A Load-Balanced Complete-Exchange Multicast Protocol for Wireless Ad-Hoc Networks

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Abstract [illegible] **of control packets flooding all over the network. Instead of** [illegible] **to balance the traffic loads and further avoids the overloads of nodes or traffic congestion on the route. Simulation results** [illegible] **packets during route discovery and increase the efficiency of** [illegible]

Keywords: Load balance, multicast, passive clustering, wireless ad hoc networks

I. Introduction

A wireless ad-hoc network [1] is a network architecture that can be rapidly deployed without relying on a pre-existing fixed network infrastructure. Because an ad hoc network is infrastructureless and self-organized, it is appropriate for providing impromptu communication facilities in inhospitable environments or a place inconvenient or inappropriate to build basic infrastructures. Typically, such networks are applied to battlefields, emergency search and rescue sites, or data acquisition in remote areas, and so on.

Currently, most of the routing protocols adopt the shortest path method to establish the route paths. They do not take load balance into consideration. Thus, it has high chance that the route paths constructed are overlapped. Overlapping nodes are always the bottleneck of the network, even causing the network congested, especially in complete-exchange multicasting.

In addition, much research has been done on multicast routing protocols for wireless ad hoc networks [2], [3]. However, the communication patterns are either one-to-many or many-to-many. A similar but different case of a multicasting is all-to-all multicasting, which is termed as *complete-exchange multicasting*. Complete-exchange multicasting is that every node in the multicast group has its own data to send to all the other nodes in the group. In other words, every node are both the source node and the destination node in the network. The applications of complete-exchange multicasting can be found in many circumstances, such as in ad-hoc classrooms, convention center, video conferencing, and so on.

Complete-exchange multicasting is the most severe communication. Complete-exchange multicasting will cause a large amount of traffic flowing over the network. If the traffic is on some particular nodes, it will cause these nodes overloaded and the network may be congested consequently. As a result, how to construct different routing paths from members to the other members to balance the traffic loads of nodes is very important. Therefore, the paper presents a load-balanced complete-exchange multicast (LCM) protocol. In LCM, each multicast group member constructs its own cluster structure in order to balance the traffic loads among nodes. LCM is to enhance the passive clustering (PC) technique [4] such that each node plays different roles, such as cluster head, gateway, or ordinary node, in different cluster structures. LCM preserves all the advantages of PC, but performs much efficient in complete-exchange multicasting. Simulation results also verify the advantages of LCM.

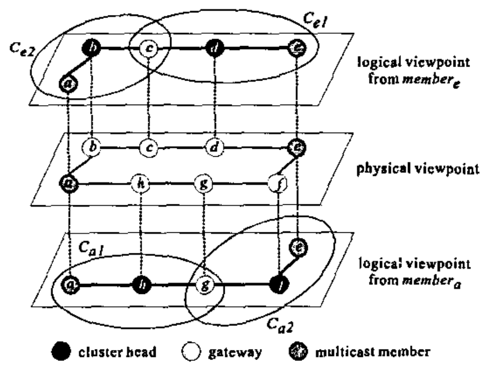

Fig. 1. A two-level cluster structure.

The rest of the paper is organized as follows. Section II introduces the basic idea of the paper. Section III describes the proposed load-balanced complete-exchange multicast protocol, LCM, in detail. The simulation model, performance metrics, and simulation results are presented in Section IV. Finally, Section V concludes the paper.

II. Basic Idea

In the paper, a load-balanced complete-exchange multicast (LCM) protocol is proposed. Fig. 1 shows a two-level cluster framework, which has two disjoint paths between two multicast group members a and e, respectively. The physical viewpoint of the network is demonstrated by the middle layer. The framework in the logical viewpoint can be regarded as two layers. The lower layer, a scenario that member a transmits data to member e, comprises two clusters (i.e., C_{a1} and C_{a2}) with heads h and f. In the upper layer, the cluster structures, C_{e1} and C_{e2}, whose heads are respectively d and b, serves as the routing path from member e to member a. Based on the idea described above, LCM constructs different cluster structures for each member to balance the traffic loads of nodes participated.

A great advantage of the cluster structure over the flat structure is that the transmission overhead during flooding can be dramatically reduced. However, clustering requires periodic refreshment of neighbor information. It could be quite a large amount of communication maintenance overhead. Fortunately, the passive clustering (PC) technique can overcome the shortage. PC does not require periodic neighbor information refreshment, which is maintained by user data packets instead of explicit control packet. As a result, PC can preserve the advantages of clustering, but exclude the disadvantages of clustering.

Passive clustering technique dynamically partitions the network into clusters in the passive manner. Unlike conventional cluster-related protocols, PC uses on-going data packets instead of extra explicit control packets to build and maintain clusters. Cluster-related information such as the state as well as IP address of a node is piggybacked in the on-going data packet. In passive clustering protocol, each node can be one of two internal and five external states. CH_READY and GW_READY are internal states, while INITIAL_NODE, CLUSTER_HEAD, GW_NODE, DIST_GW, and ORDINARY_NODE are external states. The internal states are to represent the tentative role (e.g., candidate cluster head or candidate gateway) of nodes. The internal state is changed to one of the external states when a node sends out a packet. States transition is performed on sending or receiving packet. Besides, two innovative mechanisms, namely, *First Declaration Wins* and *Gateway Selection Heuristic* are invoked during the cluster formation. The detailed description is represented in [4].

PC possesses many good properties. However, if PC is used directly with complete-exchange multicasting, it will cause the traffic loads to be flowed only on some particular nodes, such as cluster head or gateway nodes. Since complete-exchange multicasting is the most severe communication, if the traffic is only on some particular nodes, it will cause these nodes overloaded and result in bottleneck or traffic jam at these nodes. Therefore, some enhancements to PC need to be made such that complete-exchange multicasting can be done more efficiently. In LCM, each multicast group member will on-demand construct its own cluster structure by using PC. A node will have multiple roles, each for a cluster structure. Basically, a node playing the ordinary node in one cluster structure will have high probability to play a cluster head or gateway in another cluster structure. On the other hand, a node playing the roles of cluster head or gateway in one cluster structure will has low chance to be a cluster head or gateway again in another cluster structure. Doing so can avoid traffic jammed in cluster head or gateway nodes and balance the traffic loads among nodes.

III. Load-balanced Complete-exchange Multicast Protocol (LCM)

Motivated by the idea in Section II, the purpose of LCM is to enhance PC technique such that each node plays the different roles in various cluster structures. In this section, we propose a method to determine the roles of nodes and establish the multicast routing paths among group members.

A. Multi-role Determination Scheme

In the classical cluster-based approaches, the roles of all nodes are not changed. The property incurs the problem that packets may not be delivered successfully to the destination

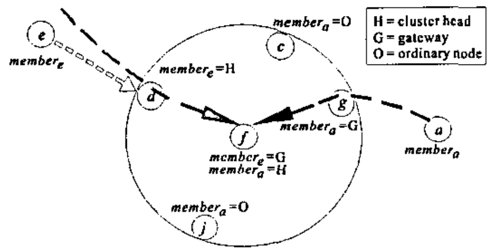

Fig. 2. A role-overlap example for two multicast group members.

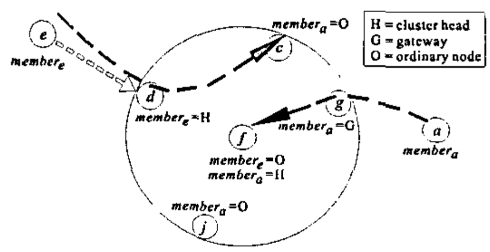

Fig. 3. The result of traffic loads distribution at node f.

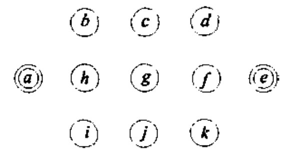

Fig. 4. An example of the initial network in which node a and node e are multicast group members.

due to the constraint that only cluster heads and gateways are allowed to propagate packets, especially for complete-exchange multicasting. Thus, role-overlap, a scenario where a node plays different roles for different cluster structures, has becoming a critical issue that has to be dealt with in LCM.

The main idea of multi-role determination scheme is to select some appropriate ordinary or initial nodes to act as the relay nodes for data communication. Packets may not be always delivered through the same paths because the traffic loads on the cluster heads or gateways are distributed to other ordinary or initial nodes. The main procedure of LCM is that upon receiving a packet, the cluster head or gateway first checks the number of its neighbors, and then tries to seek for the alternative nodes for relaying the received packet. If these nodes exist, a *"backup node checking scheme"* is invoked to determine the role of the different cluster structures by means of neighbors' information. PC is carried out in case of no backup neighbors are available.

Under the consideration of role-overlap, LCM deals with four cases categorized as cluster head/cluster head, cluster head/gateway, gateway/cluster head, and gateway/gateway. For lack of space, we only give the description of the case in which a node taking on the role of cluster head receives the packet sent from another cluster head belonging to a different cluster structure. Other cases are addressed in detail in [5].

Fig. 2 is an example in which nodes a and e are multicast group members. Nodes c, d, and g are node f's neighbors. Nodes d and f play the roles of cluster head and gateway for member e, while nodes c, f, and g play ordinary, cluster head, as well as gateway roles for member a, respectively. In this scenario, node f obviously becomes the bottleneck of communication between nodes a and e. If node f properly selects its neighbors, especially ordinary or initial nodes, for relaying packets, the traffic load will be obviously lighten.

According to LCM, when receiving the packets transmitted from node d, node f checks all of its role tables to determine its role. Since node d has the ordinary neighbor (i.e., node c) for member a, node f selects node c as its substitute for packet relay for member e. At the time, node f sends the backup node-checking packet to node c, and then waits for the acknowledgement. Once node f receives the acknowledgement from node c, it changes its role to ORDINARY_NODE for member e. Consequently, the traffic load at node f is diverted to node c. Fig. 3 shows the result of traffic load distribution for members a and e.

B. Multicast Routing Path Establishment

Similar to the majority of the existing multicast protocols, LCM has route request and route reply phases that establish multicast routing paths. During the route request phase, the source first broadcasts a MREQ packet to all of its neighbors. Once receiving a new MREQ packet, a node checks its neighboring multi-role tables which consists of the roles for different source members. If the information in the MREQ packet matches that in the neighboring multi-role tables, the node's role is determined by the PC technique. Otherwise, the proposed multi-role determination scheme is carried out to determine the role of the node.

During the route reply phase, roles of the undetermined nodes have to be assigned. The destination node sends out the MREP packet to the source node backward along the discovered path when it receives the MREQ packet. On receiving the MREP packet, the intermediate node sets the multicast flag if it is in the Next_hop field of the MREP packet, otherwise it does not propagate the MREP packet, but adds the new entry with source node's ID onto its neighboring multi-role table. The role of the node is consequently changed according to the neighboring roles.

Fig. 4 shows an example of the initial network, where

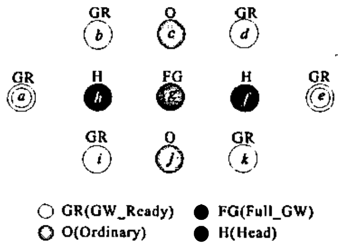

Fig. 5. The result of route request phase.

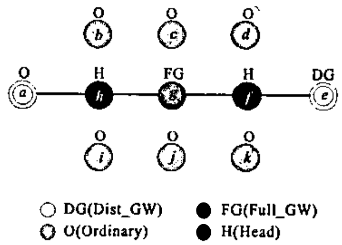

Fig. 6. The result of route reply phase.

node a is assumed to send the data packet prior to node e. Packet flooding obviously begins with MREQ packet originating on node a. As a result, roles of all nodes in the network will be determined by means of multi-role determination scheme. The result of performing the route request phase is illustrated in Fig. 5. At the time, node e transmits the MREP packet back to node a. In case the intermediate nodes have received the MREP packet, they not only ignore the MREP packet but also reset themselves as the ordinary nodes for member e if these nodes are absent in the Next_hop field. These intermediate nodes are consequently responsible for relaying packets to other group members. Fig. 6 shows the result of the route reply phase (i.e., the routing path is a-h-g-f-e). In the same manner, it is highly probable that a disjoint route will be established when node e wants to communicate with node a.

IV. Performance Evaluations

In this section, we present performance evaluation of LCM. The simulations differ in the number of multicast group members in order to evaluate network performances. Previous research has mentioned that ODMRP is an adequate multicast protocol for wireless ad-hoc networks[6], [7], thus, LCM, ODMRP and ODMRP+PC, an ODMRP-based approach with the aid of the PC technique, are compared in our simulations.

Experiments are carried out in the network with 100 nodes randomly placed within a square field of size of $1000m \times 1000m$.The radio propagation range and the channel capacity for each node are $25m$ and $2Mbps$, respectively.

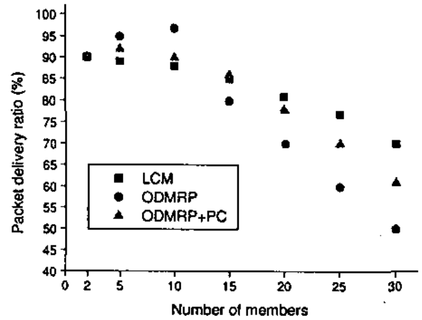

Fig. 7. Packet delivery ratio vs. number of members.

The network traffic load is kept at 20 packets/sec. Each simulation executes for 300 seconds.

The metrics used to investigate the performance of LCM are as follows:

- Packet Delivery Ratio: The ratio of the number of data packets that the destinations actually receive over the number of data packets desired to reach the destinations.
- Throughput: The number of the multicast packets per second excluding duplicated ones received at all group members.
- Normalized control overhead: The ratio of the number of control packets over the number of data packets.
- Delay: The duration of creating the multicast routes between group members. The transmission delay and queuing delay are both involved.

Fig. 7 illustrates that ODMRP outperforms LCM and ODMRP+PC in case the the network has fewer multicast group members. Since ODMRP discovers more paths between the source and the destination nodes, especially in a dense multicast structure, the packet delivery ratio, thus, increases even when the main route is broken. For the scenarios in which the number of multicast group members exceeds 15, LCM has a higher packet delivery ratio. The reason for this result is that with multiple clusters structures, traffic loads at some nodes such as cluster heads or gateways, would be distributed to other nodes whose role are neither cluster heads nor gateways in the same cluster. Therefore, network congestion is significantly mitigated.

In LCM, the network congestion is reduced due to traffic diversion. The result is verified in Fig. 8, in which LCM has the higher throughput when the number of group members increases. Fig. 9 shows that the performance of the normalized control overhead in different methods. LCM and ODMRP+PC both utilize the cluster structure

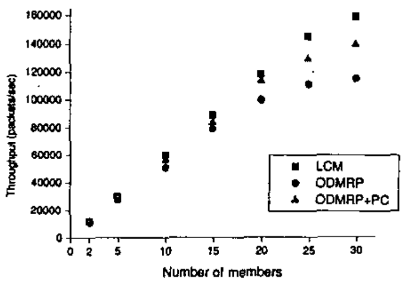

Fig. 8. Throughput vs. number of members.

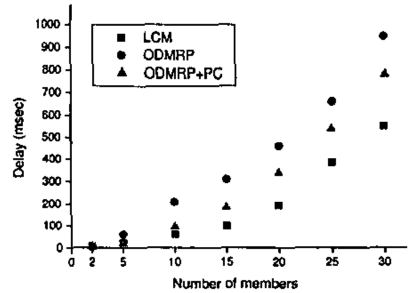

Fig. 10. Delay vs. number of members.

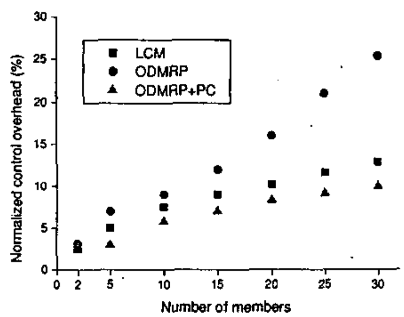

Fig. 9. Normalized control packet vs. number of members.

to diminish the flooding of control packets, therefore the normalized control overheads of them are less than that in ODMRP. Moreover, in comparison with ODMRP+PC, LCM incurs more control packets because applying the multi-role determination scheme generates more packets to obtain the required information. The simulation in terms of delay shown in Fig. 10 illustrates that LCM obtains the better result in comparison with both ODMRP and ODMRP+PC. That's because LCM not only has the advantages of the cluster structure but also possesses the property of the load balance.

V. Conclusions

Complete-exchange multicasting is quite useful for numerous applications. In this paper, we explicate a protocol, LCM, based on the Passive Clustering for load-balanced complete-exchange multicasting on wireless ad hoc networks. Form the logical viewpoint, LCM constructs multiple cluster structures to balance the traffic loads among all group members. In LCM, an innovative scheme is devised to deal with the scenario in which a node plays different roles for different cluster structures. The simulation results show that LCM not only preserves all the advantages of passive clustering, but also performs much efficient in complete-exchange multicasting. Consequently, LCM is really a feasible solution for load-balanced complete-exchange multicasting especially for dense networks. Our on-going work is to investigate the issues in terms of mobility, that nodes are capable of movement, and channel assignment, that the suitable channel is assigned to a node for data communications to avoid interference. We are going to enhance LCM to deal with the mobile environment and explore the minimal number of channels for load-balanced complete-exchange multicasting.

Acknowledgement

This work was supported by the National Science Council of the Republic of China under Grants NSC 93-2524-S-032-003 and NSC 92-2213-E-156-002.

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