Analytic Models for Gateway Selections for Inter-clusters in Wireless Ad hoc Networks

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Abstract

Packet transmitting among the clusterheads which is the head of a cluster in wireless ad hoc networks are carried out through gateway nodes. Nodes in a cluster communicate through the head node to other nodes. Existence of multiple gateways between the clusters means multiple path existence. Multiple transmissions of packet though redundancy paths may not desire for efficient resource usage. Therefore, the communications between clusterheads by selecting the most stable and effective gateway are a fascinate solution. In this paper, we propose gateway selection methods to support a stable path connection. The comparisons by characteristics of proposed methods are analyzed.

Keywords: *Stable gateway node, Beacon, Multiple routing paths, Clustered ad hoc networks, Threshold, Node distance, Hybrid method*

1. Introduction

An ad hoc network doesn't depend on any preexisting communication infrastructure, such as fixed base stations and the connecting backbone network. In some cases, such as emergency disaster relief or battlefield operation, when a wired network is not available, an wireless ad hoc network can be used to allow communication [1-2]. Clustering is a concept of dividing the geographical region into small wireless zones [3]. It provides a convenient framework for resource management and the spatial reuse of resource to increase the system capacity. It can support many important features such as channel access, code separation, power control, bandwidth allocation, and virtual circuit support [4-15]. A clustered ad hoc network consist of three kinds of nodes: clusterheads, gateways, and ordinary member nodes. Clusterheads are nodes that are vested with the responsibility for routing and channel access within clusters. The communications between two adjacent clusters are conducted by the gateway nodes, because each clusterhead isn't located within direct transmission range. In existence of multiple gateways between the clusterheads, multiple transmissions of packets though redundancy paths may happen [4-5]. If we choose a node as a gateway for long and safely, we can make a stable connection among clusters for consisting an ad hoc network. In choosing the most stable gateway, the employment period is also important. Some factors like the position of the gateway, the remained battery capacity of the node, the mobility of the node, and the efficient routing possibility can be used. In this paper, we propose three kinds of the selection methods for the most stable gateway by the node positions of the candidate gateway nodes for long run. This paper is organized as

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follows. Section 2 presents introduction of clustering. Based on this architecture, Section 3 introduces gateway selecting methods. Section 4 shows some experimental results using the gateway selecting methods. Section 5 introduces a method of the gateway switching, and section 6 make conclusions.

2. Clustering in ad hoc networks

2.1 Clustering formation

The clusterhead acts as the local coordinator of transmissions within the cluster and responsible for controlling channel access, routing, bandwidth allocation, code separation and management of member nodes. Several clustering algorithms have been proposed for forming cluster architecture such as lowest-ID algorithm [8]and highest-connectivity [9]. Clusters may change dynamically, reflecting the mobility of the underlying network. The cluster algorithm is performed again for selecting the new head node when the two cluster heads are too adjacent or one head doesn't belong anymore to the cluster by using the Least Cluster Change algorithm [10].

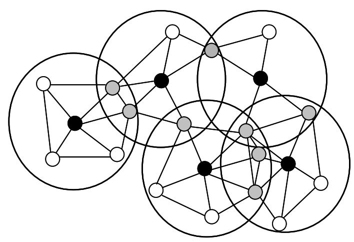


Figure 1. Clustering structure of ad hoc network

2.1 Routing in clustered ad hoc networks

Clusterheads need to control the cluster table that includes path information about every destination cluster. The CGSR (Clusterhead Gateway Switch Routing) [10] is a protocol to control routing information in the clustered ad hoc networks. A packet is transmitted to the neighbor clusterhead through a gateway node which is a non-clusterhead. Because each clusterhead doesn't exist in the direct transmission range the packet is transmitted through the gateways that exist inside the communication range of the two clusterheads. Therefore, the path of a packet is composed of the clusterheads and the gateways.

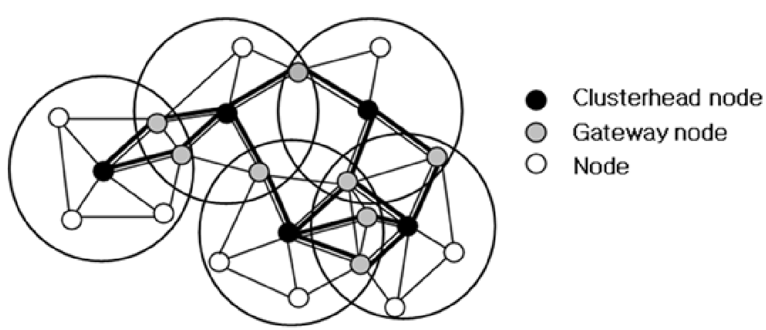


Figure 2. Routes of clustered Ad hoc network

3. Proposed gateway selection methods

Transmitting a packet in the CGSR is performed through routing paths among the clusterheads and the gateways. If there are more than two candidate gateway nodes, packet flooding through all the candidate gateway nodes may meet waste of resources. Therefore, we choose a node which will perform its role as the most stable gateway between the two clusterheads. The most stable gateway can prepare the most stable connection among clusterheads by one routing path and it can save resources. Three methods for selecting the most stable gateway are introduced.

3.1 Gateway selection using threshold

Each node broadcasts its own beacon signals periodically to let know its existence. Beacon signal strength(BSS) can be assumed in reciprocal proportion to the squared distance(d^{-2}) in the free space propagation model[16-17]. Therefore, it means that a node is located in the nearest position from the both clusterheads if it receives beacon signal of strong strength from the both clusterheads. In this case, we can assume the node is placed in the stable position between the both clusterheads. In the fig. 3, G_1 has weak beacon signals from the both clusterheads. G_2 has the strong beacon signal from the clusterhead C_1 but weak beacon signal from the clusterhead C_2. G_3 has the most strong beacon signals from the clusterheads (C_1, C_2) and is located in the most stable place from the both clusterheads. The most stable node in all the candidate gateway nodes receives the strong signal from the both clusterheads. To select the most stable gateway node, we have to find out the node which has the stongest beacon signal from the both clusterheads. We introduce a threshold method for selecting the most proper gateway.

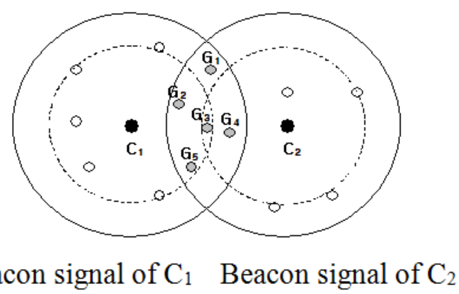


Figure 3. An example of selection of the most stable gateway node

3.1.1 Gateway selection using linearly increasing threshold

To select a stable gateway node, we assume that candidate gateway nodes receive signals from more than two cluterheads, then they broadcast their own beacon signals which include information the beacon signal strength from each clusterhead(the signal received from the clusterhead C_1 is BSS_1, the signal received from the clusterhead C_2 is BSS_2) to clusterheads. Then, the clusterhead C_1 checks if BSS_1 and BSS_2 of each candidate gateway node exceed a BSS threshold(BSS_{th}) and selects the proper nodes as gateway candidates. BSS_{th} is presented by adding the minimum signal strength and a value of increasing rate α,

$$BSS_{th} = \text{Min BSS} + \alpha \,. \quad (1)$$

Where, Min BSS is the minimum signal strength which can begin communications between noes.

Clusterheads continue n-steps gateway selection process by increasing threshold linearly until selecting just one gateway. The value of threshold in n-steps gateway selections is presented by

$$BSS_{th} = \text{Min BSS} + (n \times \alpha). \quad (2)$$

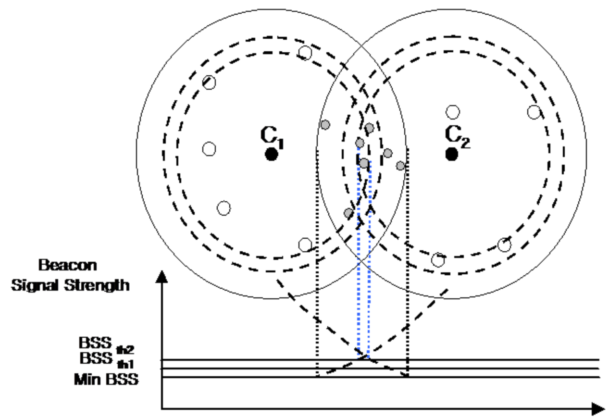


Figure 4. Gateway selection process by threshold increasing

Proposed gateway selection algorithm is as follows :

0. Initiate BSS_{th} value (BSS_{th} = Min BSS)
1. Check if $BSS_{i1} \geq BSS_{th}$ and $BSS_{i2} \geq BSS_{th}$ (for each candidate gateway node i = 1,2, …, m) and select nodes satisfying the conditions.
2. Check one of the following conditions.
   ① Finish the algorithm when the number of selected candidate gateway nodes is only one.
   ② Go step 3 when the number of selected candidate gateway nodes is more than two.
   ③ Go step 4 when there is no selected candidate gateway node.
3. Go step 1 after $BSS_{th} = BSS_{th} + n\alpha$, where n is the number of iteration.
4. For all selected nodes in the previous step, select a node satisfying following condition and finish the algorithm.

$$MAX \left\{ x \mid x \in \frac{BSS_{i1} + BSS_{i2}}{2}, \quad i = 1, 2, \cdots, m \right\}.$$

3.1.2 Gateway selection using exponentially increasing threshold

A received beacon signal strength can be assumed in reciprocal of proportion(d^{-2}) to the squared distance in the free space propagation model. The received signal strength decreases exponentially as the distance between a clusterhead and a gateway node increases. Therefore, we applied a gateway selection algorithm uses BSS threshold increasing exponentially based on the signal-distance characteristics. BSS_{th} is presented by (3)

$$BSS_{th} = \text{Min BSS} + (n^2 \times \alpha). \tag{3}$$

Figure 5 shows characteristics of two increasing thresholds between linearly and exponentially.

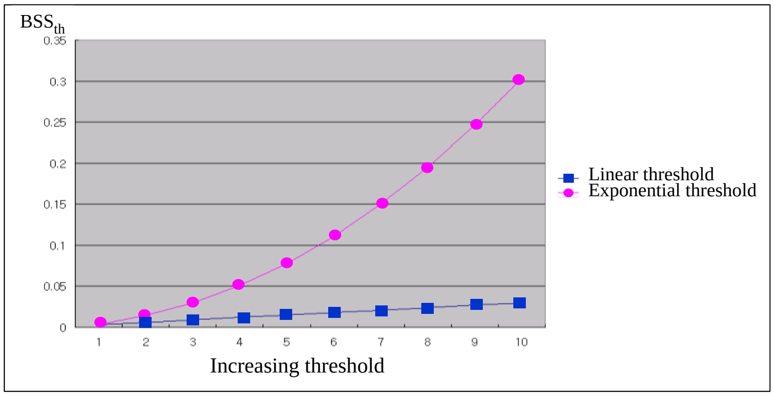


Figure 5. Gateway selection process by threshold increasing

3.2 Gateway Selection by comparison of node distance

Another proposed gateway selection method is to select the nearest candidate gateway node between clusterheads. In Figure 6, the ‘o’ is the middle point and the optimal location between two clusterheads(C_1, C_2) receives the strongest signal from all the both clusterheads. This method provide how to find out and select the nearest node from the point ‘o’ by geometry. In Figure 6, candidate gateway nodes(G_1, G_2) broadcast beacon signals including the information(BSS_1, BSS_2) of the received signal strength from clusterheads.

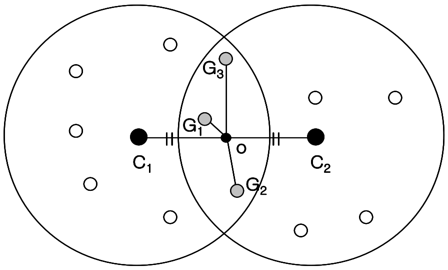


Figure 6. A model of gateway selection by using distance comparison

In Figure 7, the BSS_1 is the received signal strength from clusterhead C_1 and the BSS_2 is the received signal strength from clusterhead C_2. We assume that D_{G1C1} is the distance between the clusterhead C_1 and candidate gateway node G_1 and the D_{G1C2} is the distance between the clusterhead C_2 and candidate gateway node G_1. Distance can be expressed as a constant over the square value of the received signal strength by the friss’s free space propagation model. Therefore, the D_{G1C1} is $\frac{c}{(BSS_1\ of\ G_1)^2}$, the D_{G1C2} is $\frac{c}{(BSS_2\ of\ G_1)^2}$. The

D_{G2C1} is the distance between the clusterhead C_1 and candidate gateway node G_2 and the D_{G2C2} is the distance between the clusterhead C_2 and candidate gateway node G_2. Therefore, the D_{G2C1} is $\frac{c}{(BSS_1\ of\ G_2)^2}$, the D_{G2C2} is $\frac{c}{(BSS_2\ of\ G_2)^2}$. Clusterheads($C_1$, C_2) select the nearest node from the optimal middle point 'o' based on the distance factors.

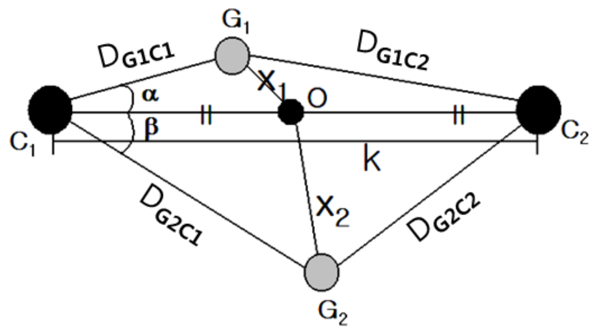


Figure 7. A calculation model of distance between nodes and the optimal point

The distance between a candidate gateway node G_1 and the optimal point is represented by

$$X_1 = \sqrt{\frac{{D_{G1C1}}^2}{2} + \frac{{D_{G1C2}}^2}{2} - \frac{k^2}{4}} \quad (4\text{-}1)$$

Where, 'k' is an arbitrary constant which shows the distance between C_1 and C_2.

The distance between candidate gateway node G_2 and the optimal point is represented by

$$X_2 = \sqrt{\frac{{D_{G2C1}}^2}{2} + \frac{{D_{G2C2}}^2}{2} - \frac{k^2}{4}} \quad (4\text{-}2)$$

A clusterhead compares with two distance(X_1, X_2) and selects the node having short distance.

3.3 Hybrid Gateway Selection

It is possible that an unstable node is selected as the gateway in the gateway selection processing by using only distance calculation method. In Figure 8, the node G_5 is selected by using the distance calculation method. This node is in the farthest from clusterhead C_1 and has high possibility to go out from the communication range of clusterhead C_1. We propose a hybrid gateway selection method to solve this problem.

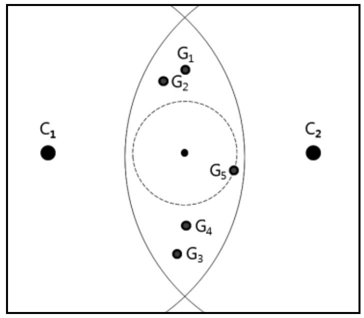


Figure 8. An example of selecting an unstable node by using distance calculation

3.3.1 Cascade hybrid

It selects a gateway by using distance calculation if there exist multiple candidate gateway nodes after gateway selection using by threshold methods. In fig. 9, G_4 is selected as the gateway by using distance calculation after gateway selection by using n-steps threshold methods. The node G_5 is excluded from the list of candidate gateway after step 1 of gateway selection using threshold method.

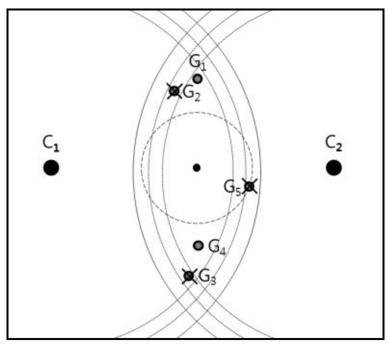


Figure 9. An example of the hybrid gateway selection

3.3.2 Parallel hybrid

Threshold method(BSS) and node distance method(D) can be used simultaneously by using partial application.

$$PH_i = \alpha \frac{\beta}{BSS_i} + (1-\alpha) D_i, \tag{5}$$

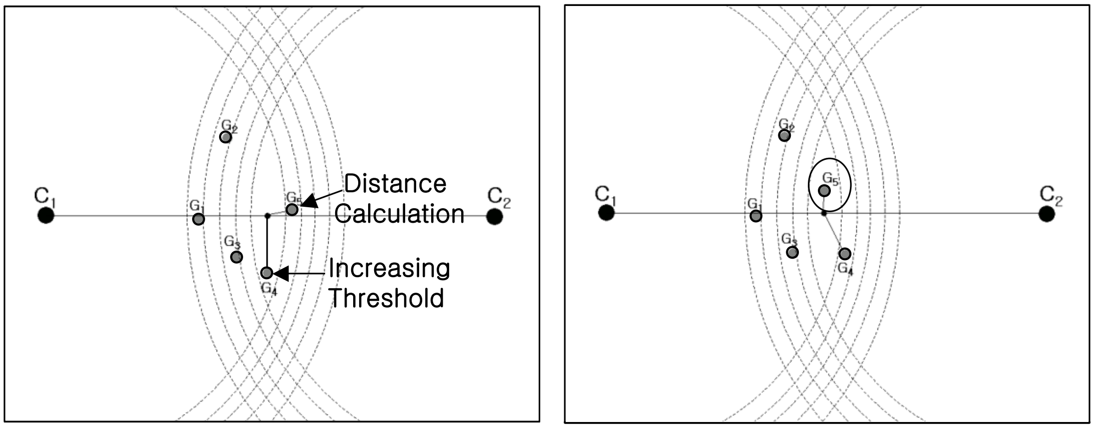
where $0 \leq \alpha \leq 1$, β is a normalization constant, BSS_i is the average signal length from both clusterheads and D_i is the distance from the middle point between two clusterheads for gateway node i.

$$BSS_i = \frac{BSS_{i1} + BSS_{i2}}{2} \tag{6}$$

The gateway selection result of the parallel hybrid method can be decided by using the decision factor α.

4. Analyses of proposed gateway selection methods

We have tried some computer simulations to select one gateway node in five candidate gateway nodes to see effects of proposed gateway selection methods. The five candidate nodes are placed at randomly different position in each simulation. The results show two cases. The one is that the same node is selected and the other is that different nodes are selected depend on only threshold and only distance comparison. In Figure 10(a), G_4 is selected by using threshold method and G_5 is selected by using distance calculation. The Figure 10(b) shows that the same node is selected in both methods.



(a) (b)

Figure 10. Two cases of selecting the same node and different nodes in gateway selection processes

5. Gateway switching

A clusterhead transmits packets to a neighbor clusterhead through the selected gateway. The selected gateway isn't stable forever, because of node's movement. In this case, another node has to be selected as the gateway. Clusterheads receive beacon signal from candidate gateway nodes and determine the time when to start for reselecting another gateway by using the information included in the beacon signal of the gateway and candidate gateway nodes.

One of the following situations may be the trigger for reselecting a new gateway in the candidates at the clusterheads.

① The gateway is disappered

② The position of the gateway is out of area decided by a previous threshold

③ Some better positioned candidates are appeared than that of present the gateway

6. Conclusions

Communications between two adjacent clusters is conducted through gateway nodes in cluster-based ad hoc networks. We proposed three gateway selection methods for selecting a stable gateway to reduce resource waste compared to flooding through multiple gateways between the clusterheads. We assumed that a node placed in stable position has low probability of path breaking between clusterheads. For a future work, the proposed methods could be compared their performance by selecting the most stable gateway in computer simulations. The proposed methods are simple and easily applicable. Performance evaluation of three methods are remained as a future work.

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