A Power-Saving Multicast Routing Scheme in 2-tier Hierarchical Mobile Ad-Hoc Networks

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Abstract

Two distributed heuristic clustering schemes for multicasting are proposed to minimize the transmission power in 2-tiered mobile ad-hoc networks. The proposed schemes are implementable, and the average consumed power per a master node in cases of using the proposed schemes are only slightly higher than the optimal results.

1 Introduction

A mobile ad-hoc network is a multi-hop wireless network in which mobile hosts communicate over a shared and limited radio channel. It is characterized by lack of a wired backbone or centralized entities. The architecture of an ad-hoc network can be either *flat* or *hierarchical*[1]. In a hierarchical network, the network elements are partitioned into several groups, called *cluster*. And in each cluster, there is a *master node*, which is selected to manage all the other nodes called *slave nodes* within the cluster. The depth of the network can vary from a single tier to multiple tiers, but the most of hierarchical networks such as Bluetooth scatternet[2][3] are 2-tier networks. The 2-tier mobile ad-hoc networks require sophisticated algorithms to perform clustering based on limited resources, such as the energy of each node to communicate each other. The cluster area of a node is related to the transmission power. Therefore, a larger cluster area means more energy consumption. Because the transmission power of each node must be set to satisfy minimum power level at the receiving node, the consumed energy in 2-tier mobile ad-hoc network could be varied with clustering configuration, i.e., the master node selection of slave nodes. Therefore, there exists optimal clustering configuration that minimizes call dropping rate and also minimizes consumed energy for the still snapshot of 2-tier mobile ad-hoc network. But the optimal clustering configuration cannot be calculated within limited time, hence the heuristic clustering scheme concerning energy conservation for the 2-tier mobile ad-hoc network, that is implementable and executable in limited time, is needed for real-time clustering. In this paper, we proposed two such heuristic clustering schemes for multicasting.

To design the power-saving routing scheme for multicasting in 2-tier hierarchical mobile ad-hoc networks, we must consider the attribute of wireless multicasting environment. Naturally, radio communication has multicasting attribute. Classical radio broadcasting system uses this characteristic, and this attribute could be used for multicasting in another wireless systems, such as cellular and mobile ad-hoc network. In this paper, we assume the system that using single channel for one multicasting group. Slave nodes which belongs to the same master node receive the multicasting streams with the same single channel, and if the slave node moves to another master node's communication area, then the multicasting streams are received through another single channel that is used by the new master node for the multicasting.

In this environment, we can derive the optimal power-saving configuration of nodes based on the arrangement of each slave nodes to master nodes. The scheme proposed in this paper is distributed, time-limited energy conserving clustering algorithm for 2-tiered mobile ad-hoc networks. Therefore, the proposed scheme is suitable for the periodic

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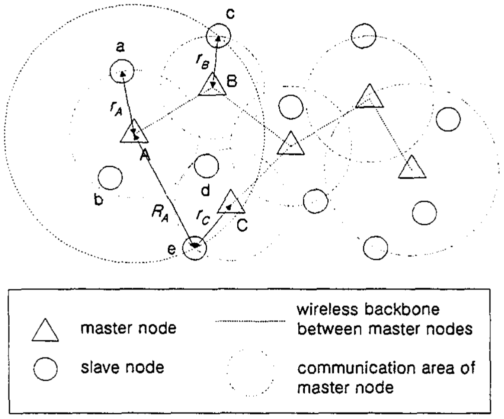

Figure 1. The average consumed power per a slave node vs. number of master nodes

or event-driven cluster re-configuration based on new call initiation, call completion and so on.

After this introduction, in section 2, we describe about network model for the proposed schemes. In section 3, we derive equations for the optimal power-saving clustering configuration, and in section 4, we propose two new clustering schemes. In section 5, we show numerical examples, and we make conclusions in section 6.

2 Network Model

The network model used in this paper is 2-tiered mobile ad-hoc network. We assume that there exist two type of nodes, master and slave. A slave node must be connected to only one master node, and the direct connection between slave nodes is prohibited. Each master node can establish a cluster based on the connection to slave nodes. The area of a cluster is determined by the farthest distance between the master node and a slave node in the cluster. When the distance between master node i and the slave node j is equal to $d(i,j)$, the relation equation between a required power transmitted by master node $P_t(i,j)$ and a required power received by slave node $P_r(i,j)$ is assumed as following[4]:

$$P_r(i,j) = d(i,j)^{-4} \cdot P_t(i,j) \tag{1}$$

We assume that the required receiving power at each slave node $P_r(i,j)$ must be the same value, P_r, hence the required transmission power of master nodes $P_t(i,j)$ could be varied based on the following equation:

$$P_t(i,j) = d(i,j)^4 \cdot P_r \tag{2}$$

In case that a slave node transmits a signal to a master node, the transmission power of slave nodes also should be varied to adjust receiving power at the master node to the same level.

Because the master node has limited energy, the value of $d(i,j)$ that is able to be serviced is also limited. When we call the maximum value d_{max}, the maximum radius of a cluster is also d_{max}, and the maximum transmission power of a node is ${d_{max}}^4 \cdot P_r$.

We also assume that each master node has the reserved multicasting channels for communicating with slave nodes, and separate unlimited channels for communicating with another master nodes. This assumption means that the number of slaves that receive multicasting stream from a master node is unlimited. And, in this paper, we only focused on one multicasting group. This assumption means that all slave nodes belong to the same multicasting group, and all slave nodes that belong to the same communication area of a master node receives the same multicasting stream from the master node.

Figure 1 shows the described network model. If a master node A sends multicasting stream with power level ${r_A}^4 \cdot P_r$, then the slave nodes a and b belongs to the master node A. Similarly, a slave node c belongs to a master node B, and slave nodes d and e belongs to a master node C. But when the master node A increases sending power level to ${R_A}^4 \cdot P_r$, all mentioned slave nodes could belong to the master node A. Based on this network model, we find the optimal configuration and the heuristic schemes in next sections.

3 Optimal Power-Saving Clustering

To analyze the proposed power-saving clustering schemes, we derived the binary integer programming (BIP) equations for the optimal power-saving clustering configuration.

The objective of the optimization is the minimization of the total consumed power of system when the call dropping rate, i.e. the rate of the number of disconnected slave nodes per the number of all slave nodes, is minimized. We can derive the following BIP equations based on this objective:

Objective:

$$\text{minimize} \sum_i y_i \tag{3}$$

Limitations:

$$\sum_i x_{i,j} = 1 \quad \text{for each } j \tag{4}$$

$$P_t(i,j) \cdot x_{i,j} \le y_i \quad \text{for each } i,j \tag{5}$$

The binary integer variable $x_{i,j}$ represents the connection status between the master node i and the slave node j, where $x_{i,j} = 0$ if i and j are not connected, and $x_{i,j} = 1$ if i and j are connected. In case that the distance between a master node i and a slave node j, $d_{i,j}$ is farther than d_{max}, the corresponding binary integer variable $x_{i,j}$ is excepted from the set of variables of this BIP equations. Hence, for a slave node i, unless any master node i that satisfies $d_{i,j} \geq d_{max}$ exists, then the BIP variables $x_{i,j}$ do not exist for all i, and we assume that the slave node i is dropped. The positive real variable y_i represents the transmission power for multicasting from master node i. Eq 3 shows that the objective of the BIP is the minimization of total consumed power, i.e. the sum of transmission powers for multicasting from master nodes. Eq 4 means that each slave node must be connected to only one master node, and the required transmission power for each slave node must not be greater than the transmission power for multicasting from master node as described by Eq 5.

Even if we could configure optimal power-saving clustering for multicasting based on above BIP equations, this optimization is not suitable for the real-time power-saving scheme for multicasting in 2-tiered mobile ad-hoc networks. Because the problem to solve above BIP equations, also known as generalized assignment problem (GAP), is proved to be NP-hard[5].

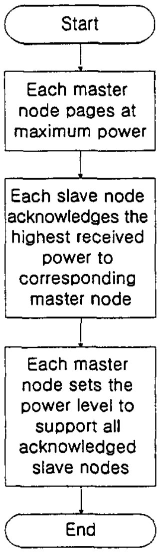

Figure 2. The flowchart of the proposed single-phase clustering scheme for multicasting

4 Proposed Clustering Schemes

To provide the implementable and real-time executable pseudo-optimal power-saving clustering solution, two heuristic schemes are proposed in this paper. First scheme is called *single-phase clustering scheme*, and the other is *multi-phase clustering scheme*.

Single-phase clustering scheme operates with only one paging from master nodes and one acknowledgement from slave nodes. Therefore, the power optimization time could be relatively short. Each master node pages at the same maximum power $d_{max}{}^4 \cdot P_r$, and each slave node acknowledges with the highest received power level to corresponding master node. The highest received power at a slave node means that the paging master node is nearest to the slave node, hence the transmission power could be saved when the slave node selects the master node that provides highest received power level. When slave nodes send acknowledge signals to each master node, master nodes set the transmission power level to support all acknowledged slave nodes. The flowchart of the proposed single-phase clustering scheme is shown in Figure 2.

Multi-phase clustering scheme is more complex than the above single-phase clustering scheme. This scheme is constructed with the dropping-rate-down phase and power-saving phase. In the dropping-rate-down phase, master nodes search the slave nodes which could receive the multicasting stream from only one master node. The corresponding master nodes set the transmission power level to support those slave nodes, and then the searched slave nodes belong to the corresponding master node. After this phase, each master node pages the information about current power level P_o by the maximum transmission power $d_{max}{}^4 \cdot P_r$. Paged slave nodes must have two or more candidate master nodes, hence each slave node selects one master node based on the value of $P_n - P_o$, where P_n is the power level to support the master node. When the master node is selected, the slave node acknowledges P_n to the master node, and each master node resets the transmission power level with the maximum value of acknowledged P_n values. The flowchart of the proposed multi-phase clustering scheme is shown in Figure 3.

5 Numerical Examples

Our simulated network consist of 10, 20 and 30 mobile nodes in an area of 10 m by 10 m. The number of master nodes is varied from 1 to 5, and the other nodes in mobile nodes are slave nodes. For example, the number of slave nodes when the number of mobile nodes is 20 and the number of master nodes is 3, is 17. Each mobile node is uniformly random distributed in simulated area, and below nu-

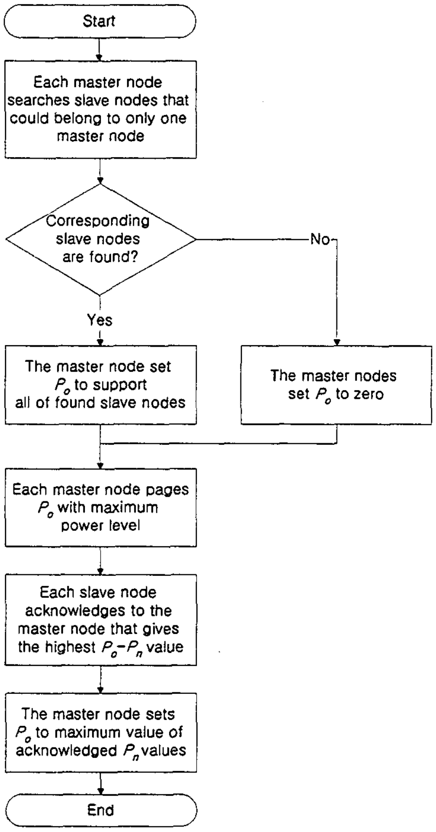

Figure 3. The flowchart of the proposed multi-phase clustering scheme for multicasting

merical examples are statistic results that is the mean value of 1,000 random configurations of mobile nodes.

Simulation of the proposed scheme is based on the assumption that the network topology remains fixed during a clustering process. We also assume that there is no MAC layer channel contention and that packets are received under error-free conditions only within the maximum radius of the paging area, d_{max}, from the transmitter. We set d_{max} to 5 m.

The results from the optimal configuration is calculated with CPLEX, based on the BIP equations Eq 3, 4 and 5.

We choose the average consumed power per a master node as performance measures. The average consumed power per a master node is the normalized value of total consumed power of system at a snapshot by the number of master nodes. The total consumed power of system is defined as the sum of powers that are needed to make connection between each master node and each slave node. We assume that the power to make connection is proportional to the forth power of the distance between two nodes[4], hence we choose the forth power of the distance between a master node and farther slave node that belongs to the master node for the measure of the power that are needed to make connection. Hence, the average consumed power per a master node in the numerical example is normalized sum of forth power of transmission power level y_i from each master node i by the number of master nodes, as shown in following equations:

$$\begin{aligned}&\text{(the average consumed power per a master node)}\\&\quad= \frac{\sum_i y_i}{\text{(number of master nodes)}} \qquad (6)\end{aligned}$$

The graph of the average consumed power per a master node versus the number of master nodes is shown in Figure 4. From the numerical example, the average consumed power per a master node decreases with the decrease of the number of all nodes and the increase of the number of master nodes. When the number of master nodes are the same, the decrease of the number of all nodes means the decrease of the number of slave nodes, hence the communication area of each master nodes also decreases. The decrease of the communication area of master nodes effects the decrease of the average consumed power per a master node by Eq 6. In case that the number of master nodes increases, the corresponding communication area of each master node decreases because the number of slave node that must be supported decreases. Therefore, the average consumed power per a master node decreases with the increase of the number of master nodes.

Considering about the possibility of implementation and real-time execution with the small differences from the optimal configuration in view of the consumed power, the proposed multi-phase clustering scheme could be used as the pseudo-optimal heuristic solutions of the power-saving clustering for multicasting in the 2-tiered mobile ad-hoc networks.

The proposed single-phase clustering scheme could be suitable under the specific environment that makes the difference between performances of the single-phase and the multi-phase schemes relatively small. For example, when the number of nodes is under 20, the heuristic scheme could be executed with relatively smaller computing power and high speed by selection of the single-phase scheme.

6 Conclusions

In this paper, we proposed two distributed heuristic clustering schemes for multicasting concerning energy con-

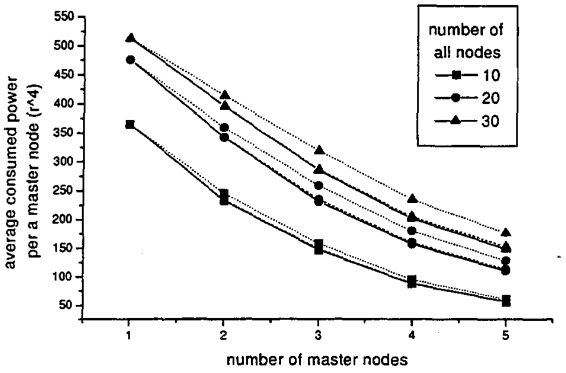

Figure 4. The average consumed power per a slave node vs. number of master nodes (solid line: optimal case, dashed line: multi-phase scheme, dotted line: single-phase scheme)

servation in 2-tiered mobile ad-hoc networks. The proposed schemes are implementable and real-time executable, and the mean transmission power based on the proposed schemes has small difference from the optimal results. Hence, the proposed scheme is suitable for the periodic or event-driven cluster re-configuration in multicasting environment. The proposed multi-phase scheme is desirable when the energy conservation and call completion is more important than the computing power and the computing speed of the scheme. In the opposite case, the proposed single-phase scheme could be adopted.

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