An Energy Efficient Scheme for IoT (EES4IoT)

Vasileios A. Memos, Kostas E. Psannis, Georgios Minopoulos, George Kokkonis
Dept. of Applied Informatics, University of Macedonia
Thessaloniki, Greece
e-mail: {vmemos, kpsannis, gminopoulos, gkokkonis}@uom.edu.gr

Yutaka Ishibashi
Dept. of Computer Science, Nagoya Institute of Technology
Nagoya, Japan
e-mail: ishibasi@nitech.ac.jp

***Abstract*—Internet of Things (IoT) is a new technological revolution which brings many advantages to its users. However, IoT devices and sensor nodes in Wireless Sensor Networks (WSNs) have limited resources, such as energy, memory, computational speed, and communication bandwidth. Thus, better utilization of energy is necessary to avoid problems like high energy consumption and low network lifetime. This paper presents the most well-known and current methods for energy efficiency in both WSNs and the expandable IoT. In addition, a novel low-energy approach for maximizing energy efficiency in IoT, called Energy Efficient Scheme for IoT (EES4IoT), is proposed. This scheme merges efficiently two other schemes for energy efficiency, network lifetime enhancement, maintenance cost reduction and shortest path finding for data transmission. The new proposed scheme demonstrates energy savings in the sensor nodes and extending lifetime of WSNs.**

Keywords-energy efficiency; energy harvesting; IoT; network lifetime; routing; WSN

I. INTRODUCTION

Last decade, Internet of Things (IoT) has been established as the new technological revolution that aspires to connect all the everyday physical objects to the Internet. IoT is going to make a huge global network of unique things which can share information amongst each other and complete scheduled tasks, bringing significant benefits to its users [1]. However, there are many factors which should be taken into account so as to provide the optimum efficiency.

In cyber-physical systems (CPS) the IoT uses a substantial number of sensors with limited sensing, storage, and computing [2]. One of the biggest challenges is regarded as the energy consumption, which depends on the method of the utilization of the limited energy in the sensor nodes. It is known that the sensor nodes in a Wireless Sensor Network (WSN) have limited resources such as energy, memory, computational speed, and communication bandwidth [2].

Therefore, network performance needs an evaluation based on various parameters like the average control packet overhead, average energy consumption, end-to-end delay, packet delivery ratio, network lifetime, etc. It is reasonable that reducing the amount of data transmitted and/or energy consumed per transmission could bring significantly longer network lifetime and reduced costs of nodes redeployment, maintenance, and network power failure [3].

Other studies highlight the clustering concept. Clustering in WSNs is an effective way to minimize the energy consumption of the sensor nodes. This method can be applied to routing algorithms for their improvement so as to improve the lifetime of WSNs [4]. It is fact that a single IoT device has limited computation, storage, and communication resources, which cannot meet the requirement to complete specific tasks. Therefore, it is necessary to find and use resources beyond the IoT device so as to help it finish the scheduled tasks. A well-known technique is the cloud computing [5]. However, cloud computing may cause high latency, due to the fact that the cloud server is far from the IoT devices [6].

To solve this problem, Cisco launched the concept of fog computing in 2012 [7]. Fog computing is a promising technique for the future industry, which enables the low-latency services in IoT. However, the communication problem for the implementation of this technique in IoT remains a challenging issue. Although the computation and storage capacity of fog nodes are high, without the communication between the IoT devices and fog nodes, the IoT devices cannot use the resources provided by the fog nodes. In other words, a small amount of communication resources is used so as to replace a large amount of computation, storage and other resources of fog nodes in some cases [7].

Sensor nodes are usually static in the sensing area. The radio range of the sensor node is short, thus multi-hop communication is substantial between source node sensors and the base station. A data collector, like a sink, plays an important role in multi-hop data transmission to the base station by collecting data from source-sensing devices. This is also known as a device for the fog-computing architecture [6], [8]. The problem is that the nodes close to the data collector empty their batteries faster than other nodes. This problem is known as “energy-hole problem” [9]. Therefore, the improvement of the energy efficiency in IoT networks is important, especially for battery limited IoT devices. Energy harvesting [10] refers to collecting energy from surroundings (like the sun and/or the wind) or other energy sources (e.g. body heat, finger stroke, and foot strikes) and transforming these energies to electrical energy. Energies from external sources can be collected to power the nodes to increase their periods they remain alive (lifetime).

In a WSN, the sensor nodes have an important drawback, which is the limited energy in their primary power storage unit, which may be quickly depleted if the sensor node operates over long periods of time. Thus, the concept of harvesting enclosure energy from the immediate surroundings of the deployed sensors has already been proposed to recharge their batteries and to directly power the sensor nodes. The deployment of energy harvesting in environmental field systems eliminates the reliance of sensor nodes on battery power, and significantly reduces the maintenance costs which are required to replace the batteries [11]. Energy harvesting has notably enhanced the lifetime of a WSN and made the new devices much more reliable. Thanks to energy harvesting, the general scheme of getting the longest possible lifetime, while still giving a good adequate result, provides best possible results with the quantity of available energy [12].

In this paper, we present a new Energy Efficient Scheme for IoT (EES4IoT) which merges two different techniques, energy harvesting and delaying packet transmission. This is the objective of our proposed method. Experimental results demonstrate network lifetime enhancement, maintenance cost reduction and shortest path finding for data transmission.

The rest of the paper is organized as follows. A summary of the related work is given in Section II. Section III presents the methods and performance metrics which are recommended in the literature. Section IV includes our proposed energy efficient scheme, while Section V finalizes the paper with useful conclusions about the research and gives possible future directions.

II. RELATED WORK

Many researches have been conducted in the scientific area of IoT which faces the big challenge of energy efficiency. A complete tracking and localization algorithm for WSNs is presented by M. Akter et al. in [13], which faces the challenges of energy consumption, faulty tracking, and inaccurate localization. M. Nikolov and Z. J. Haas propose a new encoded sensing for energy efficient WSNs in [3], which achieves at least 80% the energy savings of theoretically optimal cooperative transmission transmission distributed beamforming architectures.

In order to utilize the energy of each node more efficiently in WSNs and balance their energy consumption, the concept of mobile sink nodes is proposed by Y. Gu et al. in [14]. Those sink nodes have the ability to move at a specific speed in the network at a specified or random path, and collect data from the close nodes during the mobile task. Thus, there will not be some nodes being always close to the sink nodes to become hot spots, thanks to the continuous motion of the sink nodes. Therefore, the energy consumption of nodes around the sink nodes is also balanced.

P. Zhong and F. Ruan propose an energy efficient multiple mobile sinks based routing algorithm for WSNs in [15], where the whole network is divided into several clusters in order to investigate in which number of mobile sinks the best network performance is achieved. A Low Energy Consumption Routing Protocol for Mobile Sensor Networks with a Path-Constrained Mobile Sink is presented by M. T. Nuruzzaman and H. W. Ferng in [16]. Experimental results show that their proposed scheme can effectively reduce energy consumption and increase the delivery ratio even for the high-speed mobile sink.

S. S. Roy et al. present a new data-routing technique in [2] which achieves many advantages in the big challenge of the better utilization of the limited energy of the sensor node to prolong the network lifetime. Simulation results show that the performance of the proposed routing is superior in terms of the average control packet energy consumption, average energy consumption, data delivery latency, and low end-to-end latency, while it solves the energy-hole problem and has great potential for IoT applications [2].

L. Guntupalli et al. propose a new On-demand Energy Requesting (OER) mechanism in [17] which promises improvement of the delay performance of a wireless energy harvesting powered IoT network, especially under low traffic or low energy harvesting conditions. B. M. Lee investigates the energy efficiency gain of massive MIMO-OFDM in battery-limited IoT networks in [18]. The proposed research shows that the closed-form approaches can be used as useful tools to design high energy efficiency massive MIMO-OFDM based battery limited IoT networks. H. Qin et al. propose a Dual-Interface Dual-Pipeline Scheduling (DIPS) scheme in [19] for multi-hop data delivery in IoT, which offers energy efficiency, due to the fact that it minimizes network energy consumption and satisfies specific end-to-end delay requirements.

In [6], X. Shao et al. introduce multiple access technique, called Non-orthogonal multiple access (NOMA), so as to provide communication service between the fog layer and the IoT device layer in fog computing, and thus they propose a dynamic cooperative framework containing two stages which has the ability to achieve higher spectrum efficiency, while ensures fairness among IoT devices compared to other existing schemes.

B. Khodabakhshi and M. Khalily propose an energy-efficient algorithm in [20] for linear network coding coefficient selection in multicast wireless sensor networks, and a solution to ensure that the sinks have the ability to decode data. The proposed algorithm provides reduction of energy consumption, while it increases the network throughput and energy efficiency. Therefore, network issues like load balancing, reliability, and lifetime in WSNs are improved. In [21], R. M. Zuhairy and M. GH Al Zamil propose an energy-efficient load balancing strategy based on the proposed prediction model for the purpose of enhancing the lifetime of wireless infrastructure. This strategy significantly reduces the error rate and clearly maximizes the lifetime of WSNs.

In [22], clustering concept and its benefits are analyzed by G. Ramamurthy who proposes a new scheme to improve the energy efficiency of WSN. This scheme places the base stations in the appropriate locations such that the squared Euclidean distances from the sensors to the base stations are minimized. Another novel clustering mechanism is proposed by A. Shankar and N. Jaisankar in [23] which selects cluster head with highest residual energy in each communication round of transmission and also takes into account, the shortest distance to the base station from the cluster heads. Simulation results show that the proposed mechanism prolongs the lifetime of the network compared to other known clustering schemes.

Finally, other researches highlight to the energy harvesting of the WSNs. A. Rashid et al. propose an energy harvesting system for Cluster Heads which improves the energy conservation in a clustering based WSN in [12]. By using energy-aware clustering standards, the battery usage and computation overhead can be reduced.

III. Analysis of Perfomance Methods and Metrics

In this section, we present the methods which are used to improve the total energy efficiency in a network (such as WSN or IoT). They include all of the most known techniques which have been proposed the last years, and present proven significant improvements in a range of network performance metrics. Then, we describe the performance metrics which deal with network problems such as the energy-hole problem, the packet loss, the packet delay, and the network lifetime.

A. *Energy Efficiency Methods*

As described above, there are several techniques for ensuring a good level of Energy Efficiency (EE) rate in WSNs. We can categorize these techniques into five general methods as follows:

Cloud Computing (CC): This is a known technique which offers available resources beyond the IoT device so as to help it finish scheduled tasks. This solution is recommended due to the fact that a single IoT device has limited computation, storage, and communication resources, which cannot meet the requirement to complete specific tasks [5].

Fog Computing: This is a promising technique for the future industry which enables the low-latency services in IoT [6]. Note that sensor nodes are usually static in the sensing area. The radio range of the sensor node is short, thus multihop communication is essential between source sensors and the base station. A data collector (like a sink in sensor networks) plays an important role in multihop data transmission to the base station by collecting data from source-sensing devices. This is also known as a device for the fog-computing architecture.

Clustering: This is a method in which sensor nodes are hierarchically organized on the basis of their relevant closeness to each other. Clustering of sensor nodes helps in compressing the routing table so that the discovery mode between sensor nodes is done more easily. Clustering can also maintain the communication bandwidth because it limits the scope of inter-cluster interactions to cluster heads and avoids unnecessary exchange of messages between the sensor nodes [23]. Clustering in WSNs is regarded to be an effective way to minimize the energy consumption of sensor nodes. This method can be applied to routing algorithms for their improvement so as to enhance the lifetime of WSNs [4].

Network Coding Methods: Various network coding schemes, strategy layout mechanisms for load balancing, and routing algorithms can offer important benefits such as energy savings and throughput for a single multicast session in wireless networks [20]. For example, reducing the number of transmissions in a broadcast session, achieves better energy savings and throughput.

Energy Harvesting (EH): This is a method in which the collected energy from surrounding (like the sun and/or the wind) or other external energy sources can be transformed to electrical energy [10] so as to power the nodes and increase their period they remain alive. Thus, this method has notably enhanced the lifetime of WSNs and established the new devices much more reliable [12].

B. *Performance Metrics*

There are several performance metrics which are used to analyze efficiency. As evidenced by the literature, the most frequently used metrics are the following:

Average Energy Consumption: The average energy consumption of a node is the energy consumed in transmitting and receiving data packets and control packets in a network. It is obvious that energy consumption of routing protocols should be reduced to improve the network effectiveness.

Throughput: This metric refers to the node/network throughput rate which is defined as the average number of packets successfully delivered by a node in a cycle.

Packet Reliability Ratio (PRR): This metric refers to the successful transmission without being discarded, and it is defined as the number of packets delivered successfully per collision. In other words, PRR is a similar meaning to the *Packet Delivery Ratio (PDR)* which is the ratio of received packets to the packets delivered. It is needed for a good delivery ratio. PDR or PRR should be as high as possible, because in other words, it shows how reliable the communication is.

Packet Loss Probability (PLP): Data packets arrive to a node randomly. A packet enters into its data queue if there is a space available. Otherwise, the packet would be dropped. Therefore, buffer overflow is the main reason for packet drop. It is obvious that the total number of packets generated is the sum of the number of dropped packets and the number of transmitted packets, and so the PLP is defined as the ratio of the number of dropped packets to the number of generated packets. PLP should be as small as possible.

Average Packet Delay: Finding the data collector's location and then forwarding the data packets to the collector node is a time-consuming task, and is known as the packet delay or *End-to-End Delay* or *Latency* of the network. In other words, a packet that has entered the queue of a node would remain there until it is delivered successfully. Thus, the delay is the duration elapsed until it is delivered, counted from its entry instant into the buffer. The average packet delay should be as short as possible.

Network Lifetime: Network lifetime of sensor nodes refers to the time taken until the first node "dies" in the network. Network lifetime plays a vital role when time sensors are used to sense the network. The objective should be the alive nodes which can prolong and maximize the lifetime of a WSN.

IV. Proposed Scheme And Discussion

In this section, we present our proposed method for maximizing energy savings and network lifetime in IoT, called EES4IoT. Our proposed direction is the shift to energy harvesting from surrounding or other external sources which can transform to electrical energy so as to power the sensor nodes and increase their life period.

As mentioned earlier, the corresponding scheme of L. Guntupalli et al. [17] offers Successful Transmission Probability (STP), low average packet delay, high node and network throughput, low packet loss, and a high packet reliability ratio, while it achieves high network lifetime of the sensor nodes, especially under low traffic or low energy harvesting conditions. In this scheme, packet transmission is initiated only when there are both packets and sufficient energy for this process. In the case where a sensor node does not have energy, the sensor node requests the sink (wireless energy transmitter) to transfer energy and then completes the transmission with the received energy. This technique could also be applied to other proposed energy efficient models for IoT.

The proposal of M. T. Nuruzzaman and H. W. Ferng [16] is to delay sending packets until the mobile sink is approaching the position that guarantees the shortest path, which provides reduction of the energy consumption, due to the fact that it avoids unnecessary buffering and transferring overhead. In our opinion, this technique could be more efficient by adopting L. Guntupalli et al.'s EH scheme [17]. This is the point of our contribution with the proposed scheme. Specifically, while a sensor node is in operation of waiting the mobile sink to reach the position that ensures the shortest path so as to avoid unnecessary buffering and transferring overhead, it can also check earlier and may request the sink for energy feedback, which it receives from surrounding or external sources (sun, wind, etc.), in the case of insufficient energy for packet transmission. The sensor node which is on hold may have energy loss, until the sink approaches the position which guarantees the shortest path for transmission. This problem can be solved by requesting from the sink the appropriate energy to complete this task when the shortest path will be found.

Algorithm 1 presents our proposed approach EES4IoT for low-energy forwarding of the transmitted packets from the wireless sensors to the desired destination. The first action for the node is to check its energy level. If it is low and prohibitive for beginning transmission of the collected data of the sensed surrounding, it requests for the remaining required energy from the sink, until the level of its energy reaches the required energy for transmission. Subsequently, it waits for the sink for getting the shortest path so as to manage to complete the transmission of the data packets. Therefore, EES4IoT can achieve not only time costs reduction, but also energy efficiency enhancement by improving the lifetime of sensor nodes which have limited battery power available, and maintenance costs of the sensor nodes (no need to replace their batteries).

At this point, let us assume that specific information should be sent from a sensor node which has a 20% energy/battery level to another one or the end user. The information consists of many data packets. For simplicity, we assume that they are as follows:

$$data = \{p1, p2, p3, p4, p5, p6, p7, p8\} \qquad (1)$$

where *p1 – p8* are the data packets which are transmitted. In this case, we assume that the packets have the same size, and therefore each packet is the *1/8* of the total size of the data.

Algorithm 1. Low-energy packet routing scheme

```
/*Proposed Algorithm for Packet Forwarding*/
start {
check node_energy;
while (node_energy < required_energy){
        remaining_energy=required_energy - node_energy;
        request remaining_energy from sink;
}
end while
get remaining_energy;
while (sink has not reached the path){
        wait shortest_path from sink;
}
end while
get shortest_path;
transmit packets;
complete transmission;
}
end
```

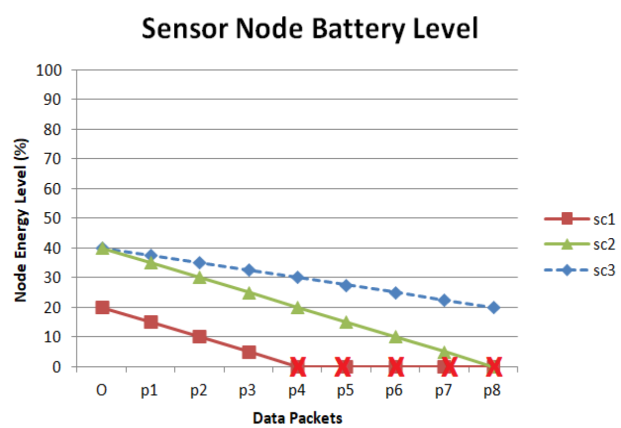

Figure 1. Sensor node battery level for transmission data packets: sc1 depicts the unsuccessful transmission of the information (data packets p4-p8, denoted by 'X' symbol), sc2 depicts the successful transmission after the necessary EH from the mobile sink, and sc3 depicts the successful transmission and energy saving which is occurred by using the shortest path finding operation before the transmission begins.

The experiments are based on Algorithm 1 and mathematical calculations. Although the experiments are not conducted in real-world conditions, they show a first estimation which is quite close to reality. Figure 1 shows the sensor node battery level for transmission data packets *p1-p8* and the corresponding potential energy savings for three indicative scenarios.

If the energy level of the sensor node is reduced by 5% for each data packet transmission, the transmission of the information is not completed successfully, as it is shown in Figure 1, scenario 1 (denoted by sc1 in the figure). In this case, based on Algorithm 1, the sensor node asks for energy from the mobile sink so as to be able to complete the transmission task. The amount of the requested energy is equal to the remaining amount which is needed to transmit the information. In this case, according to the equation *remaining_energy* = *required_energy* – *node_energy*, it is 20%. Figure 1, scenario 2, depicts the successful transmission of the information after the necessary amount of energy harvesting from the sink. Finally, Figure 1, scenario 3, presents the conditional sensor node battery level for our proposed scheme by using the shortest path to harvest the necessary level before the sensor node starts the data transmission. The energy saving for this operation is set to 20% according to our estimation in this test.

V. CONCLUSIONS AND FUTURE WORK

An Energy Efficient Scheme for IoT (EES4IoT) was proposed. The scheme is based on two energy efficient schemes and deals with network problems, such as the energy-hole problem, the packet loss, the packet delay, and the network lifetime. In addition, the scheme ensures both the shortest path finding for packet transmission, and the energy feedback of the sensor node before it.

Our future work includes the implementation and experimental analysis of our proposed scheme for a WSN and the expandable futuristic IoT. The energy savings which our proposed scheme can offer to the sensor nodes of a WSN should be calculated and compared with related schemes under real-world conditions. Finally, transmission latency, which may include the waiting time for a sink node to move on the shortest path, should also be evaluated and compared with the existing methods.

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