On the contrary, it takes more time and power to perform due to the change in header and the stack. [4]. Fig.2 shows different representations of network stacks.

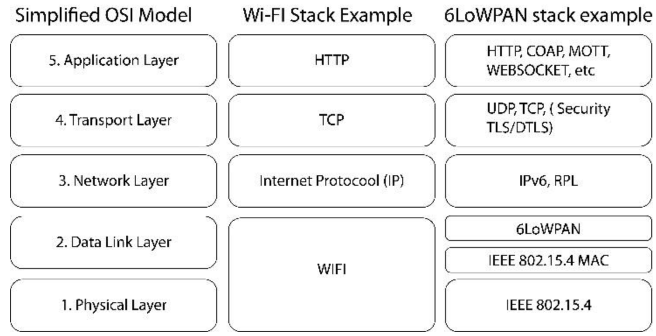

Fig.2 Network stacks.

A priority to find a solution to compromise between the advantage of the richness of ipv6 and low power devices. The result is 6LoWPAN stack, which is an intermediate layer between MAC and Network layer to support the adaption process. IETF works on 6lowPAN using IEEE802.15.4 which supports 127 Bytes as the maximum frame size. Consequently, Fragmentation and reassembling should be applied since the minimum MTU of ipv6 is 1280 Bytes. [5]

The simulation environment is an important part of the research, as is the selection of a proper simulation tool that fulfils the network environment requirements. Most simulators nowadays are discrete and event-based, therefore it is easier to extract the desire information in order to select a proper simulator, the programming language used, compatibility between nodes and protocols, as well as supporting documentations must be taken in account, especially when is open source.

OMNET++ is an open source based on C++, mainly used for educational purposes. It has a large community developing many frameworks for continuous enhancement and adding more modules to be supported like the INET framework. [6].

TABLE I - MERITS AND DEMERITS OF NETWORK SIMULATION TOOLS.

Name	Pro	Con
NS-2	- Popular. - Numerous protocols. - Expandable.	- Only 802.11 and TDMA. - No GUI. - Not large number of nodes
NS-3	- numerous libraries - expandable in C++ - wireless networks	- no computability with NS2.
OMNET++	- scalable. - expandable in C++ - Support GUI - simulate power consumption problems in WSNs	- limited protocols - incompatibility between models

After comparing 3 simulators in **TABLE I**, OMNET++ is the most suitable for the network scenarios in the proposed model.

In OMNET++, the network model is specified via Network Description Language (NED). NED files are not directly used; however, they are translated into C++ codes by the NED

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compiler, then compiled by the C++ compiler and linked into the simulation executable as shown in Fig.3

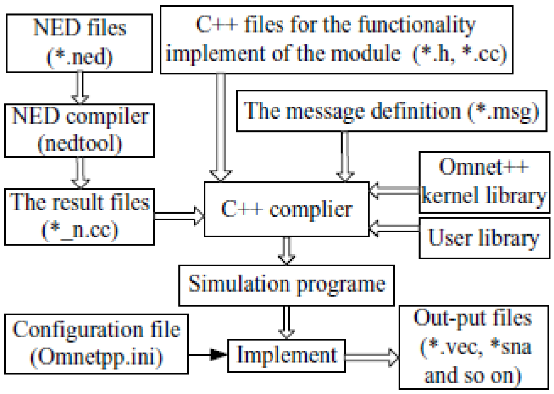

Fig.3 The simulation process in OMNeT++.

III. PROPOSED SYSTEM

The main objective of this paper is to propose an enhanced energy controller for wireless sensor network to optimize and balance power consumption. Multiple studies attempted to achieve power consumption efficiency.

The proposed solution in this network is to minimize the power consumed for transmission and control of communication modes. The sensor is kept in stand-by mode at a certain energy level in which the sensor will always be ready to send and receive messages. Therefore, the energy needed to wake the sensor to be in active state is optimized. In addition, it adds benefit since it decreases delay time and avoids data loss while the sensor is in idle or off state.

The proposed model is powered by two batteries. The main battery B1 is usually a rechargeable AA battery, whereas the second battery B2 is an alternative, and B2 depends on energy harvesting techniques based on the type of environment. In the simulation assumption solar energy harvesting plays a main role as a renewal energy source. B2 is operated when B1 reached the predetermined threshold. In order to maintain balance in power consumption and avoid high fluctuation during switching in communication process and Fig.4. demonstrates how the controller can reduce the fluctuation as mentioned. B2 will continue working until B1 is recharged and then sensor switch back to B1 again as illustrated Fig.5**Error! Reference source not found.** The power gainer controller manages the swapping policy between the main battery B1 and secondary battery B2. It monitors the energy level consumed and gets the residual energy from the power consumption module in 802.15.4 sensor node.

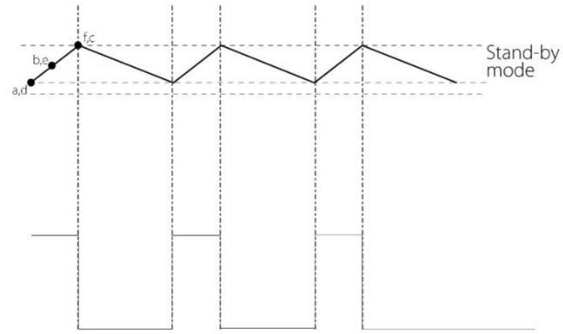

Fig.4 hysteresis control.

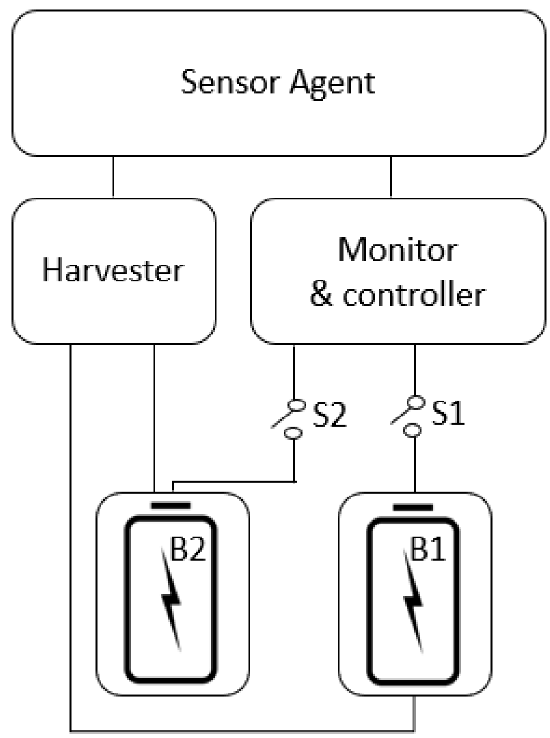

Fig.5 The Proposed system.

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The proposed solution follows the hysteresis theory, and it represents the lag between making a change, such as increasing or decreasing power, and the response or effect of that change as illustrated in Fig.6. It typically refers to turn-on and turn-off.

The main aim is to keep the loop curve smoother (less slop) over time to avoid abrupt changes in consumption. Applying the hysteresis loop to the current scenario shows the upward curve (representing the charging process) and the downward curve (representing the consumption). This loop shows the on and off changes.

As shown, point (a) is the threshold of the battery in which the controller can switch to the main battery and continue charging through the harvesting sources. Point (e) is the warning level at 50% of the battery that the controller starts to check the energy level of alternative battery if it is above 50% point (b), the controller can switch to B2. Otherwise, B2 will be allowed to rechange until it reaches the 50% and B1 continue consume up to the minimum threshold point(a), thus the controller will switch to an alternative battery once it reaches 50% and before B1 reaches the threshold level. This permits the controller to have time to check and announce to the central agent if there is no enough power that it needs to find and synchronize the power harvesting storage.

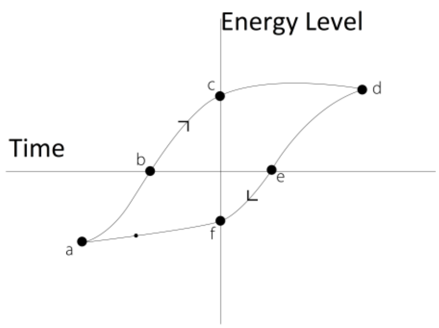

Fig.6 hysteresis loop.

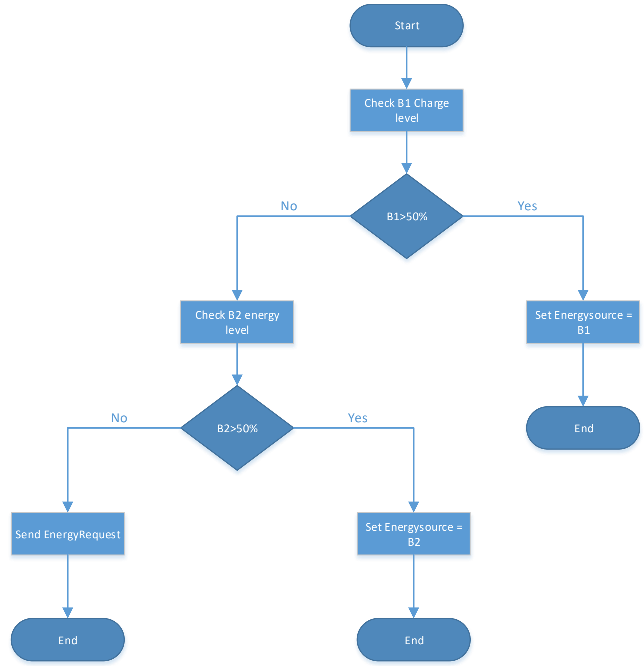

Fig. 7 Battery selection in startup

The primary role of the sensor is to gather information through monitoring and sensing the surrounding environment, then send it to the gateway or process it internally and take action based on the triggered event. In general, the power consumption of the sensor can be summarized as follows [7]:

1) Radio transmission and reception are considered the highest consumption of the power source.
2) Collisions occur when more than one node needs to be transmitted when the medium is already busy. [8]
3) Overhearing occurs when the sensor node keeps receiving data that has already been addressed to another node.
4) Control packet overhead for transmission that adds more power consumption by limiting the number of control packets while maintaining reliability which is considered a challenge to meet the quality required for many applications or Realtime apps.
5) Idle listening is the waiting status in the node. It keeps the node ready to receive or send data when there is no data to be send or receive which considered wasted power.

The energy consumption in a sensor node is determined by the average rate of the power consumption of the operational time of the node. Accordingly, the sensor operation time includes the communication process of transmitting and receiving signals, sensing, and processing. Furthermore, the sensor can be used in data routing. Each sensor can forward data received from its neighbour directly to the sink node or the closest sensor and then to the sink node. Sensor node uses the highest energy in communication followed by data processing and the least amount of energy is consumed in sensing. By examining the power consumption in the sensor node communication process through Fig.8

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$$Pc = Po + Ptx + Prx \quad (1)$$

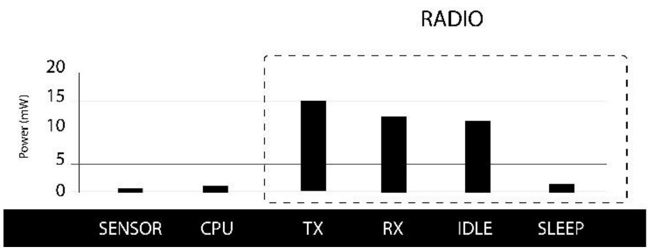

Fig.8 sensor power consumption model

Po refers to the output transmit power while P_{tx} is the transmit power and P_{rx} is the receiver power. *Po* and P_{tx} can be considered one term with the highest value of consumption. The differences between transmitting and receiving power in low-power devices are relatively close, nonetheless, the previous power consumption equation model is abstracted as it indicates the basic variables of power consumption through sensor transceiver in the communication process. Therefore, researchers study more comprehensive models attempting to find the optimum solution.

The detailed power consumption cycle model of the sensor leads to finding that switching between different modes SLEEP, TRANSMITTER and RECEIVER can save some power consumption. Nevertheless, fluctuation between active and sleep mode consumes power due to the start-up time every time the node switch between active and sleep mode, which increases the wasted energy consumption.

This is represented in equation (2) and Fig.9. Where N_T is a number of transmissions, P_{te} is the power of transmission per time, T_{on} is time spent in sending, while T_{st} time of steady state. Similarly, for receiving, N_R a number of received packets, R_{on} time while revering and R_{st} is steady state. P_0 is the power consumed at start-up and added to the transmission terms.

$$P_c = N_T[P_{te}(T_{on} + T_{st}) + P_0(T_{on})] + N_R[P_{re}(R_{on} + R_{st})] \quad (2)$$

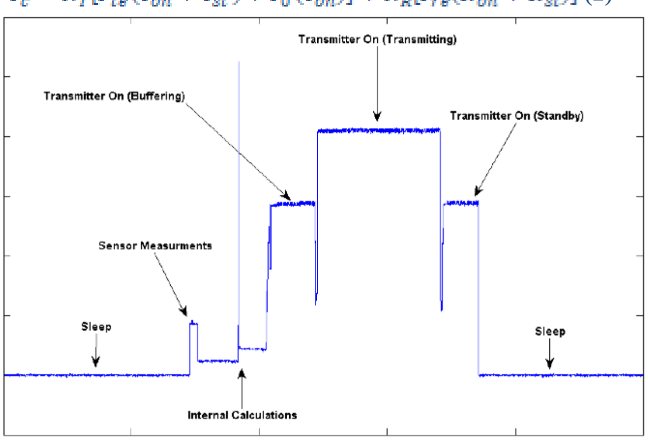

Fig.9 Transmission sensor power consumption

Many approaches and techniques are proposed to come up with a solution to reduce power consumption, as well as to extend battery lifetime of the sensor.

Fig.10 below shows the classification of all trials that contributed to achieve this reduction.

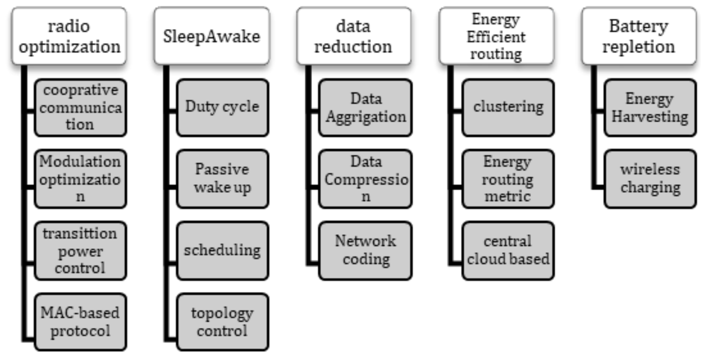

Fig.10 ISO model classification of energy saving techniques

IV. SIMULATION SETUP

This section aims to monitor and discuss measurements in terms of power consumption while simultaneously using different protocols and technologies. Moreover, this section examines proposed changes to enhance the measurements while using IEEE802.11 and IEEE802.15.4 since the different protocols come within low-power networks.

The current environment simulates different networks of 90m * 90 m. The first network is based on IEEE802.15.4 using narrowband, contains 20 sensors and 2 controllers randomly distributed over the area.

TABLE II - 802.11 NETWORK SETUP

SIMULATION SCENARIO	
Simulation Time	1800sec
X, Y Dimensions	90m * 90 m
Mobility Model	Mass Mobility
Packet size	512 kb
Initial energy	0.5 J
Number of nodes	20 SENSORS
Routing protocol	DYMO ,AODV

TABLE III - 802.15.4 NETWORK SETUP

SIMULATION SCENARIO	
Simulation time	1800 sec

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X, Y Dimensions	90m * 90 m
Mobility model	Mass Mobility
MTU	127 Bytes
Initial energy	0.5 J
Number of nodes	20 SENSORS
Routing protocol	DYMO, AODV

Wi-Fi AdHoc network is the second network to adopt the IEEE802.11 standard. It supports IPv4 and ipv6 network protocol. This setup is considered part of the wide grid network, where there is a central station or master agent that collects data from all nodes, monitor and control. Every sensor agent is attached to a harvester that is responsible for regenerating energy for sensor power and energy controller, in addition to being responsible for power source switching.

The master agent can help rerouting data in case the node fails. Each node advertises its energy level. Based on the advertised energy level, the master agent can keep balance in the network.

Initially, two scenarios are run to monitor power consumption in the network to be analysed in case of one power source. In addition, two different protocols AODV and DYMO are tested to determine which will consume less power, which is the first attempt to minimize power consumed in all the simulation.

As previously mentioned,, in this method, the sensor is equipped with a single power source represented as a battery. The network contains two controllers representing the sink node. Sensor nodes are subjected to increased energy consumption due to data transmission and mobility.

As a result of the continuous generation of data from the sensor being sent to the controller packets, queuing may occur, consequently the sensor data experiences a delay to reach the sink node. The average end-to-end delay is the total time taken for the data packet initiated by the sensor to be fully received by the sink node.

Unlike traditional networks, 6LoWPAN nodes are commonly battery-powered, and they always work in tough circumstances for a long time. Therefore, the issue of energy consumption is one of the highest priorities of 6LoWPAN. The issue of optimizing power consumption is discussed by considering 3 main aspects: power consumption, power supply and power management [9][10].

Energy consumption model is always one of interests in studying MAC protocols such as IEEE 802.15.4 devised for energy constrained wireless applications. In the proposed model, to measure the energy consumed in the radio, MAC module in OMNET++ is allowed to keep tracking all radio states in the PHY module passing through a message passing module. Consequently, the results only show all the counts of changes in the radio state as well as durations. As long as the power for each state is identified in the radio consumption module in OMNET++, the total energy consumption can be easily computed in the proposed model. Different states are used here as an attempt to cover most of the possible working state in a real radio, idle, listening and receiving. It is sensible to find that difference between a transmitting state as receiving is not very far compared to the sleep state.

As previously explained in equation (2), the sensor switching process consumes a lot of the total battery due to the fluctuation between active and sleep mode. The switching process consumes more power to start the sensor from scratch to reach the active mode every time the sensor wakes up. All of the above are illustrated and represented in Fig.11 and Fig.12.[11].

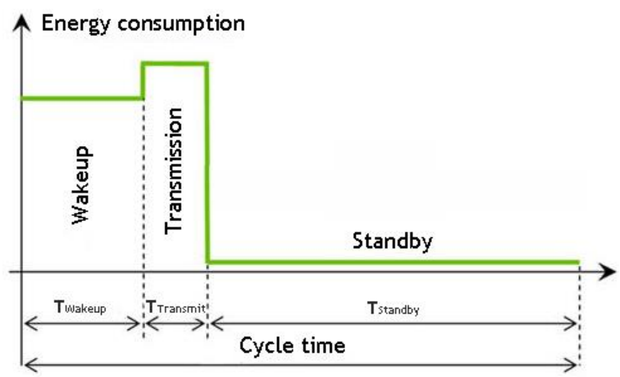

Fig.11 power consumption cycle

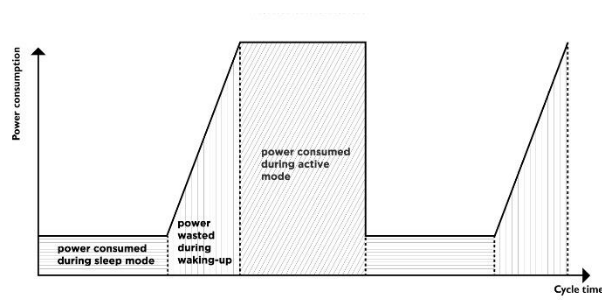

Fig.12 Power wasted during waking up

V. RESULTS

System performance is measured by Vectors that record data values as a function of time.

Different scenarios are taken into consideration to figure out the best results through experiments.

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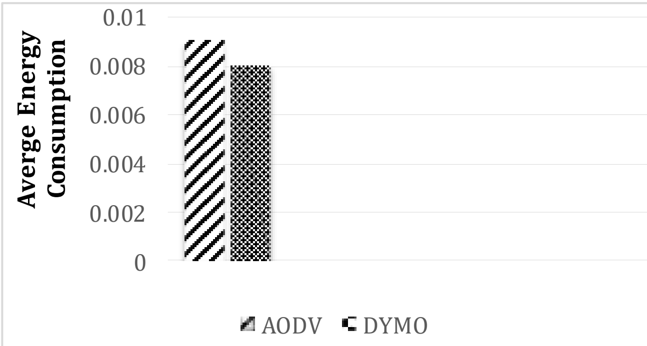

Fig.13 Average power consumption in AODV and DYMO IEEE802.15.4

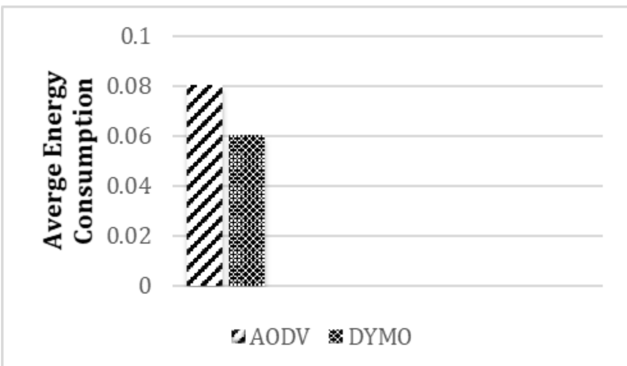

Fig.14 Average power consumption in IEEE802.11

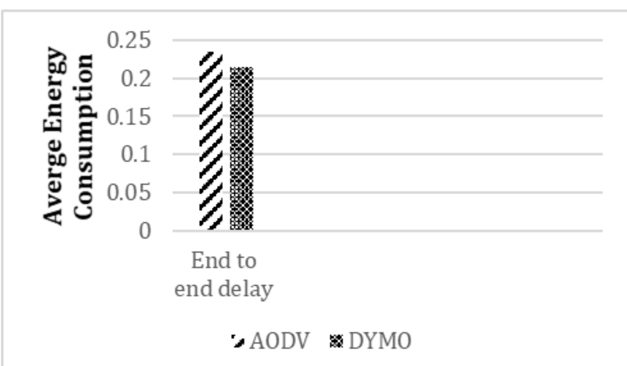

Fig.15 Average end-to-end delay in IEEE802.15.4

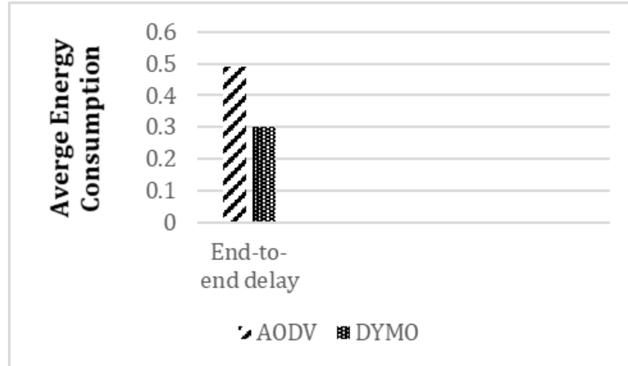

Fig.16 Average end-to-end delay in IEEE802.11

The outcome of running the simulation is presented according to the setup in TABLE II and TABLE III. The outcome data from simulation in displayed in Fig.13, Fig.14, Fig.15 and Fig.16 indicate that the DYMO protocol provides a steady performance for the running network with fast performance in finding the route for the data through the dynamic environment changes and ends with less end-to-end delay time. Furthermore, it provides better performance as an On-Demand protocol with less energy

consumption. The network results may present further improvement in terms of considering various propagation models, pause times, mobility models over the routing protocol [12].

Close examination of Fig.17 and Fig.18 shows power consumption of the sensor from waking up to communication state. The highest value went to the start-up process. It took 0.6 seconds to go up, going from 0 watts to 0.0065 watts which is the highest value of the power consumed in the sensor records. With this process repeated, each time the sensor switches from sleep or off mode to the active mode aiming to transmit or receive data, besides additional power will be consumed that can be saved by applying the proposed solution to minimize fluctuating intervals [13].

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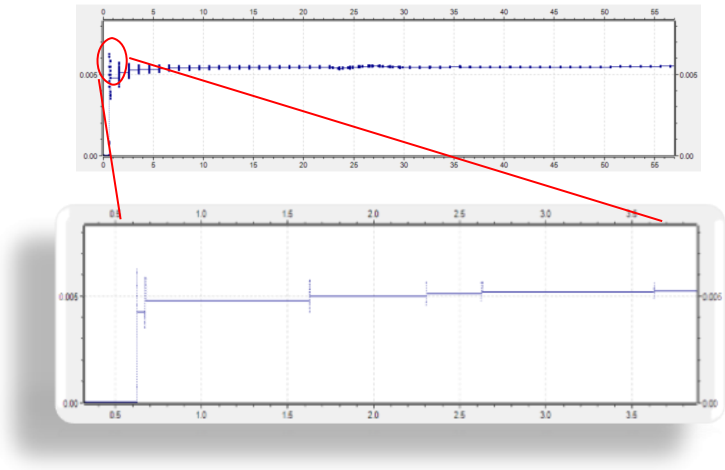

Fig.17 start-up power consumption

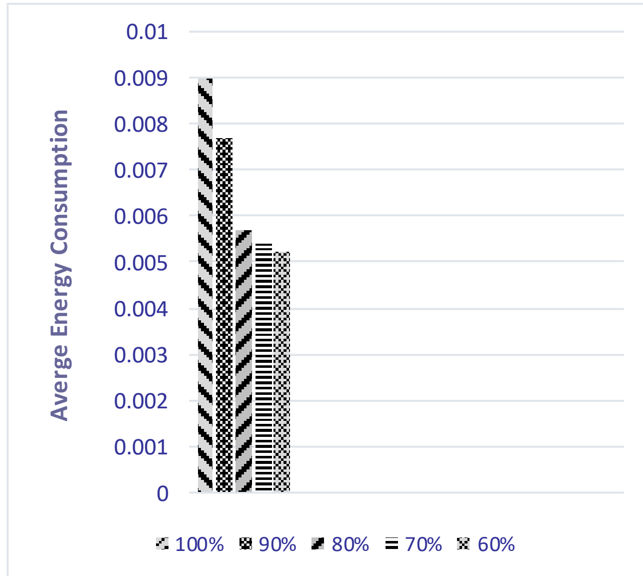

Fig.19 Average power consumption in scenario 1

Table IV- Average power consumption in scenario 1

Battery Level	100%	90%	80%	70%	60%
Average power consumption	0.009	0.0077	0.0057	0.0054	0.0052

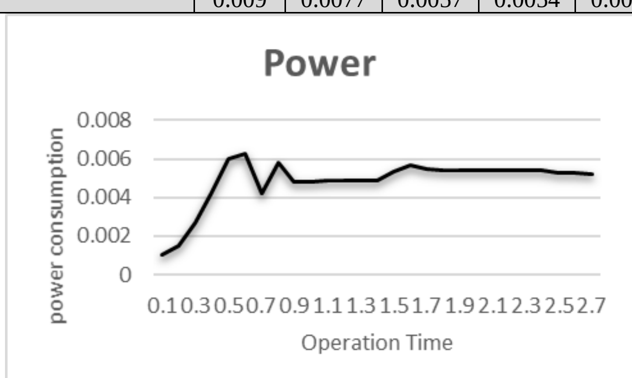

Fig.18 Start-up power consumption in the proposed model

As stated in the proposed enhanced model, two batteries are attached to the sensor, B1 being the main and B2 being the alternative.
The first scenario is to determine the threshold of the main

Battery B1 starts fully powered and B2 starts with 20% of B1 value. By running the simulation and observing the change in values of B1, it was found that from 80% to 60% the consumption is optimized and inconstancy state.

The first run shows that the system can depend on B2 with a 20% of B1 value, while B1 values can range from 80% to 60%.

The second method is to find out the threshold range of the secondary battery to maintain optimum consumption.
Therefore, B1 will start at 60% of its original value as a minimum threshold that is already determined from the previous method. B2 starts with 50% of the B1 value. The sensor will adopt B2 first and B1 will use the alternative renewal power source to recharge. In conjunction with that, the simulator records the value as B2 going down. Starting from 50% to 20% of B2 values, the records are very close which means less fluctuated and less wasted power. Noting that at the level of 70% of B1 which is in the range of power optimization, power consumption is constant through the different levels of B2 from 50% at the start to 20% which is the lowest level of B2 value.

Table V- B1 started with 60%

Battery Level	20%	30%	40%	50%
Average power consumption	0.0052	0.0054	0.0054	0.0054

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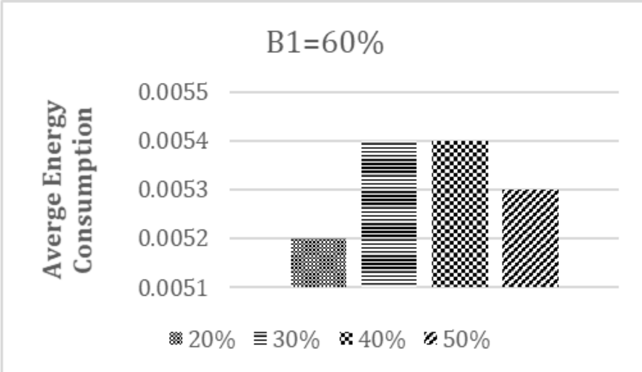

Fig. 20 - B2 started with 60%

Table VI- B2 started at 70%

Battery Level	20%	30%	40%	50%
Average power consumption	0.0054	0.0054	0.0054	0.0054

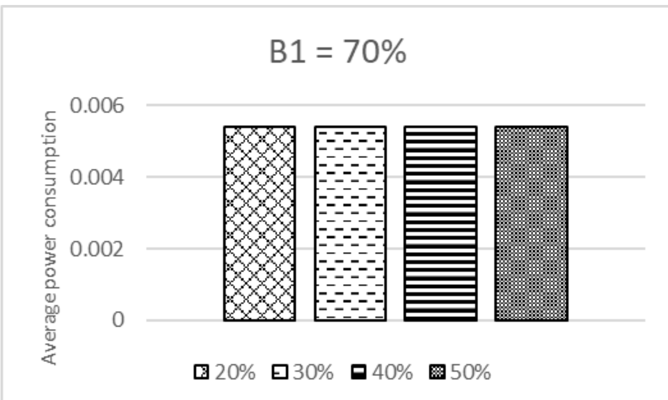

Fig. 21 - B2 started with 70%

Table VII B1 Started with 80%

Battery Level	20%	30%	40%	50%
Average power consumption	0.0057	0.0055	0.0055	0.0055

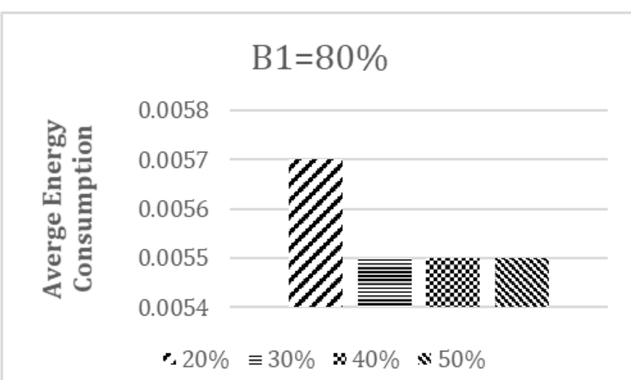

Fig. 22 - B2 started with 80%

Table VIII - B2 started with 90%

Battery Level	20%	30%	40%	50%
Average power consumption	0.0077	0.0075	0.0075	0.0075

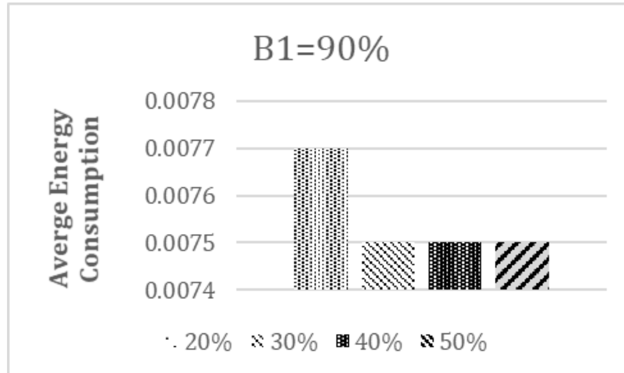

Fig. 23 - B2 started with 90%

By comparing the fluctuation between methods, 90% value was found outside the recommended range and the recommended 70% in our solution that the fluctuation values vary between 5% up and down around the steady state power consumption.

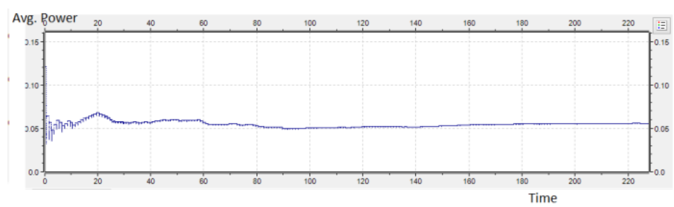

Fig.24 - power consumption at the recommended threshold.

From the graphs shown in the results section, power consumption used in the first method when main battery is full. When the alternative battery is 20%, it indicates that the best optimization for power consumption occurs in the range 80% to 60%. The sensor can consume from B1 until the minimum threshold. The energy levels of both batteries cannot fall below 20% as the lowest level. Less fluctuation and variation in Fig.24 represent increased consumption and more power saving that on the battery.

VI. CONCLUSION

Two batteries are attached to the sensor with the energy manager controller to supervise and control the battery affecting its lifetime as well as consumption. It determines which battery works or needs to work simultaneously with the other battery during harvesting. Setting an energy consumption threshold reduces fluctuations by minimizing the wasted power during the wakeup process by considering Standby mode in active modes. The simulation results showed enhancement in the average network consumption starting from 34% up to 60%. Based on the Experiment, this

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enhancement extended battery lifetime, besides the lower fluctuation, not only saves wasted power, but also minimizes start-up time to get the node into transceiver mode to be able to send or receive. Consequently, the sensor node became more reliable and the Quality of Service (QoS) of the network has improved. After the experiment, it is recommended to use two power sources with harvesting techniques and maintaining battery between levels of 60% to 80%. However, future harvesting techniques must be considered, as well as the energy synchronization process between nodes. We believe that enhancing sensor battery recharge time and handling energy requests coming from the sensor energy controller to local storage of the network should increase stability and reliability of the network.

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Salma El-Shaarawi was born in Cairo, Egypt. She received the B.Sc degree in computer science from Ahram Canadian University, in 2013.
She is a teaching assistant in department of networks in Ahram Canadian University since 2014, and researcher at The British University in Egypt.

Sami Goniemy obtained his B.Sc. in Communications and Computer Engineering, and his M.Sc. and Ph.D. in Systems and Computer Engineering from Carleton University, Canada. Also, he has extensive professional and consultancy experience in ICT. He worked and now a consultant for National and multinational ICT private companies. He authored and co-authored more than 100 research work which has been published in well-known international refereed journals such as IEEE, Springer, and Elsevier, that are indexed by ISI, SCOPUS, Science Direct, Google Scholar, etc. Finally, Dr. Ghoniemy, received local and international grants for various research and projects in artificial intelligence areas; such as cognitive informatics, health surveillance and health-care services.

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