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Study on Information Quality and Energy Consumption in Wireless Sensor Networks

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***Abstract*—As the advance of IoT technology, wireless sensor networks are deployed for a variety of applications. Moreover, with the reduction of the cost of wireless sensors, the development of a wireless sensor network israpid and cost-effective. The characteristics of a sensor include independent computing, low cost, and limited resources. Therefore, how to reduce the energy consumed by sensor nodes in operation to improve the energy efficiency of wireless sensor networks has become one of the important research topics. This study investigateshow the information quality affects by the energy consumption for different data transmission methods and different sizes of communication regions.A Super Cluster Head (SCH) scheme was proposed for improving thetraditional cluster-based (CBS) scheme. Simulation study was conducted to validate the proposed approach. The delivery time and lifetime are improved with the cost of more control packets as well as much energy consumed per node.**

***Index Terms*—Wireless Sensors, Power Consumption, Information Quality, Service Quality.**

I. INTRODUCTION

Due to the characteristics of the sensor nodes, they are generally deployed in the objects or the environment to be observed, and they will be deployed near the data source for the convenience of collecting data. Due to the various applications of wireless network sensors, there are five categories of these applications.The military applications may include monitoring the status on the battlefield, reconnaissance and determination of nuclear, biological and chemical attacks, etc. For the environmental applications, millions of sensors could be deployed in the forest for monitoring the wildfire. If there is a wildfire, it will provide the fastest information to determine the location of the fire, monitor air pollution, water pollution and soil pollution. For the health application,sensors can be deployed in the house and bodyfor remote monitoring of various health data of the human body and various behaviors of people.

When the sensor node senses an object or event, the data will start to be sent to the data sink. If the amount of data generated is too much or the bandwidth is insufficient, it is very likely to cause network congestion. The performance is reduced and the transmission time may be extended. Therefore, muchenergy of sensor node will be consumed. Since the sensor uses batteries to supply the energy required for operation and transmission, therelationships between energy consumption and transmission distance is a crucial problem to be explored. If the sensor is too far away from the base station, the sensor needs to use the multiple-hop relay mechanism to establish a network route to transfer the data.

Due to the wide range of deploying wireless sensor networks, each node is supposed to independently transmit data directly to the sink.Thus, the consumed energy and the transmission time will vary due to the distance. The longer the distance, the more energy will be consumed, and finally the node will be damaged. Therefore, this studyexplore how to maximize the efficiency under the limitsof battery energy and successful data transmission. In this study, we proposed four traffic models: event-baseddelivery, continuous delivery, query-baseddelivery, hybrid delivery to test and evaluate which method minimizes energy consumption and maximizes the amount of data transferred.

II. RELATED WORK

A. Quality of Information and Quality of Service

In [1,3-4], Quality of Service (QoS) refers to the general term for the quality of network services, including traffic, speed, priority rights, etc. And QoS is also a guarantee for the use of network components or technologies to meet specific application service requirements. To provide stable and predictable data transmission services, such as guaranteed bandwidth and minimum delay time is required to achieve the QoS of application services. Moreover, the quality of information (QoI) [2] is respect to the user's point of view, which can be measured with the following metrics: (1) Accuracy: It is refers to how accurately the wireless network sensor transmits the sensing data to the base node. If the accuracy is higher, the signal will be known more accurately in the detection range, and a certain detection efficiency can also be achieved. (2) Immediacy (Timeliness): The time it takes to detect the monitored area, such as the faster the speed when a point is detected and sent back, the faster it can be processed and arrived at the area for inspection. (3) Completeness: In the same area under investigation, the wider and denser the distribution of sensors, the smaller the search area when the message is sent back, saving more time for detection. (4) Usability: The usability of wireless network depends on its location and sensing range, so when users inquire, they can know the flow of signals to increase its practicability. (5) Security: It ensures that users do not allow others to steal information when using it. The privacy also requires comprehensive planning and security protection.

As mentioned in [2], wireless sensor networks are with many characteristics, such as low cost, small size, easy deployment, and simple structure, etc., so the applicationof WSNs is quite popular. In these applications, accurate detection of environmental data and transmission of

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information to the base station are crucial functions. However, due to the small size of the sensor, there are not many resources that can be used. Therefore, data transmission is limited by memory, energy consumption, etc., so the QoS of wireless sensor network is also one of the important research topics. QoS, from the network point of view, can be measured in terms of following metrics: (1) Lifetime (Network Lifetime), (2) Penetrability (Throughput), (3) Density (Jitter), (4)Bandwidth, (5) Delay, (6) Packet Loss Rate, (7) Reliability. It is obvious that the QoS is required for transmitting a packet to the base station completely and quickly, so that the sensor can be developed in the future.

B. Node Energy Consumption

The wireless network sensor network is a network that consists of many sensors. In [5], LEACH routing protocol is proposed. The data transmitted by a sensor is limited on communication range.So,the complete data transmission is achieved by several transmissions inmany layers.Assuming that the sensor transmits data in a single hop manner, the hierarchical routing protocol is required [5, 6]. Thus, there will be some communication problems between the clusterhead and the base station during long-distance transmission [7]. If the scope of the network becomes larger, the hierarchical routing protocol is not suitable. So, the clusterhead [8] that proposes the binding plan solves this problem. Our scheme is suitable for vast wireless sensor networks, and it was found from simulation results that the proposed scheme will perform better than the general hierarchical routing protocols. Simulation study was conducted to compare LEACH and our proposed method. The following performance metrics are investigated: the transmission distance, energy consumption, and network lifetime. The following is the energy consumption formula:

$$ET\,(k, d) = ETelec(k) + ETamp(k, d) \qquad (1)$$

The cost of sending a k-bits packet to a receiving node at distance d is:

$$E_{Tx}(k,d) = E_{elect} * k + Emp * k * d^2,\ \ d > d0(2)$$

$$E_{Tx}(k,d) = \ Eelect * k + Emp * k * d^4, d \le d0 \qquad (3)$$

C. Routing Methods for Wireless Sensor Networks

(1) Point-to-Point Direct Communication: When each sensor node transmits packets or control messages, it is directly connected to a receiver node (sink node) and sends data to it.Then the receiving node sends it to the back-end manager for further processing as shown in Fig. 1.

(2) Cluster Communication: First, the sensor nodes are divided into many clusters, and each cluster has a cluster head, which is responsible for collecting the data sensed by all sensor nodes in the cluster.And then, the collected information is unified by the cluster head. Thereafter, the cluster head sends the unified data to sink node. This type of network architecture can reduce energy consumption during data transmission and has better scalability.However, the disadvantage is that the network architecture is relatively complex. Figure 2 illustrates the cluster communication.

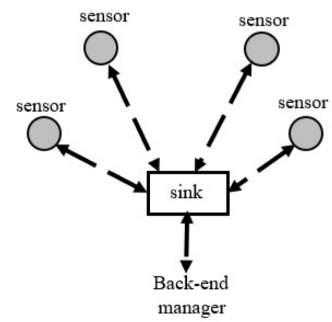


Fig. 1:point-to-point direct communication.

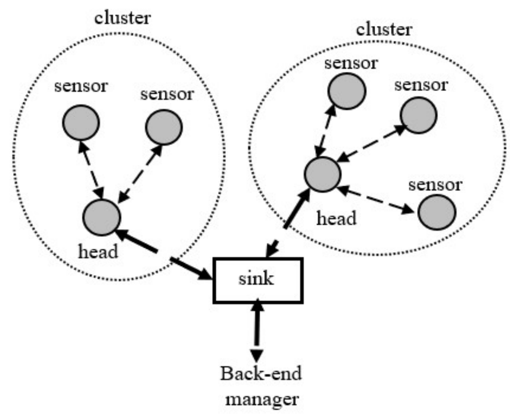


Fig. 2: Cluster communication

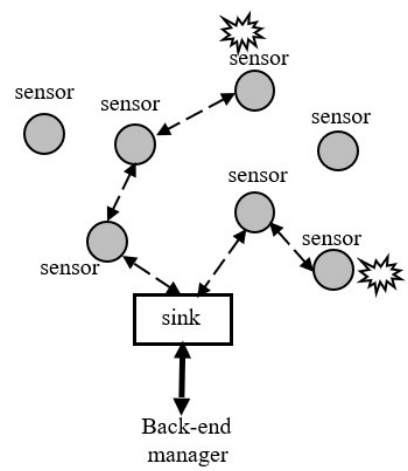


Fig. 3: Multi-hops communication

(3) Multi-hops Communication: Each sensor node in the sensor network can be regarded as a routing device, and everyone works together to forward the packet to the sink node. Figure 3 shows the multi-hops communication.

III. Research Methods

A. Clustered Sensor Networks

Based on the analysis in [6], the energy is highly

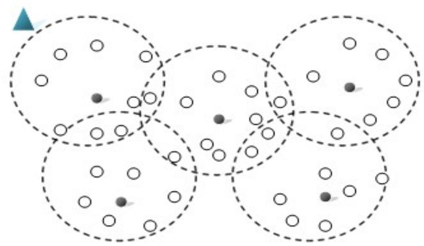


Fig. 4: Selection of cluster heads.

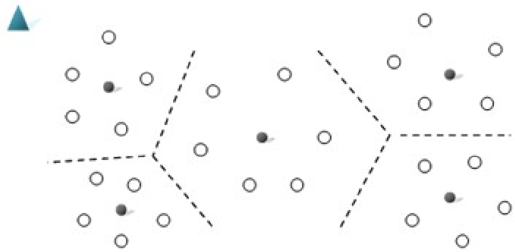


Fig. 5: Blocks of clusters.

consumedin data transmission.And. the longer the distance, the more energy will be consumed. After the cluster head collects the data from the other sensors, it needs to compress the data and send it to the base station. Although the cluster head can effectivelyreduce the energy consumed, but the cluster head itself will consume its energy quickly since the transmission distance remains unchanged. So, several methods were proposed to reduce the distance traveled by the cluster head to transmit data to the base station to reduce the energy consumption caused by long distances.

LEACH is one of the most representative architectures of the cluster-based sensor network. When the entire architecture is established, it will enter a stable stage. The cluster will collect and compress the collected data, and then transfer it to the base station to complete the data transmission. Moreover,the cluster head is elected in a round-robin manner to resolve the quick energy consumption of cluster head. However, there are also some problems:

(1) The selection process of the cluster head: In the protocol of the cluster network, the selection method of the cluster head does not take energy into consideration.It is selected purely by random values. Therefore, in the case of uneven network deployment, it will increase the burden of the cluster head in a specific area.Once a node with low energy is used as the cluster head, it will accelerate the death of the node. This causes the lifetime of the network to decline. Figure 4 illustrates how to select a cluster head within a certain range.

(2) In the LEACH protocol, the distance between cluster heads is not considered. Thus,the areafor a cluster is highly overlapped.Thus,some areas have a relatively high energy consumption. Thiscausesthe rapid energy consumption of some cluster head and affects the lifetime of the overall network. Figure 5 shows that after the cluster head is selected, the area to which it belongs is divided into blocks.

(3) The loading of the cluster head: The selection of the cluster head does not consider the energy. When a node is selected as the cluster head, it is responsible for data

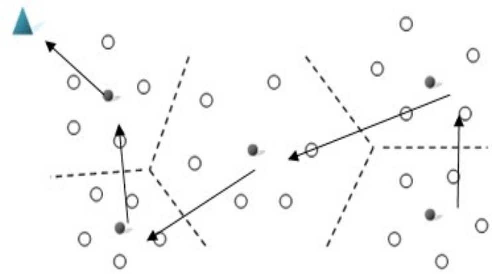


Fig. 6: Shortest path routing.

collection, aggregation and forwarding. The loading is heavy, and the energy is easily exhausted quickly. Therefore, a mechanism is crucial to share the energy consumption among some cluster heads. This mechanism can prolong the lifetime of network. Figure 6 shows that the data collected by each cluster head is sent back to the base station by the shortest path.

Based on the above observations on some shortcomings of LEACH, we propose ways to improve these shortcomings. When the cluster heads are excessively dense, it causes some cluster heads to consume too much energy in the network. Therefore, we can reduce the traffic loading as much as possible for the denser cluster header area. There is a significant difference in packet size between the packets sent by the cluster during the establishment stage and the packets sent during the stable stage. By incorporating some steps during the establishment stage, the energy consumed by cluster heads when transmitting data to the base station during the stable stage can be reduced.

This study proposes a cluster head routing scheme that can reduce the distance that data is transmitted from neighboring cluster heads to the base station. After the cluster head receives request messages from nodes, this scheme will then transmit a broadcast message again to all cluster heads.And a Super Cluster Head is selected according to some conditions. The Super Cluster Head not only bears the responsibility of the nodes in the original cluster, but also serves as the transfer point of other cluster heads to transmit data to the base station.The original cluster head will compress and merge the data collected from the nodes within the cluster, and then transmit it to the super cluster head.The data is then forwarded to the base station through the super cluster head.

Some conditions for selecting a supercluster head are as flows. (1) Selecting a cluster head with less traffic loading as the super cluster head can reduce the rate at which the super cluster head's energy consumption.On the other hand, if the super cluster head has a heavy burden of its own, and also has to serve as a data transfer point for other cluster heads, its energy will be excessively consumed and then it will quickly die. (2)Selecting a cluster head that is closer to the base station as the super cluster head to achieve the shortest transmission distance. In addition, make the cluster head directional in the transfer process, and do not choose the cluster head in the opposite direction of the base station as the super cluster head.(3) In order to avoid the rapid death of cluster heads, select the cluster head with more remaining energy as the super cluster head, so that it can share the energy consumed by other cluster heads.

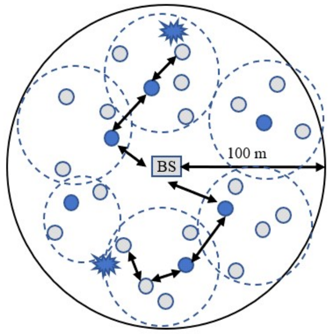


Fig. 7: Simulation environment.

B. *Simulation Environment*

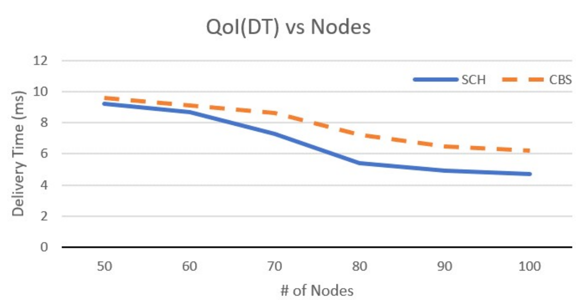
The simulation study was conducted to evaluate the proposed Super Cluster Head scheme (SCH) and cluster-based scheme (CBS) with respect to the QoI and energy consumption. The QoI metrics are summarized into two factors. One is the delivery time (DT) which represents the accuracy, immediacy, and completeness. The other one is lifetime (LT) of the wireless sensor network. The lifetime is used to measure the usability of the WSN. The assumptions for this study are as follows. First, all nodes are located within the range of a circle area as shown in Fig. 7. The radiusof this circle is 100 meters. The number of sensor nodes is from 50 to 100, and the sensor nodes are randomly deployed in the circle area. One base station is located at the center of the circle area, and some events are randomly generated in the circle area. When an event occurs, the sensor node that is close to the event location will detect the event and generate some data for delivering to the base station.

IV. Simulation Results

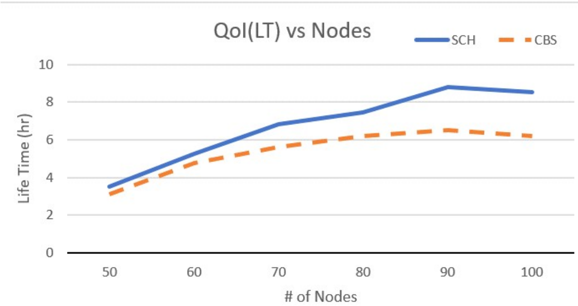
As shown in Fig. 8(a), the delivery time for SCH scheme and CBS scheme is evaluated by the simulation study. The delivery time implies the three QoI metrics: accuracy, immediacy, and completeness. Obviously, the proposed SCH scheme has less delivery time than that of the traditional CBS scheme. When the number of nodes is small, the performance of the two schemes is approximately equal. As the number of node increases, the performance of SCH scheme is better than that of CBS scheme. The simulation result validates that the SCH scheme selects the super cluster head by considering node's residual energy, distance from base station, and less traffic loading. Thus, the data is forwarded by the cluster head to the base station quickly, and the delivery time is shorter than that of CBS scheme, which selects the cluster head randomly.

Figure 8(b) shows the lifetime of the wireless sensor network versus the number of nodes. When the number of nodes is small, the difference between the two schemes is small. As the number of nodes increases, the lifetime of the SCH scheme is longer than that of CBS scheme. This means that SCH can select a better cluster head according to its residual energy, distance from base station, and less traffic loading, so that the lifetime of WSN is lengthened. On the other hand, the traditional CBS scheme randomly selects a cluster head without considering the residual energy, distance from base station, and less traffic loading. Thus, the cluster head in the WSN may use up of the energy and then the WSN will not function as usual.

Though the SCH scheme has better performance in terms of delivery time and lifetime, it also suffers from some costs, such as energy consumed per node and number of control packets. Figure 9(a) shows the energy consumed per node for

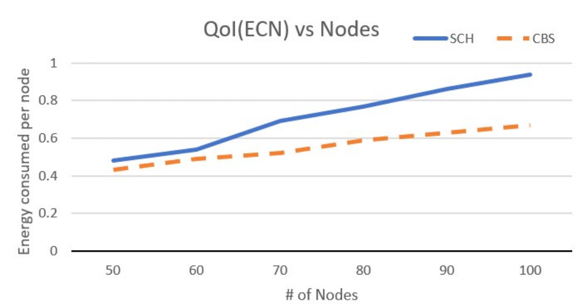


(a) QoI(DT) vs. Nodes

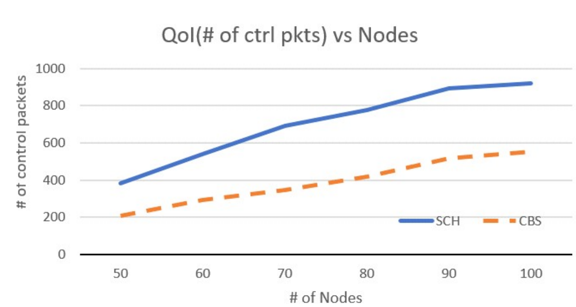


(b) QoI(LT) vs. Nodes

Fig. 8: Simulation results.



(a) Energy consumed per node vs. Nodes



(b) Number of control packets vs. Nodes

Fig. 9: Costs of the SCH scheme.

the two schemes. The node in the proposed SCH scheme will consume much energy that the node in CBS scheme since the SCH scheme use more complex protocol to establish the cluster and maintain the re-election of super cluster head. Similarly, the control packets sent by the SCH scheme is more than that of CBS scheme as shown in Fig. 9(b).

V. CONCLUSION

The wireless sensor networks (WSNs) are promising technology nowadays. Itcan bedeployed for a variety of applications, such as remote monitoring, remote health care, etc. Moreover, with the reduction of the cost of wireless sensors, the development of a wireless sensor network is rapid and cost-effective. The characteristics of a sensor include independent computing, low cost, and limited resources. Therefore, how to reduce the energy consumed by sensor nodes in operation to improve the energy efficiency of wireless sensor networks has become one of the important research topics. This study investigates the information quality, which can be measured in terms of accuracy, timeliness, completeness, etc. Moreover, the relationships between information quality and the energy consumption for different data transmission methods and different sizes of communication regions should be explored.In the paper, a Super Cluster Head (SCH) scheme was proposed for improving thetraditional cluster-based (CBS) scheme. A simulation study was conducted to validate the proposed approach. Simulation results show that the delivery time and lifetime are improved. However, the proposed scheme has the cost of more control packets as well as much energy consumed per node.

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