An Efficient Approach for Representing and Sending Data in Wireless Sensor Networks

Mustafa Hammad[1], Mohammad Bsoul[2], Maen Hammad[3], and Muna Al-Hawawreh[1]
[1] Department of Computer Science, Mutah University, Al Karak, Jordan
[2] Department of Computer Science and Applications, The Hashemite University, Zarqa, Jordan
[3]Department of Software Engineering, The Hashemite University, Zarqa, Jordan
Email: hammad@mutah.edu.jo; {mbsoul, mhammad}@hu.edu.jo; munahawari1@gmail.com

Abstract —Wireless Sensor Networks (WSNs) became a major impact in terms of remote surveillance and data collection process. Limited power supply for a sensor node is one of the most significant challenges in WSNs. In WSNs, sensor nodes' energy plays a vital role in the network lifetime. The total number of bits to be sent over the WSN has a significant impact on the sensor nodes' power consumption. Therefore, reducing the size of the transmitted data is an important key to use the sensor node's energy efficiently. In this paper, a new approach is proposed to reduce the energy consumption in sensor nodes. The proposed approach is based on only transmitting the difference between the current sensed reading value and the previous reading value that is represented by the least number of bits instead of the new reading value itself. Since the differences between the consecutive sensed readings (e.g. temperatures) are expected to be small, the lengths of the differences are expected to have less size than the size of the sensed readings. The proposed approach is evaluated on real sensors data. Results show that the proposed approach reduces the energy consumption of sensor nodes and prolongs the sensor network lifetime.

Index Terms—WSNs, difference value, power consumption, network lifetime, packet size.

I. Introduction

A Wireless Sensor Network (WSN) is composed of a set of spatially distributed intelligent devices called sensors or nodes. These nodes perform limited processes, such as sensing the target field phenomena and sending the collected data through the WSN. A WSN gathers data from all sensor nodes and delivers it to a single processing node, which is called a base station [1]. However, a sensor node has a low and limited power bank, which affect the overall WSN's lifetime.

Data transmission in WSNs is an active area of research. Transmitting the data through the antenna has a major role in WSNs' lifetime. About 80% of a sensor node's power is consumed in the data transmission process [2].

Reducing the energy consumption is one of the most main issues in WSNs. Sensor nodes have batteries with limited energy. In some environments, it is very hard or impossible to replace or recharge the batteries in the network due to many physically sparse and embedded sensor nodes [3]. As a result, various works have been engaged to reduce the energy consumption in the sensor node with respect to hardware, software, and communication protocols.

This paper presents a new approach to reduce the energy consumption in WSNs. The proposed approach is built on a simple and efficient idea, that, in general, sending the difference between the current reading and the previous reading is expected to consume less energy than sending the reading itself since it is expected to have less size when represented by the least number of bits.

The rest of this paper is organized as follows; Section 2 presents the related work in the area. Section 3 presents the general structure and the energy consumption for WSNs. The proposed sending approach is detailed in Section 4. The approach of represented the difference value is discussed in Section 5. The evaluation of the approach is discussed in Section 6 followed by our conclusions.

II. Related Work

In this section, the promising techniques and methodologies that aim to preserve network energy through efficient data transmission are discussed.

One active research area is on the compression of transmitted data [4]-[9]. The goal of compression is to reduce the packet size and hence reduce the amount of consumed energy. But these algorithms and techniques require heavy computations using adaptive dictionary construction.

Raja *et al.* [10] and Santini *et al.* [11] proposed a data reduction approach based on the least mean adaptive algorithm. The goal is to reduce the amount of data node that sends to a sink node. Arunraja *et al.* [12] presented a two-level data reduction approach named (DEAP). It groups nodes that are in similar clusters based on their temporal correlation. Their approach achieved up to 68% of data reduction.

Another data reduction approach based on Artificial Neural Network (ANN) is presented in [13], [14]. The ANN was used to predict the sensed values. The control central unit selects and decides the new sensing time for a set of selected sensor nodes.

Manuscript received June 26, 2018; revised January 15, 2019.
doi:10.12720/jcm.14.2.104-109

Aderohunmu *et al*. [15] proposed SWIFTNET which is a reactive data acquisition structure. SWIFTNET was implemented based on a mixture of energy-efficient data compression and data reduction approaches.

Other researchers have worked on minimizing the number of transmitted bits by sensors as in [16]-[19]. The main ideas behind these approaches are redundancy elimination of bits and reducing the transmissions to base stations to save more energy.

An efficient energy approach is presented in [20] by Bsoul *et al*. The approach is an indexed based that achieves saves energy. The approach also has two more advantages; short elapsed time, and small transmitted packet. The idea is to send the index that corresponds to the readings instead of the reading itself which results in reducing the packet size. The approach has a limited range of sensing readings. Moreover, there is a need to keep all the dissimilar reading values and produces an index table at the startup time.

Our work is distinguished by reducing the number of transmitted bits without compression or artificial techniques. The approach saves energy to provide a longer network lifetime. Our proposed approach consumes less memory because both base station and sensor node retain only the last reading value. In addition, our proposed approach sends a value with a size that depends on the difference between the last two readings.

III. WSNs Structure and Energy Consumption Model

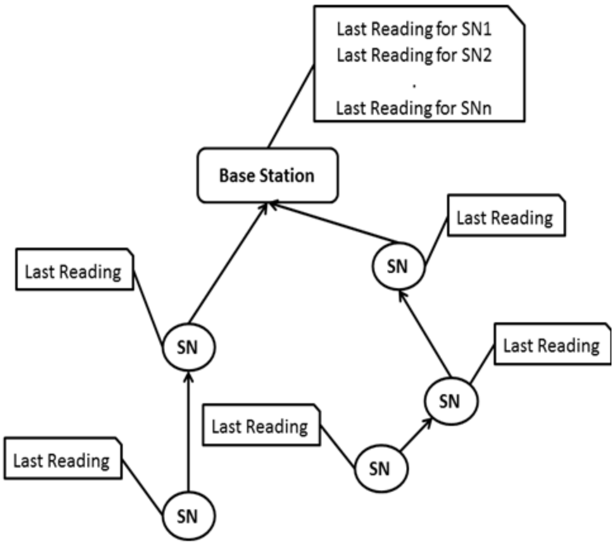

Fig. 1. WSN Structure

The structure of WSN consists of a base station and a set of sensor nodes as shown in Fig. 1. In this structure, every sensor node senses the environmental measures, and then sends the collected data to the base station through the shortest path, and save the last reading to its local memory. This process is repeated periodically for the WSN lifetime. Eventually, the base station receives all sensor nodes data and keeps a record that saves the last reading for each sensor node in the network. The base station is considered to be connected to a continuous power supply, unlike sensor nodes, which has limited power supply.

For a sensor node, the most expended amount of energy is done in the data communication processes. Consequently, the number of bits that are exchanged between two sensor nodes are included in the calculations of the energy cost. This paper applied the energy consumption model that is used in many related works in the area as in [3], [20]-[25], [27]. In this model, the needed energy for sending a k-bit packet for a distance d is given by:

$$E_{tx}(k,d) = E_{elec} \times k + \varepsilon_{amp} \times k \times d^2 \quad (1)$$

where E_{elec} is the required energy for a transmitter or receiver circuitry. ε_{amp} is the required energy for a transmitter amplifier. We assume that d is not greater than the crossover distance.

Additionally, the needed energy for receiving a k-bit packet is given by:

$$E_{rx}(k) = E_{elec} \times k \quad (2)$$

From the combination of (1) and (2), we can conclude that the needed energy to transmit a k-bit data from a sensor node n to a sensor node m with a distance d is:

$$E_{n,m}(k,d) = k \times \left(2 \times E_{elec} + \varepsilon_{amp} \times d^2\right) \quad (3)$$

IV. Overview of the Proposed Sending Approach

In this section, we present the proposed data-sending approach that reduces the overall power-consumption of WSNs. The proposed approach saves energy by reducing the number of transmitted bits. As a result, the lifetime of a WSN is extended. The proposed approach is based on changing what a sensor node sends through the network. Each sensor node transmits the difference between the current and the previous reading values represented by the least number of bits. Therefore, each sensor node needs to keep the last reading value, as well as, the base station keeps the last reading values for all sensor nodes in the WSN. The flow of the proposed approach is described in Fig. 2.

As shown in Fig. 2, in the Startup phase, the sensor node sends the first reading to the base station, and this initial reading is saved in the sensor node memory. When this initial reading is received by the base station, it is saved in the base station memory along with the sensor node that sent it. In the data collection phase, the sensor node computes the difference value between the new reading value and the previous reading (represented by the least number of bits). The equation for computing the difference value is:

$$Diff_{val} = (New\_Reading) - (Last\_Reading) \quad (4)$$

The sensor node sends the $Diff_{value}$ through the shortest path to the base station. Then, the base station will calculate the new reading as follows:

$$New\_Reading = (Diff_{val}) + (Last\_Reading) \quad (5)$$

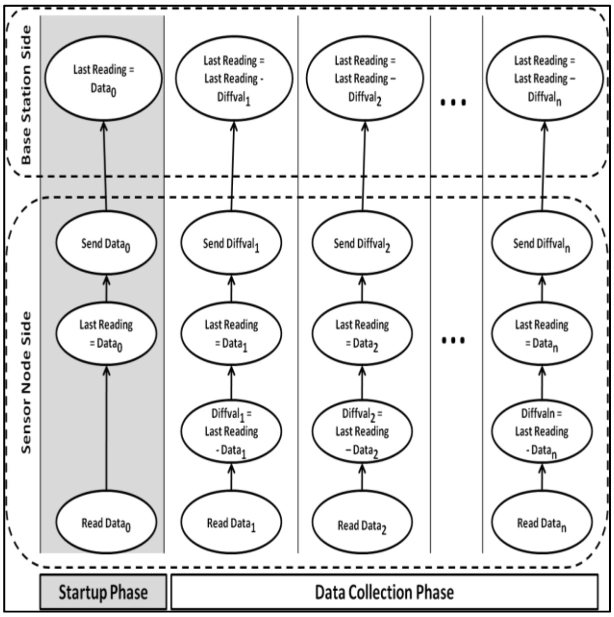

Fig. 2 Flow of the proposed approach

Algorithm 1: The Proposed Approach for a Sensor Node in a WSN.

- **For** each sample S_i **Do**:
  1. Read the current sensed $data_i$
  2. **If** the sensor node is in the Startup Phase **Then**
     i. Save the current data as the Last Reading
     ii. Represent the current data using the proposed bit representation
     iii. Send represented current data through the network to the base station
  3. **Else**
     i. Calculate $Diff_{val}$= New reading – Last Reading
     ii. Represent $Diff_{val}$ using the proposed bit representation
     iii. Send represented $Diff_{val}$ through the network to the base station
     iv. Save the $data_i$ as the Last Reading
  4. **End If**
- **End For**

For each sending process in the data collection phase, the sensor node, and eventually the base station, will save the new reading as the last reading and wait for future readings. Algorithm 1 summarizes the sensor node actions in the proposed approach.

As shown in Algorithm 1, a sensor node saves the current reading as the last reading. During the sensor node life, $Diff_{val}$ is calculated for each data sampling process and represented by the proposed approach before sending it to the base station. The proposed bit representation that is used in our approach is described in the following section.

V. The Proposed Difference Value Representation Approach

This section shows how the proposed approach works through an example and describes the proposed bit representation. Suppose that the fields being interested in are temperature and humidity. Assume that the value of the last reading for a sensor node for the temperature is 25°C (11001_2) and for the humidity is 18% (10010_2). Then, assume the temperature is increased by 5°C degrees, and the humidity is increased by 2%. The new reading values that are set to be sent, are 30°C (11110_2) and 20% (10100_2). In the proposed approached, only the difference between the old and the new values are set to be sent to the base station. In this example, the temperature difference is (30-25=5°C) (101_2), and the humidity difference is (20-18=2%) (10_2). Note that the total number of bits that need to be sent is decreased. We need to send 3 bits instead of 5 bits for the new temperature reading, and 2 bits instead of 5 bits for the new humidity reading.

However, for real environmental data, the difference between two successive sensor readings can be negative and may have a fraction. So, we propose the least number of bits representation for the difference value. The proposed representation reduces the total number of transmitted bits with a fraction.

Consider the difference value is +5.3. The proposed bit representation is generated as follows:

- Move the decimal point one position to the right to get the integer 53
- Represent 53 in binary to get 110101
- Add one bit (1) to the left to indicate the position (one position) of the decimal point to get 1110101.
- Add one bit (1) to the left to indicate the sign (+) to get 11110101.

As a result, the bits 11110101 are transmitted for the difference value +5.3. Two more bits are added to the integer representation of the difference value. The first bit indicates the sign and the second one indicates the position of the decimal point. In case the difference value is -5.3, the transmitted bits are 01110101. The first bit is set to 0 to represent the negative sign. The position bit is set to 0 when the difference value has no fraction. For example, suppose the difference value is +53. The bit representation for 53 is 110101. The transmitted bit will be 10110101. The first bit is 1 for the positive sign and the second bit is 0 because there is no decimal point.

The proposed bit representation is designed to deal with different values that have only one digit after the decimal point. Therefore, difference values that have more than one digit after the decimal point are rounded to have only one digit after the decimal point before they processed for transmission.

At the base station, the difference value is obtained by getting the decimal representation of bits sequence that starts from the third bit. Then, the remaining first two bits are checked. In case the value of the second bit is one, a decimal point is placed after the first decimal digit from the right. Finally, the sign of the difference value is determined based on the first bit.

VI. EVALUATION

In this paper, we proposed a new approach to represent the transmitted sensed data. The approach sends the difference between the last two measured values instead of the last sensed value represented in binary.

The goal of the evaluation is to prove the effectiveness of our approach in saving energy and reducing the number of transmitted bits by a sensor node in WSNs. The evaluation is done based on real datasets for measured weather temperatures collected from three different locations. The source of these sets is a research project for Professor Martin Vetterli [26]. The details of the three datasets are listed in Table I. Each location is shown in the table with the total number of measured samples and the days when these samples are obtained.

TABLE I. DETAILS OF THE USED THREE DATASETS

City	# of Samples	Days
Le Gènepi, Switzerland	43086	8/28/2007 to 10/31/2007
Le Borien, Switzerland	14246	8/6/2007 to 09/02/2007
PlaineMorte, Switzerland	3213	3/13/2007 to 03/15/2007

For the evaluation purposes, we implemented a Java event-driven simulator. The goal is to evaluate the effectiveness of the proposed approach in reducing the size of transmitted data compared to sending the exact value represented in binary. The simulator was validated using randomly selected values by matching the obtained output with the hand calculations. A performance comparison between the two approaches is made based on the three real datasets mentioned in Table I.

In each simulation, we assumed that all sent values are from the same sensor node. The idea is to compare the size of transmitted data by a single sensor in which the result can be generalized to any number of sensors. In each simulation, the sensor node is located in one of the three previously mentioned locations and is set to employ one of the two approaches.

Fig. 3 shows the evaluation results for the three datasets based on the size of transmitted data. As shown in the figure, the total number of transmitted bits, using the exact value approach (referred to by Exact), is 138624, 23556 and 329835 for the three data sets Le Borien, PlaineMorte, and Le Gènepi respectively. The result of each data set was compared with the result of using the difference value approach (referred to by Diff) for the same data set. Based on this comparison, the difference value approach reduced the number of transmitted bits by 36% in Le Borien, 61% in PlaineMorte and 49% in Le Gènepi. The results prove that the difference value approach reduced effectively the size of transmitted bits by that sensor.

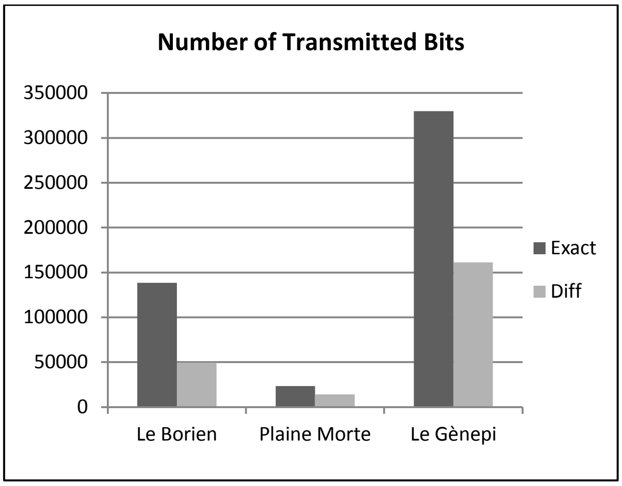

Fig. 3. Total number of transmitted bits using exact value (Exact) and difference value (Diff) approaches

Based on the number of transmitted bits, the energy consumption is calculated. Fig. 4 shows the energy consumptions for the three datasets. As shown in the figure, the total energy consumption, using the exact value approach, is 0.00694506239999929 J, 0.0011801556 J and 0.0165247334999999J for the three data sets Le Borien, PlaineMorte and Le Gènepi respectively. The result of each data set was compared with the result of using the difference value approach for the same data set. The difference value approach reduced total energy consumption by 36% in Le Borien, 61% in PlaineMorte and 49% in Le Gènepi.

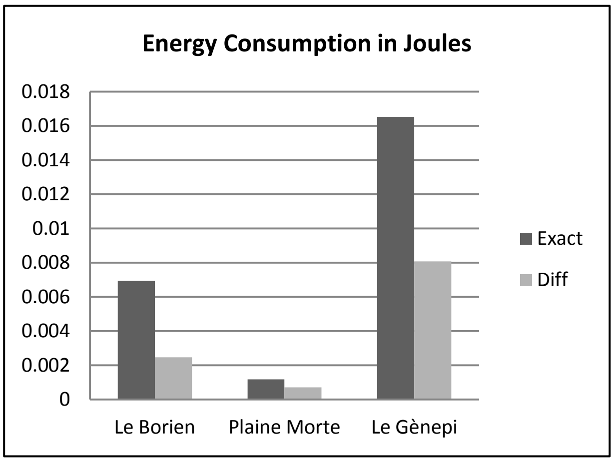

Fig. 4. Total energy consumption using exact value (Exact) and difference value (Diff) approaches

Table II shows another comparison based on the maximum and the minimum number of transmitted bits in packets. The median values are also shown. The first three columns, "Exact Value" columns, show results of using exact bit representation for values. The other three columns, "Diff Value Approach" columns, show the results from using the difference value representation. The difference value representation has much less median values (1, 2 and 1) compared to (8, 6 and 6) for the three cities. The same observation is also noticed in Table III with comparing energy consumption. The median values for the proposed approach are less than those values with exact value bit representation.

TABLE II. NUMBER OF TRANSMITTED BITS RESULTS BASED ON MAX, MIN AND MEDIAN COMPARISON

	Exact Value			Diff Value Approach		
	Max	Min	Avg	Max	Min	Avg
Le Borien	9	6	8	9	1	1
Le Gènepi	8	1	6	8	1	2
PlaineMor.	8	1	6	9	1	1

TABLE III. ENERGY CONSUMPTION RESULTS BASED ON MAX, MIN AND MEDIAN COMPARISON

	Exact Value			Diff Value Approach		
	Max	Min	Avg	Max	Min	Avg
Le Borien	5.51E-07	4.01E-07	5.01E-07	5.51E-07	1.5E-07	1.5E-07
Le Gènepi	5.01E-07	1.5E-07	4.01E-07	5.01E-07	1.5E-07	2.0E-07
PlaineMor.	5.01E-07	1.5E-07	4.01E-07	5.51E-07	1.5E-07	1.5E-07

VII. CONCLUSION

Due to the limited energy in sensor nodes, data transmission and representation play a crucial role in WSNs lifetime. This paper presented an approach to reduce the energy consumption for a sensor node based on sending the difference value of two successive readings instead of the actual reading values. This difference value reduces the size of the payload of the transmitted data. A special simulator is implemented to evaluate the proposed approach on a real sensors data sets. Results show that the Difference value approach achieved better performance than the exact value approach.

Our future work aims to consider more enhancements on bit representation as compression. Another possible extension of this work is to utilize clustering techniques to send the proposed difference values by a subset of sensor nodes.

REFERENCES

[1] X. Liu, "Atypical hierarchical routing protocols for wireless sensor networks: A review," *IEEE Sensors Journal*, vol. 15, no. 10, pp. 5372-5383, 2015.

[2] S. Jancy and C. Jaya Kumar, "Sequential coded data compression techniques for wireless sensor networks," *International Journal of Engineering Research and Technology*, vol. 3, no. 9, 2014.

[3] Q. Iqbal, "Traffic based energy consumption optimization to improve the lifetime and performance of ad-hoc wireless sensor networks," Doctoral dissertation, Aston University, 2011.

[4] T. Schoellhammer, B. Greenstein, E. Osterweil, M. Wimbrow, and D. Estrin, "Lightweight temporal compression of microclimate datasets," in *Proc. 29th Annual IEEE International Conference on Local Computer Networks*, 2004.

[5] A. K. Maurya, D. Singh, and A. K. Sarje, "Median predictor based data compression algorithm for wireless sensor network," *International Journal of Smart Sensors and Ad Hoc Networks*, vol. 1, no. 1, pp. 62-65, 2011.

[6] C. Tharini and P. Vanaja, "Design of modified adaptive Huffman data compression algorithm for wireless sensor network," *Journal of Computer Science*, vol. 5, no. 6, pp. 466-470, 2009.

[7] H. P. Medeiros, M. C. Maciel, R. D. Souza, and M. E. Pellenz, "Lightweight data compression in wireless sensor networks using huffman coding," *International Journal of Distributed Sensor Networks*, vol. 10, no. 1, 2014.

[8] M. Yuanbin, Q. Yubing, L. Jizhong, and L. Yanxia, "A data compression algorithm based on adaptive Huffman code for wireless sensor networks," in *Proc. International Conference on Intelligent Computation Technology and Automation*, 2011, pp. 3-6.

[9] J. G. Kolo, L. Ang, S. A. Shanmugam, D. W. G. Lim, K. P. Seng, "A simple data compression algorithm for wireless sensor networks," in *Soft Computing Models in Industrial and Environmental Applications*, Springer Berlin Heidelberg, 2013, pp. 327-336.

[10] M. A. Raja and V. Malathi, "An LMS based data reduction technique for energy conservation in wireless sensor network (WSN)," *International Journal of Computer Technology and Applications*, vol. 3, no. 4, 2012.

[11] S. Santini and K. Romer "An adaptive strategy for quality-based data reduction in wireless sensor networks," in *Proc. 3rd International Conference on Networked Sensing Systems*, 2006, pp. 29-36.

[12] M. Arunraja, V. Malathi, and E. Sakthivel, "Energy conservation in WSN through multilevel data reduction scheme," *Microprocessors and Microsystems*, vol. 39, no. 6, pp. 348-357, 2015.

[13] L. Mesin, S. Aram, and E. Pasero, "A neural data-driven algorithm for smart sampling in wireless sensor networks," *EURASIP Journal on Wireless Communications and Networking*, no. 1, pp. 1-8, 2014.

[14] S. Aram, I. Khosa, and E. Pasero, "Conserving energy through neural prediction of sensed data," *Journal of Wireless Mobile Networks, Ubiquitous Computing and Dependable Applications*, vol. 6, no. 1, pp. 74-97, 2015.

[15] F. A. Aderohunmu, D. Brunelli, J. D. Deng, and M. K. Purvis, "A data acquisition protocol for a reactive wireless sensor network monitoring application," *Sensors*, vol. 15, no. 5, pp. 10221-10254, 2015.

[16] J. Heidemann, F. Silva, C. Intanagonwiwat, R. Govindan, D. Estrin, and D. Ganesan, "Building efficient wireless sensor networks with low-level naming," *ACM SIGOPS Operating Systems Review*, vol. 35, no. 5, pp. 146-159, 2001.

[17] C. Intanagonwiwat, R. Govindan, and D. Estrin, "Directed diffusion: A scalable and robust communication paradigm for sensor networks," in *Proc. 6th Annual International Conference on Mobile Computing and Networking*, 2000, pp. 56-67.

[18] B. Krishnamachari, D. Estrin, and S. Wicker, “The impact of data aggregation in wireless sensor networks,” in *Proc. 22nd International Conference on Distributed Computing Systems Workshops*, 2002, pp. 575-578.

[19] A. Rooshenas, H. R. Rabiee, A. Movaghar, and M. Yousof Naderi, “Reducing the data transmission in wireless sensor networks using the principal component analysis,” in *Proc. 6th International Conference on Intelligent Sensors, Sensor Networks and Information Processing*, 2010, pp. 133-138.

[20] M. Bsoul, Y. Kilani, M. Hammad, E. E. Abdallah, and A. Alsarhan, “An index-based approach for wireless sensor networks,” *Wireless Personal Communications*, vol. 82, no. 4, pp. 2185-2197, 2015.

[21] E. J. Duarte-Melo and M. Liu, “Analysis of energy consumption and lifetime of heterogeneous wireless sensor networks,” in *Proc. IEEE Global Telecommunications Conference*, 2002, pp. 21-25.

[22] P. Casari, A. Marcucci, M. Nati, C. Petrioli, and M. Zorzi, “A detailed simulation study of geographic random forwarding (GeRaF) in wireless sensor networks,” in *Proc. IEEE Military Communications Conference*, 2005, pp. 59-68.

[23] S. Du, A. K. Saha, and D. B. Johnson, “RMAC: A routing-enhanced duty-cycle MAC protocol for wireless sensor networks,” in *Proc. 26th IEEE International Conference on Computer Communications*, 2007, pp. 1478-1486.

[24] Y. Sun, S. Du, O. Gurewitz, and D. B. Johnson, “DW-MAC: A low latency, energy efficient demand-wakeup MAC protocol for wireless sensor networks,” in *Proc. 9th ACM International Symposium on Mobile ad Hoc Networking and Computing*, 2008, pp. 53-62.

[25] S. Bahrami, H. Yousefi, and A. Movaghar, “Daca: Data-aware clustering and aggregation in query-driven wireless sensor networks,” in *Proc. 21st International Conference on Computer Communications and Networks*, 2012, pp. 1-7.

[26] Sensorscope: Sensor Networks for Environmental Monitoring. [Online]. Available: http://lcav.epfl.ch/sensorscope-en

[27] M. Bsoul, “A differential indexing approach for wireless sensor networks,” *Wireless Personal Communications*, vol. 97, no. 2, pp. 2649-2663, 2017.

Mustafa Hammad is an Associate Professor at the Department of Computer Science in Mutah University - Jordan. He received his PhD. in Computer Science from New Mexico State University - USA in 2010. He received his Master’s degree in Computer Science from Al-Balqa Applied University - Jordan in 2005 and his B.Sc. in Computer Science from The Hashemite University - Jordan in 2002. His research interest is in Software Engineering with focus on static and dynamic analysis and software evolution.

Mohammad Bsoul is an Associate Professor in the Computer Science Department of the Hashemite University. He received his B.Sc. in Computer Science from Jordan University of Science and Technology, Jordan, his Master from University of Western Sydney, Australia, and his Ph.D. from Loughborough University, UK. His research interests include wireless sensor networks, grid computing, cloud computing, distributed systems, and performance evaluation.

Maen Hammad is an Associate Professor in the Software Engineering Department at The Hashemite University, Jordan. He completed his Ph.D. in computer science at Kent State University, USA in 2010. He received his Master in computer science from Al-Yarmouk University—Jordan and his B.S. in Computer Science from The Hashemite University—Jordan. His research interest is Software Engineering with focus on software evolution and maintenance, program comprehension and mining software repositories.

Muna Al-Hawawreh is a Ph.D. candidate of Computer Science in the University of New South Wales (UNSW), Australia. She has a Master’s degree in Computer Science from Mutah University, Jordan and Bachelor’s degree in Computer Science from Al-Hussein bin Talal University, Jordan. Her main research interests are cybersecurity, computer networks with a focus on deep and machine learning applications.