A Measurement of Energy Efficiency in Heterogeneous Wireless Sensor Networks

Sung-Min Jung[1], *Tae-Kyung Kim[2], and Tai-Myoung Chung[1]

[1] Department of Computer Engineering, Sungkyunkwan University
300 Cheoncheon-dong, Jangan-gu, Suwon-si, Gyeonggi-do, 440-746, Korea
`smjung@imtl.skku.ac.kr,tmchung@ece.skku.ac.kr`
[2] Department of Liberal Art, Seoul Theological University
Sosabon-dong, Sosa-gu, Bucheon-si, Gyeonggi-do, 422-742, Korea
`tkkim@stu.ac.kr`

Abstract. The wireless sensor network consists of many sensor nodes with sensing, processing and wireless communication capabilities. Wireless sensor networks are expected to apply many industry fields. Sensor nodes cooperate with other nodes for monitoring and collecting data around themselves. As time goes by, some sensor nodes are failed and the total performance of sensor networks is decreased because sensor nodes have restricted resources. In particular, sensor nodes have a restricted battery because of its small size. Moreover, it is impossible to recharge or replace the battery. Therefore, the battery is the most important resource. We need to predict the network lifetime to make efficient use of resources. In this paper we suggest the way to find the performance bound to predict network lifetime and the proposed method is useful to heterogeneous sensor networks. Simulation results show that overall network lifetime is influenced by the difference of job execution time between the fastest node and slowest node in heterogeneous sensor networks. Also, it is affected a cluster ratio which is the number of clusters in sensor networks.

Keywords: Heterogenous sensor networks, Optimal performance, Job execution time

1   Introduction

Wireless sensor networks are generally composed of many sensor nodes and one sink node. Fig. 1 shows these components of sensor networks. Sensor nodes can monitor their environment, process data and send it to neighbor nodes. The sink node collects data of a sensor network and sends these date to a user through the internet [1].

Due to its small size, sensor nodes have restricted battery. Because it is impossible to recharge or replace the battery, exhaustion of the energy may lead to failure of sensor node. Therefore, it can be said that the lifetime of sensor

---

* corresponding author : Tae-Kyung Kim

networks depends on the number of working sensor nodes in sensor networks. It is important to study a performance bound which shows optimal performance to decide the network lifetime. However, it is difficult to find the performance bound because there are many sensor nodes with different capability in heterogeneous sensor networks. In this study, we propose the method to decide the performance bound by analysis of job execution time based on some mathematical equations.
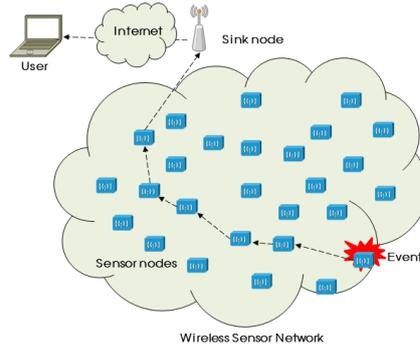

Fig. 1. Wireless sensor networks

The remainder of this paper is organized as follows. Section 2 discusses a hierarchical routing protocol in sensor networks. Section 3 discusses a heterogeneous sensor network which is based on a hierarchical routing protocol. Also, we explain some mathematical models to calculate job execution time of sensor nodes to analyze performance bound. Finally, we evaluate the proposed scheme base on some equations. Finally, section 4 concludes the paper.

2 Related Work

2.1 Hierarchical-based routing protocol

As we mentioned previous chapter, the energy is important to manage the sensor network efficiently. Therefore, we may prevent that some sensor nodes exhaust their energy and control to consume the energy evenly among sensor nodes. In general, routing protocols for sensor networks can be divided into a flat-based and hierarchical-based routing protocol by its architecture in wireless sensor networks[2].

In a flat-based routing protocol, the large number of sensor nodes deliver their monitoring data to a sink node by using a flooding method. However, due to the structural features of sensor networks, neighbor sensor nodes of a sink node would rapidly consume more energy than the other sensor nodes due to an increase of data. Because neighbor sensor nodes may collect similar data considering the

characteristics of position and operation, it is significant to reduce size of data by data aggregation in a specific location[3]. In this study, we assume that it is used a hierarchical routing protocol. The operation of a hierarchical routing protocol is commonly as follows:

First of all, cluster heads are elected by a specific formula among sensor nodes in a hierarchical-based routing protocol. It is divided whole sensor networks into several areas called a cluster. Clusters are formed around cluster heads. Cluster heads are responsible for gathering data from their cluster. All sensor nodes take the role of a cluster head by turns. After a sensor network is separated several clusters, the node which is not cluster head sends its data to cluster head which is responsible for a cluster. Then each cluster head performs data aggregation, makes to reduce size of monitoring data and delivers it to the sink node located outside from sensor networks.

One of the famous hierarchical-based routing protocols is LEACH(Low Energy Adaptive Clustering Hierarchy). It elects several cluster-heads among the sensor nodes in sensor networks. Then, the several clusters are made with the cluster heads as a central. In every certain time, the other node is elected as a cluster head by turns and it results in efficient energy consumption. The operation of LEACH is broken up into rounds, where each round begins with a set-up phase, when the clusters are organized. It is followed by a steady-state phase, when data transfers to the sink node occur. The set-up phase is divided advertisement phase, cluster setup, and schedule creation[4].

2.2 Heterogeneous sensor networks

As improving the performance of sensor nodes and applying to many industrial fields, sensor networks are increasingly consisted of heterogeneous sensor nodes. Heterogeneous sensor networks is composed of these heterogeneous sensor nodes with different performance[7]. Therefore, there are many issues such as data processing and energy consumption unlike homogeneous sensor networks. In this study, we focus on the performance of sensor networks and suggest the criteria about the optimal performance of sensor networks in related to the number of sensor nodes.

We use the mathematical model in [5] to measure the job execution time. It is useful to analyze the performance of heterogeneous sensor networks. We assume that the sensor network is based on a hierarchical-based routing protocol. Also, we assume that there are m sensor nodes which are distributed initially and the response time of the job execution in each sensor node is uniformly distributed from s seconds to t seconds. Therefore, s seconds means that it is the fastest node and t seconds means that it is the slowest node. Uniformly distributed response time means that there are heterogeneous sensor nodes with different performance[6].

3 Performance Bound in Heterogeneous WSN

Over time, if a certain percentage of sensor nodes with low performance exhaust their energy, then we can assume that the job execution time becomes a new uniform distribution in Fig. 2 and it shows this probability distribution function(PDF).
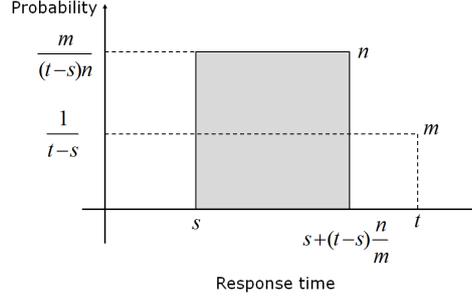

Fig. 2. Probability Distribution Function

We assume that m sensor nodes are distributed initially. After n/m of them exhausted their battery, the number of working sensor nodes in the sensor network becomes n. Therefore, response time is distributed from s seconds to $s+(t-s)(n/m)$ seconds. Equation (1) shows the mean of this PDF.

$$E\left[X\right] = s + \frac{(t-s)}{2m}n \tag{1}$$

At this time, if there are k events in sensor networks and n nodes process all these events, then it is assumed that one sensor node has to deal with k/n events. Therefore, we can calculate the mean of job execution time by using equation (1). Equation (2) indicates the job execution time of each sensor node. It means the average of job execution time in each sensor nodes.

$$T_{job} = \frac{k}{n}\left(s + \frac{(t-s)}{2m}n\right) \tag{2}$$

In this study, because we assume that a sensor network uses a hierarchical-based routing protocol, we have to consider the number of clusters and the number of sensor nodes in each cluster. If the cluster ratio of the number of working sensor nodes is p, then it can be said that the number of sensor nodes in one cluster is $1/p$. If data processing occurs sequentially among sensor nodes, then equation (2) becomes following equation. Equation (3) shows the job execution time of sensor nodes in the cluster.

$$T_{cluster} = \frac{k}{np}\left(s + \frac{(t-s)}{2m}n\right) \tag{3}$$

Based on the equation (3), we evaluate the job execution time. In this simulation, it is assumed that initial number of sensor nodes is 100 and the number of events is 10,000. Fig. 3 and Fig. 4 shows the change of job execution time according to the number of sensor nodes. The Fig. 3 shows the comparison between job execution time and the number of sensor nodes when the response time of fastest node is 0.01 and slowest node is 0.03. We can recognize that job execution time is influenced a cluster ratio greatly. The cluster ratio indicates that the rate between the number of clusters and sensor nodes. After the number of sensors is 60, the graph is increased rapidly. So, we can define the network efficiency is high until that point. Also, the Fig. 4 shows the comparison between job execution time and the number of sensor nodes when the response time of the fastest node is 0.01 and slowest node is 0.09. In this figure, after the number of sensor is 40, the graph is increased rapidly.
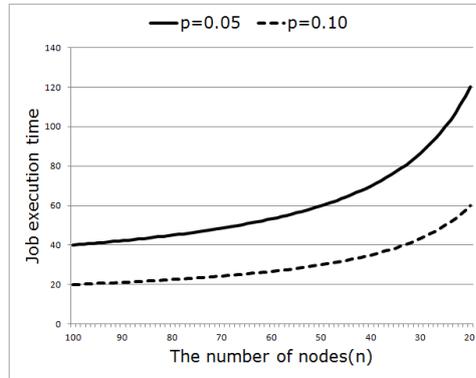

Fig. 3. The simulation results(t=0.03)

As shown the simulation results, we can expect the point which shows optimal performance. It is affected by cluster ratio and difference job execution time between the fastest and the slowest node. As difference of job execution time is large, then the total performance of sensor networks is low. Also, as cluster ratio is low, then the total performance of sensor networks is low. Thus, we have to control these factors to manage sensor networks efficiently.

4   Conclusion

A wireless sensor network is composed of many sensor nodes with a sensing, computation, and wireless communication capabilities to collect the sensing information and deliver it to other sensor nodes or to the external sink node in response to user's specific requests. In general, sensor nodes have restricted resources such as a CPU, memory size and battery capacity compare with a public
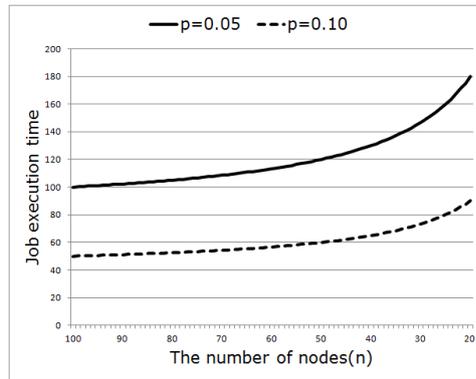
Fig. 4. The simulation results(t=0.09)

computing environment. Therefore, it is important to predict the performance bound which indicates the point of optimal performance.

In this study, we examined the performance bound of the hierarchical sensor networks. We analyze cluster ratio and job execution time based on mathematical equations and propose the criteria to decide how many sensors show the optimal performance. In the future, we wish to research the performance bound to maximize the network life time through verification using performance evaluations with various parameters.

References

1. lan F. Akyildiz, Weilian Su, Yogesh Sankarasubramaniam, and Erdal Cayirci: A Survey on Sensor Networks. In: IEEECommunications Magazine, vol. 40, no.8, pp. 102-114 (2002)
2. Sung-Min Jung, Nam-Uk Kim, and Tai-Myoung Chung: The Clusterhead Chaining Scheme Considering Scalability of the Wireless Sensor Networks. In: International Conference on Information Networking(ICOIN 2012) (2012)
3. Jamal N. Al-Karaki, Ahmed E. Kamal: Routing Techniques in Wireless Sensor Networks : A survey. In: IEEE Wireless Commun. vol. 11, no. 6, pp. 6–28 (2004)
4. W. Heinzelman, A. Chandrakasan and H. Balakrishnan: Energy-Efficient Communication Protocol for Wireless Microsensor Network. In: Proceedings of the 33rd Annual Hawaii International Conference (2000)
5. Sungkap Yeo, Hsien-Hsin S. Lee: Using Mathematical Modeling in Provisioning a Heterogeneous Cloud Computing Environment. In: IEEE COmputer, vol. 44, no. 8, pp. 55–62 (2011)
6. R. Gonzalez, M. Horowitz: Energy Dissipation in General Purpose Processors. In: IEEE J. Solid-State Circuits, vol. 31, no. 9, pp. 1277–1284 (2011)
7. E. Bouillet, M. Feblowitz, Z. Liu, A. Ranganathan, and A. Riabov, F. Ye: A Semantics-based Middleware for Utilizing Heterogeneous Sensor Networks. In: Lecture Notes in Computer Science, vol.4549, pp.174–188 (2007)