Two Phases Based Cluster Formation Scheme for Mobile Ad Hoc Networks[1]

KiCheoul Wang and Gihwan Cho

Department of Computer Science,
Chonbuk National University, Chonju, Korea
{gcwang, ghcho}@dcs.chonbuk.ac.kr

Abstract. In mobile ad hoc network, most of the cluster formation schemes consider host connectivity as a criterion for clusterhead election. However, since the highest connectivity hosts initiate the cluster formation and affiliate the neighbor hosts using a greedy method, the lowest connectivity hosts in network tend to become clusterheads. This phenomenon acts as an obstacle against producing a few clusters. In this paper, two phases based cluster formation scheme is proposed to resolve this problem. In the first phase, the lowest connectivity hosts in the neighborhood start the cluster formation, and an adjustment procedure is employed to affiliate the lowest connectivity hosts. In the second phase, the hosts not affiliated to the first phase clusters are grouped into one or more clusters based on host connectivity and host ID. The simulation results show that the proposed scheme is better and more scalable than HCCP[3].

1 Introduction

Ad hoc network is called 'multihop network' because each mobile host is connected to other hosts through some intermediate hosts. In some cases, such as disaster relief system and battlefield communications, when the fixed infrastructure is not available, this kind of network may be very useful [7].

In ad hoc network, the aggregation of hosts into groups provides a convenient framework for channel management, reducing the number of control message-exchange, and providing a flexible move management [1]. This logical host group is called "cluster " and the process of building up a cluster is called "cluster formation". A k-cluster is defined by a subset of hosts which are mutually reachable by a path of length at most k for some fixed k [6]. In general, 1-cluster, 2-cluster, and 4-cluster are well known and used frequently in ad hoc network. However, 1-cluster and 4-cluster require high overhead during cluster maintenance, especially under high mobility. This paper deals with 2-cluster only. Hereafter, 2-cluster is referred as cluster.

[1] This work was supported in part by Center for Advanced Image and Information of Chonbuk National University in South Korea.

P.M.A. Sloot et al. (Eds.): ICCS 2003, LNCS 2657, pp. 194–203, 2003.
© Springer-Verlag Berlin Heidelberg 2003

A cluster is generally configured with a clusterhead, which is connected to other hosts, so-called its members, in the cluster. A clusterhead in general maintains the topology of network, allocates resources to its members, schedules codes, and routes packets. In addition, each of them serves as a regional broadcast host[3]. When a clusterhead broadcasts a message to its members, all of them can receive the message at the same time. Therefore, this feature can be usually used for reducing the number of message retransmissions in ad hoc routing protocol, such as reactive routing protocol(DSR[12], AODV[13], etc.) and cluster based routing protocol[9]. Cluster formation schemes produce various cluster structures according to the criterion for electing clusterheads. It is well known that the cluster formation scheme which elects the highest connectivity host in the neighborhood produces fewer clusters than other schemes [3][10].

A cluster formation with a few clusters has several advantages. First, if a code is allocated to a cluster(in CDMA), spatial reuse of codes is increased. Second, since the average path length among clusterheads is shrunken, the number of broadcast message(for instance, RREQ in AODV) retransmissions is reduced and the time for route discovery is shortened. For such reasons, most previous works with respect to cluster formation scheme chose the host connectivity as a primary criterion for producing a few clusters[1][3][10]. However, since they force the highest connectivity host to initiate cluster formation and use a greedy method for affiliating the hosts to the clusters, if all dominants around the lowest connectivity host are affiliated to other clusters, the lowest connectivity host becomes a clusterhead. This phenomenon acts as an obstacle against producing a few clusters.

In this paper, two phases based cluster formation scheme is proposed to produce a few clusters. In the first phase, the lowest connectivity host in the neighborhood initiates the cluster formation. Then, an adjustment procedure for affiliating some of the lowest connectivity hosts is employed. This procedure alleviates the increase in the number of clusters caused by the lowest connectivity hosts in a network. In the second phase, the hosts not affiliated to the first phase clusters are only participated in the contention, and dominants with the highest connectivity in the neighborhood are elected as clusterheads. This procedure is repeated until all the participants in the second phase are included in one or more clusters. Since the proposed scheme makes efforts to prevent the lowest connectivity hosts in a network from being clusterheads, it produces fewer clusters than other schemes.

This paper is organized as follows; In section 2, some related works for cluster formation are shortly described, and the proposed cluster formation scheme is described in section 3. Simulation results are presented in section 4 while conclusions are offered in section 5.

2 Related Works

Most well known schemes for cluster formation are LIDCP(Lowest ID Clustering Protocol) and HCCP(Highest Connectivity Clustering Protocol)[3]. First, LIDCP elects the lowest-ID host in the neighborhood as a clusterhead through exchanges of control information(e.g. host ID) among one hop neighbors. A few variations of

LIDCP were proposed in [5], [7], and [9]. A generalization method for extending 2-cluster to 4-cluster is proposed in [10]. On the other hand, HCCP elects the highest connectivity host as a clusterhead. HCCP breaks a tie connectivity based on lower ID preference. HCCP yields fewer clusters compared with LIDCP. However, since it yields clusters through a greedy method, it cannot prevent the lowest connectivity hosts in network from being clusterheads. Hence, the number of clusters can be the same as LIDCP or even worse in some cases, though the cases are rare.

In general, it is known that using a cluster maintenance without reformation of clusters throughout network can greatly reduce the number of clusterhead changes. For this reason, LCC(Least Clusterhead Change)[4] reduced the cluster reformation region. That is, the hosts which are separated from all clusterheads or whose clusterheads are adjacent with other clusterheads are included in the cluster reformation region. Most of cluster maintenance schemes[1][4][7][8][10][11] are similar with that of LCC.

MOBIC(Lowest Relative Mobility Clustering)[8] proposed a new mobility metric for mobility based cluster formation. A relative mobility with respect to a neighbor is achieved from the ratio of received power between two successive packets. Since a host can have more than one neighbor, the aggregate mobility metric is achieved by calculating the variance of the entire set of relative mobility values with respect to its neighbors. Now, the metric is employed as the criterion for a clusterhead election. For such reason, every host exchanges this aggregate mobility metric with its neighbors every hello interval. Since this scheme forces every host to exchange two successive packets with its neighbors, it yields more communication overhead than other schemes. Moreover, because the host connectivity is not considered in the clusterhead election, it produces more clusters than the connectivity based scheme.

Generally, the cluster formation schemes which consider the host connectivity as a criterion for electing the clusterhead produce fewer clusters than other schemes. However, because it employs a greedy method, it cannot pass the limit defined by the greedy method. So, it is significant to devise a cluster formation scheme which yields fewer clusters than the greedy method. In this paper, we propose a cluster formation scheme which first affiliates the lowest connectivity hosts in a network to clusters and then produces additional clusters covering the rest hosts according to a criterion of host connectivity.

3 Two Phases Based Cluster Formation

The proposed cluster formation scheme is performed through two phases. The first phase aims to affiliate the lowest connectivity hosts in the neighborhood to some clusters. For this purpose, the exchange of {id, connectivity} with neighbors should be preceded. All the lowest connectivity hosts in the neighborhood initiate the cluster formation by sending an encouragement message to a neighbor. If they have more than one neighbor, they encourage the highest connectivity host in the neighborhood (in tie, lower ID) to be a challenge host. This procedure is needed to force the hosts which are adjacent with the lowest connectivity hosts to be clusterheads in the first phase, if possible. As a result, some of the lowest connectivity hosts in the neighborhood can be affiliated to the first phase clusters. Because the challenge host may be adjacent with other challenge hosts, a criterion for electing a dominant is required.

For instance, host 27, 28, 20, 19, 3, 16 are the lowest connectivity hosts in the neighborhood, and the challenge hosts are 9, 8, 14, 22, and 24 in figure 1. Since the host 8 and 9 are adjacent with each other, either of two hosts should be elected as the winner. This situation is also happened between host 22 and 24. To resolve this, every challenge host sends the number of the received encouragement messages and the sum of the connectivity for encouraging hosts to its neighbors except encouraging hosts. Namely, the challenge host which receives more encouragement messages becomes the winner. If the number of encouragement messages is the same as adjacent challenge hosts, the winner is judged by the sum of the connectivity with respect to encouraging hosts. Hence, the challenge host whose encouraging hosts have the lower connectivity becomes the winner. Lastly, if the above two criterions are the same, the winner can be judged by the IDs of challenge hosts. For instance, the winner between the challenge host 8 and 9 is judged by the connectivity with respect to encouraging hosts. On the contrary, the winner between challenge hosts 24 and 22 is judged by the number of the encouragement messages. On the other hand, since the challenge host 14 receives no messages, it becomes the winner by itself. The winner sends a cluster-head declare message to its neighbors, and the loser becomes a member of the winner.

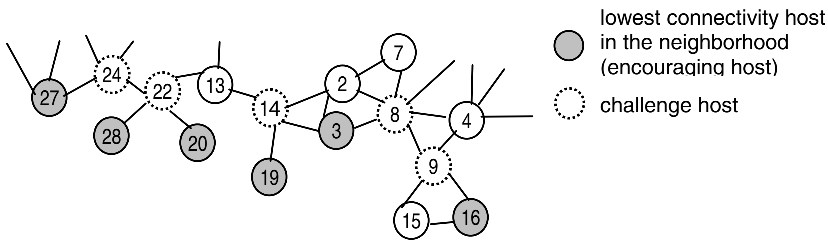


Fig. 1. A portion of ad hoc network

In the second phase, only the hosts not affiliated to the first phase clusters are participated in the contention. The highest connectivity hosts(in tie, lower ID) among the 1-hop participants initiate the second cluster formation. The maximum wait time of the initiator for starting the second cluster formation is $d = 3 \times LD$. Here, LD is calculated by adding the maximum link propagation delay and the induced delay by CTS/RTS handshaking. Why the initiator delays the second cluster formation for that time is to prevent the hosts which already participated in the first phase from participating in the second phase again. Therefore, all the hosts which participate in the first phase can determine their roles in d time. The second cluster formation is performed in the same way as a greedy method and repeated until all the participants in the second phase are grouped into one or more clusters.

In the first phase, since the proposed scheme coordinates adjacent challenge hosts through the above criterions, it doesn't produce clusters violating the definition of 2-cluster. Also, since the proposed scheme deals with the hosts which were not affiliated to any first phase cluster during the second phase, it doesn't violate the definition of 2-cluster. The proposed scheme has multiple initiators in the first and second phase and produces clusters in a fully distributed method.

An assumption for describing the proposed cluster formation is as follow.

- Each host exchanges a HELLO message with its neighbors periodically. Before broadcasting the HELLO message, {ID, connectivity} pair is included in the HELLO message.

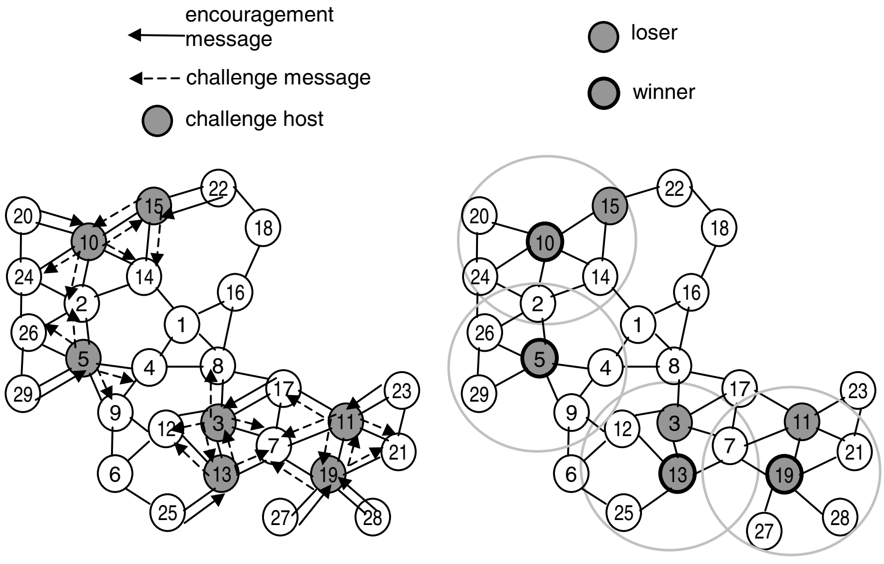
Now, the first phase of the proposed scheme is described as follows.

1. Each host judges whether it is the lowest connectivity host in the neighborhood. If so, it investigates which is the highest connectivity host among its neighbors.
2. The lowest connectivity host in the neighborhood sends an encouragement message to its highest connectivity host in the neighborhood. The encouragement message includes the host ID and the connectivity of the host.
3. The host which receives encouragement messages becomes a challenge host, and then sends a challenge message to its neighbors. The challenge message includes the host ID, the number of the received encouragement message, and the sum of the connectivity for encouraging hosts.
4. If a challenge host receives challenge messages from adjacent challenge hosts, it judges whether it is the dominant with respect to its adjacent challenge hosts according to three criterions described above. If so, it broadcasts a clusterhead declare message.
5. Each host which receives clusterhead declare messages from its neighbors affiliates itself to the clusters, and then informs its neighbors of its affiliation through a cluster affiliation message.

Next, the second phase of the proposed scheme is described as follows.

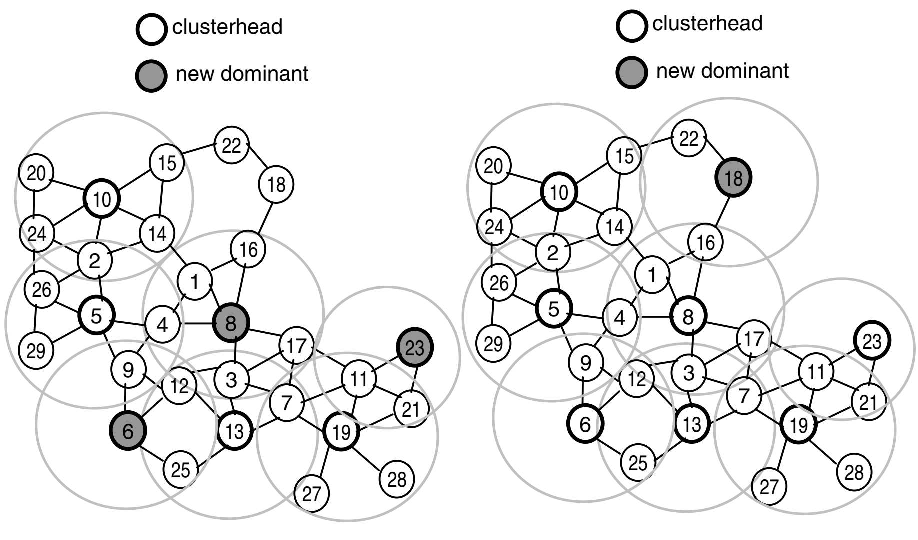
1. Each host not affiliated to the first phase clusters investigates which neighbors were not affiliated to the first phase clusters. If it has the highest connectivity among them, it broadcasts a clusterhead declare message.
2. Each host which receives clusterhead declare messages from its neighbors affiliates itself to the clusters, and then informs its neighbors of its affiliation through a cluster affiliation message.
3. If a host receives cluster affiliation messages from all hosts with higher connectivities, it broadcasts a clusterhead declare message for the first time.
4. Repeat from 2. to 3. until all the participants in the second phase are grouped into one or more clusters.

Let us provide a comprehensible example for grasping the point with respect to the proposed scheme. In figure 2, how the cluster formation is performed in the first phase of the proposed scheme is shown. In figure 2(a), the lowest connectivity hosts 17, 20, 22, 23, 25, 27, 28, and 29 send their encouragement messages to their higher connectivity hosts 3, 5, 10, 11, 13, 15, and 19, respectively. The encouraged hosts become challenge hosts without exception, and then send challenge messages to their neighbors, respectively. Through the challenge messages, the winners 5, 10, 13, and 19 become clusterheads and the rest challenge hosts become the members of the winners. This procedure is shown in figure 2(b).



(a) (b)

Fig. 2. Cluster formation procedure in the first phase of the proposed scheme



(a) (b)

Fig. 3. Cluster formation procedure in the second phase of the proposed scheme

Next, only the hosts not affiliated to the first phase clusters participate in the second phase. The highest connectivity hosts among them are hosts 6, 8, and 23. The hosts 6, 8, and 23 initiate the second cluster formation through their cluster head declare messages. This procedure is shown in figure 3(a). Lastly, since the host 18 is the dominant among the neighbors which were not affiliated to any clusters, it becomes a clusterhead. This is shown in figure 3(b).

4 Simulation Results

The simulation has been done in a system with 45 hosts on a 300×300 grid and a 500×500 grid during 900 seconds. At the beginning of simulation, 45 hosts are randomly generated inside the grid, and they are assumed to move to any direction at any time randomly. Every host selects one of three classes(A, B, C) with respect to move speed of the host. The simulation parameters are listed in Table 1.

Table 1. Simulation parameters

Parameter	Value
Number of hosts	15, 25, 35,45
Move speed of hosts	A(0~5m/s), B(5~10m/s), C(10~20m/s)
Transmission Range	20~140meter(300×300), 20~240meter(500×500)
Number of grids	300×300, 500×500
Hello period	3 seconds

A metric, the number of clusters, has been identified to measure the performance of the proposed scheme. This metric is studied for varying the transmission range, the number of grids, and the number of hosts. Figure 4 shows the variation of the average number of clusters with respect to the transmission range. The number of clusters decreases with the increase in the transmission range. This is because the increase in the transmission radius results in more hosts under the management of a clusterhead. This leads to a less number of clusters. However, as the transmission range increases even further(>60m), the rate of reduction in number of clusters decreases due to the increase in overlap between adjacent clusters. This results in an increase in the number of hosts belonging to multiple clusters. In figure 4, it is also shown that the proposed scheme yields fewer clusters as compared with HCCP at all the transmission ranges. At the transmission range from 40 to 80, the proposed scheme yields a gain of close to 19% over HCCP. Although this gain looks insignificant, the number of retransmission messages and the time for route discovery are greatly reduced by this gain.

In figure 5, the simulation boundary has been extended to 500×500 grid. This results in more clusters in the system under the same transmission range due to the more sparsely connected topology. In this situation, the proposed scheme yields fewer clusters as compared with HCCP at all the transmission ranges. At the transmission range from 80 to 140, the proposed scheme yields a gain of close to 15% over HCCP.

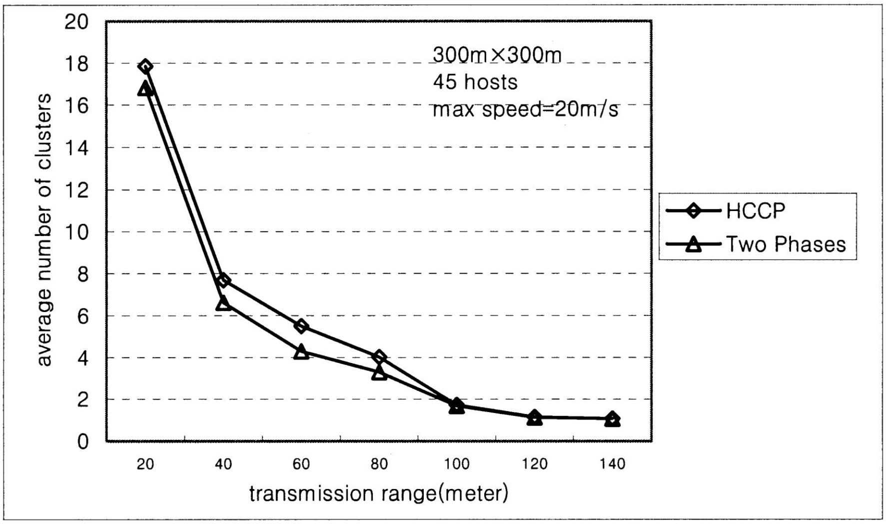


Fig. 4. Average number of clusters in 300×300 grid

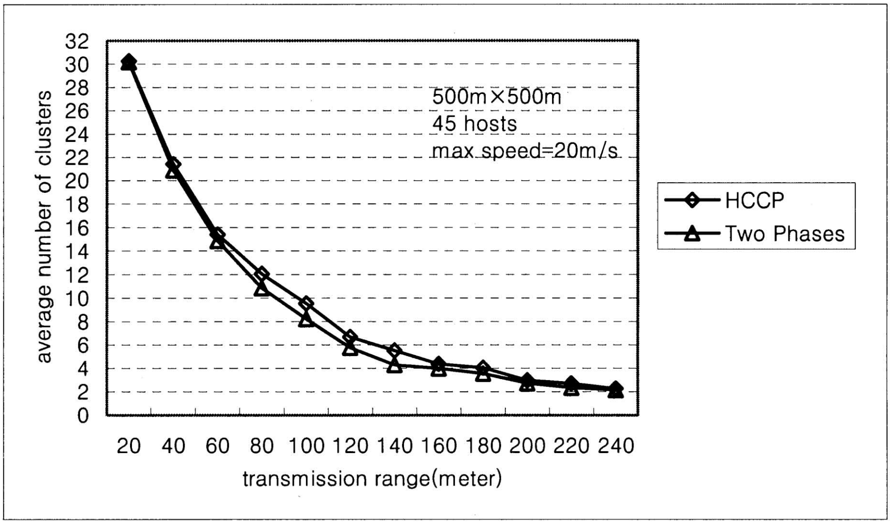


Fig. 5. Average number of clusters in 500×500 grid

Figure 6 shows the effect of varying the number of hosts on the performance of the proposed scheme with respect to HCCP at the same transmission ranges(80m, 120m, and 160m). It is depicted that for both HCCP and the proposed scheme the number of clusters increases with the increase in the number of hosts. This is because the hosts are randomly distributed in the system and a lot of hosts tend to be separated from other hosts due to the limited transmission range. Therefore, this results in the increase of the lowest connectivity hosts and the partitioned hosts in the system. Another observation is that the difference in the number of clusters between two schemes is increased with the increase in the number of hosts. Since HCCP cannot cope with the problem caused by the increase of the lowest connectivity hosts, most of the lowest connectivity hosts become clusterheads. This results in the increase of clusters. On the other hand, since the proposed scheme reduces the effect of the lowest connectivity hosts through the first phase cluster formation, it is less affected by the increase of the lowest connectivity hosts.

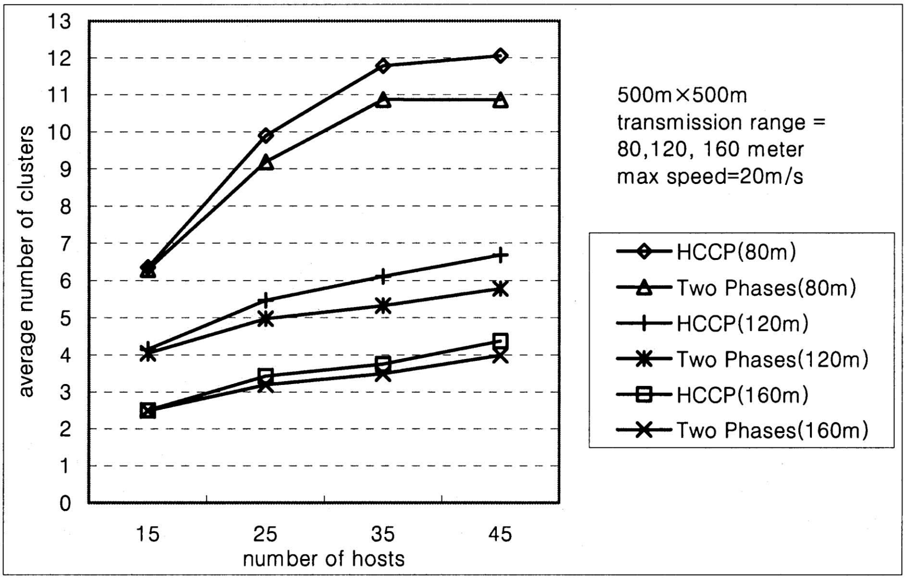


Fig. 6. Effect of varying the number of hosts

5 Conclusion

In this paper, two phases based cluster formation scheme which first affiliates the lowest connectivity hosts in the neighborhood to clusters and yields additional clusters covering the rest hosts through the connectivity criterion is proposed. In the first phase, since an adjustment procedure for affiliating some of the lowest connectivity hosts is employed, the proposed scheme yields fewer clusters compared with HCCP. This is proved by our simulation results. It was shown that the proposed scheme reduces the number of clusters by 19%(300m×300m) and 15%(500m×500m) in comparison to HCCP. It was also shown that the proposed scheme mitigates the increase in the number of clusters resulting from the increase in number of hosts. Therefore, we can conclude that the proposed scheme is better and more scalable than HCCP.

References

1. Chatterjee, M., Das, S., Turgut, D.: An On-Demand Weighted Clustering Algorithm(WCA) for Ad hoc Networks. Proc. on GLOBECOM. Vol. 3. (2000) 1697–1701
2. Basagni, S.: Distributed Clustering for Ad Hoc Networks. Int. Symp. on Parallel Architectures, Algorithms and Networks. (1999) 310–315
3. Gerla, M., Chiang, C.: Multicluster, Mobile, Multimedia Radio Network. ACM-Baltzer J. of Wireless Networks. 1(3). (1995) 255–265
4. Chiang, C., Wu, H., Liu, W., Gerla, M.: Routing in Clustered Multihop, Mobile Wireless Networks with Fading Channel(CGSR). Proc. on IEEE SICON`97. (1997) 192–211
5. Liu, K., Li, Jiangdong., Mukumoto, K., Fukuda, A.: Adaptive Control Protocol in Mobile Wireless Ad Hoc Networks. Proc. on APCCAS2000. (2000) 13–17
6. Krishna, P., Vadiya, N.H., Chatterjee, M., Pradhan, D.K.: A Cluster-based Approach for Routing in Dynamic Networks. ACM SIGCOMM, Comp. Comm. Review. 49. (1997) 49–64
7. Lin, C.R., Gerla, M.: Adaptive Clustering for Mobile Wireless Networks. IEEE JSAC. 15(3). (1997) 1265–1275
8. Basu, P., Khan, N., Little, T.D.C.: A Mobility Based Metric for Clustering in Mobile Ad Hoc Networks. Workshop on Wireless Networks and Mobile Computing. (2001) 413–418
9. Jiang, M., Li, J., Tay, Y.C.: Cluster Based Routing Protocol. IETFdraft. Work in Progress. (1999)
10. Chen, G., Garcia, F., Solano, J., Stojmenovic, I.: Connectivity based k-hop Clustering in Wireless Networks. Proc. on IEEE Int. Conf. on System Science. (2002)
11. Hou, T.C., Tsai, T.J.: An Access-Based Clustering Protocol for Multihop Wireless Ad Hoc Networks. IEEE JSAC. 19(7). (2001) 1201–1210
12. Johnson, D.B., Maltz, D.A.: Dynamic Source Routing for Multihop Wireless Ad Hoc Networks. Ad Hoc Networking, (ed.) C. E. Perkins. (2000) 139–168
13. Perkins, C.E., Royer, E.M.: Ad hoc On-Demand Distance Vector Routing. Proc. on IEEE WMCSA’ 99. (1999) 90–100
14. Gerla, M., Kwon, T. J., Pei, G.: On Demand Routing in Large Ad Hoc Wireless Networks with Passive Clustering. Proc. on IEEE WCNC2000. (2000) 100–105