A NEW ROUTING SCHEME CONCERNING ENERGY CONSERVATION IN WIRELESS HOME AD-HOC NETWORKS

Jung-hee Ryu and Dong-Ho Cho
Communication and Information Systems Lab.
Department of Electrical Engineering and Computer Science
Korea Advanced Institute of Science and Technology (KAIST)
373-1 Kusung-dong Yusung-ku Taejon, Korea
E-mail: {ryu,dhcho}@ee.kaist.ac.kr

Abstract— **Two categories of terminals can exist in a wireless home ad-hoc network. These are battery-powered and outlet-plugged terminals. A new scheme for energy conservation in battery-powered terminals in wireless home ad-hoc networks is proposed. Based on this scheme, battery-powered terminals page traffic with a minimum power to the nearest outlet-plugged terminal and only outlet-plugged terminals are used for routing. Simulation results show that the mean radius of the battery-powered terminal paging area is much smaller than the radius for conventional schemes.**

I. Introduction

Technological innovations and a market explosion in the fields of networking and computing have stimulated much public interest and consumer demand for increasingly advanced network services. Demands for local area networks (LAN) in office and home environments are rapidly increasing, and conventional fixed wired LAN environments are evolving to wireless mobile networks. Recently, the mobile ad-hoc network has been considered as a candidate for the next generation wireless LAN environment. There exist no special routers or switches for communication in mobile ad-hoc networks. However, at least some terminals must take the role of these devices. Hence, dynamic configurations of terminals are possible in mobile ad-hoc networks without any setting of devices. Because of this advantage, much research and development is in progress concerning these networks by various groups, such as the IETF MANET Workgroup and the Bluetooth Special Interest Group[1][2].

Because a mobile ad-hoc network is a multi-hop wireless network in which mobile hosts communicate over a shared and limited radio channel, a mobile ad-hoc network is characterized by lack of a wired backbone or centralized entities. Thus, ad-hoc networks require more sophisticated distributed algorithms to perform functions of coordination[3][4]. Since all communications among all network elements are preformed with limited resources, there is a significant constraint on efficient network management for mobile ad-hoc networks (e.g. conservation of the wireless spectrum and reduction of the transmission power). Thus, for communication between two entities in an ad-hoc network, multi-hop routing is required in which routing information is relayed through intermediate terminals. In addition, since the network topology changes rapidly, finding and maintaining an optimized route is a difficult problem. Therefore, an ad-hoc routing algorithm must react quickly to topology changes.

The architecture of an ad-hoc network can be either flat or hierarchical [3]. In a hierarchical network the network elements are partitioned into several groups called clusters. In each cluster there is a cluster head, which is selected to manage all the other terminals within the cluster. The depth of the network can vary from a single tier to multiple tiers. In a flat network all terminals have equal rank. That is, flat networks are equivalent to zero-tier hierarchical networks.

Hierarchical network architecture can accomplish the mobility management process more easily. However, routing is often sub-optimum because of a lack of direct connectivity between two different cluster heads. On the other hand, the most important advantage of the flat network is that there are multiple paths between source and destination. This allows congestion reduction and choice of the best route to satisfy the specific requirements of a traffic attribute. While flat addressing may be less complicated and easier to use, there are doubts as to its scalability.

For a flat network each source terminal pages traffic to neighboring terminals, and these terminals page again until the destination terminal receives the traffic from the corresponding source terminal. The terminals which act as routers are called routing terminals. The paging area of a terminal is related to the transmission power of the terminal. Therefore, a wider paging area indicates a greater transmission power. However, typical mobile ad-hoc networks in offices or homes (wireless ad-hoc networks) contain two types of terminals. These are battery-powered and outlet-plugged terminals. A battery-powered terminal has a limited energy source. Examples of terminals in this category are notebook computers, PDAs, and remote controllers. These terminals have a relatively high mobility and a small size. Outlet-plugged terminals have a stable and durable energy source. Examples include desktop com-

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puters, settop boxes, and TVs.

For battery-powered terminals the energy for data transmission is limited and power saving is an important feature. Power saving is not a major consideration for outlet-plugged terminals and more transmission power is required to increase the size of the paging area. Based on these attributes a flat network architecture is a candidate for wireless home ad-hoc networks. Because the architecture of a flat network is relatively simple compared with hierarchical networks, and only a small computing power for each mobile terminal is needed, a flat network architecture is suitable for wireless home ad-hoc networks if an energy conservation scheme is adopted.

Previous work dealing with energy conservation schemes for mobile ad-hoc networks is scarce. Shah and Flikkema proposed a power-based leader selection scheme [5] that uses a physical layer-based framework in a quasi-static environment. Uplink, downlink, and overall optimum leader terminals can be selected based on a link loss matrix and an interative algorithm. Shah and Flikkema studied the suitable leader terminal in a two-layer mobile ad-hoc network when all terminals are potential cluster heads. However, this framework can be adopted only in a hierarchical ad-hoc network and is, therefore, not suitable for wireless home ad-hoc networks with a flat architecture. Also, the proposed framework is not acceptable for real-time configuration applications, such as periodical or event-driven re-configurations, because results similar to the optimum configuration can be obtained with many iterations.

Rodoplu and Meng proposed a distributed position-based network protocol optimized for minimum energy consumption [6]. The proposed protocol is based on a position-based algorithm with an assumption of mobile terminals with embedded GPS receivers. This assumption is not suitable for light-weight mobile terminals in wireless home ad-hoc networks.

Chang and Tassiulas proposed energy conserving routing schemes [7] that solved the problem of routing terminal disconnection based on energy by focusing on maximization of the system lifetime. This protocol is suitable for static, flat ad-hoc networks, but is not suitable for real-time reconfiguration.

We propose a new scheme for power saving in battery-powered terminals in wireless home ad-hoc networks with two terminal types. The performance of both the proposed scheme and the conventional scheme under the assumption of a constant paging power level are simulated using the Cadence BONeS DESIGNER. The mean radius of the battery-powered terminal paging area, the call blocking probability, and the call drop probability are used as performance measures. Numerical results show that the average consumed energy of battery-powered terminals for paging and the call drop probability are much lower than for the conventional scheme, while the call blocking probability is higher.

We describe the proposed scheme in Section II. Section III explains the simulation environment and Section IV discusses numerical results. Conclusions are presented in Section V.

II. Descriptions of the Proposed Routing Scheme

It is assumed that networks are flat and the terminal cluster is the same as the paging area. The source terminal (battery-powered) pages with a minimum power level to transmit traffic to the nearest outlet-plugged terminal, which pages this traffic to a destination terminal or to a routing terminal, with the maximum allowed power level. Battery-powered terminals are not used as routing terminals, except where there are no outlet-plugged terminals. For outlet-plugged terminals the traffic is paged to destination terminals or to routing terminals, with the maximum power level allowed to decrease the hop number from the source to the destination terminal. For each case, if there is no outlet-plugged terminal within the maximum paging area of the source or the routing terminal, the call is blocked.

Only outlet-plugged terminals can act as routers. Like conventional demand-driven schemes, when the source terminal does not find the target terminal in the local cluster, the routing path discovery scheme is started. However, paging signals to the terminals in the cluster are received only by outlet-plugged terminals, unlike conventional schemes.

When the outlet-plugged terminal receives the paging signals there are two possible schemes to determine the routing path. The first scheme is the table-driven approach. The update rates of the routing tables among outlet-plugged terminals are comparatively low. Hence, the prepared routing table can be used without paging to find the routing path. Each battery-powered terminal is registered in the memory of the outlet-plugged terminals when the battery-powered terminal enters into the cluster of the low mobility terminals. If one of the outlet-plugged terminals receives the paging signal from the source terminal, the outlet-plugged terminal sends a terminal search page to all outlet-plugged terminals in the prepared routing table. Then, the outlet-plugged terminals seek the target terminal based on memory contents. With this approach the routing time can be shortened. However, each outlet-plugged terminal must have the capability to manage memory contents.

The second approach is demand-driven. Each outlet-plugged terminal that receives the paging signal for routing finds the target terminal in its cluster. If the search fails, the terminal forwards the routing signal to the outlet-plugged terminals in its cluster. This approach is simpler than the first approach, but the number of pages to find a route is greater. A detailed process of the proposed routing scheme with a demand-driven approach is shown in Figure 1.

Figure 2 shows an example of the proposed routing algorithm. The solid lines in this figure represent the routing path of the proposed scheme ($\mathsf{s-A-B-C-D-t}$). The dotted lines represent the routing path of the conventional scheme without concern for energy conservation

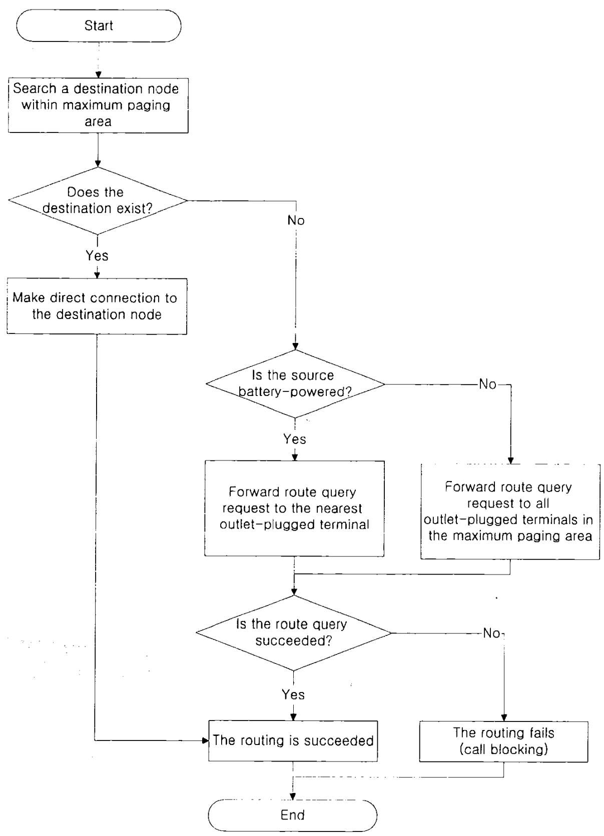

Fig. 1. A flow chart for the proposed routing scheme

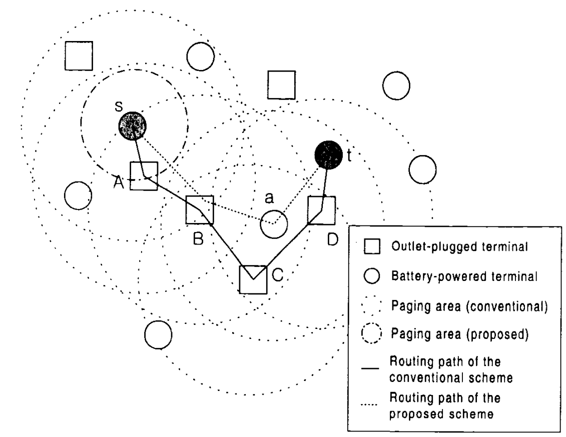

Fig. 2. An example of the routing path for the proposed routing scheme

(s − B − a − t). Even though the number of hops in the routing path of the conventional scheme is smaller, the paging area of the battery-powered terminal s in the proposed scheme is much smaller then in the conventional case.

III. Simulation Environments

Simulation environments for a performance evaluation of the proposed scheme are presented. We use the Cadence BONeS DESIGNER network simulator, which is an event driven simulation package.

Our simulated network consists of 12, 20, and 28 mobile terminals, the initial positions of which are chosen from a uniform random distribution over an area of 10 m by 10 m. All terminals move at a constant speed v with an initial direction θ, which is uniformly distributed between 0 and 2π. When a terminal reaches the edge of the simulation region it is reflected back into the coverage area by setting its direction to -θ (horizontal edges) or $\pi - \theta$ (vertical edges). The magnitude of the velocity is not altered.

We assume that outlet-plugged terminals have a relatively low mobility and battery-powered terminals have relatively high mobility, and that the routing path finding approach is demand-driven. The terminals in the conventional scheme and the outlet-plugged terminals are blocked when the routing path finding fails within 4 hops. For battery-powered terminals the nearest outlet-plugged terminal operates as the source terminal for routing path finding. In other words, the nearest outlet-plugged terminal to the source battery powered terminal tries to establish a routing path to the target terminal within 4 hops. Hence, the maximum allowed number of hops for battery-powered terminals is 5.

Simulation of the proposed scheme is based on the assumption that the network topology remains fixed during route discovery. Also, we assume that there is no MAC layer channel contention. This assumption prevents delay measurements from being biased by delays associated with any particular MAC collision avoidance scheme. In addition, we assume that any packet can be received error-free within a radius of r_{max} from the transmitter (but would be lost beyond r_{max}). Here, r_{max} is the maximum radius of the paging area (i.e., the cluster area for each terminal).

In the conventional routing scheme all terminals can be routing terminals and all source terminals can find destination terminals or routing terminals within their maximum paging area. The speeds of all terminals are defined by the same uniform distribution. The simulation parameters mentioned above are shown in Table I.

IV. Numerical Results

We choose the normalized mean consumed power of battery-powered terminals, the call blocking probability, and the call drop probability as performance measures in this simulation.

The mean consumed power of battery-powered terminals is the average power that is used to communicate from a battery-powered source terminal to the nearest outlet-plugged routing terminal, or a target terminal. The normalized mean consumed power is normalized by the mean consumed power in the conventional case. When the distance between the battery-powered terminal and the routing terminal is equal to d, the relation equation between the power transmitted by a battery-powered terminal P_t and

TABLE I
SIMULATION PARAMETERS

Parameter (Symbol)	Value
Network coverage area ($L_x \times L_y$)	10m × 10m
Number of terminals (n)	12, 20, 28
Speed of battery-powered terminals (v_{BT})	Uniform distribution (1-2m/s)
Speed of outlet-plugged terminals (v_{OT})	Uniform distribution (0-1m/s)
Speed of terminals in the conventional case (v_c)	Uniform distribution (0-2m/s)
Initial direction of terminals (θ)	Uniform distribution (0 - 2π)
Maximum paging area radius (r_{max})	8m
Percentage of battery-powered terminals among all terminals (P_{BT})	25, 50, 75%

the power received by a routing terminal P_r is assumed to be: [8]:

$$P_r = d^{-4} \cdot P_t \tag{1}$$

We assume that the received power at each terminal P_r must be the same value of P_r. Hence, the transmission power of the battery-powered terminal P_t can vary based on the following equation:

$$P_t = d^4 \cdot P_r \tag{2}$$

Therefore, the mean consumed power of the battery-powered terminal that is normalized by the mean consumed power in the conventional case is as follows:

$$\frac{\overline{d^4} \cdot P_r}{r_{max} \cdot P_r} = \frac{\overline{d^4}}{r_{max}} \tag{3}$$

where $\overline{d^4}$ is the average value of d^4.

The mean call blocking probability is defined as the probability that new call blocking occurs when neither the destination terminal nor a routing terminal exists in the maximum paging area of the source terminal and the routing terminals. Also, the mean call drop probability is defined as the probability that a call is dropped because of a disconnection between two routing terminals in the routing path. The numerical results related to these measures are shown in Figures 3, 4 and 5.

First, we can see that the mean consumed power of the battery-powered terminal in the proposed scheme is less than 30% of the mean consumed power in the conventional scheme, as shown in Figure 3. The mean radius of the battery-powered terminal paging area decreases with an increase in the number of mobile terminals, because the probability that outlet-plugged terminals exist at nearer positions is greater. When the percentage of battery-powered terminals among all terminals P_{BT} is increased, the number of outlet-plugged terminals decreases. Hence, the mean consumed power of the battery-powered terminal increases. However, when the number of terminals is relatively small, as is the case of higher values of P_{BT}, the decrease in the number of outlet-plugged terminals is insufficient to make the new call successful. Then, the mean consumed power of the battery-powered terminal decreases because only the nearest battery-powered terminals to the outlet-plugged terminals can make the new call. For example, in the case of $P_{BT} = 75\%$ and $n = 12$, this phenomenon occurs.

As shown in Figure 4, the call blocking probabilities in the proposed scheme when P_{BT} is either 50 or 75 % are higher than for the conventional scheme because only outlet-plugged terminals can be routing terminals in the proposed scheme. It is more difficult to successfully set the routing path based on these characteristics. The call blocking probability in the case of $P_{BT} = 25\%$ is slightly lower than for the conventional case because battery-powered terminals in the proposed scheme can try a maximum of 5 hops to find a routing path. The maximum number of hops in the conventional scheme is 4. The call blocking probability is decreased with an increase in the number of mobile terminals because the number of routing terminals also increases. With an increase in the value of P_{BT}, the number of outlet-plugged terminals that act as routing terminal decreases, and the call blocking probability increases.

The behavior of the call drop probabilities is similar to the behavior of the call blocking probabilities. The relatively small number of routing terminals in the proposed scheme affects these results. The similarity of numerical results between the conventional case and the proposed scheme when $P_{BT} = 25\%$ is also explained by the difference in the maximum number of hops.

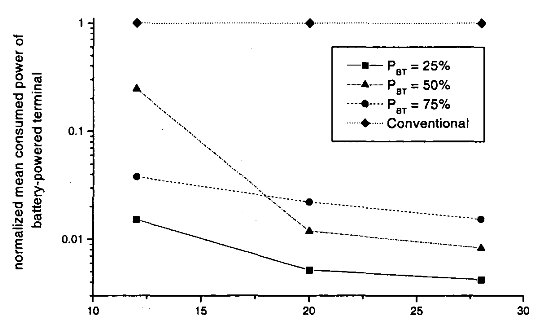

Fig. 3. Normalized mean consumed power of battery-powered terminals vs. the number of all terminals

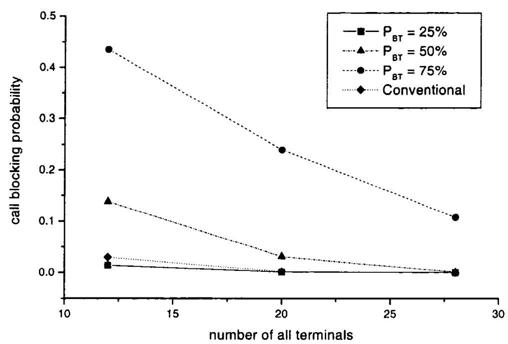

Fig. 4. The call blocking probability vs. the number of all terminals

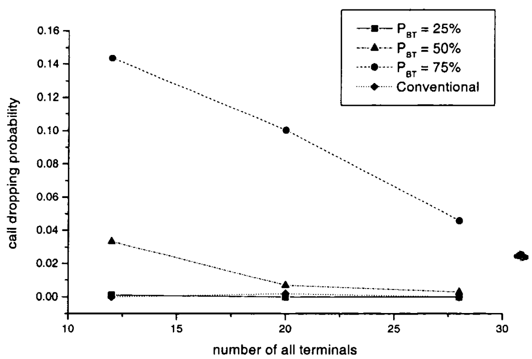

Fig. 5. The call drop probability vs. the number of all terminals

V. Conclusions

We have proposed a new routing scheme concerning energy conservation of terminals in wireless home ad-hoc networks that is designed to overcome the power dissipation problem of battery-powered terminals. A battery-powered source terminal pages with a minimum power level to transmit traffic to the nearest outlet-plugged terminal. Only outlet-plugged terminals can act as routers. Both table-driven and demand-driven approaches can be used to find routing paths in the proposed scheme because outlet-plugged terminals have a low-mobility. The mean consumed power of the battery-powered terminal is much smaller than in the conventional scheme. Hence, the energy consumption of battery-powered terminals is decreased while the call blocking and drop probabilities increase slightly.

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