Asian Journal of Information Technology 12 (6): 176-183, 2013
ISSN: 1682-3915

C-MAC: An Efficient Energy Postulate Based on Energy Cost Modeling in Wireless Sensor Network

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Abstract: Wireless Sensor Network (WSN) consists of huge collection of small, battery-powered sensor nodes. Advancements in the WSN give a new scope and dimension for implementing WSN in real-time applications. WSN is inexpensively implemented in the desired area to monitor space, things and the interaction between the things and encompassing space such as surveillance, intelligent alarm, pipeline and location monitoring, natural disaster monitoring, etc. For processing, transmission and aggregation of data for the aforementioned monitoring functions, nodes consume more energy. This becomes a daunting challenge for WSN, since WSNs are limited with the limited power, processing time and storage capacity. In order to overcome resource constraints, researchers of this study proposed a new comprehensive energy postulate that depends on the energy cost modeling named C-MAC. The model is constructed through thorough examinations of energy spend in a working WSN for deployment. The decision made in the deployment of nodes explicitly affects the sensing quality as well as the energy consumption of the entire network. Researchers mainly focused on the self rearrange for identification of the neighbour which is useful for the energy conservation. The proposed generalized model is validated by experimented through spotting toxic gas and also researchers in sighted the energy requirement for both the existing and proposed energy model.

Key words: Wireless sensor network, node deployment, poisson distribution, energy model, data aggregation, lifetime of sensor nodes

INTRODUCTION

The rapid deployment, self-organization, fault tolerance characteristics of WSN make it applicable for various applications in the recent past. Following is the few real time applications where sensor networks are deployed effectively.

To avoid human presence during scientific observations, Mainwaring *et al*. (2002) proposed a wireless sensor network to observe the habitat and behavioural patterns of some wild life animals. Likewise, for monitoring large diameter, bulk-water transmission pipeline, hydraulic and acoustic sensors are used by Stoianov *et al*. (2007). Other real time applications of WSN are precision agriculture, underground mining, health monitoring and many more. WSN are optimized depending on the nature of sensing area and also based on the deployment. While studying the implementation details of above-mentioned application, it is observed that there are some concerns in common among all the applications. Following are those concerns that are addressed by the real-time applications.

- Time synchronization
- High resolution of sample data
- Periodic sensing and sleeping
- High sampling rate for short distance
- Multi-hop communication

In addition to the above, observation, researchers also observed that each application develops its own protocol to address the preceding concerns. Though it is widely implemented its limited lifetime is the most prevalent concern. In order to perform the operations in sensor nodes the battery power is used to accomplish the task of the corresponding application. There is a significant hurdle in deployment and the size of the network since sensor nodes use exhaustible, rechargeable or replacing batteries. Because of this reason, Kim *et al*. (2007) suggested that WSN can be implemented occasionally for the inspection of pipelines and buildings. To overcome this drawback plenty of communication protocols and data processing algorithms were developed based on optimization of the network lifetime, data

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processing algorithm and communication protocols targeting efficient energy usage as their design goal.

In this study, the researchers analysed the energy cost of a fully operational WSN. Researchers proposed highly referenced, energy aware protocols for deploying nodes and running the network for the application of toxic gas detection in oil refineries. Leakage of toxic gas from the oil refinery is monitored through the proposed model. Self-organization refers the neighbour discovery and interest dissemination. A comprehensive analytic and simulation model is provided depending on which the lifetime of the network is determined. The proposed model considered few concerns such as multi-hop communication, time synchronization, distributed sleeping schedules and node density.

LITERATURE REVIEW

Low energy consumption became a major research field since most WSNs requires low energy consumption. Research scholars focus on areas of routing, one-hop neighbour discovery and data aggregation to reduce energy consumption through energy-efficient protocols and algorithms. Various protocols and algorithms were found for the different reasons.

Routing was one of the major areas where much research was undertaken to reduce the energy consumption in order to increase the lifetime of the sensor networks. Choi *et al.* (2005) proposed Cell based Energy Density Aware (CEDA) protocol to reduce the amount of energy consumed during sensor data flooding by dividing a sensor field into uniform cells. Energy density parameter of CEDA protocol was used to avoid packet flows to the subareas where the sensor nodes had lower residual energy. This property made CEDA to monitor all substations for the long period of time. Along with the reduction in energy consumption, throughput is also achieved using opportunistic routing. This technique allows the nodes to be selected based on the closeness to destination and arrange the nodes according to priority. This method of routing, discard packets if it reached the lower-priority nodes. One major challenge found by this type packet forwarding was selecting and prioritizing the nodes which consumed more energy. This challenge is overthrown by Mao *et al.* (2011) by an Energy-Efficient Opportunistic Routing strategy (EEOR). Apart from opportunistic routing, multipath routing was also used to improve the throughput but it consumed more energy. Therefore, it became essential to reduce the energy consumption in multipath routing. As a solution to this problem, research scholars of an article by Wang *et al.* (2012) discovered Network Coding-based Multipath Routing (NCMR). It employed braided multipath and network coding scheme. This combination made NCMR to consume less energy through decreasing the required number of routes and transmission. Robustness and effectiveness of the NCMR was found from the analysis of experimental results that depicted it was suitable for WSN.

All existing routing protocol chose the path with minimum energy to forward packets to sink nodes. Routing in such a way causes the residual energy among the nodes of WSN to get distributed unevenly and results in network partition. So, to balance the energy distribution researchers by Ren *et al.* (2011) designed an Energy Balanced Routing Protocol (EBRP). This protocol utilized depth, energy density and residual energy to forward packets through dense energy area towards sink node, thereby safeguard the low residual energy node. In addition to that selecting, a path having high transmission bandwidth and delivery rate can be used to reduce power consumption. With these concept researchers by Chen and Weng (2012) proposed a power-aware routing protocol named MTPCR which finds path for routing. This method of routing reduces the power consumption during data transmission.

Apart from routing, neighbour discovery was also an area where energy is consumed highly. Because of time varying environment and mobility causes, the node's neighbourhood to change frequently, consequently it added difficulty in detecting the neighbour. Due to this reason neighbour detection became an important enabler of energy conservation and network connectivity. Therefore, efficient neighbour detection mechanisms were required to optimize the energy used. An algorithm based on asynchronous, probabilistic neighbour discovery was presented to permit every node in the network to develop an incomplete list of neighbours (Borbash *et al.*, 2007). The analysis of this method showed that the number of neighbour discovered is maximized in a fixed time with less energy. Another solution was found by Yu *et al.* (2009) to discover neighbours which was targeted at synchronized low duty-cycle in Medium Access Control (MAC) to reduce the cost of network scans. It was consummated by distributing the schedule information for nodes in MAC protocol beacons. Furthermore, it used this information to establish a new communication link. Moreover, energy reduction was carried out through optimizing the beacon transmission rate. A new paradigm named compressed neighbour discovery was proposed by Zhang *et al.* (2012) that enabled the nodes of WSN to discover simultaneously immediate neighbours using single-frame of transmission. This detection method used on-off signatures to find neighbours.

Several research works were undertaken to tackle the problem of energy consumption in WSN from various angles. A vast analysis of different routing protocols was taken by Filipovic and Datta (2004) to find their energy consumption. The results by Filipovic and Datta (2004) was evident that consumption of energy through routing was not indicated the overall energy-efficient performance. Researchers of the same showed that topology information plays a very important role and the protocols that functioned in licentious mode were better prepared to handle heavy traffic loads. Ramanathan and Rosales-Hain (2000) focused on the topology and also found the problem in adjusting the node's transmit power in a multi-hop network, through which desired topology in a way that it consumes less energy. Likewise, by Yu *et al*. (2009) to increase the lifetime of network in multi-hop wireless network an Energy Efficient Domination Tree Construction (EEDTC) algorithm was used to construct a dominating tree which served as communication backbone. EEDTC performed well on the energy consumption since it used only low message complexity. Detection in WSN was also a research area for reducing the energy consumption. For energy-efficient detection, a protocol called LRI and CSI Based Access (LCBA) was discovered. This protocol was traded off between LRI and CSI to reduce overall transmission energy.

Gathering raw data in WSN was a hurdle because a very large amount of data should be transmitted over the network. This affects not only the energy consumption but also diminished the network lifetime. Data aggregation was accepted as an essential pattern for efficient energy. Few works related to the energy-efficient data aggregation was present in this subsection. A data aggregation tree was constructed by Hu *et al*. (2006) with the motivation to minimize the overall energy cost of the sensor nodes that were subjected to latency constraints. Root in this tree was called as the sink node, i.e., data center and other nodes in the tree represent the sensor nodes. Different approach was carried out by Chatterjea *et al*. (2008) that only some of the nodes in WSN were allowed to aggregate the data. Distributed scheduling algorithm was developed by Chatterjea *et al*. (2008) which has the responsibility to decide on when a particular node should aggregate the data. This approach also removes the redundant data so that the amount of data transmission got reduced through which it efficiently reduced the amount of energy consumption. Experimental result and analysis by Chatterjea *et al*. (2008) was an evident that if message transmission is reduced up to 85% which in turn prolongs the lifetime of network by 92%. Chen *et al*. (2011) considered the mobile agent-based data aggregation and energy-efficient data collection in WSN. They proposed an Itinerary Energy Minimum Algorithm (IEMA) based framework for energy-efficient data aggregation and a solution for Multi-agent Itinerary Planning (MIP). It works well than the existing methods.

A framework by Kafetzoglou and Papavassiliou (2011) adopted two different mechanisms to reduce the energy consumption. One to implement data gathering at the application layer and the other one for sleeping mechanism that to be designed as medium access control layer. Simulation result in this study denotes that the framework worked significantly than the conventional MAC layer or data aggregation approaches. A generic data compression technique named Compressed Data-stream Protocol (CDP) was proposed by Erratt and Liang (2011) to significantly support data aggregation in WSN.

BACKGROUND

Various toxic gases are emitted during oil exploration and refinery processes as a product or by product like ammonia, sulfur dioxide, etc. Among those gases, few gases are considered to be useful though it is dangerous for human life causing health and corrosion problems. Such gases are transported in pipelines to the required workstations from the refineries. The main anxiety at this stage is the perspective of leakages may cause ruthless impact on the human being and on environment causing ecological imbalance. Leakage may occur either in one of the following way:

- Pipeline repair
- Due to the deformations caused by corrosion, material flaws, earthquakes or because of intentional damage

Such leakages can be found earlier without any human intervention using WSN. The sensing and data gathering property of WSN made it applicable to the toxic gas detection application.

Existing detection system: High-risk and value and accessing difficulty of the pipeline made the management as a challenging one. The detection system for pipeline consists of both stationary and portable sensors. Stationary sensor system includes signal cables, power, sensors and a control station where the data sensed of sensors are processed. Implementation and maintenance cost of such sensing network is high so it may not satisfactorily cover the sensing field. Because of the coverage problem, research carry portable sensors during inspection. The main drawback of such a network is that it senses and reports the control system independently. It does not correlate and gather the information from spatially distributed nodes. This makes the detection of leakage tedious since, the leakage information sensed from an individual node may be either due to actual leakages or diffusion on air of the gas. It is difficult to differentiate the reasons mentioned above for leakage.

Sensor selection and calibration: A wide range of sensing technologies such as Catalytic, Capacitive, Infrared Photoionization and Semiconductor are available in the market. Among these varieties IR, electrochemical and catalytic are the popular for measurement for the past years. For detection of toxic gas, it is suggested to use electrochemical sensors. The detection equipment performs a relative measurement. So, calibration is required for accurate measurement. For toxic gases, it is recommended to use pre-calibration or scheduled calibration.

Threshold and response time: Threshold of an alarm depends on the exposure occupational limit of gas which also varies from country to country. Limit values also differs depending on short or long term exposures. Whereas the general limit is 10 ppm for short-term exposure response time is one of the major and critical metric for leakage detection. The response time will be decided based on the sensor node's response speed, processing time and transmission. Nominal time is set between 20-30 sec but most refineries set 60 sec as upper limit.

PROPOSED METHOD

The main aim of this study is to propose an efficient energy cost modeling in WSN. The approach is depicted in Fig. 1 which explains the overall process of the research.

Network model and deployment: Energy consumption and lifetime of network is based upon the network model that establishes the basic assumption on topology, density of node, distribution and connection of node. Furthermore, it defines the sensing task of the network. Deployment denotes the arrangement of nodes in an area where the sensing process carried out. It is considered as one of the most fundamental issues in monitoring or sensing the given area. Quality, cost and capability of monitoring are based upon the deployment of wireless sensor nodes. There are 3 basic types of monitoring:

- Spot monitoring
- Area monitoring
- Fence monitoring

If the pinpoint positions of the area where sensing task is to be accomplished is clearly known then spot monitoring can be carried out. This monitoring strategy uses only a limited number of sensor nodes since, it knows the exact location of sensing spots. This type of monitoring requires the more time and knowledge about the field. Whereas, other two monitoring techniques saves time in finding the pinpoints of the spots where leakage occurs. In area monitoring sensors should be deployed where there the gas may spread across the area. This technique requires huge amount of sensors. Likewise, fence monitoring also required to be deployed at the outer limit. This is more suitable for security related applications.

Traditional wired sensor networks widely use spot monitoring techniques while it is not applicable to the

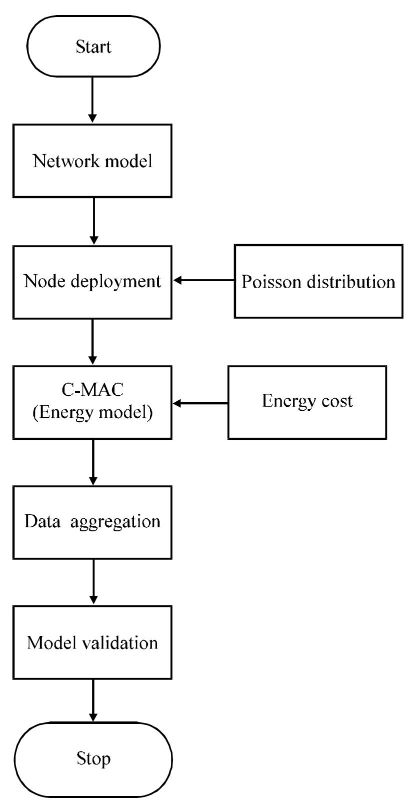

Fig. 1: Overall flow

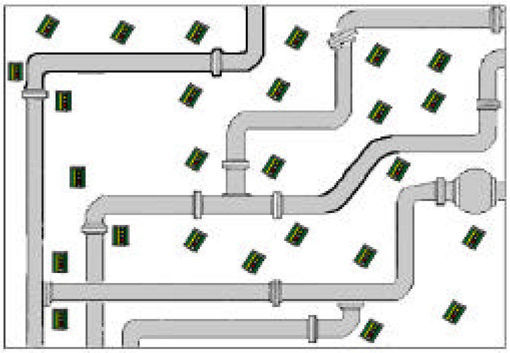

Fig. 2: Deployment of sensor nodes

wireless sensor network since it has coverage problem. Coverage depends on the density and deployment of the network. For spot monitoring only the potential area of leakage should be monitored. This consumes less energy and also the safest method. Figure 2 portrays the deployment of sensor nodes.

'N' nodes are deployed in an area where sensing task should be carried out. There are distributed randomly in a rectangular area A of size A = x×y. For generality researchersassumed that x≤y. The distribution of the nodes can be modeled using Poisson distribution with the average density of γ. Therefore, the probability of 'n' nodes in the area A can be given as using the Eq. 1:

$$P(n\,nodes \in A) = e^{\gamma A}\frac{(\gamma A)^n}{n!} \tag{1}$$

There are two essential concerns for the toxic gas releases namely short-term and long-term impacts. For long-term release impact can be on human, ecology whereas for short-term impact usually on human beings. Thus, researchers specifies two sensing tasks: periodically, every sensor node deployed in A should report to their sink node about the concentration of toxic gas. In case, if the leakage exceeds the threshold (defined by the board of safety) then an alarm should be fired within 30 sec. Here, case one is considered as normal case with normal priority and case two is the abnormal condition with high priority.

C-MAC Energy Model: The communication protocols researchers engage to launch the wireless sensor networks are the C-MAC for medium access control for affirming auto arranging and routing. Hop count is a necessary execution parameter and suggests how much hops a message is operated in the mean for a devoted far in a network. The hop count estimation is simple if the topology is deterministic. However, for Random Network

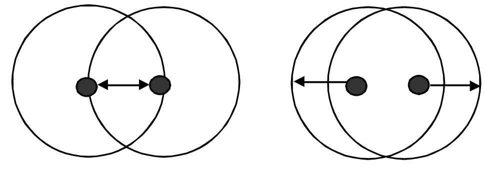

Fig. 3: Possible intersections of two neighbours

Model, more probability and statistic theories are required as a group. To calculate the minimum hop count, researchers determine the distance S between two random nodes and divide it by transmission range R. The admission probability of the nodes can be depicted from the poisson distribution. That can be denoted from the Eq. 2:

$$Admission_{Prob} = \frac{(\lambda_T)^C}{C!}\left(\sum_{n=0}^{c}\frac{(\lambda_T)^n}{n!}\right)^{-1} \tag{2}$$

All the data packets in C-MAC are unicast except the interest dissemination. The unicast packets cause control overhead because of the RTS/CTS/ACK packets. In order to manipulate the adaptive listening energy cost, it is helpful to determine the number of neighbours that are likely to catch the RTS/CTS message. This can be computed by taking the communication coverage overlaps between two random neighbours. If two nodes are in communication range then their coverage and transmission intersect. Figure 3 represents the extreme cases of this scenario.

To estimate the energy consumption of toxic gas detection network researchers framed the C-MAC Energy Model. To analyse the energy model of the C-MAC, researchers come across four steps as follows:

- All nodes in the network are active for $CORN_p$ cycles and wait for CORN packet to reach from other node. This phase also requires some amount of energy
- Nodes are resynchronized periodically in order to avoid the clock drift. All nodes continuously send the CORN packet but only few of the packets are successfully received. This is due to the packet loss and collision. This phase also consumes certain amount of energy for sending and receiving the CORN packet
- For $CORN_p$ cycles every node performs the neighbour discovery. Moreover, all the nodes in the network will not perform the discovery process at the same time. Since, some nodes will lose for the period of contention for accessing the channel. Therefore, the neighbour discovery carried out periodically will get delayed due to collision. The energy consumed for this phase can be expressed as $E_{Neighbour\_Discovery}$

- Finally, researchers compute the energy by summing the value of the above coordination values. The total energy consumed can be determined through the Eq. 3:

$$\text{Energy}_{\text{consumed}} = E_{\text{Total}} + E_{\text{Data}} + E_{\text{Neighbour\_Discovery}} + \varphi_1 \tag{3}$$

Where:

E_{total} = The total energy consumed by the network

E_{data} = The amount of energy consumed for transferring the data packet

$E_{neighbour\_Discovery}$ = The amount of energy consumed for detecting the neighbour discovery

φ_1 = The constant and already derived value

A threshold value is set to decide whether the range for communication should be selected or discarded. The threshold value can be derived using the Eq. 4:

$$\text{Threshold} = \sqrt{\frac{\ln(1 - P(\text{conn})^{\frac{1}{n}})}{-\lambda\pi}} \tag{4}$$

Where:

P(conn) = The probability that the network is connected

λ = The network density

If the energy consumption exceeds the threshold value then the range that is selected for communication is discarded. Otherwise, the range can be set for transmission of data.

Data aggregation: The data traffic can be reduced in the WSN through transferring the data only when the intensity of the toxic gas reaches a maximum level (the level is predefined depending on the industry and country). This requires the aggregation of data. The main goal of the data aggregation is to collect the data in energy efficient manner in order to improve the network lifetime. The general work flow of the data aggregation is as shown in the Fig. 4. In the research, in-network aggregation is taken which gathers the information through multi-hop network and process the data at the intermediate nodes. Here the packets received from different sources are merged at the intermediate node and the data are computed to detect the redundancies. The redundant data packet are removed by the intermediate nodes, there by reduces the number of packets routing towards the destination. This implicitly lessens network traffic and number of packets to be processed at the destination node.

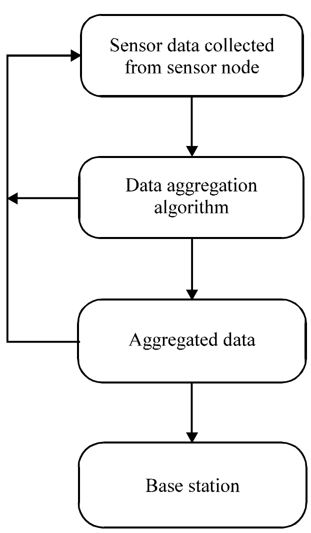

Fig. 4: General flow of data aggregation

EXPERIMENTAL RESULTS

In this study, researchers provide an experimental analysis of the proposed energy model (i.e., C-MAC). They used energy consumption, delay, loss, PDR, throughput, energy utilization as their parameter to measure the performance of C-MAC.

End to end delay: This delay personifies the time taken to deliver sensed data from the sensor node (source) to destination across the network. This depends on the traffic characteristics of the source. Initially, when the simulation starts there is very less traffic in the network the delay for delivering the packets among the source and destination are lesser. But when the process proceeds traffic increases thereby the time taken to deliver packets also increases. Figure 5 exploits the delay in transferring the sensed data from the source to the destination for both the existing and proposed energy model. It shows

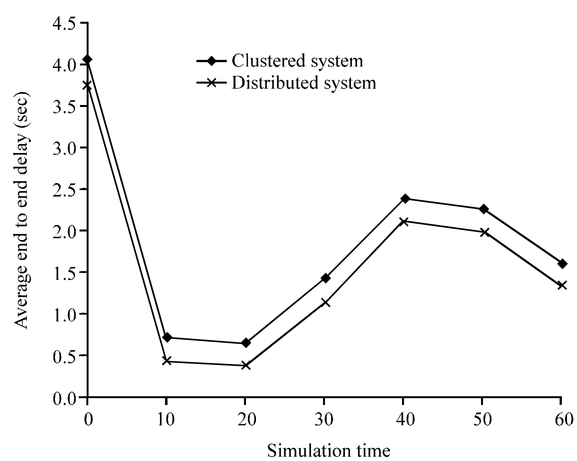

Fig. 5: End to end delay

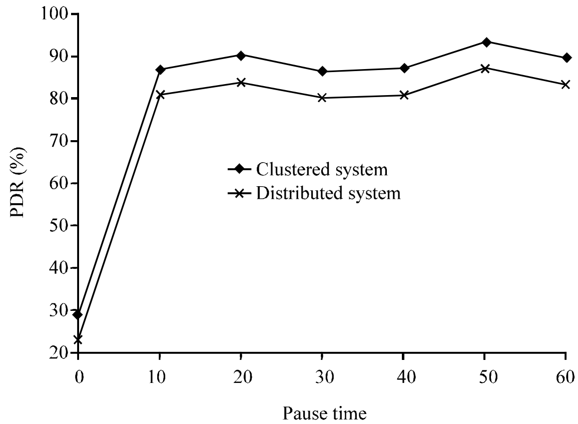

Fig. 6: Packet delivery ratio

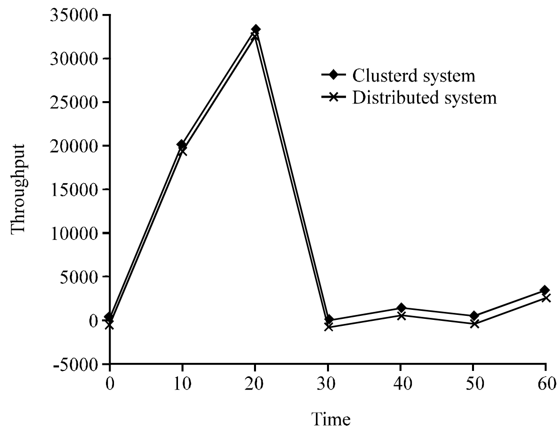

Fig. 7: Throughput

that the delay in transferring the data packet for C-MAC is lesser than the existing standard distributed based technique. Delay is expressed in seconds (sec).

Packet Delivery Ratio (PDR): The ratio between the number of packets sent by the source and the packets received by the sink node is the PDR. PDR is always higher for lighter traffic whereas when the traffic increases the delivery ratio is decreased. Researchers used PDR as a metric to find the efficiency of distributed and cluster based method. Packet delivery rate in terms of percentage for both the proposed and existing is portrayed in the Fig. 6. Packet delivery rate of the C-MAC (i.e., cluster based) is higher even in high traffic which is illustrated in the graph presented in Fig. 6.

Throughput: Throughput is the average successful rate of message delivery. This plays an effective metric to analyze the performance of the proposed and existing energy model. The technique that has the higher

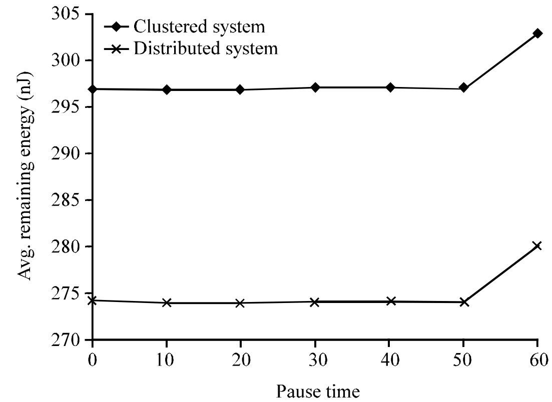

Fig. 8: Pause time vs. residual energy of a node

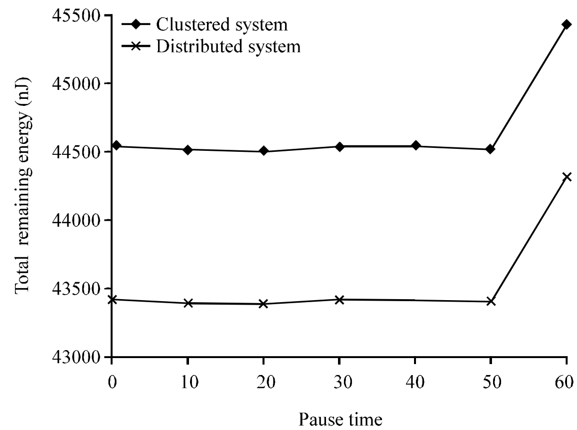

Fig. 9: Pause time vs. residual energy of entire network

throughput is considered as a best method. Figure 7 shows the throughput study of two energy models. It is apparent from the graph in Fig. 7 that the throughput of C-MAC is greater than the distributed method. Therefore, it is explicit that the method proposed by the researchers performs better than the existing techniques.

Residual energy: Residual energy of the node represents the remaining energy present after the monitoring process. Pause time is the idle time for which the mobile nodes in the wireless sensor network are in stable position. A graph in Fig. 8 denotes the remaining energy of all the nodes in the network for different pause time. The residual energy is measured using nJ. This also implicitly expresses that the amount of energy consumed by a node in the network is lesser for cluster based proposed method on comparing with the existing distributed based technique. Similar to the Fig. 6, researchers also determined the remaining energy for total network. This is expressed in the Fig. 9.

CONCLUSION

Since, a decade, WSN have been envisioned to support numerous monitoring applications. In which, energy efficient routing is much consequential to enhance the lifetime and stability of the system. Focusing that, C-MAC has been proposed in this study for determining energy cost. Here, network deployment is made with Poisson distribution that covers maximal area effectively. Further, the proposed mechanism evaluates the energy cost for various paths that involves in packet transmission from source to destination. With that evaluation, adept path is predicted for packet transmission based on the computed threshold value. Consecutively, the intermediate nodes of the selected path perform data aggregation in order to remove the data redundancy, thereby improves the overall network lifetime. The experimental results show that C-MAC performs better than the traditional models.

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