TASA: Traffic Aware Sleep Algorithm for Energy-Efficient Always-on Home Networks

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Summary
Home Gateway is always on-line for continuous services of home networks. So its power-saving is very important for green-energy and ubiquitous society. Our algorithm is for home gateway to sleep, listen or wakeup according to network traffic adaptively. This method keeps always-on service, and minimizes the power consumption for network services.

Key words:
Energy-Efficiency, Traffic-based, Home Gateway, Sleep/Wakeup

1. Introduction

There's a drift towards everyone's home automation. For example, Korea's government try to supply 1 million green home in year of 2010[1]. The Green Home needs an energy-efficient gateway and reusable energy like solar energy. And in other countries, this is important issue [2]. For this, energy home appliance including PC must have low-power solution.

Especially, the home gateway is always powered fully for continuous home service requests from outside of the home networks. So power consumption of the home gateways increases exponentially according to expansion of the home networks. We try to minimize the power consumption of the home gateway by tracing idle period, while it provides always-on services.

There are a few works on power saving for networked device[3, 4]. Peak power consumption of mode change of our home gateway is not short, we try to use simple and efficient algorithm. As the result of the research and simulation, we show our algorithm based on exponential smoothing and 24-hour use pattern.

The rest of this paper consists of 3 parts. Chapter 2 explains existing works, exponential smoothing, the definition of energy gain, proxing, profiling of 24-hour use pattern, and controlling the power mode. And chapter 3 shows the simulation results. And chapter 4 is the conclusion and further works.

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2. TASA: Traffic Aware Sleeping Algorithm

2.1 Existing works

Home network consists of a home gateway and various home appliances. Home appliances have their own basic power-saving algorithm to satisfy the requirements for each appliance. But, the home gateway is always full-powered for persistent connections. Some researches have done for power-saving method of the home gateway. There are a prediction for low-powered period [3, 4], service-based power-saving [6], 24-hour usage patterns of home networks [7], and a middleware for power-saving and service quality.

Among them, we used the prediction approach in the previous work [9]. Its focuses are as follows:

- Keeping always-on services
- Minimize overall power consumption for packet processing
- Simple algorithm for low overhead

This paper adds following ideas to the previous one.

- Profiling the pattern of the 24-hours home services and applying it to predict next idle period
- Adaptive weight for historical average sleep period and that just before.

From now on, we name this algorithm as TASA (Traffic Aware Sleeping Algorithm).

2.2 Exponential Smoothing

Before explaining, we show basic terms (see Fig. 1).

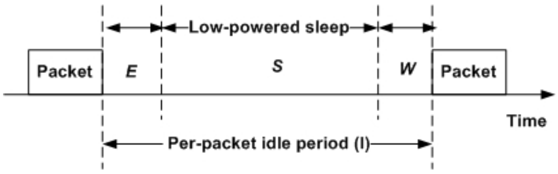

Fig. 1 Sleep period between a packet and the next packet.

In Fig.1, E means entering the sleep period, S is the sleep period, and W is the wakeup time. So, Per-packet idle period (I) = $E + S + W$, but real power-saving time is only S period. Ideal algorithm will do low-powered mode during S period. However, in real environment, available sleep time by algorithm is smaller then S period, because we don't know the per-packet sleep period in advance. The I period is random, so we try to predict that from previous sleep patterns.

For this, TASA uses the exponential smoothing. EWMA (Exponentially weighted moving average) or exponential smoothing is originally for operating systems to predict the next CPU burst time during process scheduling time. This is as showed in Eq. 1.

$$\begin{aligned} I_{n+1} &= a \bullet i_n + (1-a) \bullet I_n \\ &= a \bullet i_n + a \bullet (1-a) \bullet I_{n-1} + a \bullet (1-a)^2 \bullet I_{n-2} + \\ &\dots + a \bullet (1-a)^n \bullet i_0 + a \bullet (1-a)^{n+1} \bullet I_0 \end{aligned} \quad (1)$$

In Eq. 1, I_{n+1} is the next CPU burst time that is predicted, I_n is the accumulated average CPU burst time, and i_n is the CPU burst time just before. The weight 'a' means the influence of previous CPU burst, and is from 0 to 1. If a=0, I_{n+1}=I_n. That means that the CPU burst just before cannot influence the next CPU burst. On the other hand, if a=1, then I_{n+1}=i_n. That means that the prediction is only from previous CPU burst. Network traffic has self-similarity, we use this approach.

If the home gateway starts to run using full-power, it has to predict the next sleep period using Eq. 2.

$$P_{n+1} = a \bullet p_n + (1-a) \bullet P_{n-day} \quad (2)$$

In Eq. 2, P_{n+1} is the next sleep period that is predicted, $P_{n\text{-}day}$ is the accumulated average sleep time according to day of the week, and p_n is the sleep period just before. In our previous work, we used just P_n instead of $P_{n\text{-}day}$. That is the accumulated average sleep time from starting of the home gateway. While we use $P_{n\text{-}day}$ in this paper, because use pattern of the home networks is different in accordance with the day of the week.

The weight 'a' means the influence of previous average sleep time, and is from 0 to 1. In our previous paper, we use that a=0.5. This means that the predicted sleep period is made of 50% of previous sleep period and 50% of historical average value. We compare this P value with a critical value T, and decide to sleep or not.

As soon as there are no packets, immediate sleeping is dangerous, because the transmission of a packet can be occurred shortly. It cause $S < E+W$, then this is not energy-efficient. We define this concept as showed in section 2.2.

2.3 Definition of Energy Gain

Continuing of Fig. 1, we show the several cases and its delay for the definition of the energy gain. In case of (a) in Fig. 2, I is longer than E. This case needs the sleep mode for power saving. On the other hand, in case of (b) in Fig. 2, I is less than E. This case does not need the sleep mode. Therefore, we have to know when there is the gain from the sleep mode.

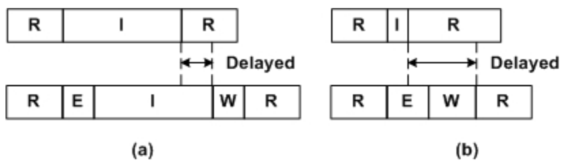

Fig. 2 Cases for the definition of Energy Gain

To define the energy gain, we use following notations.

Table 1: Symbol Definition

Symbol	*Meaning*
EG	Energy gain
P_R	Power consumption during R mode
P_S	Power consumption during S mode
P_{EW}	Average Power consumption during E period (changing overhead from R mode to S mode) or W period (changing overhead from S mode to R mode)
S_{th}	Critical value for deciding to go to sleep

Generally, $P_R \geq P_{EW} \geq P_S$. Using these symbols, we define the energy gain as showed in Eq. 3.

$$EG = I \bullet P_R - (E+W) \bullet P_{EW} - P_S \bullet S \quad (3)$$

$$I \geq E \quad (4)$$

$$\begin{aligned} EG &= I \bullet P_R - (E+W) \bullet P_{EW} - P_S \bullet S \\ &= I \bullet P_R - (E+W) \bullet P_{EW} - P_S \bullet (I-E) \end{aligned} \quad (5)$$

$$= I \bullet (P_R - P_S) - E \bullet (P_{EW} - P_S) - W \bullet P_{EW} > 0 \quad (6)$$

$$I > \frac{E \bullet (P_{EW} - P_S) - W \bullet P_{EW}}{(P_R - P_S)} \quad (7)$$

$$S_{th} = \frac{E \bullet (P_{EW} - P_S) - W \bullet P_{EW}}{(P_R - P_S)} \quad (8)$$

To gain the energy saving effect, EG must be positive as showed in Fig. 2 (a). This can be represented from Eq. 4 to Eq. 8. Especially, the idle period must be satisfied with Eq. 4 and Eq. 8. From Eq. 8, $\underline{S_{th}}$ is defined from the characteristics of the home gateway: P_R, P_S and P_{EW}.

2.4 Proxing

There are packets on the home networks although all appliances are idle. First group of them is a packet that it don't need acknowledgement. For example, broadcast packets for network management, routing, or port scanning for hacking. Second group is a packet that can be answered automatically. Examples of them are ARP packets, ICMP packets, DHCP packets, and several discovery packets. Because we can predict and make the contents of the acknowledgement packet for them, we can answer those packets automatically while the home gateway sleeps. In our work, we include periodic connection checking packets of online messenger to second group. This is a kind of proxing. We try to minimize unnecessary wakeups, our home gateway wakeups when user data packet occurs, and answers only those packets.

2.5 Profiling 24-hour use pattern

Power consumption of individual home network is variable according to their use pattern. In [7], they showed 3 patterns in home networks (see Fig. 3).

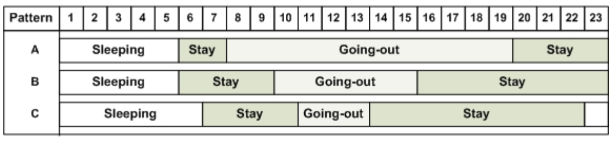

Fig. 3 Examples of 24-hour use pattern

Pattern A shows the case that all family is out during the daytime. Pattern B and C shows the case that there is someone during the daytime. During 'Sleeping' and 'Going-out' period, there are only management and security traffic. That period is from 6 hours to 12 hours, and included in *S* period. Most of that traffic can be processed by proxing.

On the other hand, especially TASA algorithm is more useful in 'Stay' period. When there is a data packet, our algorithm wakeup the gateway and 'Stay' period starts.

2.6 Correction of predicted idle period [4]

The predicted idle period can be different with real idle period. Especially, in case of Fig. 4, that difference is bigger.

In Fig. 4 (a), idle period are *I1*, *I2*, *I3*, and *I4* in order, and *I3* is longer than other the idle periods: *I3* is an impulse-like idle period. The predicted idle period of *I3* and *I4* are *I3'*, *I4'* respectively. *I3'* is shorter than *I3*, so it is underestimated. On the other hand, *I4'* is longer than *I4*, so it is overestimated. These are predication miss.

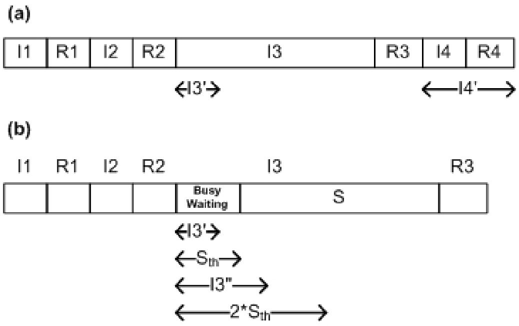

Fig. 4 Correction of prediction miss: (a) an impulse-like idle period, (b) correcting using a watchdog scheme

Correction using a watchdog scheme can be a solution of the prediction for impulse-like idle period as showed in Fig. 4 (b). If the predicted value is lower than S_{th}, TASA recalculated the predicted value. Then if the recalculated value is lower than 2 times of S_{th}. This process continues until the N^{th} predicted value is bigger than *N* times of S_{th}. This can be presented as showed in Eq. 9.

$$\begin{aligned} &if\,(a \bullet i_n + (1-a) \bullet I_n > c \bullet I_n) \\ &I_{n+1} = c \bullet I_n \end{aligned} \quad (9)$$

Constant *c* is variable according to traffic characteristics. We use the *c* as 2. That means the predicted value of the impulse-like idle period is limited by 2 times of previous threshold.

2.7 Control of Power Mode

The TASA has 3 modes: Running mode, Sleeping mode, and Correction mode (see Fig. 5). The running and correction mode use full-power, but the sleeping mode uses low-power. In all modes, the TASA accumulates the user's pattern. In Fig. 5, idle count means the period that there are no valid packets.

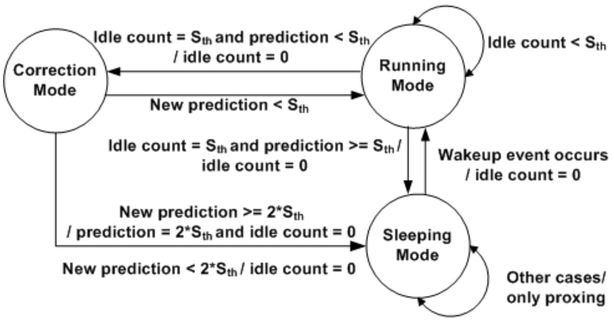

Fig. 5 State Transition Diagram for Power Mode

In the running mode, there are no valid packets during S_{th} period, then the TASA calculates the prediction of next idle period. If the prediction is lower than S_{th}, the mode is changed to correction mode. In other cases, the mode is changed to sleeping mode.

In correction mode, the TASA recalculates the prediction, and compares it with 2 times of S_{th}. If new prediction is lower than 2 times of S_{th}, new prediction will be used. In other cases, new prediction is limited to 2 times of S_{th}.

In sleeping mode, when wakeup event occurs like user's data traffic, the mode is changed to the running mode. In other cases, the gateway does proxing in the sleeping mode.

3. Simulation and its Results

From our home gateway, we use simulation environment as showed in Table 2.

Table 2: Simulation environments

Symbol	*Value*
E	1 sec
W	1 sec
P_R	19.5 Wh
P_S	7.5 Wh
P_E	13.5 Wh
P_W	21 Wh
S_{th}	2.25 sec

Our home network consists of the home gateway, 2 computer, eight home appliances, and two security appliance. We capture 24-hour traffic data using Wireshark[9] from real home networks, then use those data with the three pattern in Fig. 3.

First simulation is the energy saving according the use pattern A, B and C in Fig. 3. In this simulation, we fix the weight *a* as 2.

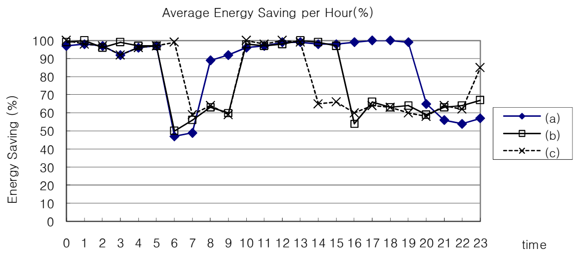

Fig. 6 Energy saving according to the use pattern A, B and C

In Fig. 6, energy saving (%) means the ratio of energy gain and energy consumption when the gateway is always running. From the first simulation's result, we get the energy gain from 47% to 68% in Stay period.

Next, the energy gain according to the weight is as showed in Fig. 7.

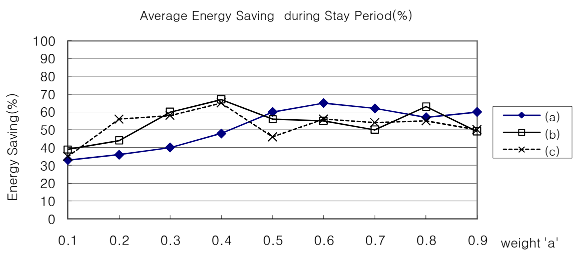

Fig. 7 Energy saving according to the weight

As showed in Fig. 7, the energy saving of the use pattern A and B is max when the weight is 0.4. On the other hand, the energy saving of the use pattern C is max when the weight is 0.6. Longer stay period is, bigger the weight of previous average idle period is good. However, because the traffic pattern is always variable, this can be general or not.

4. Conclusion

The home gateway must be energy-efficient as well as individual home appliance must be energy-efficient. To save the energy consumption of the gateway, we trace the use pattern according to the day of week and predict the next idle period. We do simulation with real traffic data from the home networks. As the result of our simulation, we get the energy saving effect to 67 % when the network is used. Average saving rate is from 79% to 86% per day.

As further works, we'll try to control the weight according to prediction hit ratio.

Acknowledgments

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