SENSOR DEPLOYMENT BASED CLUSTERING FOR WIRELESS SENSOR NETWORKS

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ABSTRACT: *With the emergence of smart technologies in different fields including health, ecological monitoring, security, smart-home, vehicles, planes, and shipboard, sensors became the key player in any of those applications. Wireless Sensor Networks (WSNs) are supposed to live for a long time using AA batteries in an unattended environment. At the same time, sensors are now the main part of the Internet of Things (IoT) and their applications. However, sensors suffer from limited energy sources, limited storage, and restricted performance capabilities. Therefore, this paper proposes a novel deployment framework for Wireless Sensor Networks (WSNs) based on clustering to save sensors energy and extend the network lifetime. The proposed approach optimizes the deployment process through clustering. The proposed deployment framework also utilizes both neural networks and fuzzy logic for offline deployment. Moreover, the framework covers heterogeneous sensor deployment. The proposed framework is extensively examined against other deployment methods for performance measures.*

Keywords: Clustering Algorithm Cluster Head; Energy IoTs; Network Lifetime; WSNs

1. INTRODUCTION

A sensor network is a collection of a large number of spatially distributed wireless sensing nodes in a monitored area. Sensor nodes serve as information generators and network relays, capable of sensing (measuring), processing data, and communicating with other sensor nodes. The end-users of the information or administrators can then make observations in a particular environment and respond to events [1,2,3]. Wireless sensor nodes are very small and cost-effective. They can measure environmental conditions or other parameters, including air quality, temperature, sound, pressure, and humidity, and send it to a common base for proper processing.

A typical setting may be a biological system, a functional world, or an information technology (IT) context. Advanced mesh topology networking protocols allow sensing nodes to create a wide area of connectivity and link cyberspace to the practical world. The sensor module analyses environmental parameters surrounding the sensor and converts the energy in the atmosphere into electrical signals. Data on events occurring in the vicinity of the sensor is collected by the processor module processing the data and the data is transmitted to a destination node via a radio transmitter. Technological advances have resulted in a reduction in the size and cost of the sensors and have therefore given rise to interest in the possibility of using large sets of unattended disposable sensors. Exhaustive work has been carried out over the past few years on the potential cooperation of sensors in sensor deployment, data collection and computation, control, and administration of sensing operation and information flow to the destination node. Sensors that communicate through wireless communication links may form an ad hoc network, a natural layout for the distribution of such collective sensors [4].

A wireless sensor network (WSN) should be able to deploy a large number of very small nodes for a common purpose to connect and configure themselves. WSN uses include, but are not limited to, frontline surveillance, environmental monitoring, disaster detection and rescue, effective and smart agriculture, medicine and health care, environmentally friendly buildings, traffic control, and object tracking. Types of environmental monitoring and object tracking could be the surveillance of underground mines to ensure the safety and position of miners at all times. Compared to wired networks, WSNs are implemented at a minimum cost. They can adapt dynamically to changes in the environment in which they are deployed and respond actively to topological changes in the network. Major components that make a network of wireless sensors are;

1. Sensor
2. CPU
3. Power source
4. Transceiver

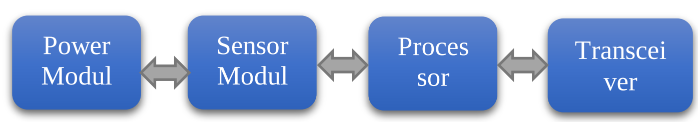

Figure 1. Various elements make a wireless sensor node

Depending on the application, the Transceiver Actuators, analog to digital converters (ADC) and monitors can be added. Image. Figure 1 displays the various elements make a wireless sensor node [4].

There is an ad hoc nature of a wireless communication network where sensor nodes can coordinate themselves without proper coordination, this is seen in most WSN applications. The source of power for the sensor nodes is a battery that is normally not rechargeable or replaceable, particularly when the sensor nodes are required to operate for a longer period during the application without human intervention [3, 5]. Careful management of assets is a major concern in the development of wireless sensor networks. Using power-saving strategies such as radio optimization, data reduction, sleep or wake-up procedures, energy-efficient routing protocols and energy harvesting [6] can be achieved.

The function of wireless sensor nodes is to detect and collect information from a field or area of interest, measure the information and forward it back to a central point or destination through a radio module [2, 4, 7, 8, 9]. This study focuses on energy-efficient routing protocols, an energy-saving approach needed to find routes between the sensor nodes and the destination node for data transmission. Some of the recently published papers dealing with communications energy efficiency were listed in [10,11,12,13]. Therefore, the development of the routing protocols should take into account the trade-offs that may occur for different network applications at the cost of energy efficiency.

A study of wireless sensor networks [14] shows a variety of attractive virtual insect societies' resources. A sensor network's environment may be its structure or effects of the physical layer on communications links as well as patterns of network traffic. Biological networks vary from designed networks because the biological networks have a cooperative opportunity that emerges naturally, while the latter will require certain node-energizing initiatives to work together[15, 16]. Randomness, multiple experiences, positive feedback, and negative feedback are the four concepts that social insects depend on to be able to organize themselves. As a product of these four principles, stigmergy emerges [17]. The ability to self-organize is called swarm intelligence and is comparatively a unique field originally defined as "protocol design by inspiring social organisms and other animal societies ' collaborative behavior"[18]. It is currently defined as the analysis of process cooperative activity that is made up of multiple components and can organize through non-centralized controls and self-organization. Engineers define swarm intelligence as a focus on a model that starts with dispersed systems that are self-sufficient and demonstrate adaptability, robustness, and scalability characteristics from bottom to top. Ant colonies [19], honey bees [20], termites [21], bats [22] and spider monkeys [23] are some examples of natural species social groups.

The way information and queries are transmitted from the source node to the sink node is an important factor in wireless sensor networks. In the past, research has centered on exploring the ability for sensors to work together to capture, store, organize, and handle data traffic to the destination [1]. A single hop communication method to accomplish this mission, where each sensor node can be directly transmitted to the sink node. An alternative approach is a multi-hop communication that uses intermediate nodes to forward data packets to the sink node [2, 9]. It is a routing algorithm's task to decide on the collection of intermediate node sets that set routes for transmitting data packets to the sink. Routing protocols can be classified by the different ways data is transmitted from the nodes to the sink.

Due to the difficulties that may occur due to the characteristics of the environment in which these networks are deployed and the specifications of the network applications, some important factors must be addressed when developing wireless sensor networks and routing protocols. Issues relating to power usage and management, fault tolerance, scalability, network connectivity, QoS, data aggregation, congestion, latency, and production costs need to be addressed in the design of wireless sensor network routing protocols. This will help address the following issues affecting the development of these networks [4];

1. **Hardware resource constraints:** the capacity of sensor nodes to process information and data processing is limited. In addition to the energy limitations in network and protocol design, the limitations must be considered.
2. **Dynamic network:** In the design of routing protocols, frequent changes in network structure must be taken into account. Keeping the data routing stable in a network where one or more network components are mobile is vital.
3. **Sensor location:** It must be managed as a matter of urgency especially at the initial discovery of routes when sensor nodes need to gain information about their environment and surroundings in order to get other nodes ' positions.
4. **Fault tolerance:** Connectivity and operation of the network must be maintained even in the case of sensor node failures that may occur due to power failures, mechanical damage, or environmental interference. Routing protocols should be configured to quickly respond and discover new routes for data transmission in the event of network failure.
5. **Latency:** Is a measure of how long it takes to send information to the sink or destination node from a single node. It is also known in wireless sensor networks as an end-to-end lag.
6. **Data aggregation:** it describes how data is collected in a sensor network that is either event-driven, time-driven query-driven, or hybrid-driven. Data collection or recording is correlated with an event that occurs in or around the sensor network. By aggregating similar data packets from multiple source nodes and thus reducing data redundancy, it reduces the number of transmissions to the sink node.
7. **Scalability**: For applications where tens of thousands of sensor nodes are deployed in a network, routing protocols should be designed in a way that they will be able to handle and respond to such a greater number of events [4].
8. **Deployment of nodes:** It depends on the desired applicatio n and can greatly affect routing protocol performance. To maintain connectivity and energy efficiency in the network , a node deployment must conform to a specific and releva nt application.
9. **Multi-hop or broadcast communications:** This type of network uses any routing protocol to allow multi-hop communications, although the use of messages sent in broadcast is also very common.
10. **Power saving:** one of these networks ' most important features. The motes actually have a small amount of energy. A sensor node should have a processor and transceiver radio that is extremely small in consumption. It is one of the apps that are most restrictive.

Because sensors may collect data from the environment, there are many application areas in a sensor network, such as habitat monitoring, fire detection, motion tracking, water control of the dam, or control of intruders. In order to control, monitor, track or detect, a large quantity of sensor nodes is needed to detect the event being monitored (light, pressure, sound, temperature, humidity, electromagnetic field, proximity, position, etc.) and to transmit it to a base station where the last action is taken. Sensor networks have become very useful for our lives and have invaded areas like education, home care, monitoring of the environment, etc.[1]. Due to the importance of the deployment process in forming effective WSN, this paper proposes a deployment-based clustering algorithm based on neuro-fuzzy techniques. the related work is presented in the next section followed by the used energy model. The proposed algorithm is described in section 3 while the experiments are shown in section 4 and the paper concludes in section 5.

1. Related Work

Due to the various applications of WSNs, the deployment problem attracted many researchers. In the following subsections, we briefly review some of the recent sensor deployment algorithms in critical fields, especially in health care.

Sensors allow control of important human body parameters such as heart rate or blood pressure to diagnose the disease and identify a specific health issue. Many related uses include tracking levels of glucose [24], monitoring of organs [24], cancer detectors [26], and monitoring of general health. The concept of integrating wireless biomedical sensors into the human body is exciting, although there are many additional challenges: I the device must be ultra-safe and reliable; (ii) minimal maintenance is needed, and (iii) must deal with power harnessing from body heat. With more work and advancement in this area, it is possible to achieve a better quality of life and reduce medical costs. One example is the Swallowable sensor [27]. It is an ingested wireless capsule that can help diagnose stomach disorders [28]. Buffalo developed a small medical device [29]. A person takes the smart pill in and begins sending data to a receiver. The receiver is held by the same person while the pill goes over it and collects data from the stomach. Some of these devices include a camera that is microscopic. This system helps to treat stomach pain and other disorders of the stomach that affect 20 percent of people.

The sensor (pill) transmits data about acidity levels, pressure, or digestive time when moving in the stomach. Two days later, the capsule is tossed out and recovered for review and data retrieval. Loren et al. gave another example in [30]. A biomedical application is described in this work: the artificial retina. Retina chip is made up of 100 microsensors that are designed and implanted in the human eye. It makes it possible for people with no sight or vision to see at an acceptable level. In order to meet the need for feedback control, object recognition, and validation, wireless communication is needed. As the interaction pattern is deterministic and periodic, TDMA is used for this application to serve the purpose of energy conservation.

Huan-Bang Li et al. suggested three types of Medical and Healthcare Applications, Disability Assistance Applications, and Media Applications for body area networks [31]. The authors suggested sensor technology Zigbee and Bluetooth. An application for rehabilitation centers was developed by Bartosz P. Jarochowski et al. [32]. A personal node is located on the patient in this system, e.g. on a belt clip or in an armband. This node stores information about the rehabilitation session exercises of the patient and some statistics can be obtained. Finally, it is possible to send information to the medical control center. Then, if necessary, it can be analyzed by the doctors to improve the treatment for the next session.

In [33], Paulo Bartolomeu Vasco Santos et al. merged health care with home automation. This modular system consists of various subsystems that can be integrated according to the needs of the person. The ability to automate the house is its most interesting contribution. It's a big step forward for people with reduced mobility. The machine can open a door, for instance; close a window or turn a blind down. In addition, some vital signals can be felt by this system.

Nuri F. Ince et al. proposed a home health system in [34]. It has a useful application for the disabled and people with cognitive disabilities. This system consists of several fixed sensors that identify a patient at home and collect data in combination with wearable sensors to assess which bathroom activities are being done to determine the patient's condition.

To control the main vital statistics and the intensity and duration of rehabilitation exercises that a patient has to make at home is possible with the system proposed by Chris Otto et al. [35]. However, its main advantage is its ubiquity, that is, wherever the patient is placed. It is possible thanks to the combination of ZigBee (or Bluetooth) and a personal device like a mobile phone or personal digital assistant (PDA) with GPRS/3G data network connection.

Applications of this type should have a non-invasive character to avoid environmental changes. It should also be a robust and accurate system in order to transport all the data without errors to the control point. It should also be a low-cost device, as it is applied with batteries outdoors and perhaps some nodes break down and should be replaced. Applications based on natural disaster detection, agricultural monitoring and control, ecosystem and geophysical studies, flood detection, precision farming, environmental mapping of biological complexity and forest fire detection can also be included in this field. Some real environmental applications are as follows:

There is a network of sensor nodes used to track microclimates in shelters and surrounding areas where marine birds nest [36] on the island of Great Duck, close to the coasts of Maine, USA. This helps scientists to track at-risk animals and their habitats. Intel Research Laboratory has spread 32 motes on the island in cooperation with Atlantic College (Bar Harbor) and Berkeley University of California. Each mote had a microcontroller, low-power radio, memory, and some batteries for mid-range monitoring of temperature, moisture, pressure, and infrared emissions. Motes send their data to the island's station bases and are connected via satellite to the Internet to allow access.

A network of small sensors has been set up for disaster detection in the River Ribble [37]. They monitor the level of water and the flow to prevent flooding. The system obtains more data and with greater accuracy than monitoring current systems and provides the appropriate decision photographs to avoid imminent risks. The final network was made up of three sensor types. Another tests the force below the water line to assess the depth and the other takes care of the speed of the water flow, using ultrasounds below the surface and web cameras above it to monitor artifacts. All these data will be sent to a checkpoint to perform the appropriate tasks in accordance with the data received.

Australian agriculture departments carried out a deployment of a network of sensors [38]. It is intended to save large quantities of water and help with the use of wireless sensor nodes to support agriculture. The system is better irrigated than other systems, thus saving water. It was set up with satisfactory results in a greenhouse and in a vineyard.

A system is shown in[39] for irrigating cotton fields in arid areas of Israel and Texas. These systems are based on the temperature of the plantation. Infrared sensors are located near the trees and water is activated when they detect temperatures above 82oF for more than 4 hours. It is proved that there is an optimum temperature between 73^{o} F and 90^{o} F for correct cotton growth.

Fire Information and Rescue Equipment (FIRE) is a program developed by the Mechanical Engineering Department of Berkeley and the Fire Department of Chicago (CFD)[40]. Fire-fighting and catastrophes create a very chaotic environment in general, where a quick decision is essential. In these situations, the possibility of having information on various aspects of the disaster becomes an inestimable value.

2. WSN Energy Model

Given a set of sensors S that are deployed randomly or using any structured methods, nodes are deployed in the monitored field. The deployment area (A) could be in any shape, and the environment obstacles (O) are ignored for the purpose of simplicity. Sensors have a limited communication range (cr_i) and constrained sensing range (sr_i). Nodes are considered connected if the distance (d_{ij}) is less than or equal to the sum of the sensors s_i (cr_i) and s_j communication ranges (cr_j)

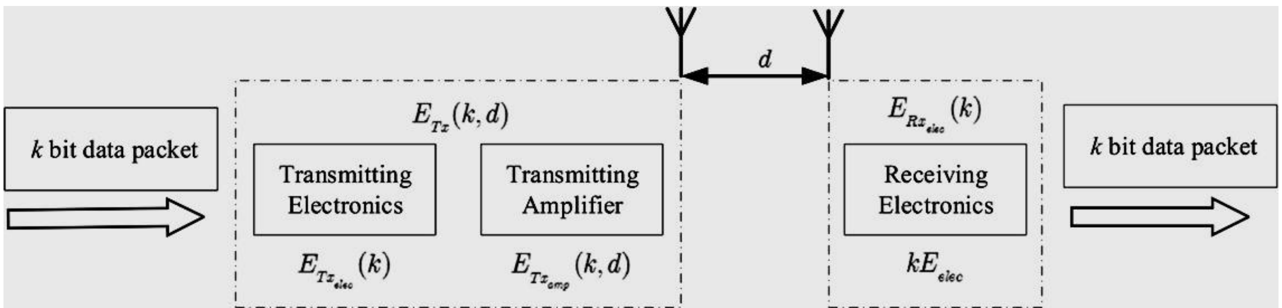

Figure 2. Wireless sensor node energy model

where d_{ij} is computed as:

$$d_{ij} = \sqrt{(x_i, y_i)^2 + (x_j, y_j)^2} \qquad \forall 1 \leq \{i, j\} \qquad \{i, j\} \leq S$$

where (x_i, y_i) and (x_j, y_j) are the locations of s_i and s_j, respectively. Sensors are assumed to be deployed in unattended areas with some distribution. They collaborate to form a network where each sensor searches for its neighbors to communicate with, as shown in Figure 1. Sensors are assumed to send their sensed data to a sink node (SN). A sink node could be anywhere in the network. Using a naïve routing algorithm, sensors will be energy depleted in almost no time due to extra required control messages, long paths, and the dropped messages.

Therefore, a proper clustering technique is assumed to minimize the consumed energy per node, where each node will be sending its data to its nearest and efficient cluster head (CH_i). However, the purpose of sensors clustering is important. There are many clustering techniques that focus only on energy-saving, which is a critical requirement. However, focusing only on energy saving due to the communication will not make a reliable wireless sensor network.

An energy consumption model involved in the interaction is provided in Figure 2 to determine the efficiency of cluster maintenance in WSNs. Remember that this analysis does not include energy wastage in measurement and processing. The communication capacity of nodes in WSNs requires energy consumption in data transmission and receiving, respectively. When sending data, energy consumption requires the energy consumed by the radio frequency transmitter circuit and the signal amplifier circuit. The receiving circuit only requires energy consumption when receiving information. Among them, signal amplifier power consumption can be measured by the free-space path or multi-path fading model according to the distance between the sender and receiver sides. For the free-space path fading model, the path loss exponent is two. It means that the energy loss is proportional to the square distance. While the path loss exponent for the multipath fading model is four. Suppose the communication channel is symmetrical. If k bit information is transmitted through the distance d system, the $E_{Tx}(k, d)$ transmission energy consumption may be given as follows:

$$E_{Tx}(k, d) = E_{Txmap}(k) + E_{Txmap}(k, d) = K E_{elec} + K \varepsilon_{fs} d^r \quad (2)$$

where $E_{Txelec}(k)$ and E_{elec} are transceiver k bit energy consumption and single bit information, respectively.

$E_{Txamp}(k, d)$ is the power amplifier energy consumption for k bit information a distance d. The ε_{fs} is the power consumption of the amplifier in the free space path fading for each bit of data transmission. R is a wireless channel constant determined by the signal distance d($r = 2$ if $d < d_0$, $else$ $r = 4$), and d_0 is the transmission distance threshold defined as [29]:

$$d = \frac{\varepsilon fs}{\varepsilon mp} \quad (3)$$

where ε_{mp} is the power amplifier's energy consumption in the multi-path fading model. The receiving side's energy consumption can be calculated as follows:

$$E_{Rx}(k) = E_{Rxelec}(k) = kE_{elec} \quad (4)$$

where $E_{Rx}(k)$ is the wireless receiver circuit's energy consumption for k bit data.

3. Proposed Neuro-Fuzzy Clustering (NFCL)

We have proposed a distributed clustering algorithm with minimum overhead. Our algorithm consists of two phases namely setup and clustering.

- ***Deployment Phase***

Sensors are deployed into the monitored field randomly or sequentially.

- **Setup Phase**

In this phase, sensors cooperate to know their neighbors by exchanging hello messages, including their IDs, energy level, location information, and their buffer size. Sensors are assumed to have a GPS location identification feature. Once a node identifies its neighbors, it computes the distance to all of them. A node forms a table with all of its neighbors' parameters for future use. This costs only one message to be sent from each node. Any node will hear from others. It will keep track of the messages it receives.

- **Clustering Phase**

Actual clustering takes place in this process, where the head of the cluster declares itself in a separate message. Neural fuzzy logic is used in this phase to build the nodes clusters. The neural network is used to select the cluster heads and the fuzzy logic provides a weight for each cluster heads.

The neural network takes three parameters as input which are the node distance from the sink node, nodes energy, and the node's transmission range. Sigmoid function (Figure 3) is used as an activation function for the neural network where the output could be 0 or 1. The formed neural network is shown in Figure 4.

The perceptron learning rule of the single-layer used to train the network is given in equation (1).

$$W_i(t-1) = W_i(t) + \mu \; x \; (O_T - O_A) x \; L \qquad (1)$$

where Wi is the weight factor of ith cell, i is the number of input cells, μ is the learning rate, L is the input of that cell, OA is the output of the network, and OT is the desired output. The adjustment of weight is given by

$$W_{new} = W_{old} + N \; x \; \mu \; x \; I_p \; x \; (O_T - O_A) \qquad (2)$$

$$where$$

$$\nabla W = N \; x \; \mu \; x \; I \; x \; (O_T - O_A) \qquad (3)$$

N here is an active neuron and Ip is the input from the previous layer.

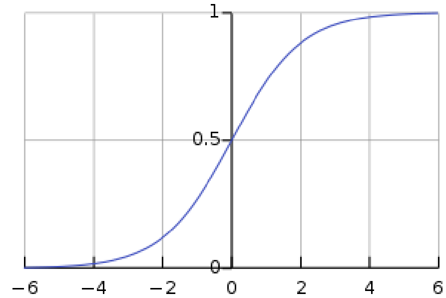

Figure 3: Sigmoid function as an activation function

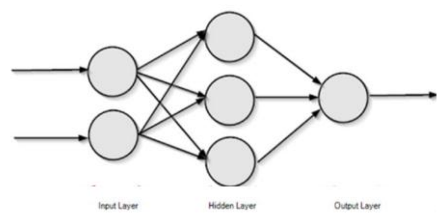

Figure 3: 3-layer neural network

The fuzzy logic technique used in this paper is based on the following memberships. The proposed fuzzy logic technique is used to favor one cluster head over another based on three parameters including Signal to Noise Ratio (SNR), buffer size, and nodes degree, in addition to the output membership. As can be seen in the input membership, there are three linguistics, small, medium, and high. The output uses the same linguistics, as well.

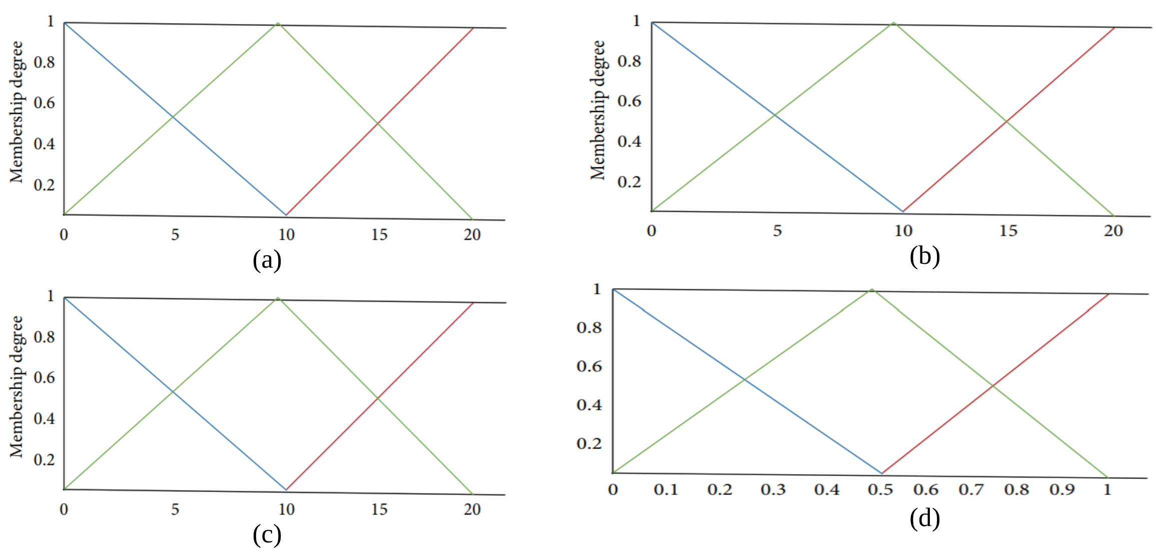

Figure 4: (a) SNR membership, (b) Buffer size membership, (c) Nodes degree, (d) Output membership

4. Simulation and Results

In this section, we experiment with the proposed algorithm Neuro-Fuzzy Clustering (NFCL) with different sizes of networks. Our algorithm is compared with the neuro-fuzzy energy-aware clustering scheme (NFEACS) [41], where it is using the same neuro-fuzzy technique for clustering but with different network parameters including energy, received signal strength, and sensors mobility. We believe that nodes degree and nodes buffer are more important than the node's sensors mobility. This has been proved in the following experiments. Our experiments work on a monitored field with 1000 m x 1000m with a variation of 100 nodes to 1000. The values of ε*mp with 100 pJ/bit/m*^{2}, E_{lec} = 50 nJ/bit and the

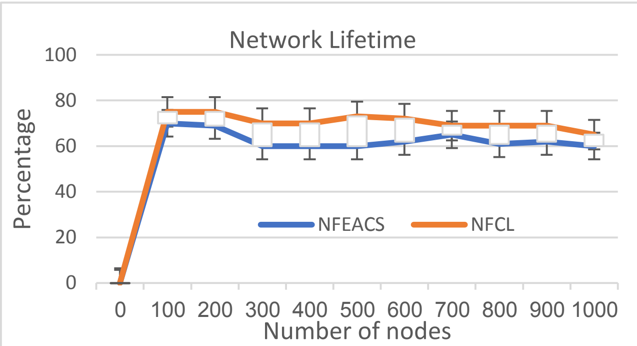

Figure 5: Network lifetime performance

aggregation ration 10% as stated in NFEACS.

- **Network Lifetime**

As can be seen in Figure 5, the lifetime performance for both NFCL and NFEACS is evaluated. The lifetime is evaluated with a different number of nodes starting from 100 nodes to 1000 nodes. NECL overperforms the NFEACS in almost all of the cases by a 10% increase in lifetime. This is clearly visible when 500 nodes were deployed in the monitored field.

- **Number of Dropped Packets**

In this set of experiments, the average number of dropped packets were measured for both NFCL and NFEACS. As can be seen in Figure 6, the difference between the two

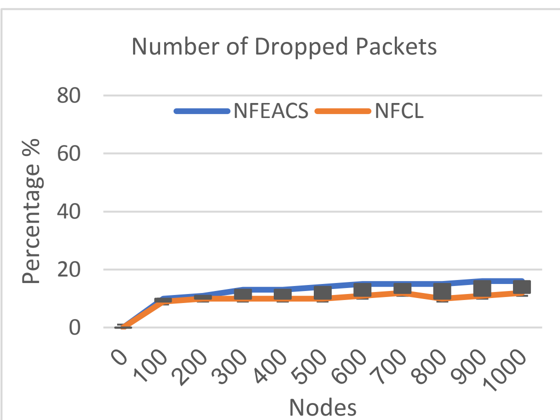

Figure 6: Number of dropped packets

algorithms were not that much; however, NFCL still overperforms the NFCL. Both act very similarly where the number of the deployed nodes are small up to 200 nodes then NFCL dropped packets are reduced. We investigated such an issue and we found that the small number of nodes does not make in some networks a completely connected network.

Received Signal Strength

Received signal strength is another measure for network quality and performance. Figure 7 shows the average of the measured signal strength for both algorithms. As can be seen, NFCL signal strength is much better than NFEACS. This is an indicator that the selection of the cluster heads was more appropriate in NFCL than in NFEACS.

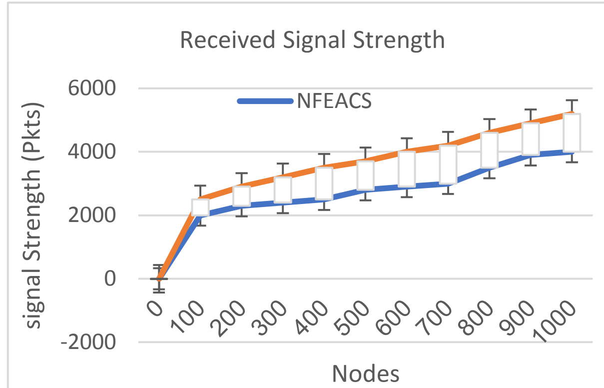

Figure 7: Signal strength ratio

5. CONCLUSION **Figure 6: Number of dropped packets ON**

This paper introduced a new sensor-based clustering algorithm. The algorithm is based on both neural networks and fuzzy logic techniques (neuro-fuzzy). The nodes are initially deployed randomly; the nodes in this context are considered heterogeneous in terms of their energy and communication range. Once they are deployed, the neural networks are used to select the best cluster heads based on the node distance from the sink node, nodes energy, and the node's transmission range. Once the cluster heads are identified, the fuzzy logic techniques rank the selected nodes based on other criteria such as nodes buffer size**,** signal to Noise Ratio (SNR), and nodes degree. With extensive experiments, the proposed algorithm (NFCL) is compared to one of the recent and similar algorithms (NFEACS). Based on our observations, NFCL seems to overperform NFEACS in all of the cases; this is due to the importance of the used parameters in NFCL.

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REFERENCES

[1] K. Akkaya, M. Younis, A survey on routing protocols for wireless sensor networks, Ad Hoc Netw. 3 (3) (2005) 325–349.

[2] K. Sohraby, D. Minoli, T. Znati, Wireless Sensor Networks, 2007.

[3] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, Wireless sensor networks: a survey, Comput. Network. 38 (4) (2002) 393–422.

[4] A.M. Zungeru, L.-M. Ang, K.P. Seng, Classical and swarm intelligence based routing protocols for wireless sensor networks: a survey and comparison, J. Netw. Comput. Appl. 35 (5) (2012) 1508–1536.

[5] S.P. Kumar, Sensor networks: evolution, opportunities, and challenges, Proc. IEEE 91 (8) (2003) 1247–1256.

[6] T. Rault, A. Bouabdallah, Y. Challal, Energy efficiency in wireless sensor networks: a top-down survey, Comput. Network. 67 (2014) 104–122.

[7] M. Faheem, M.Z. Abbas, G. Tuna, V.C. Gungor, EDHRP: energy efficient event driven hybrid routing protocol for densely deployed wireless sensor networks, J. Netw. Comput. Appl. 58 (2015) 309–326.

[8] M. Faheem, V.C. Gungor, Energy Efficient and QoS Aware Routing Protocol for Wireless Sensor Network-Based Smart Grid Applications in the Context of Industry 4.0, 2017, pp. 4–6.

[9] M. Faheem, V.C. Gungor, MQRP : mobile sinks-based QoS-aware data gathering protocol for wireless sensor networks-based smart grid applications in the context of industry 4 . 0-based on internet of things, Future Gener. Comput. Syst. 82 (2018) 358–374.

[10] S. Bilal, et al., 3D weighted centroid algorithm & RSSI ranging model strategy for node localization in WSN based on smart devices, Sustain. Cities Soc. 39 (September 2017) (2018) 298–308.

[11] E. Fadel, et al., Spectrum-aware bio-inspired routing in cognitive radio sensor networks for smart grid applications, Comput. Commun. 101 (2017) 106–120.

[12] M. Faheem, V.C. Gungor, Computer Standards & Interfaces Capacity and spectrum-aware communication framework for wireless sensor network-based smart grid applications, Comput. Stand. Interfac. 53 (March) (2017) 48–58.

[13] A. Ngadi, V.C. Gungor, Smart grid communication and information technologies in the perspective of Industry 4 . 0 : opportunities and challenges, Comput. Sci. Rev. 30 (2018) 1–30.

[14] M. Saleem, G.A. Di Caro, M. Farooq, Swarm intelligence based routing protocol for wireless sensor networks: survey and future directions, Inf. Sci. (Ny) 181 (20) (2011) 4597–4624.

[15] L. Buttyan, J.P. Hubaux, Enforcing service availability in mobile ad-hoc WANs, in: 2000 1st Annu. Work. Mob. Ad Hoc Netw. Comput. MobiHOC 2000, 2000, pp. 87–96.

[16] A. B. MacKenzie, S.B. Wicker, Game theory in communications: motivation, explanation, andnnapplication to power control, in: GLOBECOM’01. IEEE Glob. Telecommun. Conf. (Cat. No.01CH37270) 2, 2001, pp. 821–826.

[17] M. Roth, S. Wicker, “Termite : Ad-Hoc Networking with Stigmergy, 2003, pp. 2937–2941.

[18] M. Dorigo, AntNet : Distributed Stigmergetic Control for Communications Networks, 1998.

[19] H.J.A. Nasir, K.R. Ku-Mahamud, E. Kamioka, Ant Colony Optimization approaches in wireless sensor network: performance evaluation, J. Comput. Sci. 13 (6) (2017).

[20] M. Saleem, I. Ullah, M. Farooq, BeeSensor: an energy-efficient and scalable routing protocol for wireless sensor networks, Inf. Sci. (Ny) 200 (November) (2012) 38–56.

[21] A.M. Zungeru, L.M. Ang, K.P. Seng, Termite-hill: performance optimized swarm intelligence based routing algorithm for wireless sensor networks, J. Netw. Comput. Appl. 35 (6) (2012) 1901–1917.

[22] M. Sharawi, E. Emary, I.A. Saroit, H. El-mahdy, Bat swarm algorithm for wireless sensor networks lifetime optimization, Int. J. 3 (5) (2014) 654–664.

[23] T. Gui, C. Ma, F. Wang, J. Li, D.E. Wilkins, A Novel Cluster-Based Routing Protocol Wireless Sensor Networks Using Spider Monkey Optimization, IEEE Xplore, 2016, pp. 1–6.

[24] M. J. Tierney, J. A. Tamada, R. O. Potts, R. C. Eastman, K. Pitzer, N. R. Ackerman, and S. J. Fermi, “The GlucoWatch® biographer: a frequent automatic and noninvasive glucose monitor”, Annals of Medicine, vol. 32, Issue: 9, pp.632-641. 2000.

[25] J. C. Puyana, B. R. Soller, S. Zhang, et al. “Continuous measurement of gut pH with near infrared spectroscopy during hemorrhagic shock”, The Journal of Trauma: Injury, Infection, and Critical Care, vol. 46, Issue: 1, pp.9-15. January 1999.

[26] W. Soofi, “Nanoscale Surface Acoustic Wave Sensors for Early Cancer Detection”, National Nanotechnology Infrastructure Network Research Experience for Undergraduates. California 2005.

[27] C. Mc Caffrey, O. Chevalerias, C. O’Mathuna, and K. Twomey, “Swallowable-Capsule Technology”. IEEE Pervasive Computing, vol. 7, issue: 1, pp.23-29. January-March 2008.

[28] Y. Zhang, C. K.C. Lui, and B.L. Lu., “Wireless Biomedical Sensing”, Wiley Encyclopedia of Biomedical Engineering. John Wiley & Sons, Inc.

[29] The SmartPill GI Monitoring System, at http://www.smartpillcorp.com/ [June 15, 2010]

[30] L. Schwiebert, S. K. S. Gupta, and J. Weinmann, “Research challenges in wireless networks of biomedical sensors”, MOBICOM’01, Proceedings of the 7th annual international conference on Mobile computing and networking, pp.151-165. Rome, Italy, July 2001.

[31] Huan-Bang Li, Ken-ichi Takizawa, Bin Zhen, and Ryuji Kohno, “Body Area Network and Its Standardization at IEEE 802.15.MBAN”, 16th IST Mobile and Wireless Communications Summit, pp.1-5. Budapest, Hungary, July 2007.

[32] Bartosz P. Jarochowski, SeungJung Shin, DaeHyun Ryu, and HyungJun Kim, “Ubiquitous Rehabilitation Center: An Implementation of a Wireless Sensor Network Based Rehabilitation Management System”, ICCIT’07, Proceedings of the International Conference on Convergence Information Technology, pp.2349-2358. Gyeongju, Republic of Korea, 21-23 November 2007.

[33] V. Santos, P. Bartolomeu, J. Fonseca, and A. Mota, “B-Live-A Home Automation System for Disabled and Elderly People”, SIES’07, Proceedings of the International Symposium on Industrial Embedded Systems. Lisbon, Portugal, July 2007.

[34] N. F. Ince, C. Min, A. H. Tewfik, and David Vanderpool, “Detection of Early Morning Daily Activities with Static Home and Wearable Wireless Sensors”, EURASIP Journal on Advances in Signal

Processing, vol. 2008. Hindawi, 2008.

[35] Chris Otto, Aleksandar Milenković, Corey Sanders, and Emil Jovanov, "System architecture of a wireless body area sensor network for ubiquitous health monitoring", Journal of Mobile Multimedia, vol. 1, issue: 4, pp.307-326. 2006.

[36] A. Mainwaring, R. Szewczyk, J. Anderson, and J. Polastre, "Habitat Monitoring on Great Duck Island", WSNA 2002, Proceedings of the First ACM International Workshop on Wireless Sensor Networks and Applications. Atlanta, Georgia, USA, September 2002.

[37] NICTOR, National ICT Australia, at http://nicta.com.au/__data/assets/pdf_file/0003/2919/090527NICTOR1.pdf [June 15, 2010]

[38] D. Hughes, P. Greenwood, G. Blair, G. Coulson, F. Pappenberger, P. Smith, and K. Beven, "An intelligent and adaptable grid-based flood monitoring and warning system", Proceedings of the UK eScience All Hands Meeting. Nottingham, UK, 10-13 September 2006.

[39] [45] Irrigating When the Leaves Get Hot, at http://www.activefarming.org/irrigating-when-theleaves-get-hot [June 15, 2010]

[40] S. A. Summers, "Wireless Sensor Networks for Fire fighting and Fire Investigation", UCCS University of Colorado at Colorado Springs, CS526 Project. 2006.

[41] Julie, E. G., & Selvi, S. T. (2016). Development of Energy Efficient Clustering Protocol in Wireless Sensor Network Using Neuro-Fuzzy Approach. Scientific World Journal, 2016. https://doi.org/10.1155/2016/5063261