Proceedings of Asia-Pacific Conference on Communications 2007 **TPM1-4**

A Battery Saving Method Based on Coordinate and Individual Sleeps for Ad-hoc Terminals

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Abstract— **A battery saving method for ad-hoc terminals with an emergency message transfer is considered. Each terminal has a motion sensor, sends an alive message when motion is detected, and transfers alive messages from others. The terminal needs efficient transmission since the connection do not always establish due to the terminal movement and shadowing. A battery saving method of choosing two sleep modes in accordance with the packet arrival rate is proposed. For a higher packet-arrival rate, three and more ad-hoc terminals sleep simultaneously. On the other hand, ad hoc terminals store, forward, and sleep individually for a lower packet-arrival probability. A battery saving method for a large-scale network as well as the choice is discussed in this paper.**

I. INTRODUCTION

Ad-hoc networks are robust to a disaster since they do not depend on a certain infrastructure. Ad-hoc terminals transfer messages even they move because the networks autonomously configure themselves. Therefore ad-hoc networks are attractive for communications in emergency cases when cellular systems are inactive. Though ad-hoc networks do not convey a large amount of message, they are still effective for handling some important messages such as they alive.

A lower energy consumption is required for ad-hoc terminals, and effective battery saving methods has been proposed for sensor networks rather than ad-hoc networks. Each sensor terminal equips a timer and it turns the most part of the terminal off for some durations. The terminals periodically transmit the value for the attribute, and most part of the terminal power is off for other times to save the energy consumption. Low energy adaptive clustering hierarchy, or LEACH was proposed for proactive sensor networks [1]. LEACH monitors the activation ratios of the sensors to control the intervals. The enhanced adaptive periodic threshold-sensitive energy efficient sensor network protocol, or E-APTEEN has been proposed for reactive and hybrid sensor networks [2]–[4]. They can send critical data instantaneously, and the intervals are determined by the characteristics of past sensor values. A trigger method for sleep and wake-up is a key for battery saving. A wakeup radio methods are proposed [5]. The sensor terminal has two radios with different channels: one is for message transfer and another is for wake-up. The wake-up radio has a lower activation ratio than that of the communication radio. The connectivity of all ad-hoc terminals are assumed.

We have examined ad-hoc terminals for emergency use. The ad-hoc communication function is equipped with a cellular phone, for example. When in severe climate and cellular systems are inactive, the ad-hoc function is activated to know he or she is alive. Ad-hoc terminals with mobility encounter abrupt disconnections due to the terminal movement, radiowave obstructions, multipath fading and shadowing. It is natural to turn the power off for durations where terminals cannot transfer other terminals. For typical indoor and outdoor layouts, the mean expectations of life of connection availability between two ad-hoc terminals, as well as the packet arrival probability with given terminal densities, are discussed to obtain the intervals of the sleep and wake-up [6]. The packet arrival probability decreases from 1.0 to 0.45 with an increasing the terminal distance ranging from 0-m to 30-m for typical indoor cases, and the terminal distance does not effect on the packet arrival probability for outdoor cases. The life of expectation result shows that the expectation of link life is below 1 second after the discovery of the link and that the terminals require routing-information exchange duration of less than 25 seconds for a 1-m/s movement in indoor environments. The simulation was carried out with ray tracing and the random walk assumption of ad-hoc terminals.

In this paper, a battery saving method of choosing two sleep modes in accordance with the packet arrival probability. First the system description is presented. Then two sleep methods and the mathematical performance analysis are discussed, and the application for large-scale networks is shown.

II. SYSTEM DESCRIPTIONS

The ad-hoc terminals send and forward small messages to the sink terminal. We assume that the terminals broadcast a beacon for the measurement of the packet arrival probability, that each terminal has a motion sensor to know the expectation of link life and the safety of the owner, and that the packet arrival probabilities are given. The mobility assumed here are several meters a second. A small message is derived via ad-hoc terminals to the sink terminal where the safety and timestamp are recorded as shown in Fig. 1.

Each terminal sends and receives a beacon to know whether the packet arrival probability with neighbor terminals is high or not. A sleep method with a higher transmission rate provides a longer battery life since the transmission terminates in a shorter time. For three ad-hoc terminals with a sufficient higher packet-arrival probabilities among them, a sleep method of

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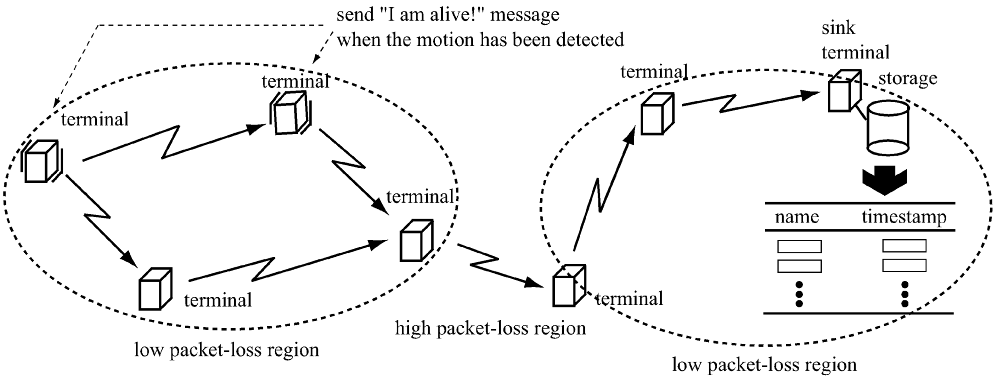

Fig. 1. Applications of the proposed battery saving method.

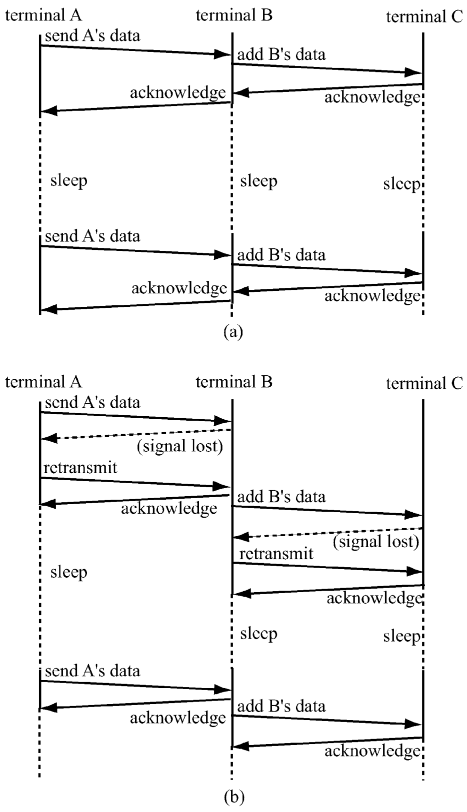

Fig. 2. Proposed two sleep methods for three ad-hoc terminals ($n = 2$): (a) coordinate sleep and (b) individual sleep.

forwarding packets instantaneously and sleeping simultaneously is efficient as shown in Fig. 2 (a). After the reception of the acknowledgment of the packet arrival, a terminal turns to sleep until a given wake-up time. The ad-hoc terminals sleep simultaneously at certain time. We call this method *coordinate sleep*. On the other hand, the retransmission has done within only two terminals as shown in Fig. 2 (b), and it is rather more effective for low packet-arrival probability conditions, because the retransmission has carried out effectively. A terminal turns to sleep regardless of other We call the method *individual sleep*.

III. TWO SLEEP METHODS AND THE SELECTION

Now we select the two sleep methods under the given number of transmission hops n (and $n+1$ ad-hoc terminals), the packet-arrival probabilities $P_1, P_2, \ldots, P_n$, and the transmission rates between the hops $S_1, S_2, \ldots, S_n$. The selection is provided with an allowable packet-loss probability L.

For coordinate sleep, since the successful probability of the transmission within the hops is $P_1 \cdot P_2 \cdots P_n$, the statistical total number of transmission that satisfy the packet loss-loss probability, T_{coord} is expressed by $(1 - \prod_{i=1}^{n} P_i)^{T_{\text{coord}}} = L$. Taking logarithms to the both sides of the equation and arranging it gives

$$T_{coord} = \frac{\log L}{\log\left(1 - \prod_{i=1}^{n} P_i\right)}.$$

Then the total transmission time t_{coord} is

$$t_{\text{coord}} = \frac{XT_{\text{coord}}}{S_{\text{min}}} = \frac{X \log L}{S_{\text{min}} \log\left(1 - \prod_{i=1}^{n} P_i\right)},$$

where $S_{\text{min}} = \min(S_1, S_2, \ldots, S_n)$ is the minimum rates and X is the total amount of the messages. The transmission rate within the hops is limited to S_{min}. Therefore, the total transmission rate R_{coord} is expressed by

$$R_{\text{coord}} = \frac{X}{t_{\text{coord}}} = \frac{S_{\text{min}} \log\left(1 - \prod_{i=1}^{n} P_i\right)}{\log L}. \quad (1)$$

For the individual sleep, the required transmission time including retransmission for i-th region T_i and it has a relationship of $(1 - P_i)^{T_i} = L$. We can rewrite the equation as $T_i = \log L / \log(1 - P_i)$, and the transmission time for the i-th hop t_i is $t_i = XT_i/S_i \log(1 - P_i)$. The total transmission

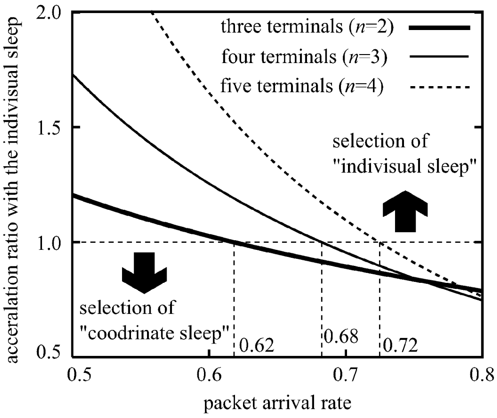

Fig. 3. The choice of coordinate sleep and individual sleep.

time t_{indiv} is a sum of all transmission hops,

$$t_{\text{indiv}} = \sum_{i=1}^{n} t_i = X \log L \sum_{i=1}^{n} \frac{1}{S_i \log(1-P_i)}.$$

Therefore the total transmission rate R_{indiv} is express by

$$R_{\text{indiv}} = \frac{X}{t_{\text{indiv}}} = \frac{1}{\log L \displaystyle\sum_{i=1}^{n} \frac{1}{S_i \log(1-P_i)}}. \tag{2}$$

For simplicity, we assume that the packet arrival rates and the transmission rates for all regions are the same, $P_1 = P_2 = \ldots = P_n = P$ and $S_1 = S_2 = \ldots = S_n = S$. With Eqs.(1)(2), we define a transmission-rate ratio γ_n as

$$\gamma_n = \frac{R_{\text{indiv}}}{R_{\text{coord}}} = \frac{1}{n} \cdot \frac{\log(1-P_i)}{\log(1-P_i{}^n)} \tag{3}$$

The individual sleep will be efficient for $\gamma_n > 1$. The ratios γ_2, γ_3, andγ_4 are plotted in Fig. 3. γ_n is a monotonically decrease function and it converges to $1/n$ for a perfect packet arrival condition $P \to 1$. For three ad-hoc terminals ($n = 2$), the individual sleep is chosen when $P < 0.62$. The transmission rate of the individual sleep is about 1.2 times higher than that of the coordinate sleep if P is 0.5. The thresholds for the packet-arrival probabilities are 0.68 and 0.72 for $n = 3$ and 4, respectively.

The transition state diagram of the proposed battery saving method is illustrated in Fig. 4. The initial state is "stand-by reception." An ad-hoc terminal broadcasts a beacon at certain duration, and receives for the other duration. There are, say, 10 broadcast packets and each consists of a sequence number. If another terminal receives the broadcast packets more than 6, the terminal proposes the coordinate sleep to the broadcast terminal. Otherwise it proposes the individual sleep. The proposed sleep is selected if accepted. If a terminal receives a proposal of either the coordinate or individual sleep, it performs.

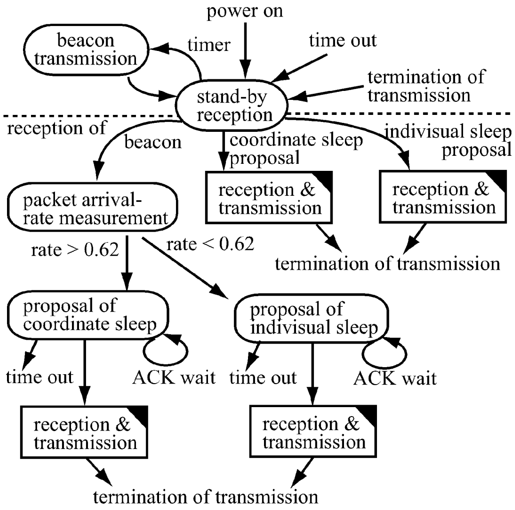

Fig. 4. Transition state diagram for the proposed ad-hoc terminal.

IV. APPLICATION OF THE PROPOSED BATTERY SAVING METHOD TO A LARGE-SCALE AD-HOC NETWORK

An example of an application of the proposed battery saving method is illustrated in Fig. 5. In the example, there are six ad-hoc terminals and one sink terminal. At the packet arrival-probability measurement stage, each terminal sends beacon packets sequentially. Then the sleep method is determined for each region in accordance with the packet arrival probability. An increase in the number of terminals with the same coordinate sleep results in a higher transmission rates and leads to a longer battery life. If P_{AB}, P_{BC}, and P_{CD} are more than γ_3, terminals A, B, and C will sleep at the same time as in Fig. 5. If P_{DE} and P_{DF} are lower than γ_2, they will sleep individually. Each terminal adds a message "I am alive" if the motion is detected. After the sleep, the packet arrival-probability measurement is performed. The procedures are done within 20 seconds when the maximum motion among the terminals is less than 1 m/s [6]. The time is 10 seconds when the maximum speed is 2 m/s.

V. CONCLUSION

In this paper, a battery saving method was proposed for ad-hoc terminals. Packets of ad-hoc networks are often lost due to the movements, fading, and shadowing. It is natural to turn the power off for durations where terminals cannot transfer other terminals, and selecting two sleep methods based on the packet-arrival probability was proposed. One sleep method turns off the power of more than three terminals at the same time, and was called the coordinate sleep. Another method determines the sleep duration from the corresponding two terminals. The coordinate sleep was selected for reliable transmission channels to transfer messages in a shorter time. Otherwise the individual sleep was selected for increasing the reliability of message transfer, and it results in reduction of

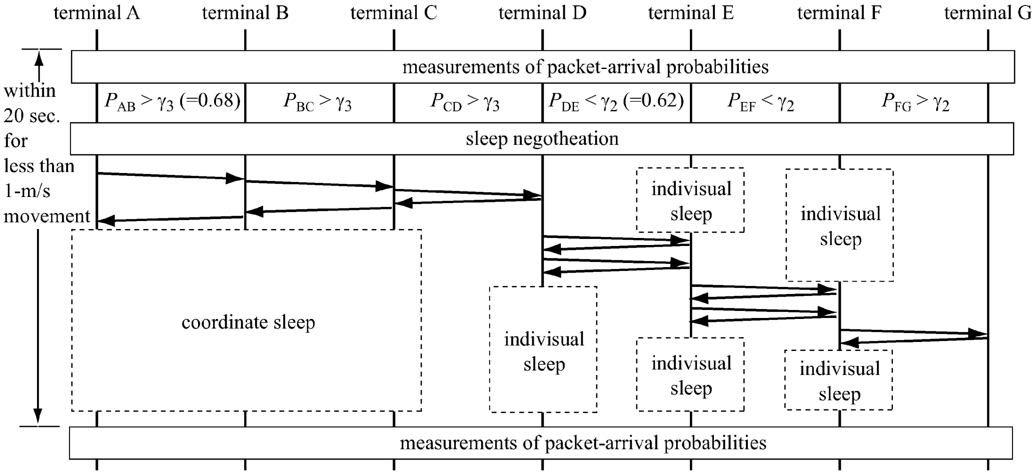

Fig. 5. A sleep example of a large-scale ad-hoc network.

the total transmission time. The threshold probabilities were also derived.

ACKNOWLEDGMENT

This work is funded in part by the research foundation entitled "research of efficient communication method considering energy consumption for ad-hoc networks" of the Telecommunications Advancement Foundation.

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