Transmission Control Method Using Hierarchical Clustering in Information-Centric Sensor Networks

Hiroto Michitsuji and Shigeki Shiokawa
Information and Computer Sciences, Kanagawa Institute of Technology
1030 Shimo-ogino, Atsugi, Kanagawa 243-0292, Japan
E-mail: shiokawa@nw.kanagawa-it.ac.jp

Abstract
The application of sensor networks that realize multiple M2M services for ICN (information-centric networking) is drawing attention. Thus far, a method of improving the efficiency of data collection using clusters has been proposed. In this method, the load of the cluster members is reduced by constructing routes and caching data only with cluster heads. However, it is assumed that there is no limit of caching capacity in the cluster head.

In this paper, we consider the case of limited caching capacity and propose a transmission control method with hierarchical clustering. In the proposed method, an upper layer cluster is formed with multiple cluster heads of lower layer clusters. Also, in the lower layer cluster, transmission power is controlled according to the distance between the cluster head and cluster members. From the results of performance evaluation, the proposed method is found to be superior to the conventional method in terms of power consumption.

1. Introduction
Recently, there have been many M2M services in which sensors autonomously collect data using a wireless network. As a means of realizing M2M services with sensor networks, the application of sensor networks to ICN [1] is drawing attention. ICN is a network used for content distribution. Therefore, it is considered that sensor networks that consist of sensor nodes distributing data are suitable for ICN. In general, since ICN is performed in a wired network environment, it is not necessary to consider the power consumption of nodes in the network. However, in a sensor network, power consumption is a very important factor because the power resource of a sensor is limited.

Thus far, a method of improving the efficiency of data collection using clusters in a sensor network applied to ICN has been proposed [2]. In this method, clusters are formed with sensors located in a specific area, and the load of the cluster members is reduced by making only the cluster head (CH) construct routes and cache data [3]. However, this method assumes that there is no limit on the caching capacity of the CH. In a realistic environment, the caching capacity of a CH is not very large, because the CH is a sensor device. In an environment where the caching capacity is limited, data transmission between the CH and cluster members increases. This is because the probability that only one cluster member has the requested data is high. This may prevent data collection from a sensor owing to its power depletion.

In this paper, therefore, we consider the case of limited caching capacity of sensors and propose a transmission control method with hierarchical clustering in information-centric sensor networks. In the proposed method, an upper layer cluster is formed with multiple CHs of lower layer clusters, and routes are constructed by only the CHs in the upper layer clusters. Also, in the lower layer cluster, transmission power is controlled according to the distance between the CH and cluster members to reduce power consumption. We evaluated the effectiveness of the proposed method in terms of power consumption and data collection delay by computer simulation.

2. ICN Using Clustering
Recently, a considerable number of studies have been devoted to ICN, a new paradigm for the future Internet. The basic idea of ICN is to change the Internet communication model by replacing host addresses with content names. NDN [4] and CCN [5] are two of the well-known current research projects in this area.

In a typical ICN, when a node requests a content, it simply broadcasts a request packet, called an interest, which includes the content name. The node that receives the request and has cached the requested content may send...
the corresponding content packets in response, otherwise it continues forwarding the interest packet.

In an environment where a sink node requests sensor data in an information-centric sensor networks, since intermediate relaying nodes have a cache function, the number of communications required for data acquisition, as well as power consumption, can be reduced. In particular, there are several network clustering methods that can improve the cache reference rate and reduce power consumption.

In a typical clustering method, the sensing area is divided into small areas, and a cluster is formed in each divided area. Each cluster has one CH only. The CH is responsible for communication between the sink node and the sensor node. It also caches the data of sensor nodes located in the same cluster as the CH.

3. Conventional Clustering Method [3]

Figure 1 shows the operation of the conventional clustered information-centric network in ref. [3]. In the figure, there are one sink node and six sensor nodes. Clusters are formed with sensors located in a specific area. In Fig. 1, nodes A, B and C form Cluster 1, and nodes D, E and F form Cluster 2. Consider a situation where the sink node requests data E, which is generated by node E. Then, the request of data E is transmitted to the CH in Cluster 2 via the CH in Cluster 1. The CH in Cluster 2 confirms its cache. If it has the requested data E, it sends the data back to the sink node. When there is no requested data in the cache, the request is transmitted to node E, which has the requested data. After receiving the request, node E sends the data back to the sink node. When the CH in the same cluster (node D) relays the data, it saves the data to the cache. On the other hand, node A, which is a CH in Cluster 1, does not cache data E, because it is not the CH of the cluster in which data-generating node E is.

To cope with an increase in the power consumption of a CH, the CH is shifted among the sensor nodes in the same cluster as needed. With this CH shift mechanism, a CH can become a cluster member node again and its power consumption is reduced. This means that the time until its power depletion occurs can be lengthened.

Figure 2 shows the procedure of the CH shift operation. When the remaining battery level falls below a threshold set in advance, the CH transmits a CH shift announcement to the sensor nodes in the same cluster and the CH in the neighboring clusters.

When the CH receives the announcement, it waits for its own CH shift until this shift has been completed. This is to preventing disconnection between two CHs in neighboring clusters. When each sensor node in the same cluster receives the announcement, it calculates its own cost depending on the remaining power, and if the cost is less than or equal to or less than the in the announcement, the node sends its candidacy including the calculated cost to the requested CH.

The requested CH waits for the candidacy of sensor nodes whose cost is smaller than it during a certain period. After the period, it compares the received costs and chooses the node with the minimum cost as the candidate for the CH shift. After deciding the candidate, it transmits a CH shift notification to the candidate. The node that receives the CH shift notification builds a route to the sink by exchanging
routing information with the other CHs. When there is no route from the node to the sink, it gives a response of ‘no’ to the requested CH. In this case, the CH chooses another node as the next candidate and repeats the same process. If there is a route to the sink node, the node gives a response of ‘yes’ to the CH. After receiving the response of ‘yes’, the CH begins to shift. Simultaneously, a CH shift finish is transmitted to the CH in the neighboring clusters.

4. Proposed Method
The conventional method described in Sec. 3 uses a single layer cluster and assumes that there is no limit on the caching capacity of the CH. In a realistic environment, the caching capacity of a CH is limited and is not very large, because the CH is a sensor device. In an environment where the caching capacity is limited, a CH in a cluster cannot cache all the data generated in nodes in the same cluster. Therefore, the transmission increases between the CH and the cluster members. This means that the power consumption of the cluster members increases. If a sensor does not work owing to its power depletion, the data cannot be collected from the node.

5. Computer Simulation
We evaluate the performance of the proposed method by computer simulation to verify its effectiveness. We compare the proposed method with the conventional method described in Sec. 3.

Figure 4 shows the simulation model of the conventional method. In the conventional method, the simulation area is divided into 16 subareas, and the nodes in each area form a cluster. Figure 5 shows the simulation model of the proposed method. In the proposed method, 16 upper layer clusters are structured similarly to the conventional method. In addition, each upper layer area is divided into four subareas, and the nodes in each area form a lower layer cluster.

The simulation area is a square with a side of 1000m, in which nodes are deployed randomly. Not only the sink node but all nodes are fixed and not moving. During a
simulation period, the sink node randomly selects a request for data.

We set two scenarios in terms of the probability of a node being requested for data. In the first scenario, denoted by “no bias”, the selection probability is the same for all the nodes, that is, $1/N$, where $N$ is the number of nodes. In the second scenario, denoted by “bias”, all the nodes are classified into four groups, and the selection probabilities of groups 1-4 are $1/10N$, $1/5N$, $3/10N$ and $2/5N$, respectively.

The cache discard method is the first in first out (FIFO) method. The power consumption of a node is based on that of a general wireless LAN module. Table 1 shows the simulation parameters.

6. Simulation Results

Figure 6 shows the average power consumption per second in a node when the cache size is 10. In both scenarios, the conventional method consumes more power than the proposed method. This indicates that the power consumption is reduced by the cache function of the lower layer cluster and the transmission power control between the lower layer CH and the cluster member. Therefore, the effectiveness of the transmission power control by the hierarchical cluster is confirmed. We also find from the figure that the power consumption in “no bias” is larger than that in “bias”. This is because cached data in the CHs is reused more frequently in “Bias”, and the power consumption of cluster members is reduced.

Figure 7 shows the average power consumption per second in a node when the cache size is 20. The proposed method markedly decreases the power consumption compared with the case when the cache size is 10. In the proposed method, the number of CHs is more than that in the conventional method, because two layers of clusters are

Table 1: Simulation parameters

| Parameter                  | Value               |
|----------------------------|---------------------|
| Area size                  | $1000(m) \times 1000(m)$ |
| Number of nodes            | 300-700             |
| Number of data             | 300-700             |
| Maximum communication range| 300(m)              |
| Number of cached contents  | 10, 20              |
| Simulation time            | 2000                |
| Battery capacity           | 5000(mWs)           |
used. This means that a large amount of data is cached in the CHs and reused frequently, and the power consumption of cluster members is reduced.

Figure 8 shows the average data collection delay, defined as the time from a request of data to the arrival of the data. It is found that the delay in the proposed method is larger than that in the conventional method. This is because the number of hops between a cluster member and the sink is three in the proposed method, whereas it is two in the conventional method. Therefore, if the data is not cached in the CH, the collection delay of the data becomes large in the proposed method. This is also shown in Fig. 9. We can see that when the cache size is larger, the delay also becomes larger.

7. Conclusions

In this paper, we propose a transmission control method with hierarchical clustering. From computer simulation results, we show the superiority of the proposed method in terms of power consumption in an environment where the cache capacity is limited. On the other hand, the delay in the proposed method becomes larger. However, the increase is on the millisecond order. Therefore, when such an increase in delay is allowable, the proposed method is effective in terms of power consumption.

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