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An Approach to Creating and Maintaining House-Watching Network in MANET

Jiahong Wang, Yuhiro Yonamine, Takashi Iokawa, Eiichiro Kodama, and Toyoo Takata

***Abstract*—It was found that in the disaster-hit area, a communication supporting system using the existing mobile ad hoc network techniques cannot function as expected and communication would be interrupted from time to time, since they have not taken into consideration the sleep operation that is a very frequently used means for users of mobile terminals to increase their battery life time. In order to solve the problem, this paper proposes a system model and two methods. The one is used to create a house-watching network taking charge of waking up the sleeping terminals, so that periodic or planned communication can be supported even though users freely get into sleep at their convenience. The other is used to incorporate the sleeping with the routing protocols, so that users' consideration for other people can be technically supported, and they can know if their terminals are functioning as routers, and when sleeping buttons of their terminals can be pushed down safely without interrupting the relaying in progress, and so without interfering with others' communication. These methods have been demonstrated to be effective by simulation experiments.**

***Index Terms*—ad hoc network, sleep operations, house-watching network, routing and sleeping protocols.**

I. Introduction

On March 11, 2011, an earthquake of magnitude 9.0, which was the largest one in Japan's history, struck off the coast of the northern part of the country, churning up a devastating tsunami that swept over cities and farmland, and took away almost everything, including power supply systems and communication systems. Experiencing the disaster, we found that it becomes necessary for us to have a communication supporting system for the emergency use in the disaster-hit area.

It is true that nowadays we have too many communication supporting systems to know which one to use. However, no one of them functioned as expected when the earthquake and tsunami occurred. The fact is that at that time, telephone, email, internet, and television became unavailable, and people were isolated from the outside world. Since no means of communication were available, they could not communicate with each other, and thus became very anxious that, e.g., whether the foods and water in hand were enough to survive the disaster, when the basic infrastructure for livelihood could be restored, and where medical cares could be provided. Such a communication supporting system was really necessary that could connect everyone together and so people could exchange information and relieve stress of each other.

We think that the Mobile Ad Hoc NETwork (MANET) can be a good candidate to serve a communication infrastructure in the disaster-hit area for emergency use. This is because

The authors are with the Faculty of Software and Information Science, Iwate Prefectural University, Takizawa, Iwate, 020-0193 JAPAN, e-mail: wjh@iwate-pu.ac.jp.

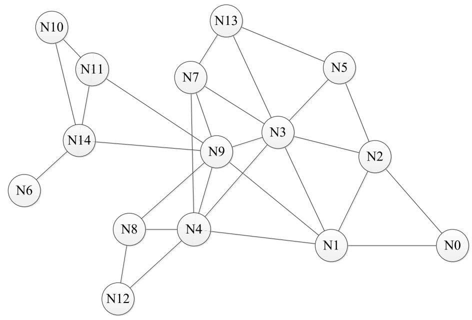

Fig. 1. In this example, terminal N_9 would function as a router for relaying data between, e.g., N_{10} and N_2.

for MANET, we can use the *mobile terminals* such as telephones, notebook type personal computers, and other mobile equipments (also called nodes thereafter) for communication. No power supply systems but the battery of mobile terminals, no center server for assisting communication, and no predetermined plan for the network backbone are needed. We can have a network at any time and any place, and use the network as we do just before disaster happens.

It was found, however, in the disaster-hit area, communication supporting systems based on the existing MANET technique cannot function as expected. The network would not last long enough, and the communication would be interrupted from time to time. This is because, on the one hand, mobile terminals are all battery-driven and the battery cannot be recharged due to the damaged power supply system, and on the other hand, the existing MANET technique has not taken into consideration the sleep operation of mobile terminal users that is very common and frequently-used means for them to increase their battery life time. For example, the owner of mobile terminal N_9 in Fig. 1 may just finish sending a mail to his / her friend and thus close his / her mobile terminal, resulting in that the communication between N_{10} and N_2 becomes interrupted, since N_9 serves also as a router for relaying data. Due to the uncontrolled seeping operations we cannot have a stable and useable network.

Fortunately, we also noted that in the disaster-hit area, people tended to be considerate of others and actively keep discipline and order. We therefore can reasonably make such an assumption that people in the disaster-hit area would not be so selfish as to turn off their mobile terminals given that they know others are using their mobile terminals for relaying data, and they would cooperate to maintain an ad hoc network given that they know it would benefit all the people there, including him/herself. The problem is that, however, they cannot know whether their mobile terminals are serving as routers or not, whether closing their mobile terminals would interrupt others' communication and trouble

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them, and for how much time they should delay closing their mobile terminals so that the communication tasks over their mobile terminals could finish without interruption.

Then in order to have an effective communication supporting system for the emergency use in the disaster-hit area, we have to solve two problems: maximize the lifetime of the ad hoc network as a whole, and make routing activities at the IP layer viewable to users. For the purpose, in this paper we present a system model and propose two methods. The one is used to create a house-watching network taking charge of waking up the sleeping terminals, so that periodic or planned communication can be supported even though users freely get into sleep at their convenience. The other is used to incorporate the sleeping with the routing protocols, so that users' consideration for other people can be technically supported, and they can know if their terminals are functioning as routers, and when sleeping buttons of their terminals can be pushed down safely without interrupting the relaying in progress, and so without interfering with others' communication. Results of simulation experiments demonstrate the effectiveness of the proposed method.

In the rest of this paper, Section II formally define the problem. Section III gives algorithms to solve the problem. Results of a performance study are discussed in Section IV. Finally, Section V concludes the paper.

II. Problem Statement

The problem to be solved in this research, as described in Section I, is formulated as follows.

Problem Statement. *Consider such a mobile ad hoc network that is located at a disaster-hit area, consists of an administration center and a group of user mobile terminals driven by batteries, and batteries cannot be recharged due to the damaged power supply system. How to support communication on the network for as long time as possible is a problem. Our objective is two-fold. On the one hand, the life time of the overall network should approach the one when a mobile terminal is used solely for its owner's purpose without the duty of relaying others' data. On the other hand, a mobile terminal can get into sleep at his / her owner's convenience to increase the battery live time, but the network can remain connected and users' communication cannot be affected. An approach is to be devised to achieve these two objectives, and ensure such an application-oriented ad hoc network that a user can communicate with another user whenever he / she wants to.*

For the first objective, a promising solution is to construct a Connected Dominating Set (CDS) [1]–[6], and to use the CDS-based routing. In general, a Dominating Set (DS) of a graph $G = (V, E)$ is a subset $V^{'} \in V$ such that each node in $V^{'} - V$ is adjacent to at least one node in $V^{'}$, and a CDS is a DS whose induced sub-graph is connected. CDS-based routing is such a routing method that selects certain nodes from the network as gateway nodes. These gateway nodes form a CDS and are responsible for routing within network.

The CDS-based approach is widely used for constructing network backbones, and here can be used as a house-watching network. That is, we can take each CDS node as a watchdog node, and let other nodes sleep freely. However, we found existing approaches cannot help solve the problem defined above satisfactorily. First, we need such a network that is of a well-defined structure, so that if a watchdog node fails to function due to, for example, battery problem or careless sleep operation, a human-intervention can be possible. Second, applications in the disaster-hit area require that a house-watching network should be initially constructed around the administration center, but migrate autonomously to the center site of the area so that the network diameter and number of watchdog nodes become minimized, and thus, the delay of broadcasting a message can be minimized and the number of sleeping nodes can be maximized. More importantly, fault-tolerance can be enhanced.

Some similar work can be found in [7]–[10], where a new factor called the diameter, which is the longest shortest path between any pair of nodes, is considered, and the problem is to minimize the diameter so that routing is easier and can adapt quickly to topology changes of a network. The difference from this research is that in this paper the diameter is the longest shortest path between the administration center or its proxy node and any other nodes, the "center" of network has to be located autonomously, and by which the diameter is minimized. Some other low cost approaches for constructing CDS have been proposed [11]–[16]. For the defined problem, however, these approaches could not be very helpful.

For the second objective, we have not found any research results dealing with the subject of integrating the sleeping and the routing protocols. In fact, they have been considered as two independent concepts for different purposes, and integrating them has been considered unnecessary and impossible. We found that, however, for the disaster-hit area the integration is really necessary so that a more effective and friendly communication supporting system can be obtained.

III. House-Watching Network and Routing Aware Sleeping Protocol

In this section, we first provide notations, definitions, and some fundamental concepts used in the subsequent sections. Then we propose an approach to solving the problem defined in Section II.

A. Definitions and Preliminaries

We use an undirected graph $G = (V, E)$ to represent an ad hoc network, where V is the set of nodes and $(u, v) \in E$ is the transmission link between nodes u and v. That is, (u, v) is in E if nodes u and v are within the transmission range of each other. Without losing generality, we assume that the nodes in V are located in a plane, and all nodes are homogeneous, meaning that they have the same transmission range.

We assume that in a disaster-hit area, there will an administration center that takes charge of running it. The administration center can assign some other node as a *proxy* to take some of its duties such as broadcasting messages.

In this paper we consider *diameter* as a metric to evaluate the constructed house-watching network, which is defined as follows.

Definition 1 (Diameter)**.** *Given an ad hoc network G = (V, E), $N_A \in V$ is the administration center, and $N_P \in V$ is a*

TABLE I
NOTATIONS USED IN THIS PAPER

notations	meanings
S_{HWN}	The house-watching network.
Administration Center N_{AdminC}	The node being responsible for initializing the house-watching network.
N_{proxy}	The proxy node of administration center.
u.Diameter	Diameter of node u.
u.House-Watch	True if u is a house-watching node
u.color	A field for assisting construction of S_{HWN}

proxy of it. The diameter of G is the length of the longest shortest paths between any $u \in V$ and N_A or N_P.

We think that a house-watching network should be some kind of CDS as defined below, with as many nodes as possible being able to sleep, and as few nodes as possible being watchdog nodes. Watchdog nodes should be able communicate with the administration center or its proxy by the shortest route, so that important messages can be broadcast to every node with little delay.

Definition 2 (DS)**.** *A Dominating Set (DS) of $G = (V, E)$ is such a node set V' that $\forall(v, w) \in E$, $v \in V'$ or $w \in V'$.*

Definition 3 (CDS)**.** *A CDS of $G = (V, E)$ is such a DS of G that the subgraph of G induced by the nodes in this set is connected. The size of a CDS is equal to its node number.*

For a given ad hoc network G, finding a house-watching network over G will be addressed below.

Definition 4 (HWN: House-Watching Network)**.** *An HWN of $G = (V, E)$ is such a CDS of G that has a tree structure and is of the minimal diameter.*

B. System Model

We model the system for solving the problem defined in Section II as an ad hoc network $G = (V, E)$ as shown in Fig. 2. A house-watching network as defined in Definition 4 is constructed. All users except the HWN ones, or all users except the proxy and the administration center can go to sleep. The sleeping nodes will be woken up in specified time interval, or according to totalized user requests.

When users are woken up, they can communicate with each other, and then go to sleep again to save their batteries. At that time, they may make requests to the administration center or its proxy to specify when they should be woken up the next time.

We also noticed that uncontrolled sleeps may make the ad hoc network unconnected, and other users' communications interrupted. Fortunately, we also found that people in the disaster-hit area would be like to help each other in various aspects, including the maintenance of an ad hoc network for their own communication. Therefore, the routing table is assumed to be viewable to users (e.g., N_9 in Fig. 2), and a user can make his / her decision of pushing down sleep button according to information from the IP layer, so as to not interfere with the users (e.g., N_{14} and N_0 in Fig. 2) who are using the node for relaying data.

To be not blocked for too long time, we assume that the users who are communicate with each other could indicate

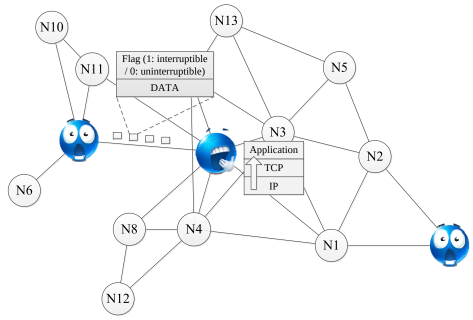

Fig. 2. An example for illustrating the system model. Node N_{14} and N_0 are exchanging messages via node N_9.

whether other users can push down their sleep buttons without any negative effect by setting a sleeping-save flag in the IP packets. User N_9, for example, may be so kind as to not trouble users N_{14} and N_0 by pushing down sleep button when he / she make sure the action is save by checking that sleeping-save flag. The time interval between two adjacent interruptible IP packets is called as a session as defined below.

Definition 5 (Communication Session)**.** *A session of a communication task is the time interval between two IP packets which sleeping-save flags have been set to 1. Assume that sleeping-save flags of the first and the last IP packets are always set to 1.*

C. The Algorithm HWN: House-Watching Network

The algorithm for constructing a house-watching network is given in Function 1. An administration center will use this function to create a house-watching network. Symbols used in the algorithm is summarized in Table I.

D. An Example for Illustrating HWN

In this section we give an example to illustrate the algorithm given above. Assume we have an ad hoc network shown in Fig. 3, where node N_0 is the administration center.

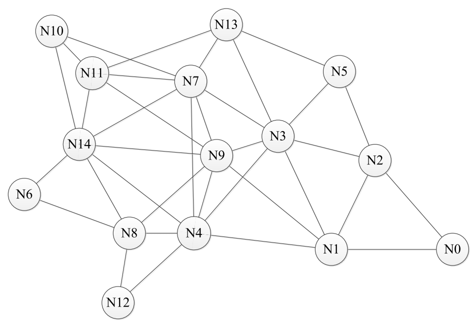

Fig. 3. An ad hoc network for illustrating HWN.

Then the algorithm will initially construct the house-watching network shown in Fig. 4.

Because the path <N_0, N_1, N_9, N_{14}> is the longest path, in the next step in pace of N_0, N_1 becomes a proxy node of

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Function 1 Construct a house-watching network

Require: A set of mobile nodes
Ensure: A house-watching network as defined in Def. 4

1: Set $N_{proxy-pre}$ and N_{proxy} to N_{AdminC}, $N_{proxy-pre}$ *.Diameter* to infinite, and $S_{HWN-pre}$ to $\emptyset$.
2: Color all nodes white. Set N_{proxy}*.House-Watch* to false, N_{proxy}*.Diameter* to 0, and S_{HWN} to $\{ N_{proxy} \}$.
3: For each node $N \in S_{HWN}$ such that *N.House-Watch* is false, set *N.House-Watch* to true, and do the following.
4: Color node N black, each white child u of N grey, and set *u.Diameter* to (*N.Diameter* + 1).
5: Each grey node invites its white child nodes to join, and sends N the set of its 1-hop white children.
6: N selects such grey nodes as temporary members of S_{HWN} that they have more children (denoted as N_{temp}), one by one until all children of all grey nodes have been covered. Then, the selected nodes are notified.
7: N_{temp} invites its white child nodes to join again, and each child node elects such N_{temp} as its parent that has more child nodes than any others. N_{temp}*.House-Watch* is set to false, and added to S_{HWN}.
8: Repeat steps 3 - 8 until all nodes have been colored black or grey.
9: If N_{proxy}*.Diameter* is less than $N_{proxy-pre}$*.Diameter*, then replace $N_{proxy-pre}$, $N_{proxy-pre}$*.Diameter* and $S_{HWN-pre}$ with N_{proxy}, N_{proxy}*.Diameter* and S_{HWN} respectively, and replace N_{proxy} with such a child node of it that is on the diameter path, and repeat steps 2 - 9.
10: Return $S_{HWN-pre}$ as a house-watching network, with diameter $N_{proxy-pre}$*.Diameter* and proxy $N_{proxy-pre}$.

the administration center, and we have the house-watching network shown in Fig. 5.

Because the path <N_1, N_9, N_{14}> is the longest path, in the next step in pace of N_0, N_9 becomes a proxy node of the administration center, and we have the resulting house-watching network shown in Fig. 6. Both the house-watching networks shown in Figs. 5 and 6 have five nodes, but that shown in Fig. 6 is of a shorter diameter.

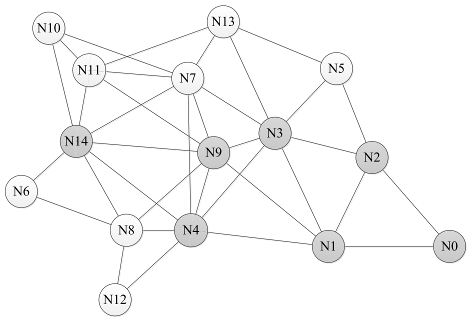

Fig. 4. Stage 1 of Func. 1. N_0 is the administrator center.

IV. Performance Evaluation

Simulation experiments have been done to study performance of the proposed approach. Network Simulator-2 were used. This section describes simulation environment, presents and discusses simulation results.

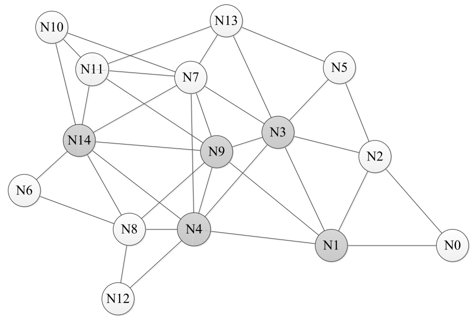

Fig. 5. Stage 2 of Func. 1. N_1 is a proxy node of the administration center.

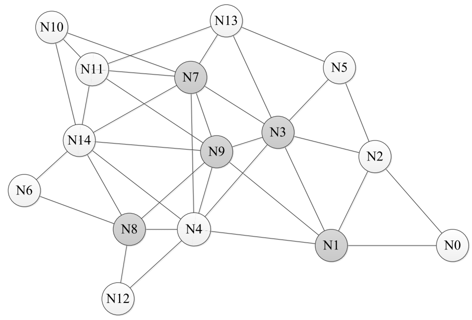

Fig. 6. Stage 3 of Func. 1. N_9 is a proxy node of the administration center.

TABLE II
Experiment Results for Experiment I

Experiment	**Number of nodes**	**House-watching network size**	**Diameter**
1	40	13 → 10	5 → 3
2	50	14 → 14	5 → 4
3	60	13 → 13	5 → 5
4	70	11 → 10	4 → 2
5	100	16 → 13	3 → 2

A. House-Watching Network Size and Diameter

In this experiment (Experiment I), the field configuration is set to 1000 m × 1000 m square. Five experiments are conducted with total 40, 50, 60, 70, and 100 nodes respectively. Nodes are randomly placed on the plane. Transmission range of each node is set to 250 m.

Experiment results are summarized in Table II. Topology corresponding to Experiment 1, 2, 3, 4, and 5 is given in Figs. 7, 8, 9, 10, and 11, respectively. Node 0 (the black node shown in Figs. 7 - 11) is taken as the administration center, and the grey nodes are the proxy nodes.

Comparing Figs. 7 - 9 with Figs. 10 - 11, it is known that if nodes are more evenly distributed, a smaller diameter can be achieved. This is because that, on the one hand, the algorithm can more effectively find the center of the area, if it has a well defined one. On the other hand, as shown in Fig. 9, in some cases the diameter could not be reduced any way. For this, some other kind definition of the "center of an area" than the "minimal diameter" may be more appropriate.

B. Session Size and Its Determination

This experiment examines how the size of communication session affects the waiting time for users to go to sleep.

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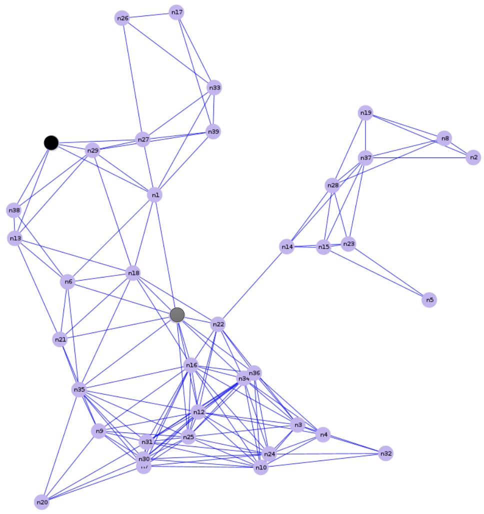

Fig. 7. Experiment 1: number of nodes is 40.

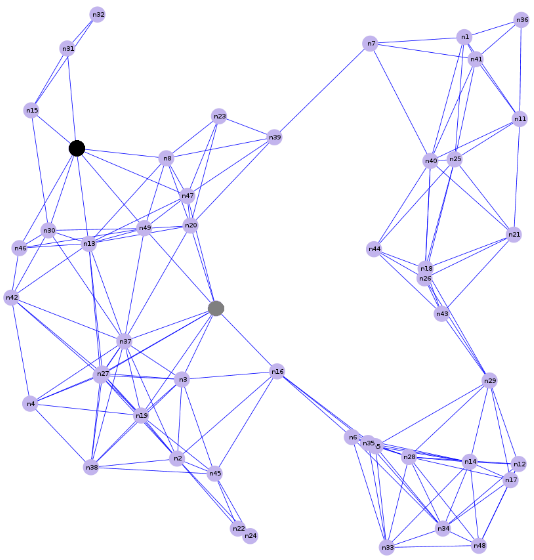

Fig. 8. Experiment 2: number of nodes is 50.

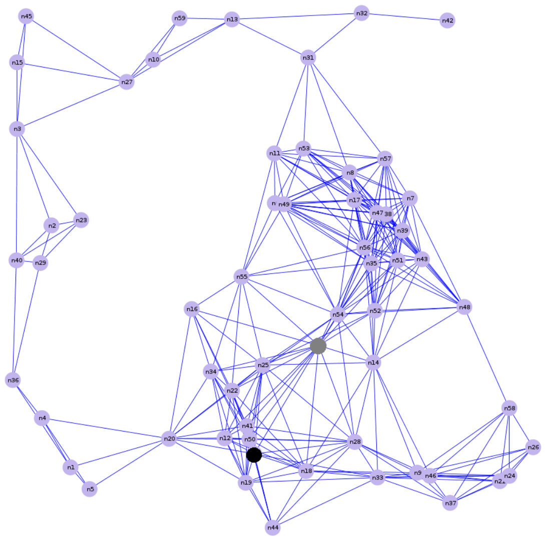

Fig. 9. Experiment 3: number of nodes is 60.

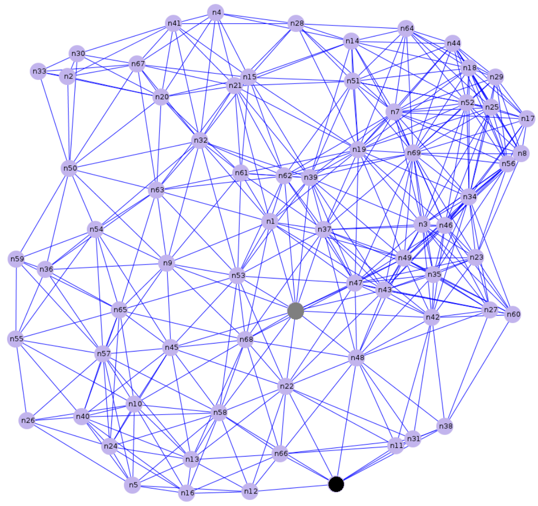

Fig. 10. Experiment 4: number of nodes is 70.

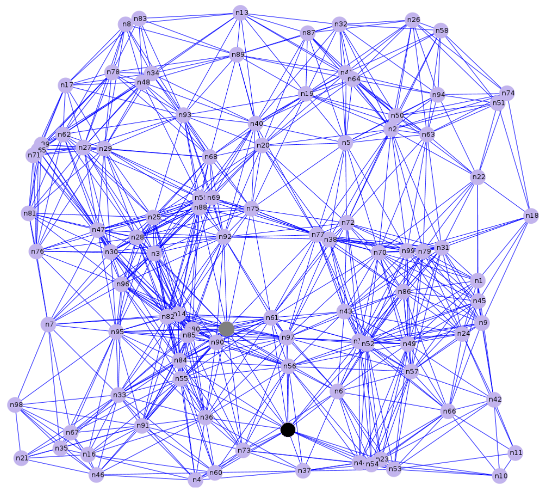

Fig. 11. Experiment 5: number of nodes is 100.

The field configuration is set to 500 m $\times$ 500 m square with total 50 nodes. Nodes are randomly placed on the plane. Transmission range of each node is set to 100 m. For traffic model, one node at one corner of the field is used to send files continuously to another node at the opposite corner.

As expected, experiment results show that larger session size increases average waiting time. For example, when we increased the session size from 50 packets to 200 packets, waiting time increased from about 1.1 to about 1.8 second.

Interestingly, it is also found that, in the case that more nodes are going to sleep, larger session size tends to increase packet arrival ratio. For example when we increased the session size from 50 packets to 200 packets, in the case of 5 nodes going to sleep, packet arrival ratios remained almost unchanged. In the case of 20 nodes going to sleep, however, packet arrival ratio increased from about 71% for size 50 to about 80% for size 200.

Therefore, we should determine the session size according two factors: the session size should not be so long that other users could not endure it; the session size should not be so short that the arrival ratio becomes negatively affecting users' communication.

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V. Conclusions

We have addressed the subject of communication problems at the disaster-hit area. It is found that in the disaster-hit area, a communication supporting system using the existing mobile ad hoc network techniques could not function as expected and communication processes would be interrupted from time to time, since they have not taken into consideration the sleep operations of mobile terminals that are very frequently used means for mobile users to increase their battery life time. We have presented a system model for solving this problem, and proposed two methods.

Simulation experiments have been conducted to study performance of the proposed approach. Experiment results have shown that using the proposed approach, only a few terminals need to be powered on and all the others can go to sleep mode safely, and when a terminal user wants to sleep, he / she can have the chance to decide at what time the sleeping button should be pushed down so that other users would not be affected by his / her sleeping.

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