Computers and Electrical Engineering 000 (2017) 1–19

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

Usage of mobile elements in internet of things environment for data aggregation in wireless sensor networks☆

Hanady M. Abdulsalam*, Bader A. Ali, Eman AlRoumi

Department of Information Science, Kuwait University, Kuwait

ARTICLE INFO

Article history:
Received 29 May 2017
Revised 12 December 2017
Accepted 13 December 2017
Available online xxx

Keywords:
Wireless sensor networks
Data aggregation
Data streams
Internet of things (IoT)

ABSTRACT

The main issue to be addressed in Wireless Sensor networks (WSN) applications is the limited life time of sensors and short communication range. Professional data aggregation techniques are, therefore, needed. In this paper, we consider the problem of increasing the WSN lifetime using a cluster-based data aggregation algorithm. We propose a novel method in tackling the problem. We use Mobile Elements (ME) in Internet of Things (IoT) environment to act as Cluster Heads in a cluster-based aggregation algorithm. We believe that utilizing the IoT technology by mixing it with the WSN technology leads to good results. Our experiments show an impressive extend the network lifetime, while not effecting the quality of data gathering.

1. Introduction

Wireless Sensor Networks (WSN) are wireless networks that consist of a large number of sensing devices (sensors) that are either distributed among geographical areas such as environmental monitoring and flood detection or attached to specific objects such as patients in health-care and cars in traffic control applications. A typical WSN collects data records from the sensors and sends them to base stations to be processed and analyzed depending on the application that it is used for. Decisions are, then, taken based on the analysis. Examples of the data that can be collected include temperature, humidity, light conditions, seismic activities, etc.

Data aggregation in WSN form an ongoing active research area due to its importance in solving the main drawbacks of using WSNs, namely, the limited life time for battery powered sensors, and the short communication range of the sensors. A number of data aggregation methods appear in the literature, such as LEACH, DD, FEDA, TAG, OCABTR, CLUDDA, SUMAC, etc. [1–8]. Many of the existing aggregation algorithms for WSNs are designed to work with cluster-based routing algorithms [1–6], while some others are based on other ways of routing [7,8] such as direct connection between sensors and the base station.

In this paper, we only consider the cluster-based routing algorithms. The cluster-based routing algorithms form a two layer sending procedure. They group nearby sensors together to form a number of clusters. Each cluster has one representative sensor called Cluster Head (CH). CHs are required to collect data from other sensors in their cluster and send the aggregated data to the base station. The decision of choosing CHs in cluster-based aggregation algorithms can be either centralized; decided by the base station, or distributed; based on the decision of the sensors. The key feature of cluster-based

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Associate Editor Dr. V. Sai.

* Corresponding author.
E-mail address: hanady.abdulsalam@ku.edu.kw (H.M. Abdulsalam).

https://doi.org/10.1016/j.compeleceng.2017.12.028

algorithms in increasing the network life-time is that, because not all sensors interact with the base station, more energy is saved and the network lifetime is extended.

Recently, several WSN architectures based on mobile elements (MEs) have been proposed [9–13]. Mobile Elements can be any external device that is passing through the network with sensing and sending capabilities. For cluster-based networks, the role of MEs in each architecture is different [14]. MEs can be:

Regular sensor nodes that are sources of data, responsible for sensing the data records and sending them to CHs,
Base stations that are the destinations of data and, are usually the processing elements in the network, and/or
Cluster heads that aggregate data as intermediate data collectors or gateways to base stations.

We consider the scenario where MEs take only the role of cluster heads. However, we assume that the MEs that are used in transferring the data are not WSN-registered mobile sensors. They are, instead, anonymous MEs that are passing through the network, then got discovered by the Internet of Things (IoT) technology, and connected to the wireless network. Internet of Things (IoT) [15] is a recent technology and an active research area in the field of objects communication and data transmission. It is a technology that connects different objects, such as smart-phones, sensors, and people to the Internet in order to allow accessibility to the data.

We propose an energy-efficient data-aggregation technique for WSN using MEs in an IoT environment. The proposed solution is a cluster-based algorithm such that the MEs act as CHs. We take into consideration the frequency at which MEs enter the network as well as their space distribution among the network area. Depending on the flow of MEs into the WSNs, we define four possible scenarios:

Scenario 0 is the basic scenario where it is assumed that the MEs continuously flow into the network, and uniformly distributed while traveling through the network area. Clearly, such situation is basic and ideal since in real applications it can not be guaranteed that there will be MEs passing through the network all the time and yet traveling uniformly through it. The only new issue for Scenario 0 is that the CHs are not regular sensors anymore, instead, they are MEs that are interchangeably passing through the network with high power capabilities when compared to regular sensors. Hence, the battery power limit is no more an issue like when using regular sensor.

Scenario 1 is the scenario that introduces the concept of nonuniform distribution of MEs among the area of WSN while frequently having them presented in the network. In this scenario, the MEs do not uniformly travel through the network. We assume having them biased towards one side of the network area. The main issue to be addressed for this scenario is, therefore, the coverage of the areas with no MEs passing through them.

Scenario 2 is the case that assumes there are time periods of the network lifetime during which there are few or probably no MEs passing through the network. This case defines the nonuniform entrance frequency of the MEs to the network. The coverage of these time periods with no MEs are the concern of this scenario.

Scenario 3 is the most general case, where it assumes a mixture between all the above scenarios through different time periods, such that each time period of this scenario can be either Scenario 0, 1, or 2, or an overlap of two scenarios. All of the previously mentioned scenarios are, therefore, special cases of Scenario 3 at some time period.

To handle the different scenarios while not affecting the data aggregation accuracy, we further improve our proposal into a hybrid solution that switches the aggregation from ME dependent technology to the regular WSN technology based on the unavailability of the MEs to act as CHs into the network. This ensures that the aggregation is independent of the presence of the MEs.

We simulate our algorithm using the different above mentioned scenarios. Our results show that the network lifetime is improved, while not significantly affecting the data aggregation accuracy.

The remainder of the paper is organized as follows: Section 2 states background and related work. Section 3 proposes our basic and hybrid data aggregation algorithm using MEs in IoT environment. Section 4 explains the implementation and experimental settings. Section 5 states the discussion and results. Finally, Section 6 draws our conclusions and future work.

2. Background and related work

2.1. Background

2.1.1. Internet of things

The Internet of Things (IoT) computing model has gained a lot of popularity in the last decade. Recently, an increasing number of IoT projects are being done in different areas like agriculture, environmental monitoring, and security surveillance. Initially, the term IoT used to refer to the interoperability of uniquely identifiable objects with radio-frequency identification (RFID) technology [15]. Later, the definition of the IoT has expanded to refer to a network of interconnected objects/devices such as RFID tags, sensors, actuators, smart phones, and single board computers. These objects are able to collect data from its environment through sensors, interact with the physical world by processing and applying actions, and establish communication by utilizing the existing communication protocol standards. In an IoT environment, the objects are expected to cooperate to reach common goals [16].

A number of underlying key technologies form the foundation on which the IoT relies [17,18]. One of the main technologies is RFID which allows chips to transmit identification information through wireless communication. RFIDs have been widely used in logistics, and tracking applications. Another key technology is the wireless sensor networks (WSNs) utilizing large number of intelligent sensors to collect, aggregate, and disseminate important information from different environments such as environmental monitoring, industrial monitoring, traffic monitoring, and others. The different communication/Internet protocols (i.e., TCP/IP, WiFi, Bluetooth, Zigbee, etc) provides essential support for the IoT by enabling users to control the objects and objects to communicate with each other. In addition, other technologies like smart devices, social networks and cloud computing are being used to support the IoT.

There are several application domains in which IoT technology is being developed [17,19,20]. One of the main domains in which IoT is being used is mobile IoT applications. These applications are concerned with monitoring and sensing of different environments implemented through traditional WSNs like traffic monitoring, environmental monitoring, and logisitics. In monitoring applications, getting accurate timely information is of importance. Utilizing IoT technology by recruiting smart mobile objects equipped with sensors to participate in sensing tasks can greatly improve the efficiency, accuracy, coverage, and availability of traditional WSNs as well as increase the life span of WSNs.

2.2. Related work

Recent work on WSN cluster-based aggregation involves using mobile cluster heads instead of regular still sensors [9–13]. The idea behind that is to reduce the distance between the CH and the base station, hence, less energy is consumed. To the best of our knowledge, none of the recent research in the area consider mixing the IoT and the WSN technologies in aggregating the data, such that external arbitrary MEs are CHs only and all other sensing devices are regular sensors.

Banerjee et al.propose a scheme for enhancing the network lifetime using multiple energy rich nodes mobile CHs that can move in the WSN in a controllable manner [9]. The goal is to enhance the lifetime of the WSN by proposing event-driven mobility strategies for CHs. Once the cluster formation step is completed, they are kept fixed, and only the CHs move in the direction of the event, keeping the other members of the cluster static. The CH controllably moves toward the energy-rich sensors or the event area, offering the benefits of maintaining the remaining energy more evenly, or eliminating multihop transmission.

Ma and Yang [10] have proposed an algorithm that works on positioning of mobile cluster heads and balancing traffic load in sensor network that consists of static and mobile nodes. They state that the location of the cluster head in the clustered network can significantly affect the network lifetime. Moving cluster heads to better location network load can, therefore, balance the load and prolong the network lifetime accordingly.

Kunmar et al. [12] enhance the LEACH-Mobile technique [11], which supports the mobility of all sensors including the CHs. While LEACH-Mobile elects a node with less mobility than its neighbours as cluster head, the Enhanced LEACH-Mobile protocol is based on a mobility metric ”remoteness” for cluster head election, such that mobility measure should have a linear relationship with link change rate. This ensures high success rate in data transfer between the cluster head and the collector nodes even though nodes are moving.

LEACH-MAE [13] improves the LEACH protocol to support mobility along with a new average energy based CH selection technique which is optimized for the mobile nodes. This proposed modification is made on the basis of CH selection algorithm to ensure that power resource is equally distributed among the sensor nodes and every sensor node has an ability to become cluster head.

3. Data aggregation in WSNs using mobile elements (MEs) in IoT environment

As it has been mentioned earlier, the main issue to be addressed in WSNs environments is the limited battery power of the sensors. The power drops as the sensors send data. The main parameter that effects the power drop is the distance of sending the data. Many aggregation techniques do, therefore, use clusters to limit the distance of sending the data, so that regular sensors send the data to the cluster heads, while only the cluster heads send the data further to the base stations. Hence, more power is saved. The CHs role is, then, rotated among different sensors either randomly or based on some metrics, such as the remaining energy or the distance to base station, or probably only replaced when they are out of power.

3.1. Basic solution details

We propose a solution of having the CHs as external MEs that pass through the network. For each round, as MEs are passing through the network, they get discovered by the base station through IoT environment, then their locations are published to all the sensors in the network after taking their permission to participate in the network and act as cluster heads. Permissions are taken to ensure that the main function of the MEs do not collapse. The MEs, then, collect data from the sensors through IoT, and finally send the collected data to the base station of the WSN. A ME can be a car sensor, a mobile phone sensor, a smart watch sensor, etc. Each round of data collection can be basically thought of having four phases:

ME discovery where each ME is discovered through the base station
ME location broadcast where the base station broadcasts the location of each ME to the sensors

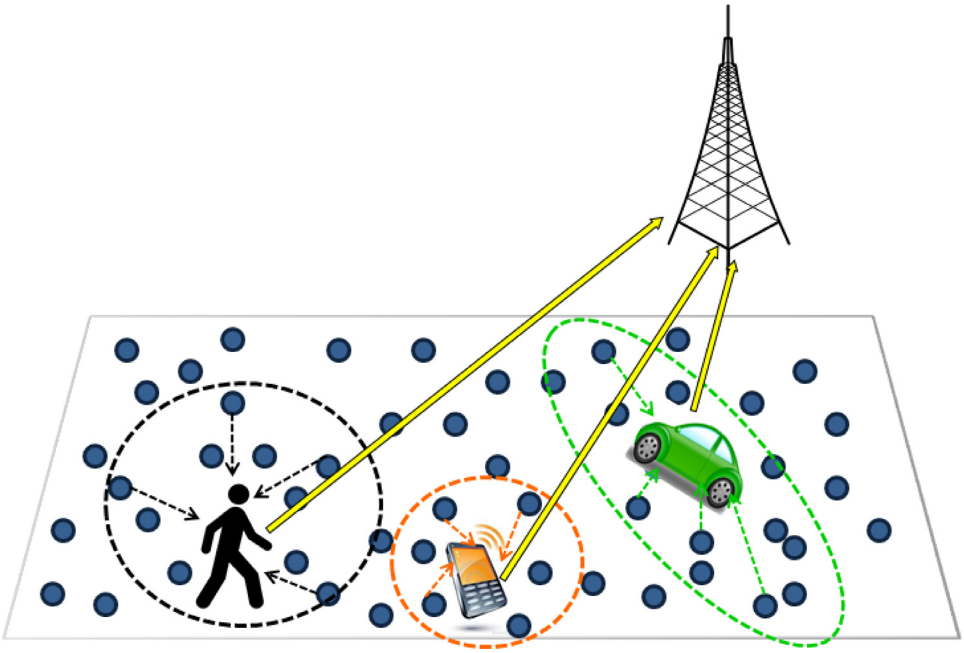


Fig. 1. General solution.

ME data collection where each ME receives the data records from its close by sensors
Base station data collection where each ME sends the collected data to the base station

Fig. 1 shows the general view of the proposed solution. This solution can only handle Scenario 0- described in the introduction section- where it is assumed that MEs are always presented and uniformly scattered among the network area. the next subsection proposes a modification to handle Scenarios 1 through 3.

3.2. Hybrid solution details

We further extend our solution to handle the cases of Scenarios 1 through 3, where MEs are not uniformly distributed among the network area and/or MEs are not presented during some time periods.

We first propose a measure to check wether there are sensors that are not sending data records for a number of rounds because no MEs have passed through them for some time period. Reasons of not having MEs passing through them are either because of lack of MEs for some time periods or the nonuniform distribution of MEs through the network area.

Assume that the network is divided into equal number of square zones n_z. Each zone z_i where $0 \leq i \leq n_z$ covers part of the network. If at any round r_j, where $0 \leq j \leq R$, and R is the total number of rounds, a sensor s_{z_i} that is located in zone z_i sends data to a ME, the zone z_i is said to be a covered zone during round r_j. Otherwise, zone z_i is said to be an uncovered zone during r_j. If a zone z_i stays uncovered for c numbers of rounds, then this zone should alternatingly switch to a regular cluster-based aggregation algorithm where the zone is considered a cluster, and a CH is elected based on the maximum remaining energy of the sensors in this cluster. Members of the cluster, then, send data to the elected CH sensor, and the CH forwards the data to the base station using the regular setting of the WSN. Fig. 2 shows the hybrid solution.

3.3. Solution algorithm

Based on the above explanation, the steps of performing the proposed solution can be summarized in Algorithm 1.

3.4. System architecture

The proposed solution can be applied using the architecture in Fig. 3. An existing WSN is built on top of an IoT environment. The MEs that are mentioned in the solution are assumed to be part of the IoT environment. The interaction and communication between the different components of the system are explained in details in the next subsections.

3.4.1. Interaction

A number of interactions take place between the components of the system. From Fig. 3, the static sensors in the WSN are responsible for collecting data from the sensed field. Each round, the sensors send the sensed data to the closest ME that

Please cite this article as: H.M. Abdulsalam et al., Usage of mobile elements in internet of things environment for data aggregation in wireless sensor networks, Computers and Electrical Engineering (2017), https://doi.org/10.1016/j.compeleceng.2017.12.028

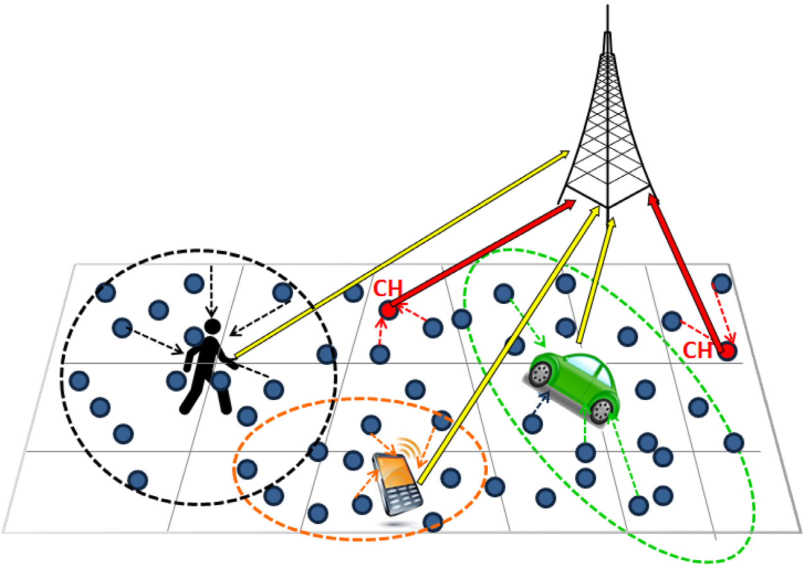


Fig. 2. Hybrid solution.

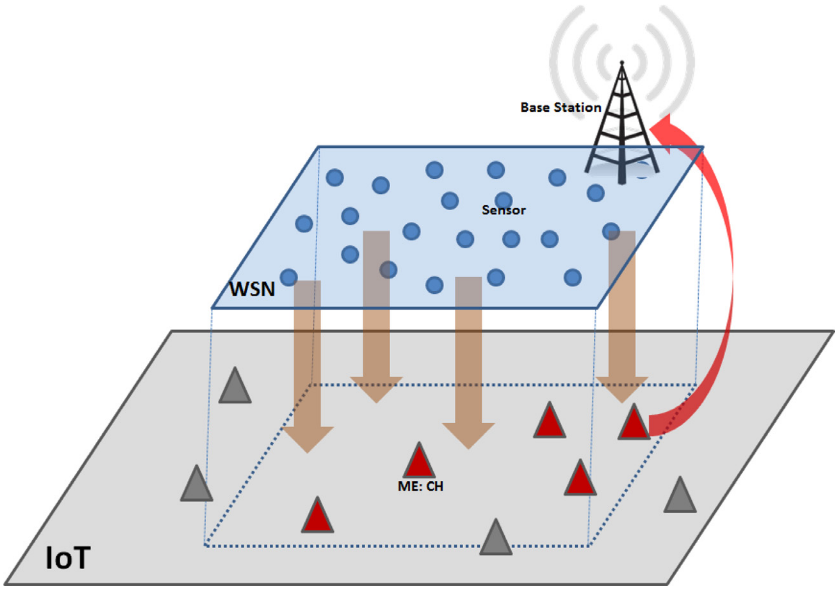
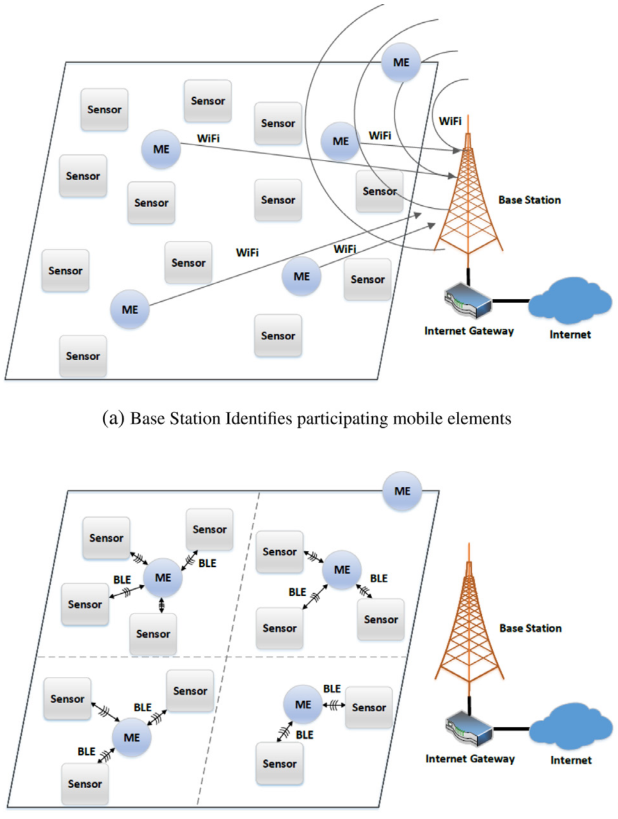


Fig. 3. System Architecture.

is passing through the area of the WSN. The MEs relay the aggregated data to the base station. The MEs passing through the WSN are discovered and identified by the base station in each round. Finally, the base station is equipped with an Internet gateway through which the data records are sent to the backend servers or the cloud for processing and storage.

3.4.2. Communication

The communication between the different components of the system is achieved through a number of protocols. Most of the existing wireless sensors networks communicate using IEEE 802.15.4/ZigBee standards [21] to relay data to the base station. Recently, wireless sensors equipped with other communication protocols like WiFi and Bluetooth low energy (BLE) are starting to emerge [22,23]. Bluetooth Low-Energy (BLE) uses a short range radio and minimum amount of power to operate. Its coverage range is around (100 m) and have a very short latency [24]. BLE can be operated at a transmission power between 0.01 mW to 10 mW. Compared to ZigBee, BLE is more efficient in terms of energy consumption [24] which makes it a good candidate for WSNs. In both cases, it has been shown that the energy consumption from employing WiFi and BLE is very low leaving the sensors with a long life span. In addition, WSNs are proved to have more flexibility from utilizing these mainstream communication technologies to achieve easier interaction with external elements.



(a) Base Station Identifies participating mobile elements
(b) Base station broadcasts list of participating mobile elements to sensors
(c) Sensors send collected data to mobile elements
(d) Mobile elements push collected data to Base Station

Fig. 4. The different steps of the proposed data aggregation solution.

The MEs need to communicate with the wireless sensors to collect the sensed data and at the same time need to communicate with the base station to relay the collected data. The MEs that we consider in our system like smart phones, smart cars, and single board computers (e.g., Arduino, Raspberry etc.) are assumed to have simple processing capabilities, moderate storage, and communication capabilities like WiFi/Bluetooth. Therefore, the MEs use the available WiFi /Bluetooth capabilities to communicate with the sensors and the base station. At the base station end, a wireless internet gateway with wide coverage is setup to allow the data to be collected from the mobile elements and later pushed to the servers or cloud.

3.4.3. *Architecture example*

We explain the different stages of the system through an example. Figs. 4a though d show the different stages of interaction between the components of the system.

In the system, MEs pass through various parts of sensed field at different times. At the beginning of each data aggregation round, Fig. 4a, the base station discovers the position of the ME that are available within the sensing field. This is done by sending a broadcast message (beacon) using WiFi over the sensing field. The ME that is willing to participate in the current round reply back with an acknowledge message identifying their GPS position within the field. In the next step, the base station announces the position of the participating ME to all the static sensors in the field as shown in Fig. 4b. Using the list of ME positions, each sensor determines its closest ME by applying a simple computation. Once the closest ME is identified, the sensor communicates with the ME over BLE and sends the sensed data as its presented in Fig. 4c. At this stage all the ME elements have collected the data from the static sensors. In the final step, demonstrated in Fig. 4d, the mobile elements relay the data to the base station and the base station later sends the data through the gateway to the dedicate servers or cloud service for further processing.

4. Implementation and experimental settings

We simulate our algorithm using C-Language and test it on Scenarios 0 to 3. We also simulate LEACH [1] as being well-known cluster-based algorithm to compare it with our proposed solution. For our simulation, we assume that all sensors can directly reach each others and reach the base station. Hence, no specific routing algorithm is used. We also assume that

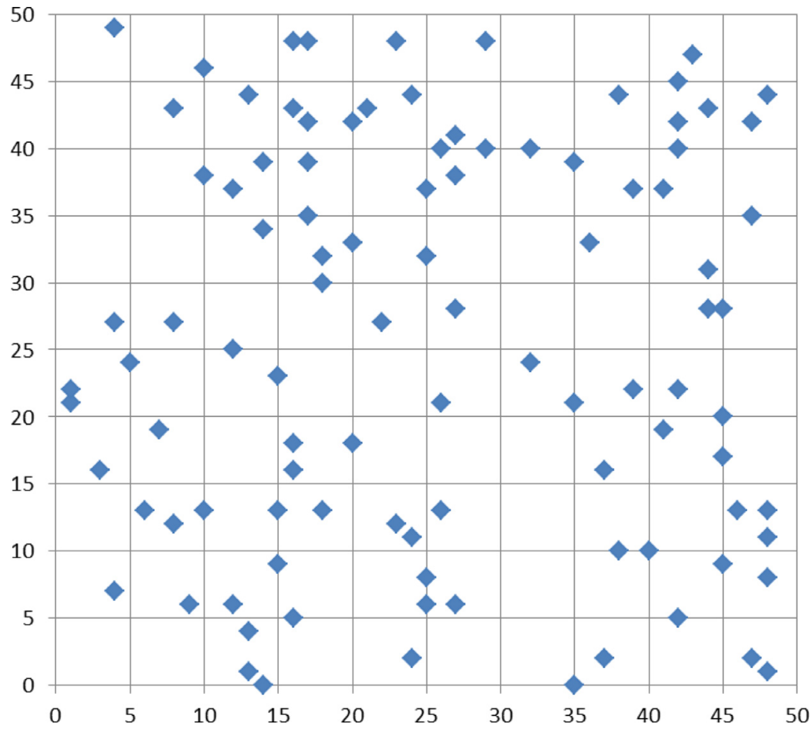


Fig. 5. Network structure.

once the data is sent then it is received at the other end since calculating the success rate of data delivery is out the scope of the paper.

4.1. Testing criteria

The criteria by which we evaluate our work are:

- *First node dies, last node dies, and average sensor lifetime:* records the rounds at which the first sensor in the network dies and the last sensor in the network dies, and computes the average of lifetimes for sensors in number of rounds. Note that the network lifetime can be adjusted according to the objectives of the network. If the objectives of the network state that the network is only considered alive when having at least u alive sensors, then the last node dies is set to be when u sensors are dead.
- *Number of alive sensors:* records the number of sensors that are still alive at each round.
- *Remaining energy:* calculates the total remaining energy for the network for each round.
- *Network coverage:* shows how the network zones are covered in term of sending sensors during each round.

Results for all criteria are averages over 20 runs, while randomly selecting CHs/sending sensors for each run. Note that each result represents a full complete run for the simulation, which means each run is set to continue running until the last node dies, and that explains the different number of rounds resulting from each run.

4.2. Simulation settings

4.2.1. Parameters settings

We test the algorithms using an initial number of alive sensors $n = 100$, each with a sending range of $r = 10$ meters. We use a network of size 50×50 meters, with a base station located at point [50,100]. The network we base our testing on is shown in Fig. 5.

The chosen network size and number of sensors are widely used in the area of aggregation in WSN [1,25]. According to standards, the communication range of sensors can grow up to 100 m for outdoor sensors and 20 to 30 m for indoor sensors depending on the used sensors. We use a short sending range to be considered as the worst case. Based on the application, higher range sensors can be used and the network size can accordingly be increased as well.

We empirically set the size of the zones to $z = 10 \times 10 = 100$ m^2, assuming it's a reasonable distance to be covered by walking people, which are our slowest assumed MEs as it will be explained in Section 4.2.2. We also empirically test two

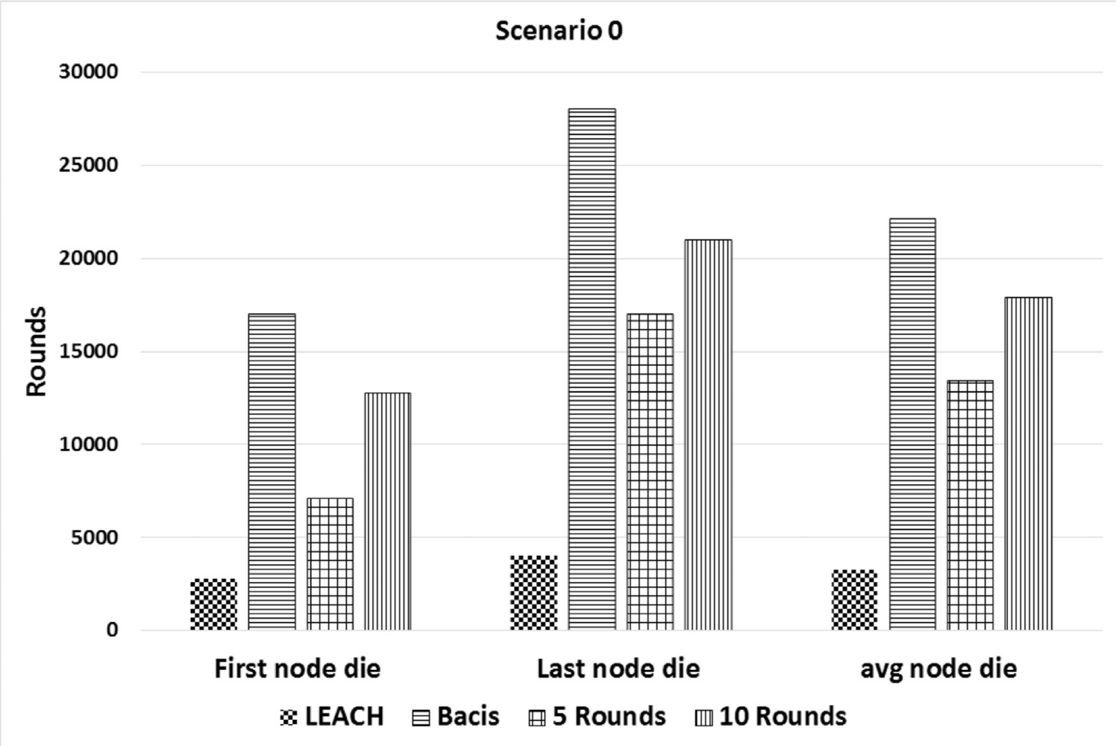


Fig. 6. First node dies, last node dies, and average lifetime for LEACH, basic solution of Scenario 0, and hybrid solution for Scenario 0.

Table 1
Radio characteristics.

Operation	Energy dissipation
Transmitter/Receiver electronics e_{elec}	50 nJ/bit
Transmit amplifier ϵ_{amp}	100 pJ/bit/m^2

values of c, which is the number of non sending rounds at which the hybrid solution gets activated, such that $c = 5$ and 10 rounds. Each round is set to be one minute. This setting can be changed based on the application.

The energy calculations are based on the energy settings by LEACH [1]. The initial energy $e_{initial}$ of each sensor is set to 1 J. The sensors' energy consumption for transimiting/receiving data in our work is based on the radio model and equations shown in Table 1.

For transmitting a message,

$$e_T(k, d) = e_{elec} * k + \epsilon_{amp} * k * d^2,$$

and for receiving a message,

$$e_R(k) = e_{elec} * k,$$

where d is the distance of sending the message, and k is the size of the transmitted/received message. We set k, the size of transmitted message to 2000 bits.

4.2.2. Mobile elements settings

For the sake of reality, we define three types of MEs with speeds 1, 2, and 5, where the speed unit is just a step into the network. We assume that an ME with speed 1 would be a walking person, while the MEs with speeds 2 and 5 are bicycle and cars with low speeds respectively. We do not consider the high speed elements in our work. We also assume when an ME is entering the network then it can be of any type of the three defined MEs with equal probability. In addition, when an ME enters the network then its travel direction is chosen randomly with the possibility to travel vertically, horizontally, or diagonally. If two MEs collide, then each ME randomly chooses another direction and continue its travel. Note that this is considered to be the worst case scenario since in reality this proposed system would be practically applied on road maps, which has defined paths to walk through for both automobiles and pedestrians.

Please cite this article as: H.M. Abdulsalam et al., Usage of mobile elements in internet of things environment for data aggregation in wireless sensor networks, Computers and Electrical Engineering (2017), https://doi.org/10.1016/j.compeleceng.2017.12.028

4.2.3. Scenarios settings

The assumptions on which we base our simulation for Scenarios 0 through 3 are:

Scenario 0 Is the basic scenario which assumes the following:

- Initially, 5 MEs enter the network.
- For each subsequent round, the probability of having new MEs to enter the network is 10%
- The maximum number of MEs to enter the network in each round is 5 MEs
- Each ME enters the network uniformly randomly from any of the four network borders
- At each round, there must be at least 5 MEs in the network

Scenario 1 Is the same as Scenario 0, with a difference in the space distribution of MEs in the network such that MEs enter the network with 70% probability from the top border while entering from the other three borders with equal probability of 10% each.

Scenario 2 Divides the 24 h day into two times periods to represent the day and night time periods. Since the round is set to be one minute, the day time period is set to be 16 h length (from round 1 to 960), while the night time period is set to be 8 h length (from round 961 to 1440). For the day time period, the settings are exactly the same of Scenario 0, whereas for the night time period, the settings are changed to:

- For each round, the probability of having new MEs to enter the network is 3%.
- The maximum number of MEs to enter the network at each round is 2.
- At each round, there is no limit on the minimum number of MEs in the network. Hence, there might be some rounds with no MEs around.

Scenario 3 Is the case where different scenarios overlap in a realistic manner. We divide the 24 h day such that:

- Scenario 0 is applied for rounds 1 to 1250
- Scenario 1 takes place for rounds 1251 to 1440

While at the same time the following holds:

- Scenario 0 is applied for rounds 0 to 960
- Scenario 2 takes place assuming the night settings from round 961 to 1440

This division leads to having Scenario 0 from round 1 to 960. Then having an overlap of Scenario 0 and Scenario 2 from round 961 to round 1250, which means less MEs are entering the network uniformly from all sides of the network. Finally, having an overlap of Scenario 1 and Scenario 2 from round 1251 to round 1440, which means less MEs are entering the network non-uniformly from the network sides.

5. Results and discussions

5.1. First node dies, last node dies, and average lifetime

Figs. 6–9 represent the number of rounds at which the first node dies, last node dies, and show the average lifetime of sensors for Scenarios 0 through 3 respectively when applied as basic or hybrid with $c = 5$ and 10. All figures include the LEACH as a typical base algorithm to compare with.

The figures show that the basic solution extremely extends LEACH in terms of the first node dies, the last nodes dies, and the average lifetime for all scenarios. This is because the cluster head role is not assigned to any regular sensor anymore, instead, the MEs entirely handle the role of cluster head. As for the difference between the basic and the hybrid algorithm for different scenarios, its clear that increasing the value of c to 10 gives higher lifetimes for first node dies and last node dies, and higher average lifetime than for the value of $c = 5$. Some data records might, however, be missed for $c = 10$, so using the value of $c = 10$ might not be suitable for sensitive applications.

It can also be noticed that for Scenario 0, the difference between the last node dies of the basic and hybrid is around 7000 rounds which is about 25% decrease of the lifetime from the basic algorithm of Scenario 0, while the difference between the last node dies of the basic and hybrid for other scenarios ranges from 16,000 to 22,000 rounds which is about 40–50% decrease of the network lifetime from the basic solution. Whereas the differences in average lifetime range from 15% to 30% decrease in the network lifetime from the basic solution. This can be explained as follows: since the MEs in Scenario 0 are uniformly distributed in terms of area and time, the basic solution performs well as the entire network is covered mostly by only MEs without the need to switch to hybrid regularly. While for the other scenarios, there is always a place or a time period that has the network uncovered by MEs, and so needs to switch to the hybrid solution almost regularly. MEs, however, still work as CHs most of the time, which can be shown from the extend in results when comparing the hybrid solution to LEACH. Note also that the first node dies for Scenario 1 of the hybrid solution with $c = 10$ is close to the first node dies of the basic solution, since for Scenario 1, there are some areas that switch to hybrid more regular than others, which make the CHs role assigned to some sensors more than others, and hence these sensors die quickly. Whereas for Scenarios 2 and 3, there are times at which almost all the network has no MEs and so the CH role is rotated among different sensors, and therefore the energy is better preserved.

Please cite this article as: H.M. Abdulsalam et al., Usage of mobile elements in internet of things environment for data aggregation in wireless sensor networks, Computers and Electrical Engineering (2017), https://doi.org/10.1016/j.compeleceng.2017.12.028

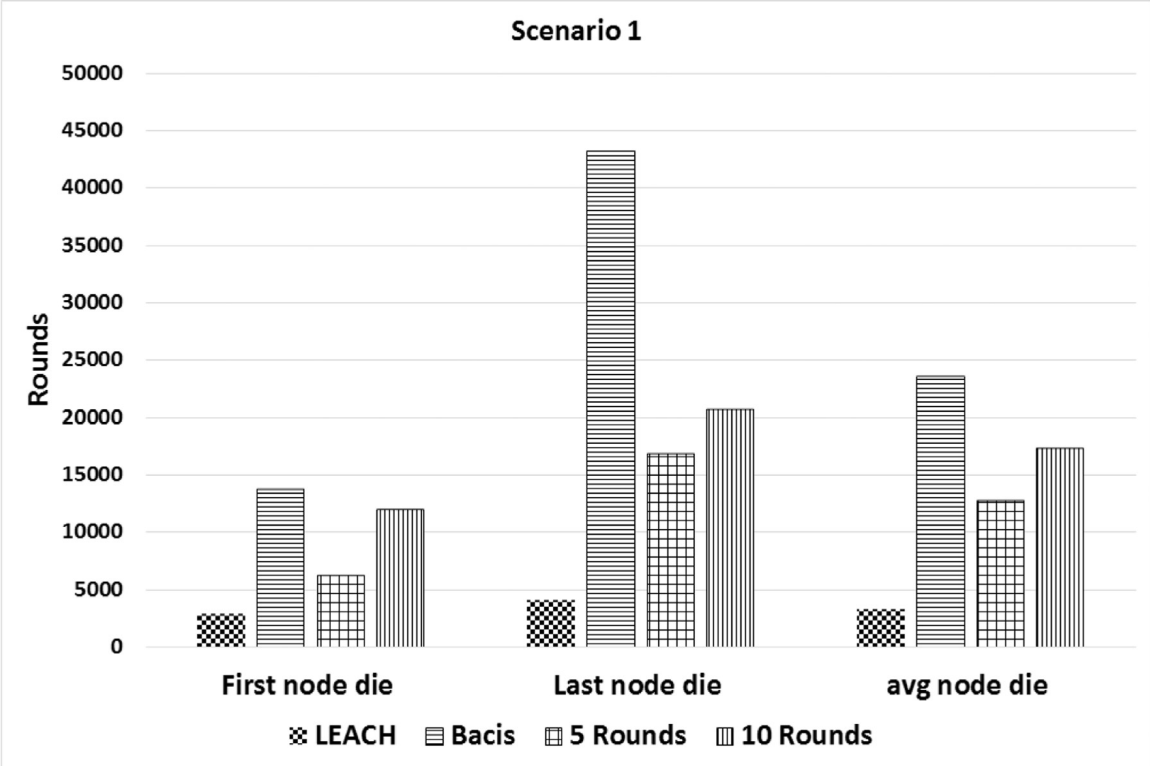


Fig. 7. First node dies, last node dies, and average lifetime for LEACH, basic solution of Scenario 1, and hybrid solution for Scenario 1.

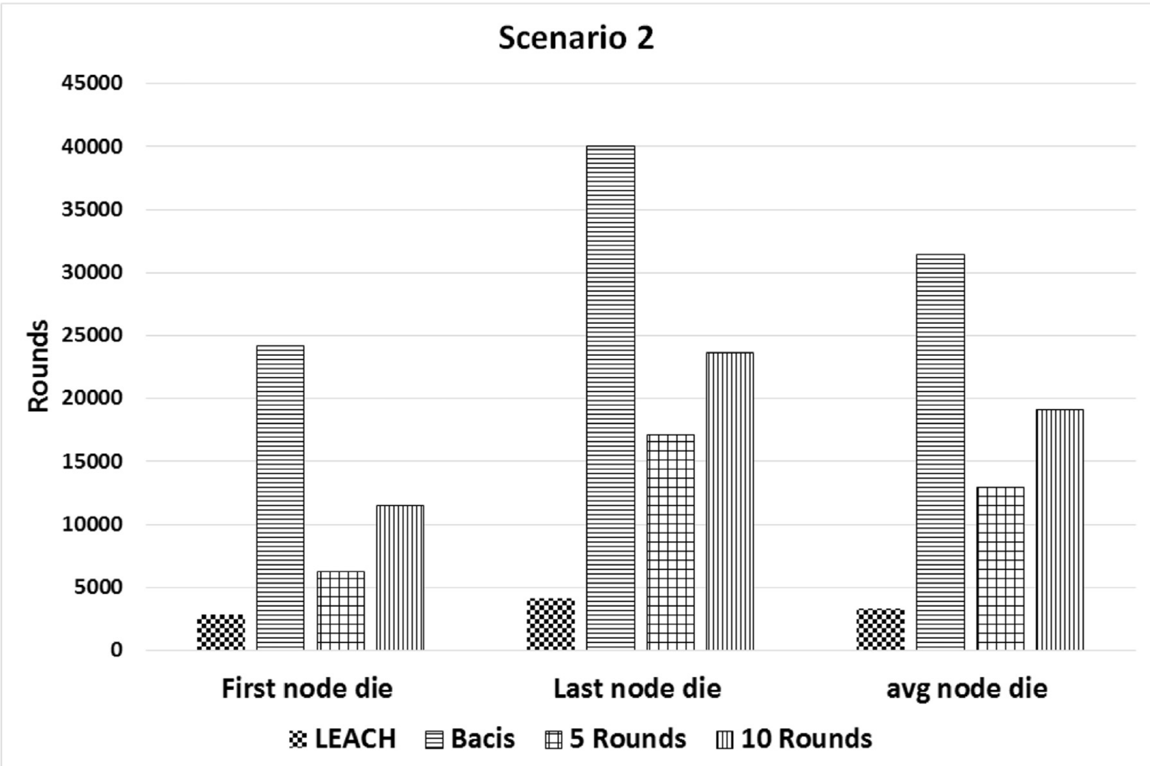


Fig. 8. First node dies, last node dies, and average lifetime for LEACH, basic solution of Scenario 2, and hybrid solution for Scenario 2..

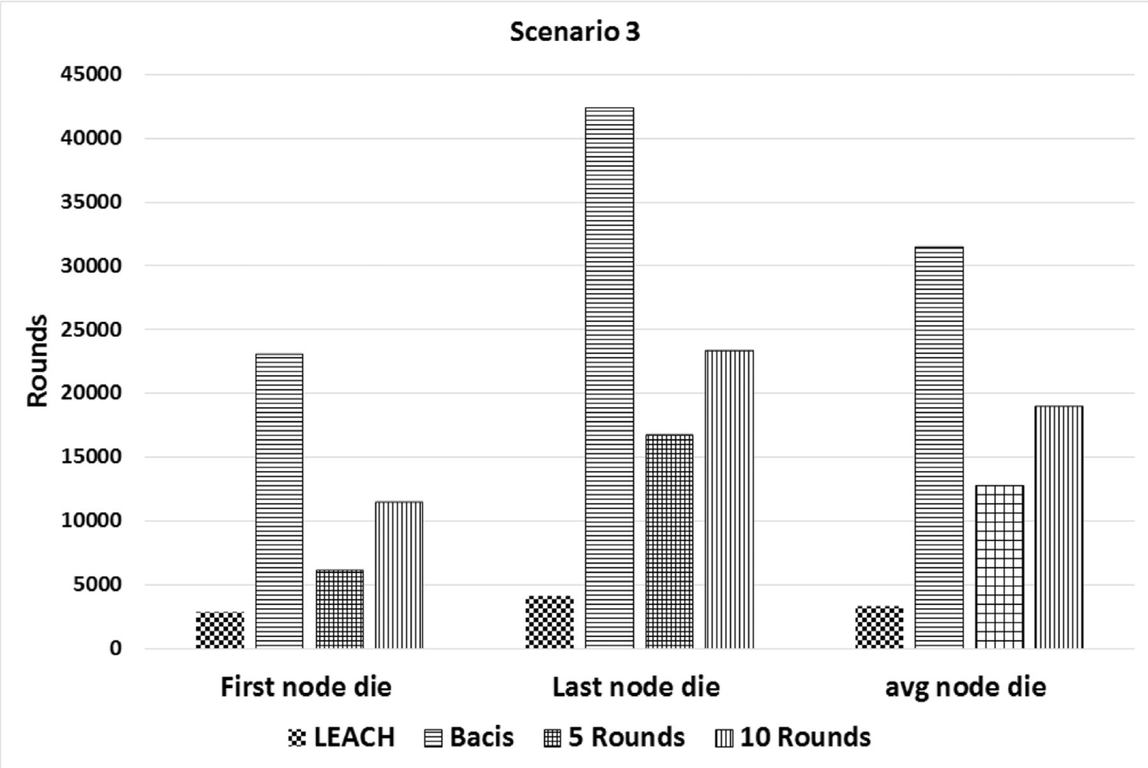


Fig. 9. First node dies, last node dies, and average lifetime for for LEACH, basic solution of Scenario 3, and hybrid solution for Scenario 3.

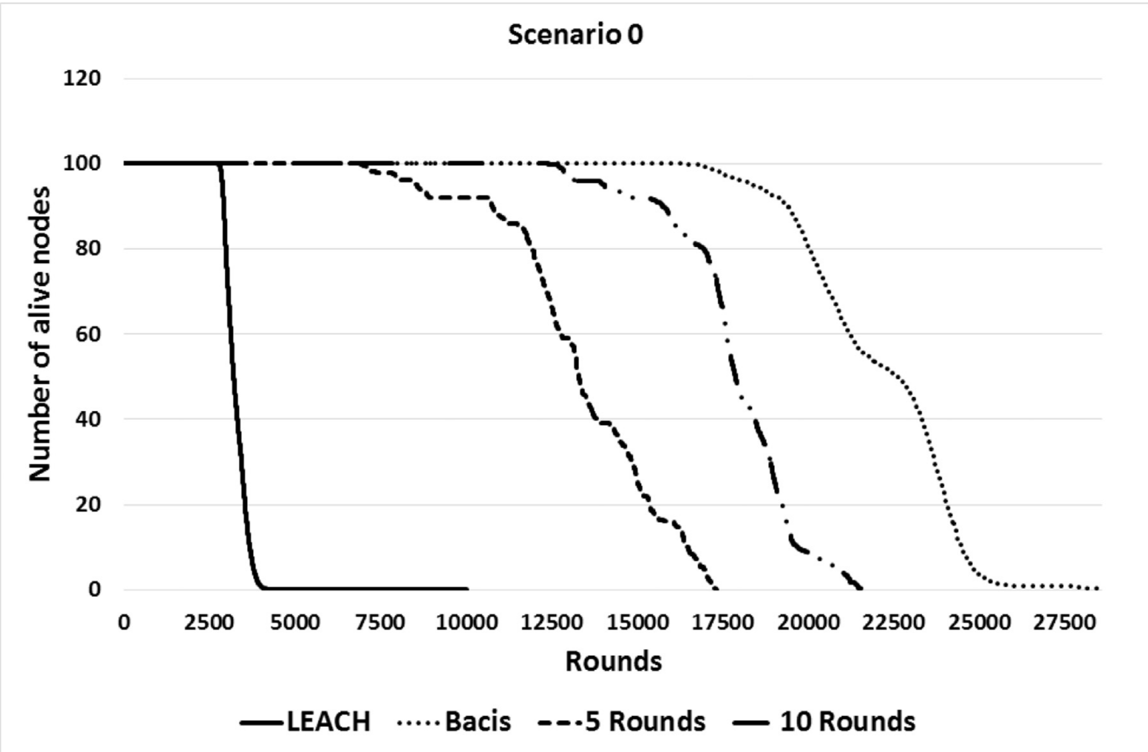


Fig. 10. Number of alive sensors versus rounds for LEACH, basic solution of Scenario 0, and hybrid solution for Scenario 0.

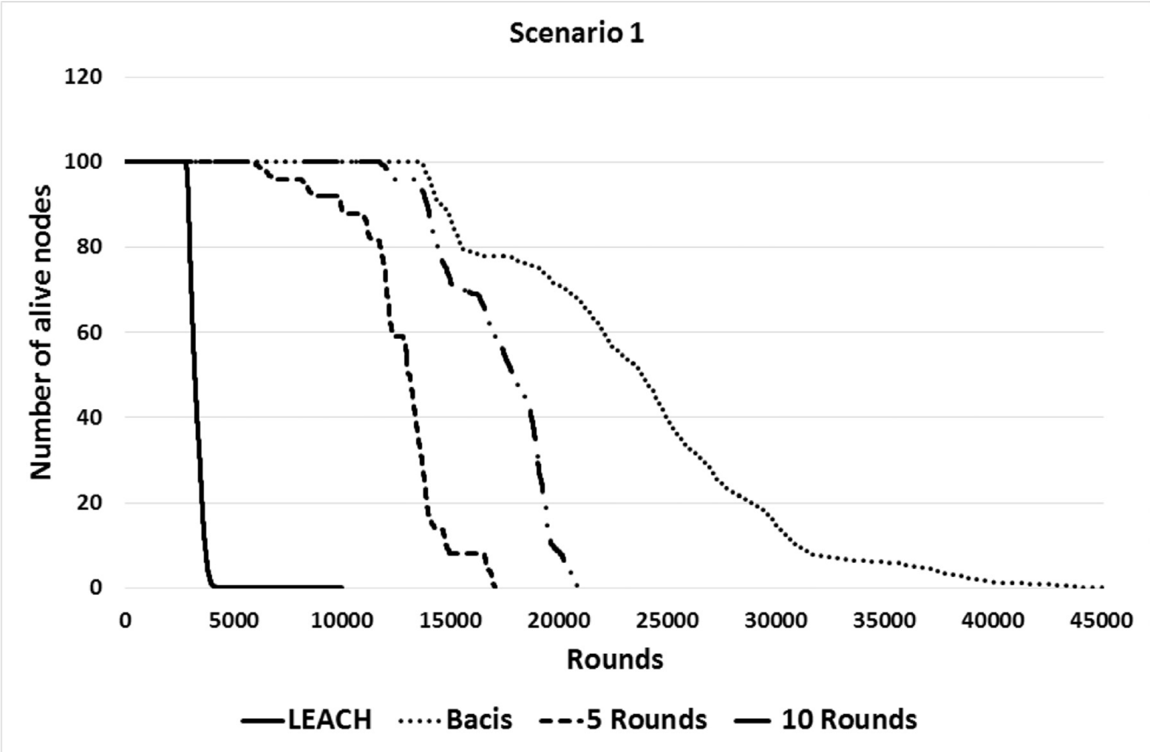


Fig. 11. Number of alive sensors versus rounds for LEACH, basic solution of Scenario 1, and hybrid solution for Scenario 1.

5.2. Number of alive sensors

Figs. 10–13 demonstrate the number of alive sensors versus the number of rounds for LEACH as a base algorithm to compare with Scenarios 0 through 3 respectively when applied as basic or hybrid with $c = 5$ and 10.

The figures clearly indicate that all basic and hybrid algorithms extend the network lifetime when compared to LEACH. When observing the nature of the graph of LEACH and the basic algorithm of all scenarios, we can see that the network is performing with one or two sensors for around 3000 to 5000 rounds at the end of the network lifetime. These rounds are considered to be useless having only 1% to 2% of the data sending sensors. While for the hybrid solution, although the network lifetime is reduced when compared to the basic solution, the network behaviour is better having almost all sensors alive until about 75% to 80% of the total network lifetime.

5.3. Remaining energy

Figs. 14–17 present the total remaining energy of the network with respect to the number of rounds of LEACH compared with Scenarios 0 through 3 respectively when applied as basic or hybrid with $c = 5$ and 10.

The figures clearly demonstrate that there is an extreme save of energy for our solution over LEACH. Note that almost all graphs of LEACH and the basic solution have near zero energy at the last 3000 to 5000 rounds, which confirms what we have discussed earlier about the number of alive sensors graphs. The remaining energy graph of the basic solution of Scenario 1 is the steepest when compared to all other scenarios and has about 15,000 rounds with less than 3% energy. This is because, as explained above, Scenario 1 has specific areas in which no MEs are presented for a long time, and hence, the energy distribution of sending sensors is biased and some nodes die faster than others.

5.4. Network coverage

Figs. 18–21 compare randomly chosen snapshots of the network for basic and hybrid algorithms of Scenarios 0 through 3 respectively. Each figure has two sub-figures (a) and (b), such that for a chosen number of rounds, sub-figure (a) shows the snapshot of the network for the basic version of the solution while sub-figure (b) represents the snapshot of the hybrid solution. When comparing the sub-figures of each figure, it is clearly shown that if there are some zones in the basic solution that are not covered during some rounds (shaded in gray), then they are guaranteed to be covered during the hybrid solution. The zones in black are zones that are not covered by the distribution of the sensors in the WSN settings.

Please cite this article as: H.M. Abdulsalam et al., Usage of mobile elements in internet of things environment for data aggregation in wireless sensor networks, Computers and Electrical Engineering (2017), https://doi.org/10.1016/j.compeleceng.2017.12.028

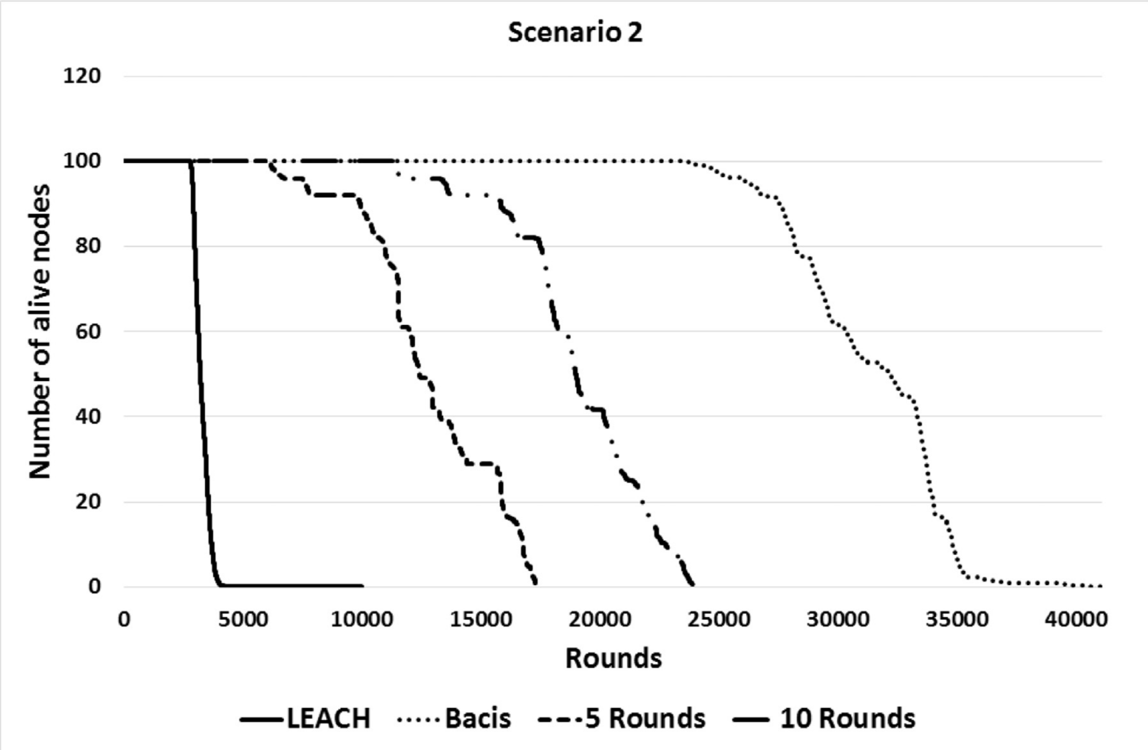


Fig. 12. Number of alive sensors versus rounds for LEACH, basic solution of Scenario 2, and hybrid solution for Scenario 2.

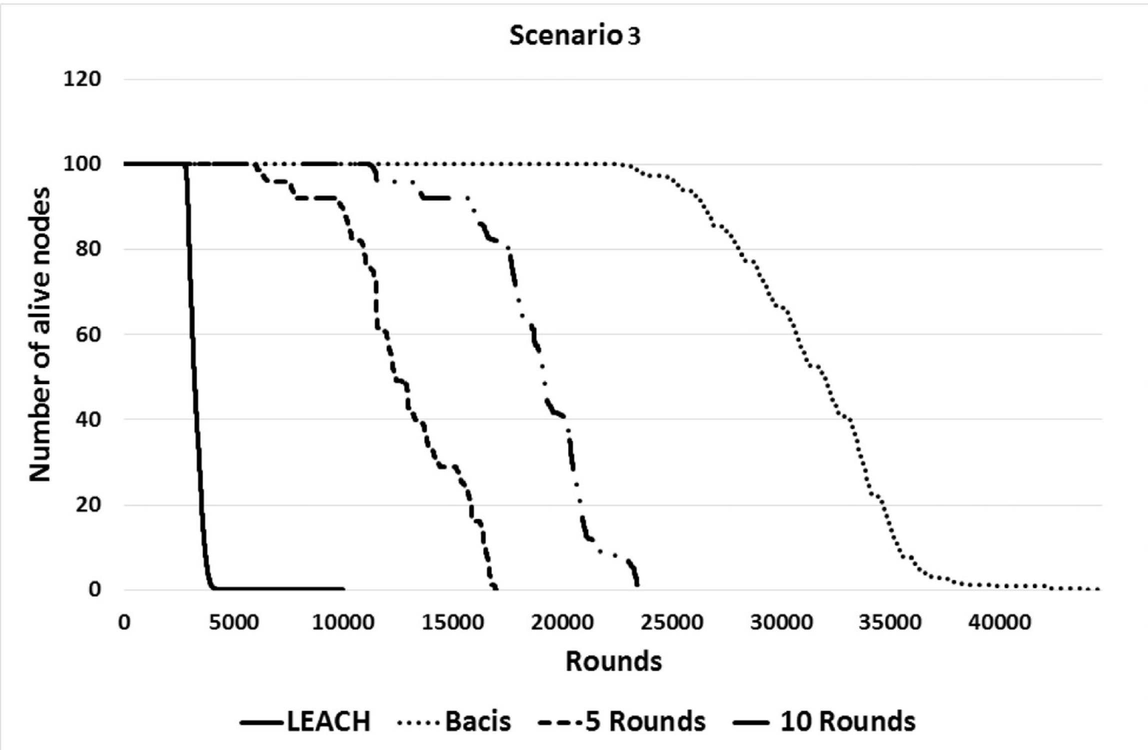


Fig. 13. Number of alive sensors versus rounds for LEACH, basic solution of Scenario 3, and hybrid solution for Scenario 3.

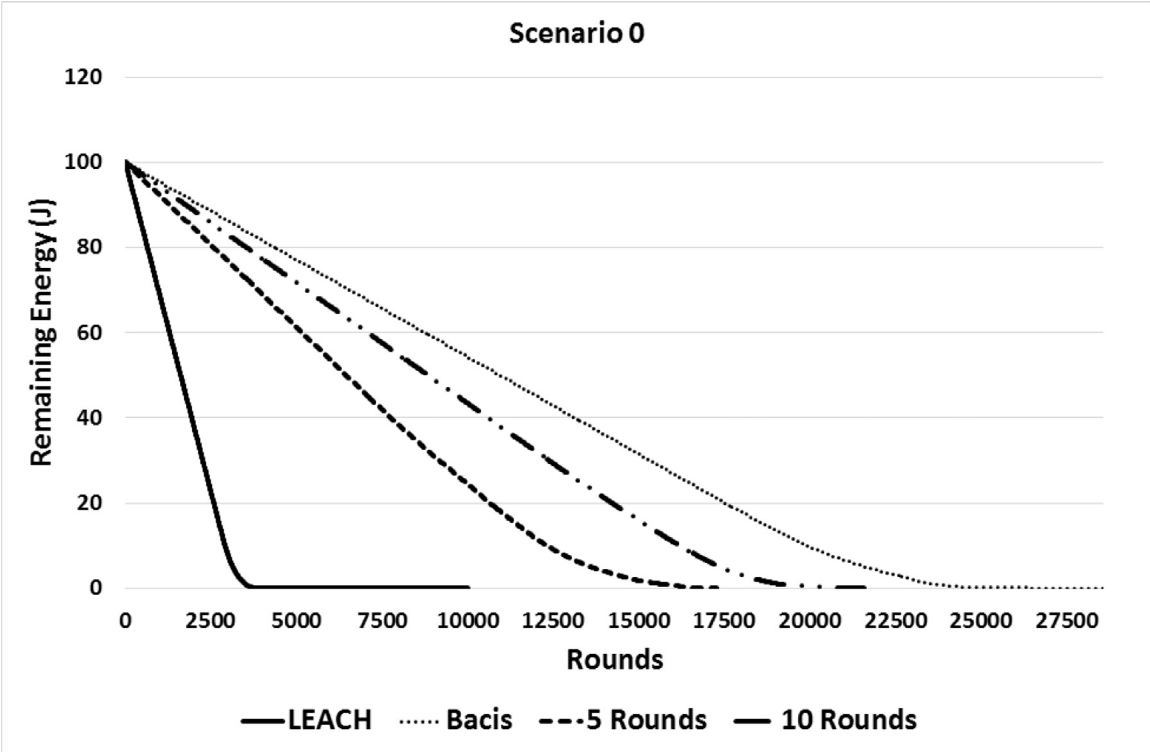


Fig. 14. Remaining energy versus rounds for LEACH, basic and hybrid solution of Scenario 0.

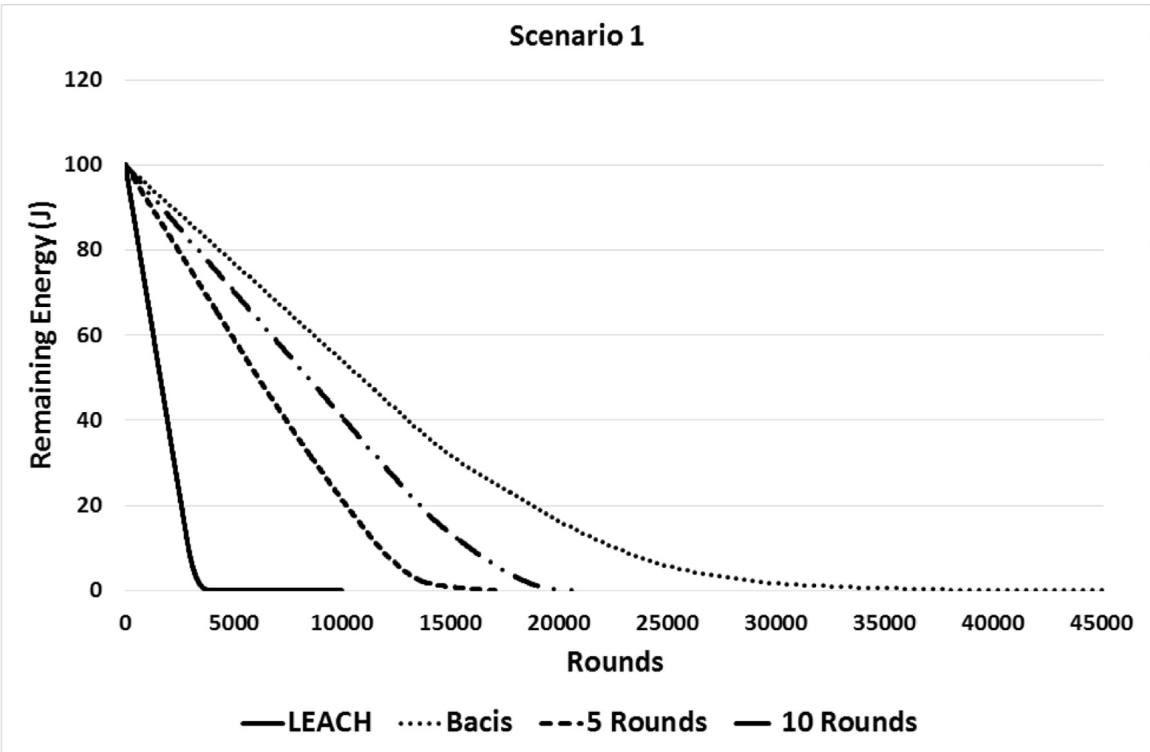


Fig. 15. Remaining energy sensors versus rounds for LEACH, basic and hybrid solution of Scenario 1.

Please cite this article as: H.M. Abdulsalam et al., Usage of mobile elements in internet of things environment for data aggregation in wireless sensor networks, Computers and Electrical Engineering (2017), https://doi.org/10.1016/j.compeleceng.2017.12.028

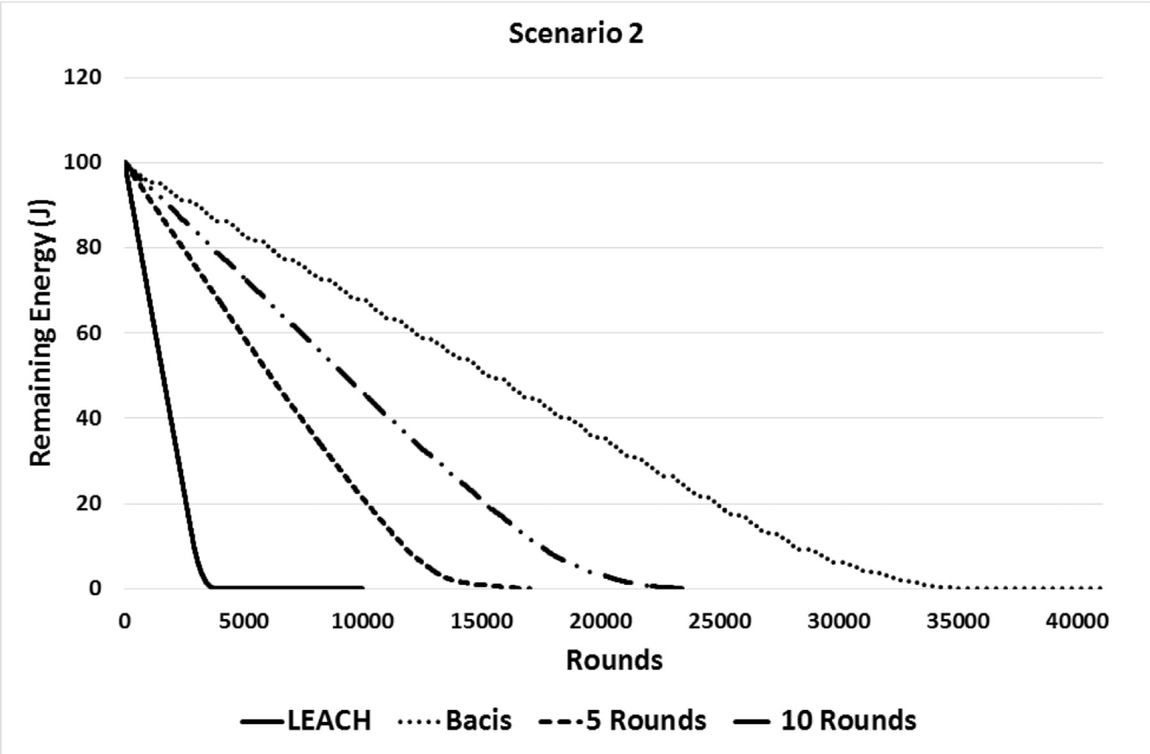


Fig. 16. Remaining energy versus rounds for LEACH, basic and hybrid solution of Scenario 2.

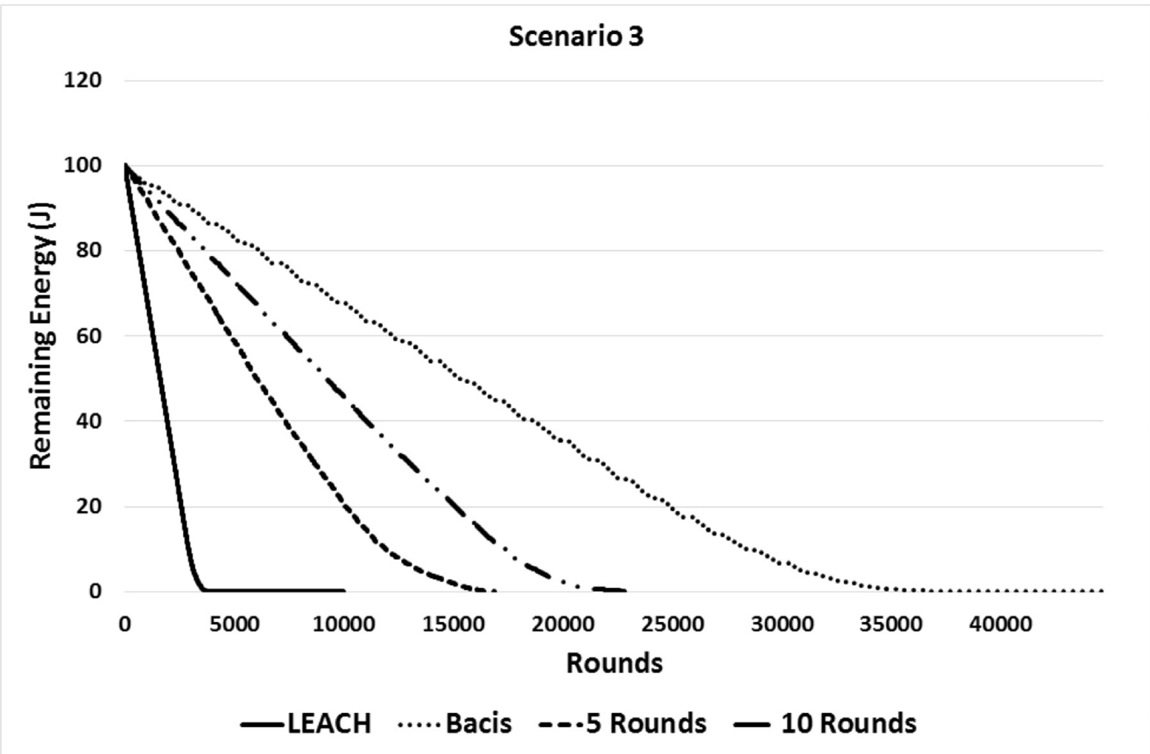
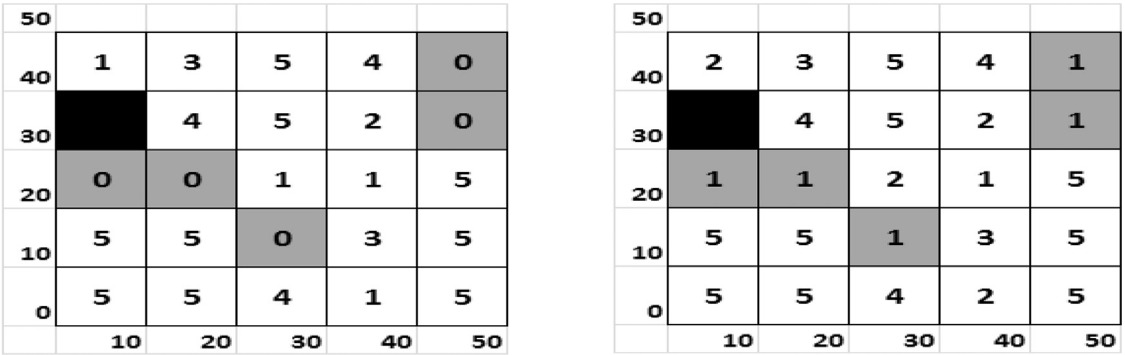
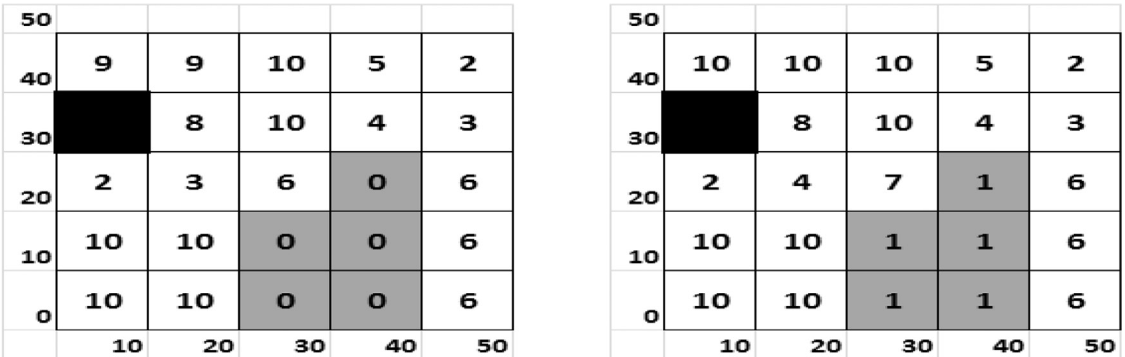


Fig. 17. Remaining energy versus rounds for LEACH, basic and hybrid solution of Scenario 3.



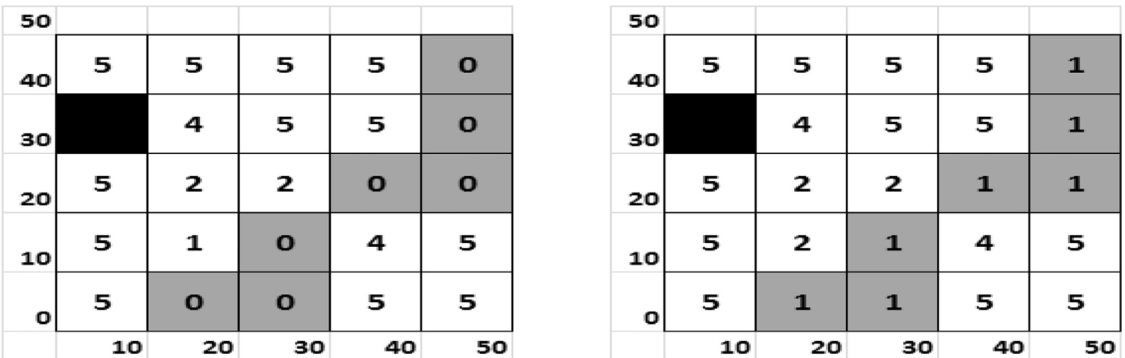
(a) Basic version (b) Hybrid version

Fig. 18. Snapshots of basic and hybrid solution of Scenario 0 for rounds 2501 to 2505.



(a) Basic version (b) Hybrid version

Fig. 19. Snapshots of basic and hybrid solution of Scenario 1 for rounds 5051 to 5060.

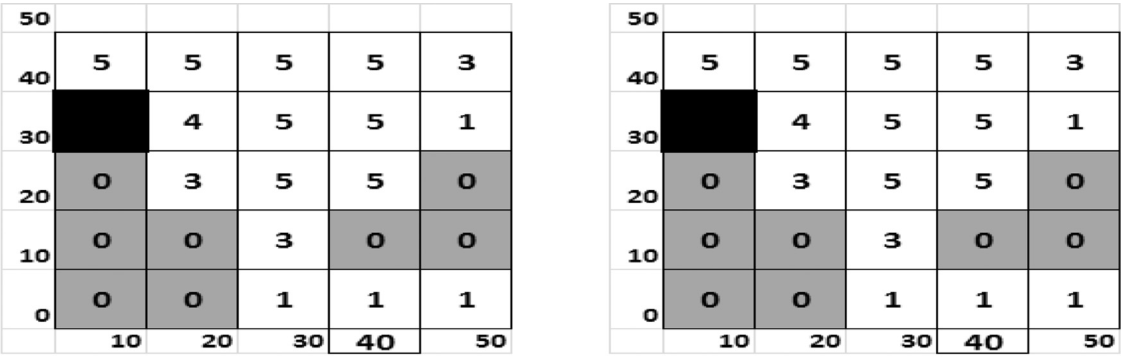


(a) Basic version (b) Hybrid version

Fig. 20. Snapshots of basic and hybrid solution of Scenario 2 for rounds 5001 to 5005.

Hence, these zones are said to be inactive and not considered in our experimental observations. Each other active zone is marked with an integer. This integer represents the number of rounds at which at least one sensor that belongs to this zone has sent data during the snapshot.

Please cite this article as: H.M. Abdulsalam et al., Usage of mobile elements in internet of things environment for data aggregation in wireless sensor networks, Computers and Electrical Engineering (2017), https://doi.org/10.1016/j.compeleceng.2017.12.028



(a) Basic version (b) Hybrid version

Fig. 21. Snapshots of basic and hybrid solution of Scenario 3 for rounds 2891 to 2895.

Algorithm 1 Solution Algorithm.

1. **Initialize** sensor location and energy for all n sensors
2. **Initialize** zones of the network
3. **repeat**
   - 3.1 Base station discovers m MEs
   - 3.2 Base station publishes coordinates of MEs to network sensors
   - 3.3 **repeat**
     - 3.3.1 sensor s_i finds the closest ME in its range r_{s_i}
     - 3.3.2 sensor s_i sends the recorded data to its the closest ME

     until $i \leq n$;
   - 3.4 **repeat**
     - 3.4.1 ME_j send collected data to the base station

     until $j \leq m$;
   - 3.5 **if** *x zones are not covered for c times, where $x > 0$* **then**
     - 3.5.1 **repeat**
       - 3.5.1.1 Set sensor with maximum energy for zone z_w to be CH_{z_w}
       - 3.5.2.1 All sensors in zone z_w send data to CH_{z_w}
       - 3.5.3.2 CH_{z_w} send data to base station

       until $w \leq x$;

     end

   until *no more alive sensors in WSN*;

6. Conclusions and future work

This paper has proposed a data aggregation algorithm for WSNs using Mobile Elements (MEs) in the IoT environment. The proposed algorithm is a cluster-based aggregation algorithm, which assigns the role of Cluster Head (CH) to arbitrary MEs that pass through the WSN. The goal of doing so is mainly to save the energy of sensors and, therefore, to extend the network lifetime, while effectively employing the existing IoT technology.

The proposed algorithm has been developed into two phases, namely, the basic algorithm and the hybrid algorithm. The basic case assumes the availability of ME and so always assigns the role of CHs to the MEs. Whereas the hybrid solution realistically considers the case of the unavailability of MEs. In this case, the CH role is switched back to be assigned to regular sensors to ensure that data is not lost. The hybrid solution also divides the network into zones, such that if a zone is not covered by MEs for a defined time period, then it is considered as a separate cluster and elects one of its regular sensors to be a CH.

Simulation results show that our proposed solution is effective in terms of extending the network lifetime, and saving the energy of the sensors. Results also present that the algorithm reacts efficiently to unavailability of MEs and guarantees that data is not lost. Hence, ensuring the quality of the data aggregation of the network.

As for future work, we intend to consider the behavior of the external mobile elements that pass through the network. Our aim is to introduce a trust layer in the system in order to select the most reliable mobile elements who are qualified enough to transmit the data. We believe that this selection of the trusted sensors increases the transmission rate since the data loss is expected to be reduced.

References

[1] Heinzelman WR, Chandrakasan A, Balakrishnan H. Energy-efficient communication protocol for wireless microsensor networks. In: Proceedings of the 33rd Hawaii international conference on system sciences; 2000. p. 3005–14.
[2] Thein M, Thein T. An energy efficient cluster-head selection for wireless sensor networks. In: Proceedings of international conference on intelligent systems, modelling and simulation, Liverpool, England; 2010. p. 287–91.
[3] Xiangning F, Yulin S. Improvement on LEACH protocol of wireless sensor network. In: Proceedings of international conference on sensor technologies and applications, Valencia, Spain; 2007. p. 260–4.
[4] Abdulsalam HM, Kamel LK. W-LEACH: Weighted low energy adaptive clustering hierarchy aggregation algorithm for data streams in wireless sensor networks. In: Proceedings of workshops of the 10th IEEE international conference on data mining (ICDM 2010), Sydney, Australia; 2010. p. 1–8.
[5] Abdulsalam HM, Kamel LK. Data aggregation for evolving wireless sensor networks using W-LEACH. In: Proceedings of the second Kuwait conference on e-services and e-systems. Kuwait City, Kuwait; 2011. p. 1–5.
[6] Abdulsalam HM, Ali BA. W-LEACH Based dynamic adaptive data aggregation algorithm for wireless sensor networks. Int J Distrib Sens Netw 2013.
[7] Pradhan J, Sarje A. A fault tolerant approach for data aggregation in wireless sensor networks. In: Proceedings of the international conference on advances in computing, communications and informatics. Chennai, India; 2012. p. 382–6.
[8] Jurdak R, Nafaa A, Barbirato A. Large scale environmental monitoring through integration of sensor and mesh networks. Sensors 2008;8(11):7493–517.
[9] Banerjee T, Xie B, Jun JH, Agrawal DP. Increasing lifetime of wireless sensor networks using controllable mobile cluster heads. Wireless Commun Mobile Comput 2010;10(3):313–36.
[10] Ma M, Yang Y. Clustering and load balancing in hybrid sensor networks with mobile cluster heads. In: Proceedings of the 3rd international conference on quality of service in heterogeneous wired/wireless networks. ACM; 2006.
[11] Kim DS, Chung YJ. Self-organization routing protocol supporting mobile nodes for wireless sensor network. In: Computer and computational sciences, 2006. IMSCCS '06. first international multi-symposiums on, 2; 2006. p. 622–6.
[12] Kumar GS, Vinu PMV, Jacob KP. Mobility metric based leach-mobile protocol. In: 16th International conference on advanced computing and communications; 2008. p. 248–53.
[13] Ahmed A, Qazi S. Cluster head selection algorithm for mobile wireless sensor networks. In: International conference on open source systems and technologies; 2013. p. 120–5.
[14] Di Francesco M, Das SK, Anastasi G. Data collection in wireless sensor networks with mobile elements: a survey. ACM Trans Sens Netw 2011;8(1):1–31.
[15] Ashton. K. 2009. "Internet of things. RFID J.", http://www.rfidjournal.com/articles/view?4986.
[16] Van Kranenburg R, Anzelmo E, Bassi A, Caprio D, Dodson S, Ratto M. The internet of things. A critique of ambient technology and the all-seeing network of RFID, Network Notebooks 2011;2.
[17] Gubbi J, Buyya R, Marusic S, Palaniswami M. Internet of things (iot): a vision, architectural elements, and future directions. Future Generation Comput Syst 2013;29(7):1645–60.
[18] Da Xu L, He W, Li S. Internet of things in industries: a survey. Ind Inf IEEE Trans 2014;10(4):2233–43.
[19] Atzori L, Iera A, Morabito G. The internet of things: a survey. Comput Netw 2010;54(15):2787–805.
[20] Miorandi D, Sicari S, Pellegrini DF, Chlamtac I. Internet of things: vision, applications and research challenges. Ad Hoc Netw 2012;10(7):1497–516.
[21] Baronti P, Pillai P, Chook V, Chessa S, Gotta A, Hu YF. Wireless sensor networks: a survey on the state of the art and the 802.15. 4 and zigbee standards. Comput Commun 2007;30(7):1655–95.
[22] 2016. "AutoLog Data Sheet", http://www.ff-automation.com/download/Documents/English/AutoLog_DATASHEETS/FFAutomation_DATASHEET_AutoLog_WiFi_Sensor.pdf.
[23] DeCuir J. Introducing bluetooth smart: part 1: a look at both classic and new technologies. IEEE Consum Electron Mag 2014;3(1):12–18.
[24] Siekkinen M, Hiienkari M, Nurminen JK, Nieminen J. How low energy is bluetooth low energy? comparative measurements with zigbee/802.15.4. In: Wireless communications and networking conference workshops (WCNCW), 2012 IEEE; 2012. p. 232–7.
[25] Yassein MB, Al-zou'bi A, Khamayseh Y, Mardini W. Improvement on leach protocol of wireless sensor network (vleach). Int J Digital Content Technol Appl 2009;3(2):132–6.

Please cite this article as: H.M. Abdulsalam et al., Usage of mobile elements in internet of things environment for data aggregation in wireless sensor networks, Computers and Electrical Engineering (2017), https://doi.org/10.1016/j.compeleceng.2017.12.028

Hanady M. Abdulsalam is an Assistant Professor in the Department of Information Science, Kuwait University, Kuwait. She received her B.Sc and M.Sc degrees in Computer Engineering from Kuwait University, and her Ph.D from the School of Computing, Queen's University, Canada. Her research interests are in the areas of data management in WSN, internet of things, trust schemas and software engineering.

Bader A. Ali is an Assistant Professor in the Department of Information Science, Kuwait University, Kuwait. He received his B.Sc in computer engineering from UMC, Columbia, M.Sc in computer science from the USC, California, and his Ph.D in computer science from the School of Computer Science, McGill University. His research interests include large scale distributed systems, social networks and WSN.

Eman AlRoumi is an Teacher Assistant in the Department of Information Science, Kuwait University, Kuwait. She received her B.Sc and M.Sc degrees in Computer Engineering from Kuwait University. Her research interests include wireless sensor networks and internet of things.

Please cite this article as: H.M. Abdulsalam et al., Usage of mobile elements in internet of things environment for data aggregation in wireless sensor networks, Computers and Electrical Engineering (2017), https://doi.org/10.1016/j.compeleceng.2017.12.028