EHA-BeeSensor: Hybrid Protocol for Energy Proficient Routing in IoT Network using Swarm Intelligence

Abdul Nasir[1], Hassaan Khaliq Qureshi[1], Israr Ullah[2], Muttukrishnan Rajarajan[3]
[1]School of Electrical Engineering and Computer Science (SEECS),
National University of Sciences and Technology (NUST), Islamabad, Pakistan
(abdulnasir.msee16seecs, hassaan.khaliq)@seecs.edu.pk
[2]Department of Computer Engineering, Jeju National University, South Korea
israr.ullah@jejunu.ac.kr
[3]School of Mathematics, Computer Science and Engineering, City University of London, UK
r.muttukrishnan@city.ac.uk

Modern communication technologies, Internet protocols, tiny intelligence devices, Cloud/Fog computing have enabled the IoT explosion which will revolutionize the world we live in. IoT devices are mostly battery powered and hence their life mainly depends on their battery power. Energy harvesting is a viable alternative which can actually achieve a near-infinite lifetime for such wireless battery powered nodes. In this paper, we investigate the impact of energy-harvesting feature in IoT network. We extend the existing design of *BeeSensor* routing protocol, a swarm-intelligence (SI) based protocol, by adding energy harvesting capabilities to network nodes. We then perform empirical evaluations of the extended version, *EHA-BeeSensor* and compare its performance with the existing protocols. The results show that *EHA-BeeSensor* not only achieves near-infinite network lifetime, it also performs better in terms of packet delivery ratio, latency and routing overhead.

***Index Terms*—IoTs, WSN, Energy Harvesting, Swarm Intelligence, BeeSensor**

I. Introduction

The size of Internet of Things (IoT) is growing at an unprecedented rate and due to availability of enabling technologies it is resulting in proliferation of more smart objects [1], [2]. These smart objects can see, listen, interpret and react to monitor and control their surroundings. Consequently, the application domain of such an intelligent IoT network encompasses transportation, health-care, industrial process control, smart homes and vehicular networks etc [3]. As the IoT network gets bigger [4], the challenge of designing and standardizing the relevant protocols is getting the focus of researchers in the last few years. Large address space requirements, security & privacy, monitoring & management of IoT and energy-efficient operation of the network are some of the major issues that are being investigated.

Energy-efficient operation of a wireless network in IoT, has been tackled in various ways. This includes the energy-efficient & light-weight communication protocols [1], low power radio transceivers [5] and the use of energy harvesting techniques [12]. In parallel, swarm intelligence based routing is another relevant area explored for robust and light-weight routing protocols [7]. Insect colonies resemble IoT network in which resource-constrained entities collaborate intelligently to achieve a collective common goal. The focus of this research is to add energy-harvesting features to an existing swarm intelligence based communication protocol, *BeeSensor* [8], and analyze its performance in the context of IoT network. The major objective of this work is to achieve a near-infinite network lifetime.

Our work proposes an enhanced version of *BeeSensor*, hereby called Energy Harvesting Aware BeeSensor Routing (*EHA-BeeSensor*). By energy harvesting, which assures continuous energy supply from ambient energy sources, near-infinite network lifetime can be achieved for energy limited WSN-based IoTs network. Similar to a bee colony, *BeeSensor* consists three types of agents; Scouts, Foragers and Packers. Scouts discover new destinations while, Foragers evaluate the path quality while carrying the data packet towards its destination. Packers, on the other hand, perform in-house activities where discovered paths are continuously evaluated and utilized according to their quality. *EHA-BeeSensor* incorporates an energy prediction algorithm which is based on previous and current energy profile and efficiently predicts the energy availability to be harvested for the next time period. Energy prediction in *EHA-BeeSensor* creates knowledge of its current and future availability of energy resources and schedules its network activity accordingly. The *EHA-BeeSensor* also uses an energy consumption scheme which makes it aware of energy being used for processing at a certain node or processing certain packet.

In this work, the proposed scheme *EHA-BeeSensor* is evaluated empirically and compared with several existing approaches including *BeeSensor*, *Ad Hoc On-Demand Distance Vector (AODV)* and *Destination-Sequenced Distance-Vector Routing (DSDV)*. The performance evaluations is based on four metrics; packet delivery ratio, latency, routing load and residual energy. The results show that *EHA-BeeSensor* outperforms other protocols in terms of packet delivery ratio, latency and routing overhead. It also achieves higher residual energy level due to its energy harvesting feature.

The remaining paper is organized as follows: In section II, we review some of the existing routing protocols for wireless networks. Background of energy harvesting is presented in section III. Section IV presents the energy harvesting aware version of *BeeSensor* protocol i-e *EHA-BeeSensor*. Simulation results and analysis is presented in section V with conclusion & future work in section VI.

II. Related Work

With advancements in wireless communications significant work has been done in field of wireless sensor based network. An overview about advancements in wireless sensors and IoT networks and the communication algorithms are described in [3], [13]. In wireless networks route is established from a source node to a destination. Multiple algorithms have been worked for routing in wireless networks such as *AODV*, *DSDV*, *DSR*. These protocols are studied and evaluated in detail in several studies [9], [10].

In wireless networks, energy availability comes in as an important factor for route selection when multiple paths are available. For route selection based on energy availability, several energy-aware routing protocols in wireless sensor networks have been proposed and developed [14]. The authors in [11] propose schemes for reducing communication cost incurred during the routing process and also present overview of various network lifetime enhancement techniques. Wireless sensor based network comprises of sensor nodes that are generally deployed randomly and at remote area. Continuous power supply therefore becomes a big challenge. Thus the devices have been designed to use very little energy so they remain alive for relatively longer time period. With energy being the key in lifetime of a node and in turn the lifetime of wireless network, advancements have been done to extend node lifetime. The authors in [2], [5], [15] present energy efficient routing based algorithms for wireless sensor based networks. All these approaches can be classified as energy efficient design.

Longstanding and self sufficient wireless sensor nodes are the key for near infinite lifetime of IoT network. With energy harvesting as a viable solution, researchers are studying energy harvesting in sensor networks and various schemes have been proposed. The authors in [5], [16] present popular techniques for energy harvesting in sensor networks from various ambient energy sources using energy prediction and management method. Harvesting energy from multiple sources has also got attraction from researchers. The authors in [6], [18] present overview of solar and RF energy harvesting for sensor network and also present an overview of harvesting energy by selecting from multiple energy sources.

In parallel, researchers have developed a new class of routing algorithms for wireless networks inspired from swarm intelligence (SI), which is a combined behaviour of autonomous, self managed and self controlled natural or artificial objects capable of interacting with each other and observing the environmental changes. SI systems are based on simple rules with no central control. The common example of Swarm intelligence include Bee Colony, Birds Flocking, Ant Colony in which each object is scattered and decentralized. Swarm Intelligence based routing algorithms are inspired from the natural phenomenons with capability for optimization and efficient working for complex problems [17]. Most popular swarm intelligence models are based on Ant Colony Optimization, Particle Swarm Optimization, Artificial Bee Colony algorithms as described in [7]. This is specifically interesting in the context of IoT networks which resemble the tiny insects both in terms of size and capabilities. Therefore, their collective intelligence can actually be used to develop a more stable and responsive network.

In our work, we consider *BeeSensor* [8], energy efficient routing protocol which is based on swarm intelligence and inspired from the foraging principal of honey bees. Through our this work, we will show that it has even better performance when it is enhanced with energy harvesting capabilities.

III. Energy Harvesting Background

For the the wireless sensor node, replacement and recharging of the battery module is one possible method to keep the network operational over a longer period of time. However, it is iterative, expensive (in terms of cost & man-hours) and inconvenient solution in case when IoT nodes are deployed at some far remote location. Therefore, we need IoT nodes have to fulfill their energy requirement on their own via energy

TABLE I
POWER DENSITY COMPARISON OF AMBIENT ENERGY SOURCES

Ambient Energy Source	Available Power
Solar [Indoor]	0.1 mW/cm^2
Solar [Outdoor]	100 mW/cm^2
Kinetic [Human]	0.5 m at 1 Hz 1 m/s$^2 at 50 Hz$
Kinetic [Industrial machines]	1 m at 5 Hz 10 m/s$^2 at 1 kHz$
Thermal [Human]	20 mW/cm^2
Thermal [Industrial Machines]	100 mW/cm^2
Radio Frequency [Cell phone]	0.3 uW/cm^2
Radio Frequency [Wi-Fi]	0.03 uW/cm^2

harvesting from the ambient sources. Wireless nodes in such *energy harvesting* IoT networks can benefit in two different ways. First, surplus energy can result in improved application fidelity, and second, it can lead to a near-infinite network lifetime.

Sunlight, radio frequency radiations and wind are the prominent ambient energy resources and the Table I shows the power availability comparison of various energy resources [6]. From the Table I, it can be seen that solar, among all natural ambient energy resources, is the maximum energy providing source and hence is a preferred choice for outdoor energy scavenging especially in areas where sunlight is available in abundance throughout the year. Solar energy can be harvested and subsequently stored in battery by wireless nodes. The wireless nodes with energy harvesting capabilities have been investigated recently by many researchers for enhancing wireless network lifetime.

IV. EHA-BEESENSOR

Energy Harvesting Aware BeeSenor i.e. EHA-BeeSensor is a variant of *BeeSensor* routing protocol proposed for WSNs with energy harvesting capabilities. The original *BeeSensor* protocol takes inspiration from the foraging principles of honey-bee colonies. *BeeSensor* houses three types of agents; Packers, Scouts, and Foragers. The *Scouts*, like their natural counter parts in a bee colony, discover paths to new destination and recruits the *Foragers* according to the profitability of the discovered route. *Foragers* carry the data packets to their destination and also keep evaluating the path that they follow. The *Packers* assign packets to the *Foragers*, depending upon the path quality and the destination that packet is intended for. This helps in distribution of traffic evenly across multiple paths. Through this mechanism, *BeeSensor* targets energy-efficient routing and adapts to the ever changing topology of WSNs. The empirical analysis presented in [8] illustrates that *BeeSensor* outperforms the existing protocols for WSNs.

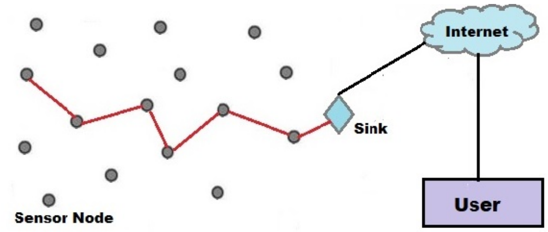

Fig. 1. Information transferring in IoT

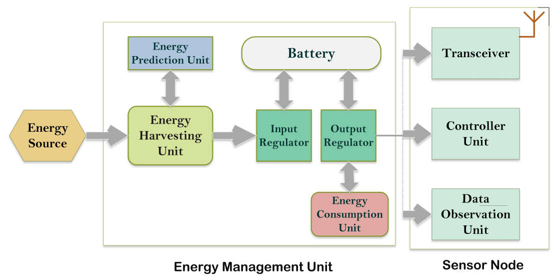

Fig. 2. Proposed EHA-BeeSensor Block Model

EHA-BeeSensor considers a multi-hop IoT network in which IoT devices are deployed randomly. All IoT devices are identical and consists of: Energy Management Unit with a battery or super-capacitor, Low-power Central Micro-controller, and Transceiver Unit. In addition to this, IoT devices are also equipped with a solar energy harvesting unit. Each IoT device, in addition to acting as a source of data, functions as a router on behalf of its neighboring nodes. The information is thus routed through the network towards a central node referred to as a sink node (see Fig 1). The sink node has a permanent power supply source and is connected to end user. Data is transferred from sink to user end for further data analysis.

We extend the original design of *BeeSensor* protocol by incorporating energy harvesting feature to achieve near infinite network lifetime. The proposed *EHA-BeeSensor* block model is illustrated in Fig 2. In the following subsections, we discuss these design extensions which is then followed by a comprehensive empirical evaluation of *EHA-BeeSensor* with the prominent existing protocols.

A. Energy Consumption

Energy consumption pattern in a wireless network e.g. IoT network is of critical importance because it affects overall performance of the network. We utilize and implement the energy consumption model used in [19] for the empirical evaluation of *EHA-BeeSensor*. Fig 3 shows how average consumed energy varies with

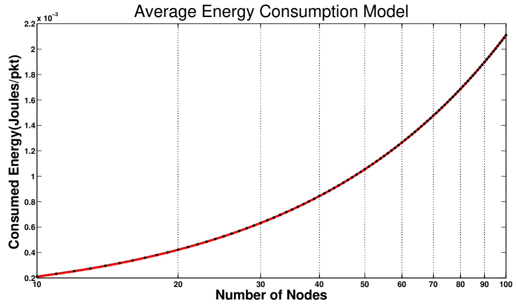

Fig. 3. Average Energy Consumption

number of nodes. A node can either be in transmission, receiving, listening or sleeping mode as defined in IEEE 802.15.4. Mathematically, we express it as in Eqn 1.

$$E_c = E_t + E_r + E_s + E_l \tag{1}$$

E_c is the total energy consumed at a node for processing a packet comprising transmission energy (E_t), receiving energy (E_r), sleep mode energy (E_s) and idle mode energy E_l. By using energy consumption model we get to know how energy is being consumed in a network for data gathering and transceiving.

B. Energy Prediction

Since all ambient sources of energy are random in nature, energy obtained through harvesting can be modeled as a stochastic process. We use energy prediction technique to get a forecast of energy availability. In our work we use *IPro-Energy* predication model, which is another important improvement introduced in *EHA-BeeSensor* [20]. IPro-Energy stores the previous month's harvested energy profile and compares it with the currently harvested profile to predict the energy availability for the future. Fig 4 shows the prediction accuracy of IPro-Energy by comparing the predicted energy and the actual energy available. More specifically, it can predict energy for the next hour, day or month.

C. Energy Harvesting

EHA-BeeSensor uses the energy harvesting technique to fulfill energy requirement of wireless nodes in IoT network. Here we consider energy being harvested from one ambient energy source that is Sun. The solar energy is harvested by energy harvesting panel and then stored in battery for further utilization by node. We assume that each nodes has some initial energy,

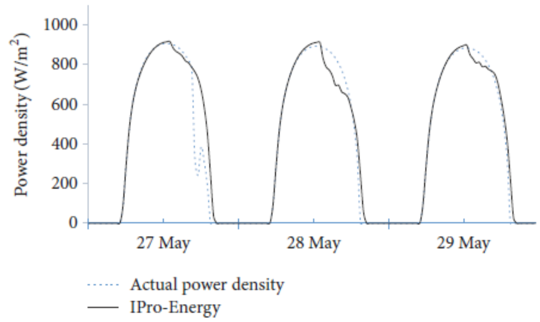

Fig. 4. Energy Prediction Comparison [20]

E_i Joules. During the empirical evaluation of *EHA-BeeSensor*, we assume E_i = 10W. Furthermore, we assume that a node battery has a maximum capacity of 70W. The wireless nodes are programmed to harvest solar energy at every half-hour interval. The harvested energy will be used to charge the node battery which is subsequently used for routine network operations e.g. data collection, transmission, and reception. Mathematically, we can express the total energy E_t available at a node as the sum of initial energy E_i and the harvested energy E_h as given by Eqn 2.

$$E_t = E_i + E_h. \tag{2}$$

As discussed earlier, sunlight has a random nature depending upon weather conditions. It could be sunny, cloudy or rainy day or a combination of the three condition. Nodes have to rely on residual energy when there is no energy being harvested like in night time or bad weather. The evening and morning time will have minimal energy available for harvesting due to less intense sunlight. Therefore, nodes activities must be scheduled to perform priority tasks to prevent nodes from running out of battery. Finally, the bright sunny days are the perfect conditions for energy harvesting and hence battery will be fully charged during the daytime. Therefore, sunny days are more favorable for any intensive data collecting and transceiving activity.

In the upcoming empirical evaluations, we utilize the average energy predicted and harvested values for the month of March, April, May, June, July and August 2019 to evaluate performance of our proposed model. This concludes our discussion on the description of enhancements made to *EHA-BeeSensor*. We now describe the experimental setup and the simulation results to elaborate the performance of *EHA-BeeSensor*.

TABLE II
SIMULATION PARAMETERS

Parameter	Value
Receiver Current [I_r]	19.7 mA
Transmitter Current [I_t]	17.4 mA
Listening Current [I_l]	0.02 mA
Sleeping Current [I_s]	0.001 mA
Voltage [V]	3 V
Initial Energy [E_i]	10 J
Battery Capacity [C]	70 J
Packet Size [P]	1,000 bits
Data Rate [C]	250 kbps
Number of Node [N]	[0, 500]

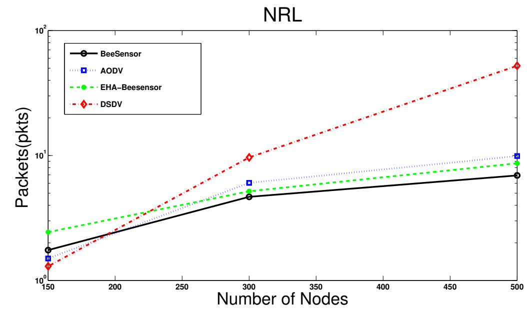

Fig. 5. Normalized Routing Load

V. SIMULATION AND RESULTS

For the simulation we assume a multi-hop wireless IoT network and used MICAz module in $ns-2$ simulations for low power wireless sensor nodes in three different simulation areas; 500m x 500m , 750m x 750m and 1000m x 1000m with 150, 300 and 500 nodes in each area respectively. Nodes generates a 1000 bits event at a rate 10 events per second. Simulation parameters are shown in table II.

Event sources are selected at random and the events are communicated to a centralized sink node. We use random Way-point model for node mobility. We selected three routing protocols for comparative analysis with EHA-BeeSensor; *AODV*, *DSDV* and *BeeSensor*. We compare the performance of four protocols based on four routing metrics; Normalized routing Load (NRL), Latency, Packet Delivery Ratio (PDR), & Residual Energy. The definitions of each metric is listed below.

- *Normalized Routing Load* is the ratio of number of control packets to the number of successfully delivered data packets as expressed by Eqn 3.

$$NRL = \frac{total\ control\ packets}{total\ delivered\ packets} \tag{3}$$

- *Latency* is the difference in time taken by a event to reach sink t_{sk} and the time at which that event was generated at source t_{sc} given by Eqn 4.

$$Latency = t_{sk} - t_{sc} \tag{4}$$

- *Packet Delivery Ratio* is the ratio of the number of data packets received at the sink to the number of data packets transmitted by all sources as given by the Eqn 5.

$$PDR = \frac{total\ packets\ received}{total\ packets\ transmitted} \tag{5}$$

- *Residual Energy* is the average amount of energy available in node battery represented by E_{res}. With some initial energy E_i after harvesting, harvested energy E_h will be added to sensor battery. Now sensor will consume some amount of energy E_c to perform its tasks. The Residual Energy E_{res} of a node is given by Eqn 6.

$$E_{res} = (E_i + E_h) - E_c \tag{6}$$

We now move on to the final part of this section in which we discuss the simulation results for each of the above mentioned metrics.

A. Normalized Routing Load

Normalized routing load (NRL) tells about controlled packets in the network. NRL of all the candidate protocols are shown in Fig 5, (note that Y-axis is on log scale). There are two trends clearly visible from the result. One, as the network size increases, the NRL of all the protocol increases. This is due to more transmission of control packets as the network size grows. Secondly, NRL of *EHA-BeeSensor* is almost near to *BeeSensor* and lower than the other two protocols *AODV* and *DSDV* because of their less packet delivery. Higher NRL of *DSDV* is primarily due to its proactive nature.

B. Latency/Delay

Latency tells about how much time will be taken by a packet to reach destination. Fig 6 shows the latency values trend for four candidate routing algorithms. For small networks each algorithm have almost similar latency but for increasing network size *BeeSensor* appears to be the winner in this case as of its effective flooding method and quick convergence. The *EHA-BeeSensor* here has more latency than *BeeSensor* as it has more active nodes due energy availability but stills its latency is better than *AODV*, *DSDV*. *DSDV* has the highest latency in this case which because it fails to converge quickly in a rapidly changing topology as nodes are mobile.

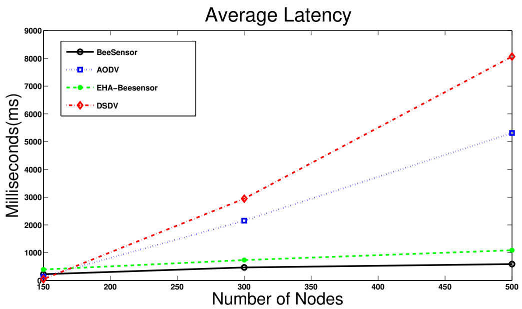

Fig. 6. Average Latency

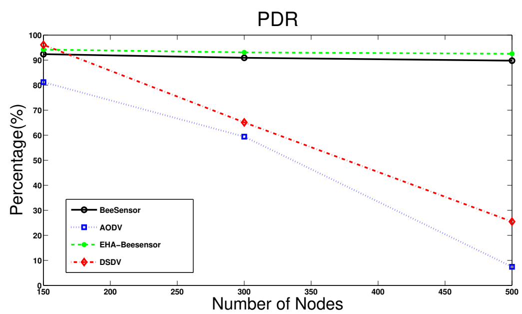

Fig. 7. Packet Delivery Ratio

C. Packet Delivery Ratio (PDR)

Packet delivery ration tells the probability that a packet can be transmitted successfully.It can be seen from results in Fig 7, *EHA-BeeSensor* performs better than the other protocols, that are, *BeeSensor*, *AODV*, *DSDV*. The high performance is of the fact that flooding by scouts is controlled which lead to quick convergence. Being capable of energy harvesting, in *EHA-BeeSensor* maximum number of nodes are active which leads to maximum packet delivery. Also the performance of *EHA-BeeSensor* is almost similar with a little dip for increasing size of the network still it is best performing than others. On the other hand, *DSDV* as well as *AODV* have low PDRs especially in large networks. It should also be noticed here that network is mobile and therefore, consistent performance of *EHA-BeeSensor* is one of its features which makes suitable for mobile nodes in IOT networks.

D. Residual Energy

One of the prime objectives of making *BeeSensor* energy harvesting-aware is to extend a node's battery life and keep it operational for much longer period of time, we refer it here as near-infinite. Once nodes kept themselves alive for a longer period, the network lifetime will increase automatically. Residual energy is

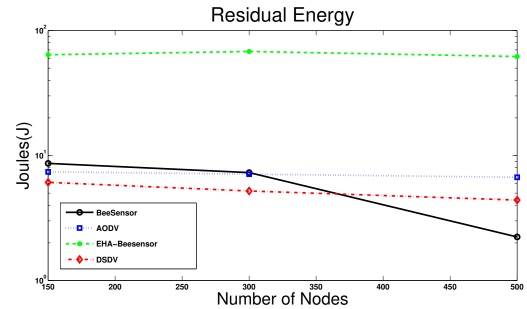

Fig. 8. Average Residual Energy

in fact an indirect measurement of the network lifetime. More Residual energy mean more lifetime. Average residual energy of the comparison of four candidate protocols is shown in Fig 8.

EHA-BeeSensor takes advantage of energy harvesting and outperforms its competitors by a greater margin. This clearly explains and proves that energy harvesting is a viable alternative for future IoT Network especially where nodes batteries or nodes are impractical to replace or recharge consistently. This concludes our discussion on the simulation results.

VI. Conclusions & Future Work

In this paper, we investigated the impact of adding energy harvesting features to an existing routing protocol for wireless networks. We utilize NS-2 simulations for performance evaluation of *EHA-BeeSensor*, a energy harvesting aware routing protocol. The empirical results show that network lifetime of a wireless network e.g. IoT network, can be significantly enhanced by investing in the development of wireless nodes with energy-harvesting feature. As a part of our future work, we intend to realize a real test-bed and study the impact of energy harvesting for IoT network with associated costs risks.

References

[1] Bongsug (Kevin) Chae, The evolution of the Internet of Things (IoT): A computational text analysis, Telecommunications Policy, Volume 43, Issue 10, 2019.

[2] Yinong Chen, IoT, Cloud, Big Data and AI in interdisciplinary domains, Simulation Modelling Practice and Theory, Volume 102, 2020.

[3] Ala Al-Fuqaha, Mohsen Guizani, Mehdi Mohammadi, Mohammed Aledhari, Moussa Ayyash, Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications. IEEE Communication Surveys Tutorials, Vol. 17, NO. 4, Fourth Quarter 2015.

[4] https://www.gartner.com/en/newsroom/press-releases/2017-02-07-gartner-says-8-billion-connected-things-will-be-in-use-in-2017-up-31-percent-from-2016.

[5] Swati S. Roy, Deepak Puthal, Suraj Sharma, Saraju P. Mohanty, and Albert Y. Zomaya, Building a Sustainable Internet of Things: Energy-efficient routing using low-power sensors will meet the need. IEEE Consumer Electronics Magazine, Volume: 7, Issue: 2, March 2018.

[6] Muhammad F. Ghuman, Adnan Iqbal, Hassaan K. Qureshi, Marios Lestas, ASIM: Solar Energy Availability Model for Wireless Sensor Networks. Proceedings of the 13th ACM Conference on Embedded Networked Sensor Systems (SenSys 2015), Workshop on Energy Harvesting Energy Neutral Sensing Systems (ENSsys), 2015.

[7] Ouarda Zedadra, Antonio Guerrieri, Nicolas Jouandeau, Giandomenico Spezzano, Hamid Seridi, and Giancarlo Fortino, Swarm Intelligence and IoT-Based Smart Cities: A Review. Technology,Communications and Computing. Chapter, January 2019.

[8] Muhammad Saleem, Israr Ullah, Muddassar Farooq, BeeSensor: An energy-efficient and scalable routing protocol for wireless sensor networks. Information Sciences 200, 38 – 56, 2012.

[9] Samad Riaz, Hassaan K. Qureshi, Muhammad Saleem, Performance Evaluation of Routing Protocols in Energy Harvesting D2D Network. Proceedings of the IEEE International Conference on Computing, Electronic and Electrical Engineering (ICE Cube), 2016.

[10] Anna Triantafyllou, Panagiotis Sarigiannidis, and Thomas D. Lagkas, Network Protocols, Schemes, and Mechanisms for Internet of Things (IoT): Features, Open Challenges, and Trends. Wireless Communications and Mobile Computing, vol. 2018, Article ID 5349894, 24 pages, https://doi.org/10.1155/2018/5349894, 2018.

[11] Junaid A. Khan, Hassaan K. Qureshi, Adnan Iqbal, Energy management in wireless sensor networks: A survey. Computers Electrical Engineering, Elsevier 2014, Volume 41, pp. 159 - 176, Jan 2015.

[12] Kofi S. Adu-Manu, Nadir Adam, Cristiano Tapparello, Hoda Ayatollahi, Wendi Heinzelman, Energy-Harvesting Wireless Sensor Networks (EH-WSNs): A Review. ACM Transactions on Sensor Networks (TOSN), Volume 14 Issue 2, July 2018.

[13] Lubdha M. Bendale, Roshani L. Jain, Gayatri D. Patil, Study of Various Routing Protocols in Mobile Ad-Hoc Networks. IJSRNSC, ISSN: 23213256, Volume-6, Issue-1, Jan 2018.

[14] Shahzad Sarwar, Sammia Rauf, Rashid Rasheed, Laeeq Aslam, Energy-aware Routing in Internet of Things (IoT). IEEE, 2nd International Conference on Communication, Computing and Digital systems (C-CODE), DOI: 10.1109/C-CODE.2019.8680974, March 2019.

[15] Jingjing Yan, Mengchu Zhou,and Zhijun Ding, Recent Advances in Energy-Efficient Routing Protocols for Wireless Sensor Networks: A Review. Digital Object Identifier 10.1109/ACCESS.2016.2598719, 2016.

[16] Hafiz Husnain Raza Sherazi, Luigi Alfredo Grieco, Gennaro Boggia, A comprehensive review on energy harvesting MAC protocols in WSNs: Challenges and tradeoffs. Ad Hoc Networks Volume 71, Pages 117 - 134, March 2018.

[17] Adam P. Piotrowski, Maciej J. Napiorkowski, Jaroslaw J. Napiorkowski, Pawel M. Rowinski, Swarm Intelligence and Evolutionary Algorithms: Performance versus speed. Information Sciences Volume 384, Pages 34 - 85, April 2017.

[18] Marwa K. Lagha, Faycal A. Aoudia, Matthieu Gautier, Olivier Berder, Feature Selection Framework for Multi-Source Energy Harvesting Wireless Sensor Networks. IEEE 87th Vehicular Technology Conference (VTC Spring), 2018.

[19] Thien D. Nguyen, Jamil Y. Khan, and Duy T. Ngo, An Effective Energy-Harvesting-Aware Routing Algorithm for WSN-based IoT Applications. IEEE International Conference on Communications (ICC), 2017.

[20] Muhammad, Hassaan K. Qureshi, Umber Saleem, Muhammad Saleem, Andreas Pitsillides, Marios Lestas, Harvested Energy Prediction Schemes for Wireless Sensor Networks: Performance Evaluation and Enhancements. Hindawi Wireless Communications and Mobile Computing, Article ID 6928325, 2017.