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Research Article

Application of Energy Efficient Cluster Based Routing Protocol using Wireless Sensor Network for Industrial Monitoring in Anambra State

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Abstract

As ad-hoc network, wireless sensor networks (WSN) have become increasingly common in several fields of human endeavours requiring information gathering and prediction in both military and civil operation. This work has presented modified energy efficient cluster-based routing in wireless sensor networks for industrial monitoring. A wireless sensor network (WSN) work model will be developed using MATLAB C code and with the propose scheme. Simulations were carried out to analyze and investigate the effectiveness of the system in terms of optimum range of clusters required to optimize energy of WSN, which revealed that at number of clusters between 20 and 54, the energy consumption by the network was approximately the same. The maximum number of clusters was 54 with 5 head-set. The variation of energy per round against the number of clusters showed that energy consumed per round by each sensor node in cluster was reduced as the number of clusters was increased. Increase in the diameter (or area) of the network results in increased energy consumed per round. This agrees with the fact that the wider the area of the WSN, the more energy was consumed by the sensor nodes since the distance between the nodes increased. In addition, energy consumption reduced as the head-set size increased such that the highest energy consumption in the network was 19.8 J when the head-set was 1 while the lowest energy consumed was 3.94 J with head-set equal to 5.

Keywords: Wireless Sensor Network; Cluster Based Routing Protocol; Industrial Monitoring; Anambra

Introduction

Technological advancement has brought about the possibility of having devices that are very small, low powered, outfitted with programmable computing, numerous parameter sensing and wireless communication potential. Despite the fact that recent technology is geared towards small sizeable computer, data processing capability and wireless communication is still being maintained. One of such technology is the wireless sensor device. Wireless sensor combines computing, communicating (radio) and sensing capabilities. A physical structure of multiple sensors that are arranged and wirelessly connected to communicate with one another to carry out specified function is called Wireless Sensor Network (WSN).

Wireless Sensor Networks (WSNs) contain sensor nodes that are usually equipped with a transducer, a radio transceiver, small-controller and a source of power (batteries) deployed in process proposed for monitoring situations and parameters at different locations. It is possible to sense or measure vast types of parameters from the environment including, temperature, light humidity, pressure, wind direction and so on with sensor nodes. The data acquired by sensor nodes are generally transmitted through Radio Frequency (RF) channel to the base station or sink. The base station is a radio transceiver that connects other wireless sensors to central hub, and may serve as a gateway between a wired network and the WSN. The base station node is the main unit of WSN that can be connected to an infrastructure or to the internet through a gateway that lets distant or inaccessible users to access the collected data (Rault, 2015). Hundreds to thousands of sensing nodes can be contained in WSNs, with a desire to make the nodes inexpensive and energy efficient while taking advantage of the vast numbers to obtain high quality performance (Nuray & Daraghma, 2015). Sensor nodes are used for real time gathering of data that are onward transferred directly or indirectly through relay nodes to sink (Ahmad et al, 2014). As a result of the ability of WSNs to accurately and reliably gather information, there is now the possibility of building systems that can provide real-time detection and early warning function.

Therefore, WSNs have been deployed in various monitoring applications such as environmental or habitat monitoring, industrial monitoring and automation process, agriculture, security, and health (Cong & Shujuan, 2016; Rozas & Araujo, 2019) including, enabling quick coordinated responses to address cases of emergency such as bushfires, tsunamis, earthquakes, and other crisis situations (Jing, 2015a & 2015b). An environmental parameter in an industry can be controlled effectively using a WSN. The network would consist of many smaller clusters which would then be inter-connected using gateways. In this work, a solution is proposed to provide continuous data streaming and monitoring to address energy consumption of sensor nodes in a wireless network deployed as Industrial Wireless Sensor Network (IWSN) for environmental sensing. Such a scheme would be able to provide energy efficient capability and lifetime extension for nodes used in sensing data and monitoring of various parameters of air such as temperature and humidity in an industry.

Literature Review

Wireless Sensor Networks (WSNs) are being used in various domains to meet the needs of many applications. WSNs consists of a number of small, inexpensive and low-power consuming devices called nodes that work together by communicating with each other through a sophisticated network. These nodes are deployed to gather sensory information and may also be used to control certain actuations that in turn control the environment (or system). Flexible installation and maintenance of nodes in locations difficult to access, wide range of deployment along with low costs make WSNs the most sought-after technology in various field varying from agriculture (Gutierrez et al., 2014) to automation in industries (Henry, 2010). The main entity, also denoted as base station or sink, can be connected to an infrastructure or to the Internet through a gateway, which allows remote users to access the collected data. The main advantage of wireless sensor networks depends in the ability to deploy a lot of tiny autonomous nodes without any pre-established infrastructure. After the deployment, nodes gather information from the physical world, and according to a defined communication protocol, they cooperate to deliver data towards the sink through single-hop or multi-hop communications. WSNs are built with small size, low cost wireless communication enabled sensors that are deployed to build various monitoring and control networks that are used in diverse fields like industrial automation, process control, agriculture, hospital monitoring systems and so on. Some examples are an automated irrigation system that optimizes the use of water for agriculture through a wireless network and also transmitted data through the internet developed by Gutierrez et al. (2014). Another implementation of WSN is the development of a network that helps in monitoring patients (with chronic diseases) who need to be observed continually but who stay at home by Dilmaghaniand et al. (2011). The network used SimpliciTI protocol and the data was uploaded to the internet for real time analysis in hospitals (Dilmaghaniand et al., 2011).

In Bonivento et al. (2006), the design of Wireless Sensor Networks (WSNs) was studied. They have explained the various measures to be taken to bridge the gap between control algorithm designs and network designs. Wireless Sensor Networks (WSNs) have evolved to a great extent through the years (Low, 2013) and different standards have been developed (Groza & Murvay, 2013). Wide Fidelity (Wi-Fi), Bluetooth (Sairam et al., 2002), Zigbee, WLAN are some of the commonly used protocols in industries (Qureshi et al., 2014). Each protocol has its own pros and cons. For example, WLAN has a high data rate but low battery life as compared to Bluetooth or Zigbee (Li et al., 2013). In selecting a protocol for a particular network many factors such as data size, speed, number of nodes, range and others have to be considered. Location routing protocols make communication between the nodes effective (Arvind et al., 2016). Cobo et al. (2015) proposed such location routing protocol using smart antennas to estimate nodes positions into the network and to deliver information basing routing decisions on neighbor's status connection and relative position. In WSNs, energy efficiency and communication reliability are key factors to be looked into (Blankenstein et al., 2015). Cook et al. (2014) showed how zero-power WSNs can be developed using RFID. Real-world implementation of RFID-based strain, temperature, water quality and noxious gas sensors.

Implementation of WSN in industries has helped in the effective automation of different processes. Requirements in the industrial systems differ from the general WSN requirements. In Somappa et al.

(2014) discussed various state-of-art WSN standards to satisfy these requirements of those industries. Zhao (2011) discussed the advantages and challenges faced in the implementation of WSN for industrial process monitoring and control. Diverse protocols that can be used for process automation in industries and the activities of international standardization have been introduced (Hayashi et al., 2009). Requirements for WSNs deployed at industrial applications include real time characteristics meeting application and communication parameters. Few state-of-art solutions for wireless communication in industrial automation are available (Frotzscher et al., 2014). Chen et al. (2010) presented a locally collaborative control algorithm, based on a distributed estimation to cope with sensory measurement noise and packet loss in wireless communications, which fully exploits the collaborations between actuators and sensors for industrial automation.

Recent advances in wireless sensing technology encourage the further optimization and improvement of the product development and service provision processes. Industrial Wireless Sensor Networks (IWSNs) are emerging class of WSN that face specific constraints linked to the particularities of the industrial production. In these terms, IWSNs faces several challenges such as the reliability and robustness in harsh environments, as well as the ability to properly execute and achieve the goal in parallel with all the other industrial processes. Furthermore, IWSN solutions should be versatile, simple to use and install, long lifetime and low-cost devices – indeed, the combination of requirements hard to meet. The deployment and the setup of Wireless Sensor Networks are extremely challenging tasks, which becomes even more challenging in industrial applications. The environment where IWSNs are deployed in order to monitor environmental or production processes is extremely dynamic. It can depend on the specific product, the phase of life of the product and the kind of service provision considered. In fact, each kind of product or phase of life has different requirements and imposes on the monitoring system different constraints. In this Section we will try to give a general description that can be useful for IWSNs' designers.

One of the challenges to face is the impact of the propagation environment. When the IWSN is deployed inside a factory to assess the production process quality, the designer has to deal with the interference and the radio environment produced by the production machines. In this case, the IWSN has to be deployed and calibrated not only to guarantee the correct assessment of the production process, but above all not to interfere with the production process. The same logic holds for IWSNs used to monitor electricity, water and gas consumption. Often nodes of the IWSN are immersed into the goods inside containers or any transportation means. For this kind of environments, the radio characteristics of the goods and the container have to be carefully investigated in order to determine the most efficient and effective way to make nodes communicate in spite of probable signal degradations.

In general, radio waves will not follow the same behavior according to the environments in which sensors are deployed. If the network is deployed outdoor, the radio propagation can be assimilated to a free-range perturbation, with an almost omnidirectional propagation. However, it will be impacted by the weather, more or less depending of the frequency used. For instance, frequencies around 2.4GHz may be stopped by a thick fog (Erdelji et al., 2013). When wireless sensor networks are deployed indoor, the data propagation is far from being omnidirectional. In this environment it is even harder to make the classical assumptions on the shape and extension of the communication range for sensors. In fact, sensors that are placed within the communication range might be invisible, whereas sensors that should be considered out of range are actually in the neighbors' set. This can be explained by the fact that waves can bounce on walls, machinery and so on. This amplifies the signal in some locations and cancels it in other locations. Indeed, metallic equipment may extend the propagation area for the radio signal or may prevent the signal to reach close areas beyond the equipment. Similarly, presence of metal and liquid greatly impacts the propagation. These challenges, strictly dependent from physical factors, are not easy to handle. The environment in which sensors will be deployed needs to be studied in order to determine the optimal locations for sensors. Operation lifetime, as a result of the power management policy, is one of the key issues in all the WSN applications, including the IWSN. Several IWSN applications, especially in the field of environmental monitoring, require the autonomous power supply from alternative power sources, such as wind or solar power. Although it is possible to obtain a constant power supply in some industrial environments, sensors tend to be battery powered in order to keep the monitoring non-intrusive. However, in most cases, batteries are not expected to be reloaded or changed. Thus, energy should be preserved. There exist many ways to do so, both in software and hardware. From the hardware point of view, it is important to carefully choose the components. These latter should be low energy consuming while providing the needed capacity. In some particular applications, energy harvesting modules can be envisioned, like solar cells or kinematic sensors, etc., but their usage is still marginal. From the software point of view, energy should be preserved by controlling the number of messages to be sent and the transmitting power. Indeed, radio activities, such as sending and receiving data are the activities that consume more energy in WSN compared with processing and sensing activities.

Some other technological challenges of IWSNs are heterogeneity, autonomous, maintainability, reliability, and security. The heterogeneity of objective network is focused especially on logistics applications. The IWSN should be able to autonomously configure and deploy when the deployment site is inaccessible for humans. In this context, maintainability is one of the important design challenges in the IWSN as well. The deployed IWSN and its components should be easily repairable or replaceable by maintenance personnel in the case of failures. The requirements of the industrial process impose the need for reliable and secure IWSN. Reliability in this context refers to the monitoring system that has to provide accurate and real-time information regarding the monitored process even in harsh industrial environments under extreme vibration, noise, and humidity or temperature conditions. The information gathered during the operation must be protected and secured.

Methodology

WSNs are built with small size, low cost wireless communication enabled sensors that are deployed to build various monitoring and control networks. The parameters for the purpose of simulation in this work were obtained from the study involving industrial monitoring of gas distribution pipelines network using WSN in Abbas et al. (2021).which will be implementation in MATLAB simulation environment.

The technique propose to realize the objectives of this work starts with the system energy model of a sensor node, hierarchical routing technique, network topology of environmental sensing wireless sensor network (WSN), and energy efficiency management model. The energy model of sensor node in a wireless communication can be represented using a radio model given by (Heinzelman et al., 2000). The radio model be of first order type provides an evaluation of energy used by sensor node when message or packet is being sent or received at every cycle. Figure 3.1 is the block diagram of a first order radio communication model (Heinzelman *et al.*, 2000).

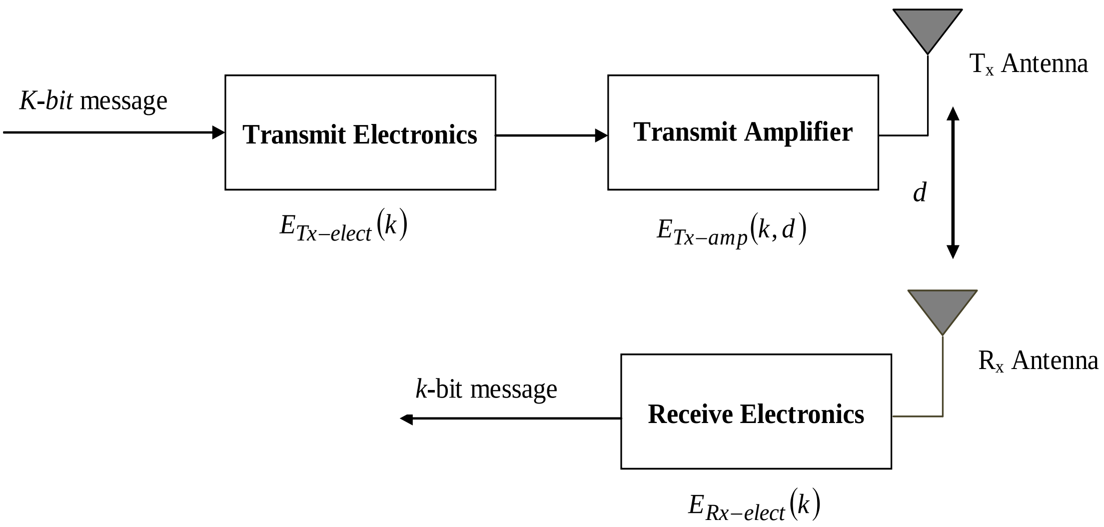

Figure 3.1 Block diagram of first order radio communication model

The mathematical expressions regarding the energy consumed when *k*-bit of message (or packet) is transmitted through a distance *d* is given by:

$$E_{Tx} = E_{elect} \times k + E_{amp} \times \left(k \times d^2\right) \quad (1)$$

Equation (1) serves well for energy dissipated for over a shorter transmission distance such as within clusters. However, for transmission over a longer distance, such as from a cluster head to the base station, Equation (1) can be expressed by:

$$E_{Tx} = E_{elect} \times k + E_{amp} \times \left(k \times d^4\right) \quad (2)$$

Similarly, the energy utilized with respect to receive of message is given by:

$$E_{Rx} = E_{elect} \times k \quad (3)$$

However, including the cost of beam forming into Equation (3) gives:

$$E_{Rx} = E_{elect} \times k + E_{bf} \times k \quad (4)$$

where: E_{Tx} is the energy consumed per *k*-bit message at transmitter, E_{Rx} is the energy consumed per *k*-bit message at receiver, E_{amp} transmit amplifier coefficient (or amplification factor), $E_{elect} = E_{Tx-elect} = E_{Rx-elect}$ is the energy consumed by the transmit electronic or the receive electronic, k is the number of bits transmitted, and d is the distance between a sensor node and its cluster head (CH) or distance between a CH and another CH nearer to the base station (BS) or simply the distance between CH and BS.

The developed solution for energy consumption optimization in wireless sensor network deployed for automation process sensing for improved quality of service (QoS) management. The solution is a hierarchical cluster-based routing technique which was based on the fact that the energy used for long range transmission of message (or packet) was very much greater than the energy required for sending message over short range. That was more energy will be consumed to send a message to a distant node than to a closer node. However, the Low Energy Adaptive Cluster Head (LEACH) technique was modified in this work by extension such that a head-set was used as a substitute for cluster head (CH). This way, a head-set that comprises many nodes was selected during each election instead of a CH. The sending of messages to distant base station (BS) was carried out by members of a head-set. The transmission operation from all the head-set members to BS was equally distributed.

For a start, the terms associated with the developed solution and the associated mathematical equations describing each process of the routing protocol developed in this work was discussed. Cluster heads (CHs) were employed in carrying out data aggregation and/or data fusion prior to the forwarding information onto a base station or sink. Hence, a CH is a node that transmits aggregated sensor data to a base station. While sensor nodes that transmit collected data to their CH are called non-cluster heads. Each cluster in the network has a head-set that comprises numerous virtual cluster heads. Nevertheless, just a head-set member is lively at a time. There are two iteration phases namely; a selection stage and a data transfer stage. During the election stage, choosing of head-sets takes place for the specified number of clusters. While data transfer stage involves the transmission of aggregated data to the BS by members of head-set. Every data transmit stage comprises many epochs, which represents the division of the entire network lifetime. All through an epoch (a period), every head-set member becomes a CH once. Each round comprises a number of iterations. Every node happens to be head-set member once for each round. The Communication steps described so far are demonstrated in figure 3.2 and the flowchart for the routing process is shown in figure 3.3.

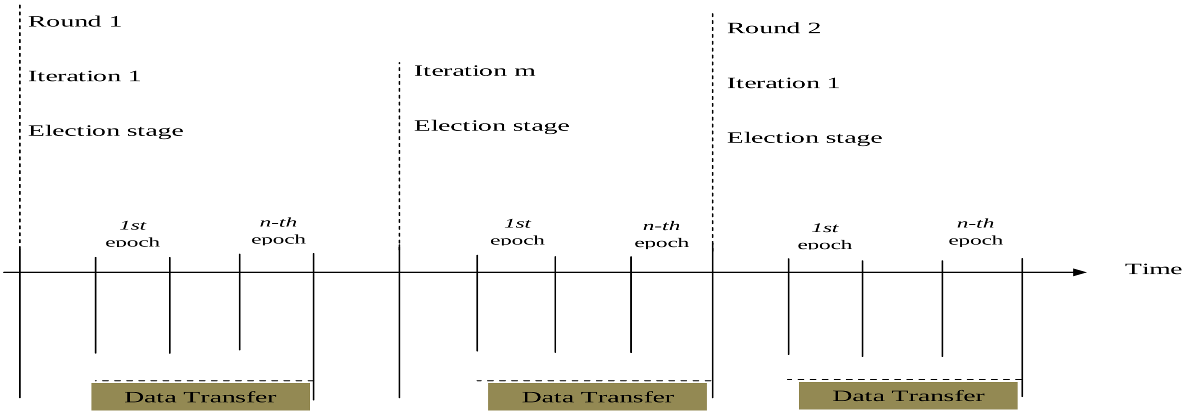

Figure 3.2: Stages of communication in a cluster of a WSN

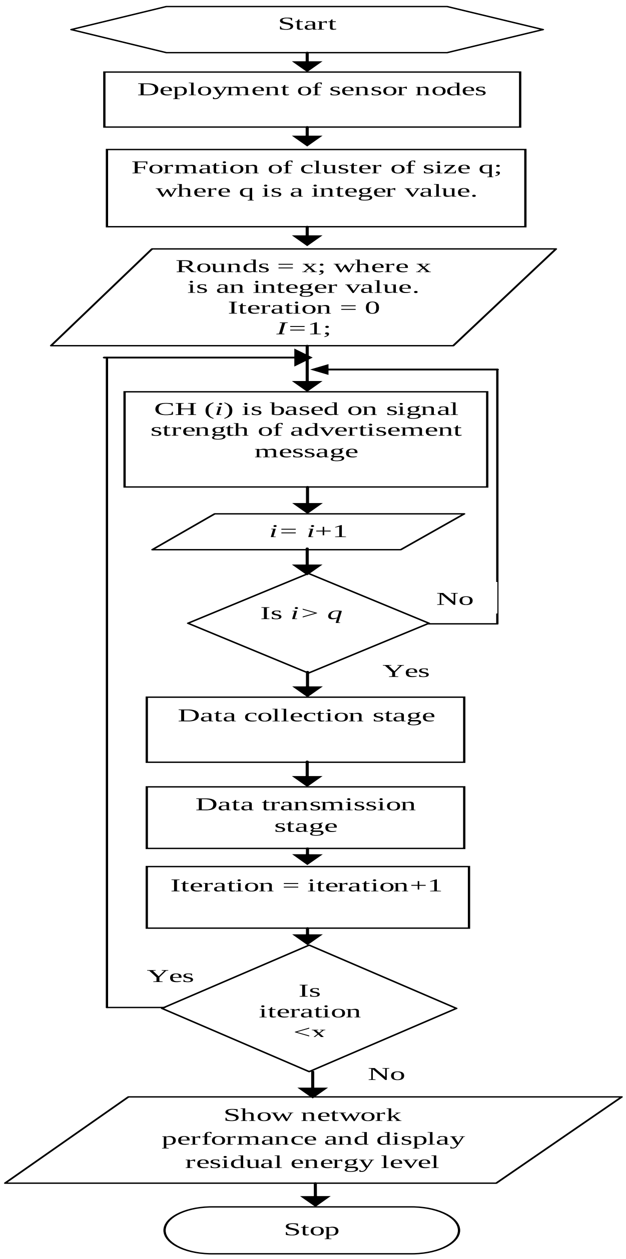

Figure 3.3 Flowchart of the energy level routing process

Results

The results are presented in terms of number of clusters against size of head-set as shown in figure 4.1 and distance of cluster from base station in figure 4.2.

Figure 4.1 Plot of maximum number of clusters against the size of head-set

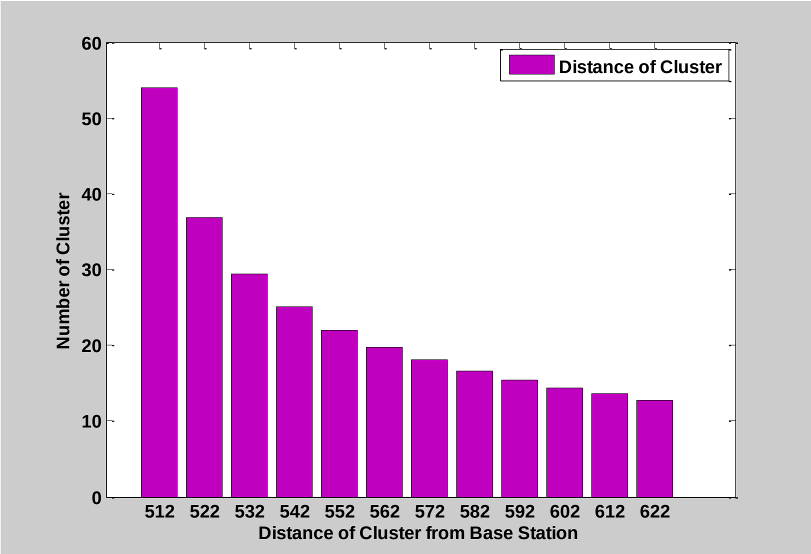

Figure 4.2 Plot of number of clusters against distance from base station

The variation in maximum number of clusters against distance from base station is shown in figure 4.2. The graph shows that increase in the distance from base station results in decreased number of clusters.

Figures 4.3 and 4.4 show residual energy per number of clusters and energy consumed per round against number of clusters.

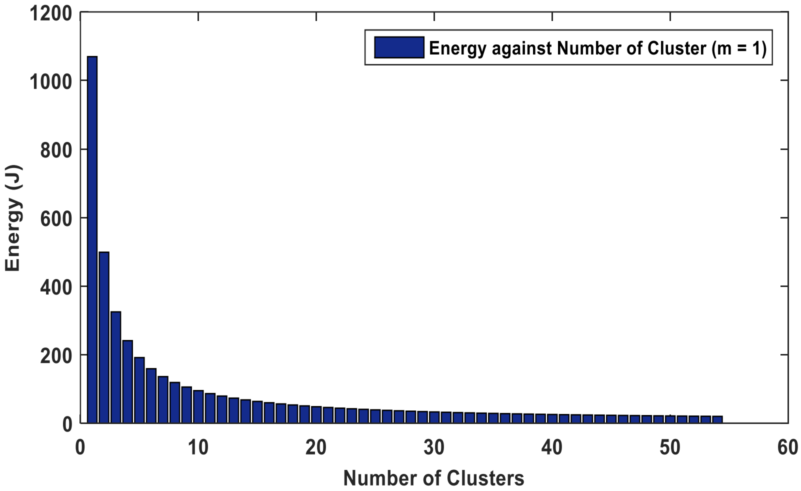

Figure 4.3a Energy per number of clusters (head-set size = 1)

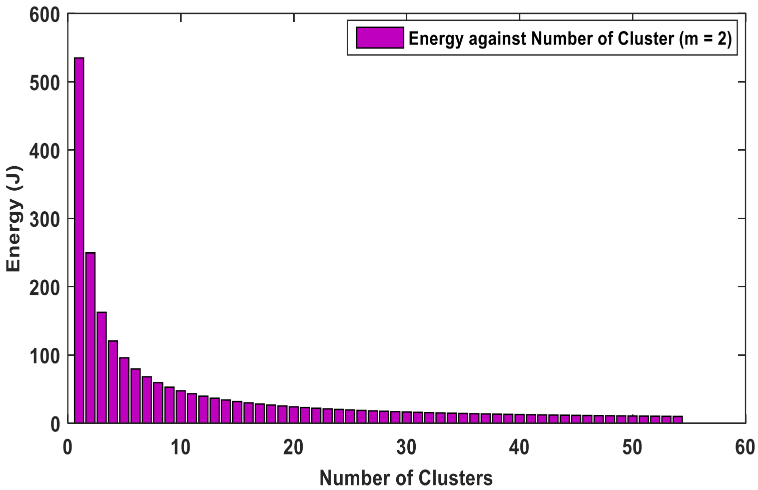

Figure 4.3b Energy per number of clusters (head-set size = 2)

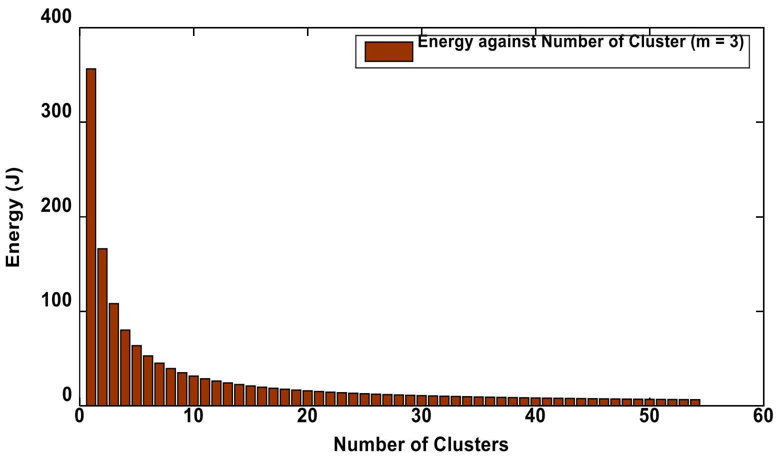

Figure 4.3c Energy per number of clusters (head-set size = 3)

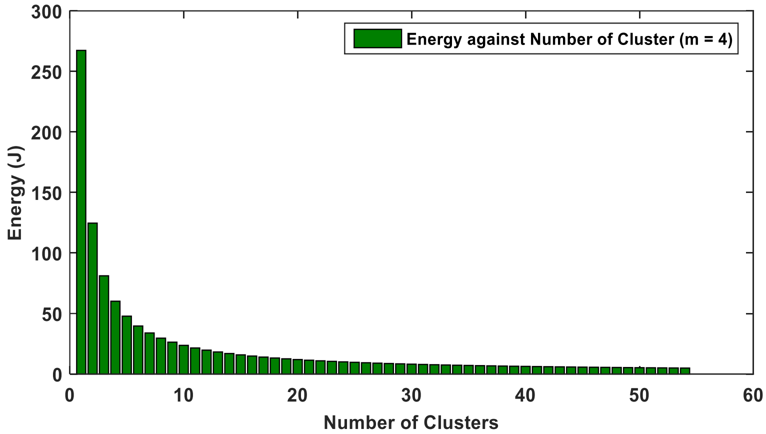

Figure 4.3d Energy per number of clusters (head-set size = 4)

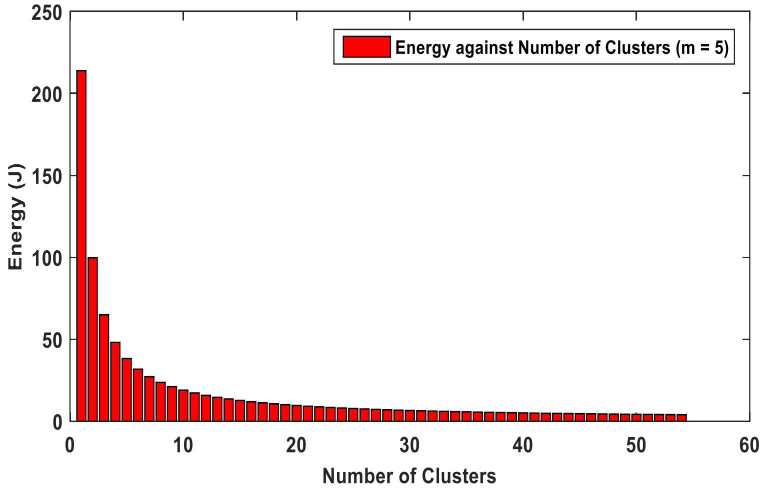

Figure 4.3e Energy per number of clusters (head-set size = 5)

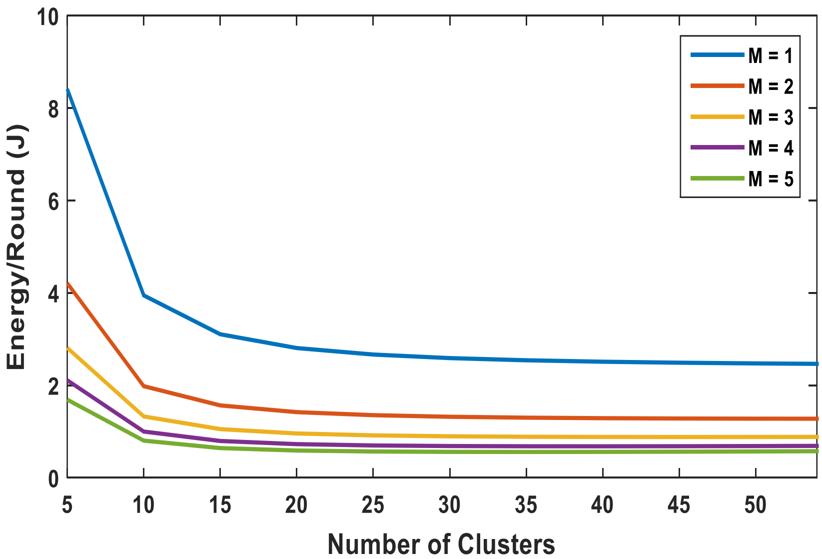

Figure 4.4 Energy per round against number of clusters

Discussion

The results of the simulation of the developed energy efficient algorithm for wireless sensor network deployed for industrial monitoring. As shown in Figure 4.1, the optimum number of clusters realized from the scheme was 54 given a maximum head set of 5. The variation of number of clusters in the network against distance from base station revealed that increasing base station (sink node) distance results in decreasing number of number clusters. The reason is that more energy is consumed to carry out distance transmission. In Figure 4.3, the result of the simulation showed that increasing the number of clusters causes the residual energy in the network to reduce. It was also observed that the optimum range of cluster to optimize the energy of the WSN was between 20 and 54. This was because from cluster number of 20 to 54, the energy consumption by the network was approximately the same in all cases with respect to size of the head-set. The variation of energy per round against the number of clusters in figure 4.4 revealed that energy consumed per round by each sensor node in cluster was reduced as the number of clusters was increased. Increase in the diameter (or area) of the network resulted in increased energy consumed per round. This agreed with the fact that the wider the area of the WSN, the more energy was consumed by the sensors node since the distance between the nodes increases.

Conclusion

This work has presented application of energy efficient cluster-based routing protocol using wireless sensor network for industrial monitoring in Anambra State. The results of the simulation analysis performed for the modified energy efficient cluster-based routing techniques indicated that by increasing the number of sensors in a head-set resulted in systematic reduction in energy consumption in WSN. The modified routing scheme resulted in satisfactorily energy conservation of WSN. The MATLAB based simulations have shown that the number of cluster in the network was optimized, which invariably resulted in the minimization of energy consumed.

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