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Wireless Sensor Networks: Balanced Energy Consumption Model With Clustering And Energy Consumption

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Abstract

The majority of apps that are a part of current living are built on wireless sensor networks (WSN). Applications for WSN include everything from blood-sugar level indicators in hospital intensive care units to fire alarms in contemporary structures.

Motes, which are teeny, mobile, battery-powered sensor nodes equipped with a microprocessor, a sensing device, and a radio for transmission, are used to build these networks. Such networks provide challenges for the network designers to meet the needs of the application because of their growing complexity and diverse applications. In this article, clustering and energy consumption are analysed, and a network lifespan analytical model is presented. Using MAC layer beacon signalling, the proposed model examines energy overhead that happened during cluster setup time in the network. On the basis of read operations per minute in TinyOS devices, it also measures energy usage in clusters in steady state. Then, based on cluster size and steady state duration, it provides a relationship between the two in order to achieve and evenly consume battery power across all nodes in order to maximise network lifetime.

Keywords: WSN, Clustering, Energy, MAC Sub-layer, Frame, Network Lifetime

I. INTRODUCTION

A network of sensing devices known as "motes" that sense physical quantities and transmit the measured values to a centralised computer for further processing is know as a "wireless sensor network" (WSN) [1]. As the name suggests, these devices act as nodes of the network which shares the data wirelessly. These networks have a wide range of uses in the business, scientific and academic sectors. These are common deployments of wireless sensor networks. In recent years, there has been a steady increase in the applications of sensor for automation and other daily tasks.

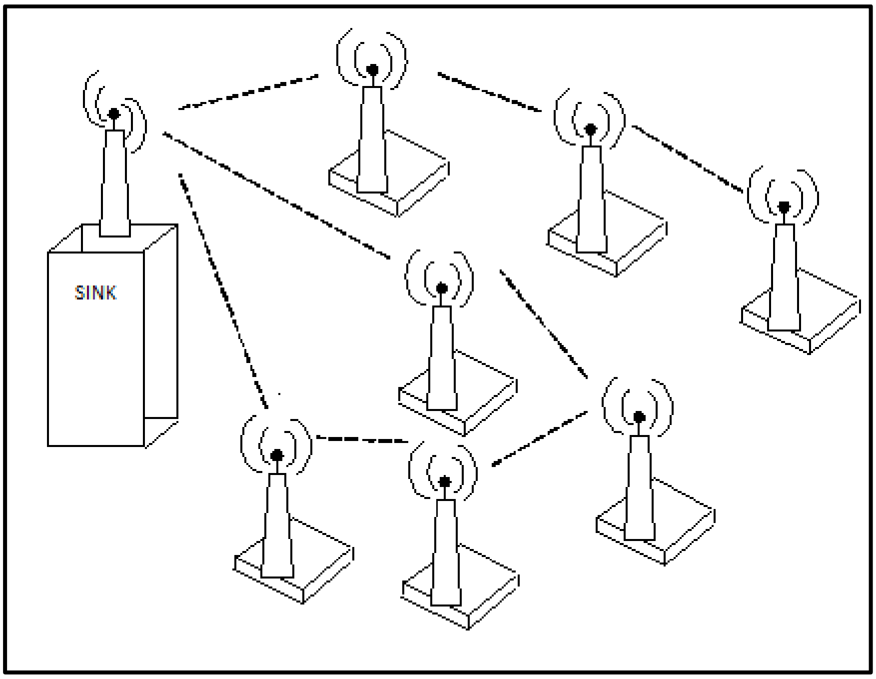

Fig. 1.1 Wireless Sensor Network

Cloud and Big Data [2-3] are the terms which are used in the context of Internet of Things (IoT) in which physical devices communicate with each other depending on the measured parameters and other conditions. For instance, if a refrigerator is set up properly to make a request in the event that it runs out of milk on a Sunday morning, it can contact a dairy stand or a milk provider. There are unlimited opportunities for WSN to change modern living to a greater level, transforming the current internet into the Internet of Things. Applications like the one described above and many more in various domains can be constructed. Figure 1.1 depicts a generalised diagram of a wireless sensor network (WSN).

Energy Efficiency: This is the most important component of practically all WSN deployment types. Since Wireless Sensor Networks are used in locations where sensor nodes must continually monitor a certain quantity for an extended period of time without running out of energy, the nodes must be built with low battery consumption in mind. The architecture of WSN nodes makes for extremely low power consumption. Low power consumption protocols are also available for wireless sensor networks. In actuality, the IEEE specifications for wireless sensor network nodes also Low Rate and Low power Protocols are referred to as [4]. By improving the nodes' duty cycle, this time on a regular basis and them awakened to perceive the data. When compared to the wake-up or active period, the sleeping period's energy is use in significantly lower, and extending battery life [5]. However, to meet the needs of wireless sensor networks for surveillance, most applications maintain sleep and waking times in the order of microseconds.

Latency: The term "latency' describes the interval of time between the occurrences of noticing something and the point at which the necessary action occurs. Low latency is a requirement for the majority of WSN deployments [6]. IoT systems and apps cannot tolerate any latency above a particular threshold. Low power consumption and low latency are incompatible objective for a wireless sensor network. The networks' increased latency is a result of the consideration of low energy usage in their design. Die to this tendency for conflict, an ideal solution must be created in order to meet the deployment's criteria. There are other factors that should be taken into account. IEEE has standardised the requirements for wireless sensor networks in its specification for 802 wireless families. Device manufacturers are responsible for the remaining specifications. The IEEE 802.14.5 specifications for wireless sensor networks are part of the Wireless Personal Areas Network (WPAN) Family of Specifications [7]. LR-WPAN (Low Rate Wireless Personal Area Network) is another acronym for these networks because they have low data rates and battery usage.

2. IEEE 802.15.4 LR-WPN STANDARD REVIEW

Some of the features of an LR-WPAN include Star or peer-to peer operation, over- the air data rates of 20 kbps, 40 kbps and 250 kbps, allocated 16-bit short or 66 bit extended addresses, carrier sense multiple access with collision avoidance (CSMA-CA) channel access, guaranteed time slots (GTSs), and a fully acknowledged protocol for transfer reliability (FFD). FFD can operate in three different modes, namely as a device, coordinator, or PAN coordinator. While an RFD can only interact with one FFS at a a time, an FFD can interact with both RFDs and other FFDs. An RFD is intended for extremely simple applications, such as a passive infrared sensor or a light switch. They could need to send the most data because they might only be connected to one FFD at once [8]. Because of this, the RFD can be implemented with a minimum amount of resources and memory.

2.1 WPAN components of IEEE 802.15.4

According to IEEE 802.15.4 a system has several different parts. The device is the most important. an item can be either RFD or FFD. A WPAN is made up of more than two devices in a POS communication on the same physical channel. However, a network must have a minimum of one FFD that serves a as the PAN coordinator. Small adjustments in position or direction could have a dramatic impact on the strength or quality of the communication link signal. Since wireless media's propagation properties are erratic and dynamic, there is no definite area of coverage [9].

2.2 TOPOLOGY OF CLUSTER TREES

A typical peer-to peer network, in which the majority of the devices are FFDs, includes the cluster-tree network. Any of the FFDs has the ability to serve as a coordinator and provide synchronisation services toother equipment or other coordinators. Other prospective devices may connect to the network and join it. It will look for another potential partner if the initial candidate device is unable to connect to eh network at the CLH device. A cluster tree network ca be formed from a single cluster or by creating a mesh of several neighbouring clusters to create bigger networks. A network topology with several clusters is formed as additional devices eventually connect. An increase in coverage area is a benefit of a multi-cluster topology, but a drawback is an increase in message delay.

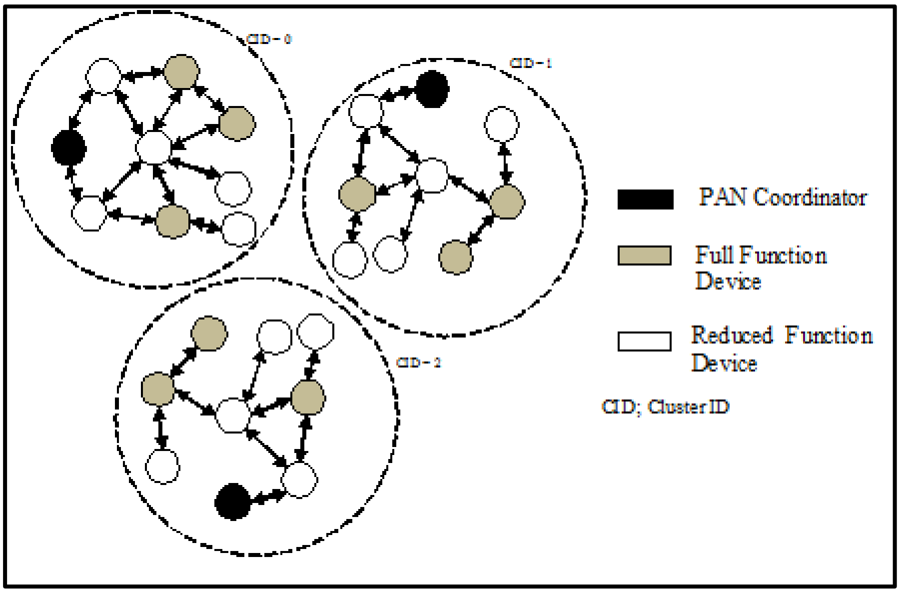

Fig. 2.1 Cluster Tree Topology Network

3.CLUSTERING AND ENERGY CONSUMPTION IN CLUSTER BASED WIRELESS SENSOR NETWORK PERFORMANCE ANALYSIS

3.1 Conflicting clustering, Data aggregation, and Latency requirements

As the sensor nodes must be installed in locations where they do not require frequent maintenance, energy consumption is a wireless sensor network's most pressing problem that must be effectively addressed. A sensor node is supposed to function for at least a year or two on a single AA battery. This is so that data can be aggregated at the PAN coordinator and the forwarded to the sink node. This is particularly crucial when multiple sensor nodes capture the dame data and send it to the base station, which provides data redundancy. These two elements make a considerable difference in the amount of energy consumption reduction. Data aggregation at a Cluster Head (CH) node causes a rise in latency, making it impossible to use above a certain limit. The choice of the cluster head and the subsequent information distribution to all of the cluster's nodes consume a large amount of energy in the clustering strategy. As a result, it cannot be performed frequently and must be optimised.

3.2 Model for Network Deloyement

The network mode taken into consideration in this study is appropriate for large-scale WSNs. In the model analysis, the following factors have been taken into account:

- Each device/mote in the network is either an FFD (Full function Device) or an RFD (Reduced Function Device)
- The PAN Coordinator, also known as the CH (Cluster Head), is an FFD periodically selected among the cluster nodes.

Figure 1 depicts a section of the network model.

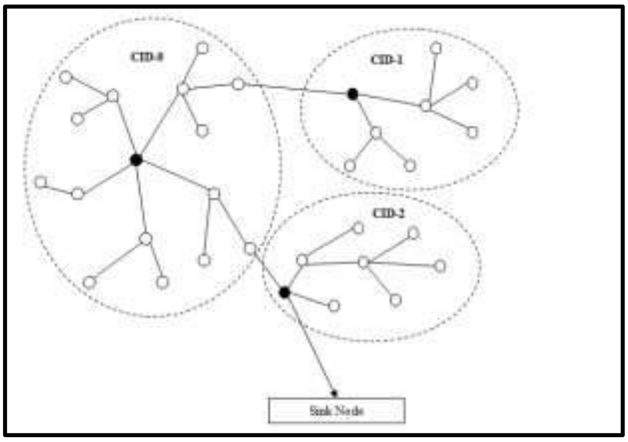

Fig. 1 Network with Cluster Topology

[10 Designed for low power, unlicensed, long range operation, LoRa is a new wireless technology operating in the ISM band. A Wide Area Network protocol called LoRaWAN integrates LoRa wireless technology into a networked architecture. The physical layer wireless and multi-gateway wide area network of these technologies were examined for both indoor and outdoor performance throughout Glasgow's CBD (Scotland). According to the findings, this technique can provide a dependable connection for low-cost remote sensing applications.]The cluster heads in this network are displayed in black. Dotted lines are used to represent the cluster. A node from the cluster is chosen as the cluster head depending on specific criteria. The Pan coordinator assigns node ids to the various nodes in order to construct cluster. Then, each node within its transmission range joins forces with a PAN coordinator. The requirements for data aggregation and latency are incompatible, as shown by figure 3.1.

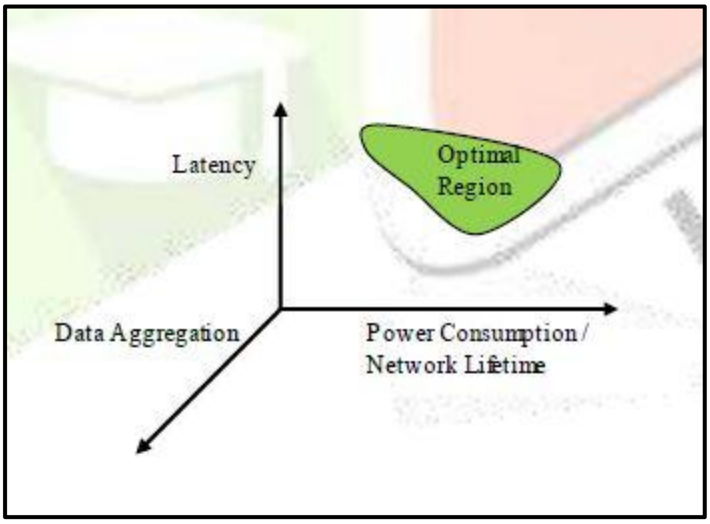

Figure 2 shows the optimal region in conflicting requirements of latency, data aggregation and energy consumption. Basically, this study employs the first order radio energy model when investigating the network at eh application layer. The significance of data aggregation can be understood form the following straightforward calculation. Consider the following figures for the energy consumption of the transmission and processing circuitry: The processing circuit needs 60*11=8*1142=6.12x11-4 to process 2 kilobyte. Accordingly, the ratio of energy used for transmission and processing is as follows: Data Aggregation Power Consumption/Network Lifetime Latency Optimal Region 300 instructions can be carried out with the same amount of energy as one instruction sent across 2 km distance. Additionally, it grows with the cube of the distance. Therefore, using clustering algorithms in WSN to enable increased battery life is promising. The analytical model takes into account the following parameter.

N: The total number of network nodes.
Network dimensions are A(=n X n).
E: Each node's initial battery level.
Et: Energy used for each read operation at a transmitting node, calculated per bit.
Data packets read in a single operation, r.
K, Bits per packet
Amount of Clusters
Te: the period of time following the Ch election

The aforementioned presumptions are based on 3XAA 1.6 v batteries, ambient temperature of 21 degree Celsius, and cyclic sleep enabled with a single transmit per wake cycle. The idea number of clusters for a given WSN depends on the node transmission range, node density, physical dimensions of the WSN, and network traffic, analytical energy dissipation relationships simple calculations yield the following conclusions.

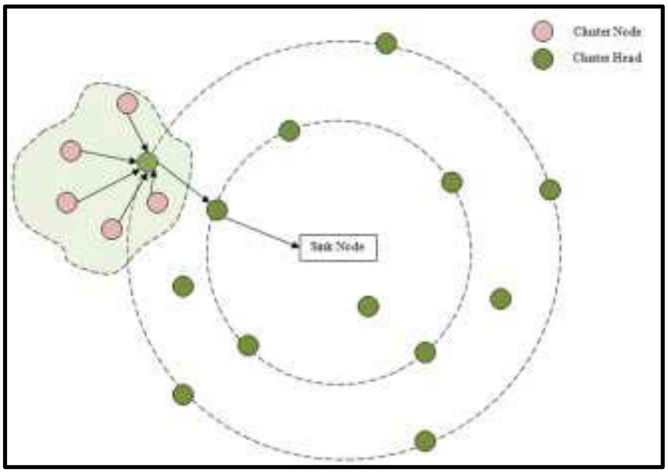

Fig 3 Data Sensing Operation of Typical WSN

Let C be the ideal numbr of cluster. C/N is the typical ratio of cluster heads ot nodes. For a while, the Cluster head stays in its positions. The energy consumption of any cluster's span, also know as the cluster head, is calculated using the formulae above. The amount of readings the CH generates on its own is te*R.

Te*R*r*k*et= E1

The CH uses the following amount of energy when reaing data form every member of the Cluster.

E2= [N/C]*[te*R]*r*k*et

The CH may implement either of the tow transmission policies listed below:

1. Data transmission and Data aggregation
2. Data aggregation and Transmission of summarised Data

According to the first scnerio, the transmission energy expense could be calculated as:

E32 is equal to [(te*R)*r*k+(C/N)*(te*r*k]*te

If a fraction k(k1) is subtracted from the consolidated data, the

E32=k*E31.

The method consists of the following two septs regardless of the cluster head selection algorithm that is used:

1. Set-up phase
2. Continuous state phase

The aforementioned formulae provide the amount of energy used during the steady state phase. The overhead for the network administration task is the amount of energy used during setup. The MAC layer's job is to provide the environment for cluster formation and CH selection.

At the CLH, a candidate device that has received beacon frame may submit a request to join the network. After adding the CLH as parent in neighbour list and starting to broadcast periodic beacons, the newly joined device will invite further candidate devices to join the network at that point.

The following steps make up the setup phase:

- Perusing the channels
- A scan of the ED (Energy Detection) channel
- Scan Active Channel
- Scan the passive channel
- Scan orphan channels
- Beginning of PAN
- Generation Beacon
- Device identification

A CH can find any coordinators within its personal operating space by doing an active scan (POS). similar to an active scan, a passive an enables a device to identify any coordinators within its POS that are emitting beacon frames. After losing synchronisation, a device can try to find its coordinator by doing an orphan scan. All frames received over the PHY data service during an orphan scan that are nor coordinator realignment MAC command packets must be discarded by the MAC sublayer. The Beacon Frame construction is shown as follows:

Only after performing an active channel scan and choosing an appropriate PAN identification may an FFD initiate a PAN. By sending beacon frames, a CH can let other devices know that it is present on a PAN. As shown in figure 3.4, there are 5+1+2+7(4or12) +k+m+n octets that are transferred in each frame beacon, enabling the other devices to perform deice discovery. It is presumable that the MAC Beacon frame needs 33 octets. For the establishment and configuration of PAN, a set of activities including scans and beacon signal broadcast are needed during the setup phase.

You can base your estimate of the energy consumption during setup on the following:

1. EED: the CH employs the energy detection scan. In an ED scan, each of the 28 valid channels takes [a base super frame duration *(2n+2)] symbol to scan, where n is the scan duration parameter's value, with a maximum value of 15 symbols.
2. EAS: with n being a number between 1 and 15, the device must enable its receiver for a maximum of [a base super frame duration *(2n+2)] symbols.
3. The wireless nodes are taken to be stationary and in dull working order. As a result, no cluster member needs to run an orphan scan before, during or after any PAN establishment.
4. EFB: the beacon frame transmission by the PAN coordinator (33 octets and the cluster members' reception of it. It is significant to remember that the spread sequence's duration for the base super frame that fixed at 860 symbols, with each symbol denoting a 5-bit chip sequence.

E=E steady state +E setup is the total battery power consumed by a cluster when any particular cluster head is in operation.
E setup= EED+(N/C)*EAS+ EFB.
Consider a network lifetime during which the maximum number of cluster heads, t/ te are chosen.
E= (t/ te) *E
E total is equal to (t/te) * (E setup + E steady state)

We are left with the following optimization constraints as a result of the study above:

1. The energy consumption of each device must be consistent in order to improve network lifetime
2. E setup must be kept to a minimum because it depends on cluster size
3. Battery usage in the cluster head during the steady state phase ought to be such that all nodes continue to function while all nodes at least briefly serve as the cluster head. However, the requirements are in conflict. Thus, selecting the right number of clusters and cluster span inessential. Therefore, the most important variables that need to be optimised for every particular network are the ideal number of clusters and the ideal cluster span.

4. **RESULTS**

The following are the simulation results of the analytical model.

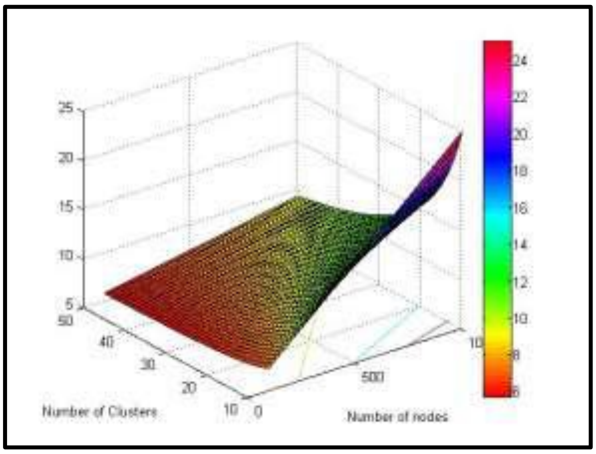

Fig 4 function of nodes and clusters

This is primarily due to Energy Detection Channel Scan by the PAN coordinator for all the available 27 channels. It also accounts for the active channel scan by all the devices in the PAN. Finally, the PAN coordinator broadcast a beacon signal to all the nodes in the network to initiate the steady state phase of data read operations. The analysis makes use of the fact that the MAC layer primitive a Max Beacon Overhead has the maximum value of 75 octats.

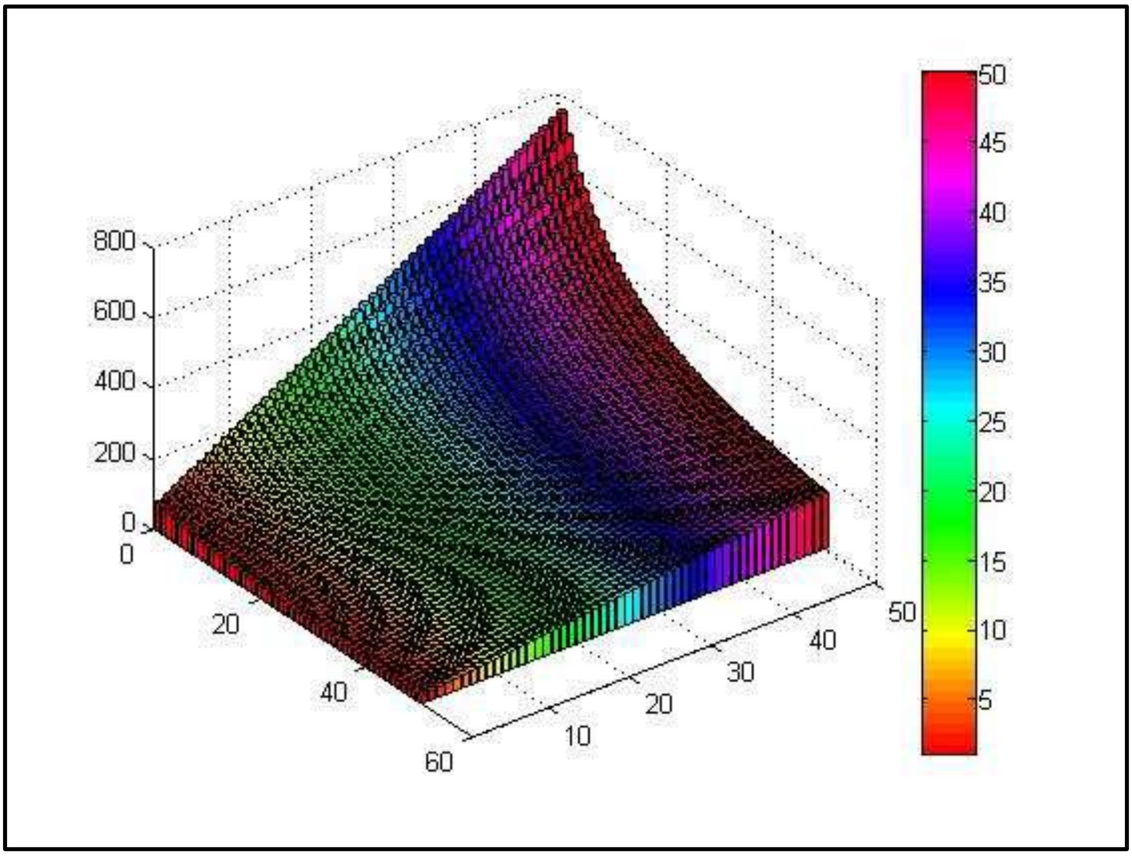

Fig 5 Energy Consumption in Steady State Phase in CH as function of number of nodes and clusters

The energy consumption depicted in the figure 5 gives the Energy Consumption in Steady State Phase in Cluster Head as a function of nodes and number of clusters, assuming Steady State time period 1000sec. During steady state phase, the cluster members read the data and transfer it to the CH. The CH itself read the data and also aggregates the data transmitted from the cluster members. It finally transmits all the aggregated data to sink node.

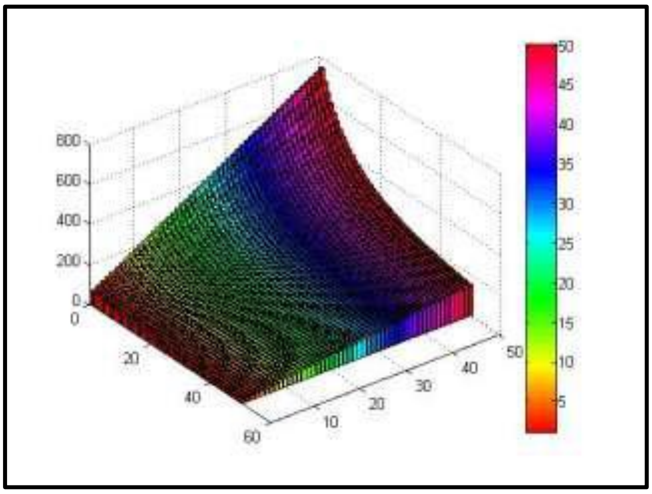

Fig 6 Energy Consumption in Steady State Phase in Cluster members as function of number of nodes and clusters

The energy consumption depicted in the figure 6 gives the Energy Consumption in Steady State Phase in all the cluster members, assuming Steady State time period 1000sec.

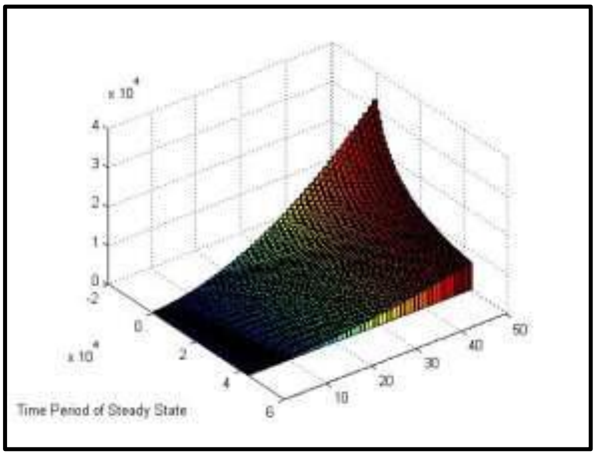

Fig 7 Energy Consumption in Steady State Phase in CH

Fig 7 shows the energy consumption in Steady State Phase in CH as a function of Steady - State Period. The time period of cluster selection ranges from one minute to one day.

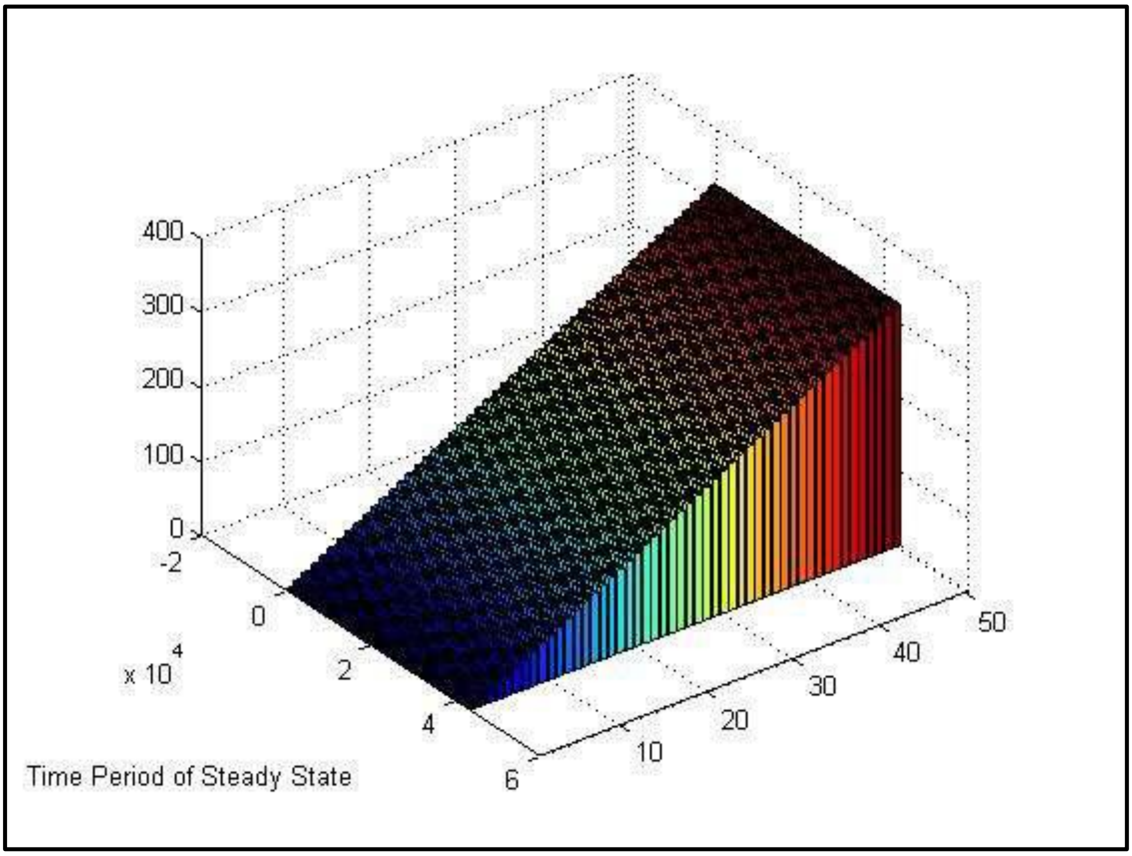

Fig 8 Energy Consumption in Steady State Phase in each Cluster Member as a function of Steady -State Period

Fig 8 shows the energy consumption in Steady State Phase in cluster members as a function of Steady -State Period. The time period of cluster selection ranges from one minute to one day.

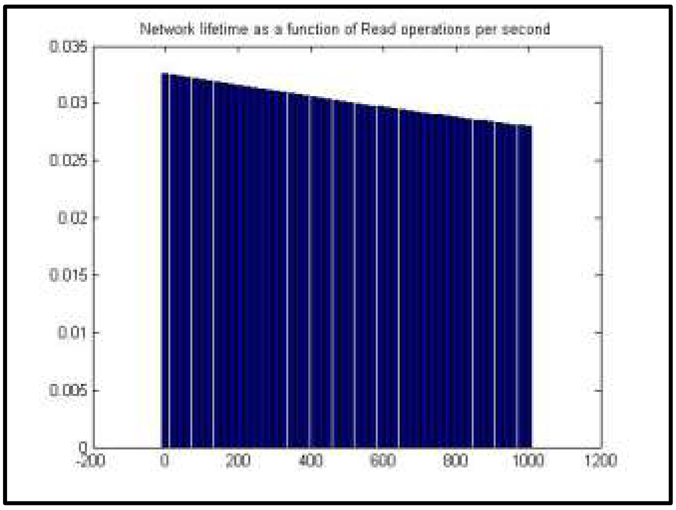

Fig 8 Network Lifet ime as a function of number of read operations per second.

Fig 8 shows the network lifetime as a function of number of read operations per second.

CONCLUSION

First order radio energy dissipation taken into consideration, the current study focuses on the trade-off between clustering and energy consumption and provides an analytical equation for the same. This study can be used to determine the best network layout for a particular WSN deployment. The future scope of the work must also take into account the details of the underlying hardware technology, as the power dissipation differs greatly depending on the kind of technology used to realise the sensor more. However, the result of this analysis qualitatively significant in any type of realisation since the ratio of energy consumption in setup phase and steady state phase is roughly constant across all IC technologies.

References

1. Jawad, H. M., Nordin, R., Gharghan, S. K., Jawad, A. M., & Ismail, M. (2017). Energy-efficient wireless sensor networks for precision agriculture: A review. Sensors, 17(8), 1781.
2. Queiroz, Diego V., Marcelo S. Alencar, Ruan D. Gomes, Iguatemi E. Fonseca, and Cesar Benavente-Peces. "Survey and systematic mapping of industrial Wireless Sensor Networks." Journal of Network and Computer Applications 97 (2017): 96-125.
3. Cui, Li, and Xiaolan Xie. "Wireless sensor networks." (2019).

4. Shinghal, Dr, and Neelam Srivastava. "Wireless sensor networks in agriculture: for potato farming." Neelam, Wireless Sensor Networks in Agriculture: For Potato Farming (September 22, 2017) (2017).
5. Zhao, L., Qu, S. and Yi, Y., 2018. A modified cluster-head selection algorithm in wireless sensor networks based on LEACH. EURASIP Journal on Wireless Communications and Networking, 2018(1), pp.1-8.
6. Sahitya, G., Balaji, N., Naidu, C.D. and Abinaya, S., 2017, January. Designing a wireless sensor network for precision agriculture using zigbee. In 2017 IEEE 7th International Advance Computing Conference (IACC) (pp. 287-291). IEEE.
7. Rao, P. C., Prasanta K. Jana, and Haider Banka. "A particle swarm optimization based energy efficient cluster head selection algorithm for wireless sensor networks." Wireless networks 23, no. 7 (2017): 2005-2020.
8. Li, X., Niu, J., Kumari, S., Wu, F., Sangaiah, A. K., & Choo, K. K. R. (2018). A three-factor anonymous authentication scheme for wireless sensor networks in internet of things environments. Journal of Network and Computer Applications, 103, 194-204.
9. Ren, Y., Liu, Y., Ji, S., Sangaiah, A.K. and Wang, J., 2018. Incentive mechanism of data storage based on blockchain for wireless sensor networks. Mobile Information Systems, 2018.
10. Wixted, Andrew J., et al. "Evaluation of LoRa and LoRaWAN for wireless sensor networks." 2016 IEEE SENSORS. IEEE, 2016.