Adaptive Standby Mode Scheduling Method Based on Analysis of Activation Pattern for Improving User Experience of Low-Power Set-Top Boxes

Hyunho Park, Junghak Kim, Eui-Suk Jung, Hyunwoo Lee, and Yong-Tae Lee

The lowest power mode (passive-standby mode) was proposed for reducing the power consumption of set-top boxes in a standby state when not receiving content. However, low-power set-top boxes equipped with the lowest power mode have been rarely commercialized because of their low-quality user experience. In the lowest power mode, they deactivates almost all of operational modules and processes, and thus require dozens of seconds for activation latency (that is, the latency for activating all modules of the set-top boxes in a standby state). They are not even updated in a standby state because they deactivate their network interfaces in a standby state. This paper proposes an adaptive standby mode scheduling method for improving the user experience of such boxes. Set-top boxes using the proposed method can analyze the activation pattern and find the frequently used time period (that is, when the set-top boxes are frequently activated). They prepare for their activation during this frequently used time period, thereby reducing the activation latency and enabling their update in a standby state.

Keywords: Set-top box, Low-power, Activation pattern, Adaptive standby mode scheduling, Activation latency.

I. Introduction

The power-saving capability of set-top boxes is a national issue because such devices consume a large amount of power while in a standby state in which they do not perform their main functions (for example, the reception of broadcast or video-on-demand services). While in a standby state, a set-top box consumes about 10 W, which is ten-times greater than the power consumption of a television during a standby period [1], [2]. Therefore, there have been a large number of studies on reducing the standby power consumed by set-top boxes during a standby state [3]–[14].

Passive-standby mode was proposed as the lowest power mode for reducing the standby power of a set-top box [7], [8]. During passive-standby mode, the set-top box operates only the remote control unit (RCU) interface, front panel, and real-time clock (RTC) timer, as well as its main memory, thereby consuming less than 1 W [12]. However, manufacturers have avoided producing low-power set-top boxes owing to their low quality of user experience. The set-top box in passive-standby also needs a lengthy period (dozens of seconds) for the activation latency (that is, the latency for activating all modules of the set-top box in a standby state) because it deactivates almost all of the modules and processes [4], [14]. In addition, a set-top box in passive-standby mode does not update its electronic program guide (EPG), software, or firmware because doing so deactivates the network interfaces (for example, an Ethernet interface) [9]–[11]. To solve the issues regarding the activation latency and update, two important methods have been proposed [7], [8], [12], [13]. To reduce the

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activation latency, the study in [12] uses a suspend-to-RAM (STR) method that enables the set-top box to store its processes in the main memory before entering passive-standby mode [15]. When a set-top box using the STR method is fully activated, the activation latency can be reduced to 7 s by resuming the stored processes in the memory. To reduce the activation latency and solve the update problem, the set-top box can schedule the time to prepare for a full activation [7], [13]. The standard in [7] proposed an auto power down (APD), which is a scheduling method using a timer. In standby state, a set-top box with APD activates almost all of the operational modules for preparing the activation of the set-top box, and outputs during a certain time limit, and thus the set-top box can be updated and activated within a short period of latency [7]. However, after the time limit, the set-top box can change its mode into passive-standby mode, and thus the set-top box cannot be updated and activated within a short latency period. The study in [13] proposed an activation pattern based scheduling method that enables the set-top box to prepare for a full activation during a frequently used time period, which is when the set-top box is frequently activated. However, the STR method is insufficient to solve the update problem, and the APD and activation pattern based scheduling method do not enable the set-top box to prepare for a full activation when the frequently used time is changed. The scheduling method needs to be improved to cope with the change in frequently used time.

This paper proposes an adaptive standby mode scheduling method to solve the problem of previous studies regarding the change in frequently used time. When the frequently used time is changed, the adaptive standby mode scheduling method enables the set-top box to adjust the criterion (that is, the activation threshold) used to analyze the frequently used time. For example, if a set-top box is activated during a seldom-used time period (that is, when the set-top box is seldom activated) and does not prepare for a full activation, the set-top box adjusts its criterion value, and thus updates the change in frequently used time period. Therefore, the set-top box can prepare for a full activation during this newly changed frequently used time period.

Figure 1 describes the operation steps used for the adaptive standby mode scheduling method. The activation history is a log that indicates when a set-top box is activated by an RCU's activation signal, as shown in step (a) of Fig. 1 [13]. In step (b), the set-top box compares its accumulated activation histories with the activation threshold (that is, the criterion for analyzing the frequently used time), and then classifies the frequently and seldom-used time periods. The activation threshold can be adjusted depending on the change in the activation histories of the set-top box. In step (c), the set-top box prepares for a full activation during the frequently used time period to reduce the activation latency, and then updates its EPG, software, and firmware. The adaptive standby mode scheduling method is easy to be implemented and can further reduce the activation latency by cooperating with the STR method.

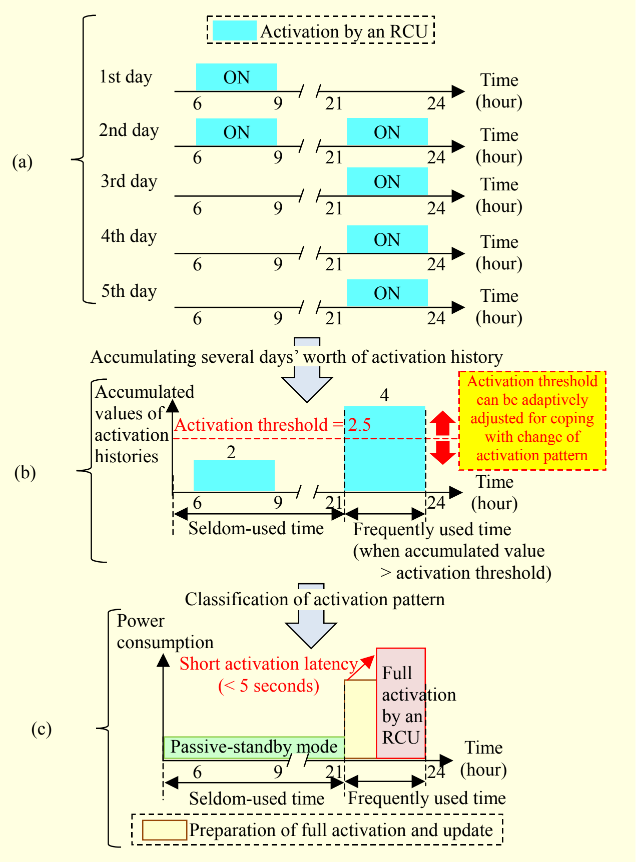


Fig. 1. Operation steps for adaptive standby mode scheduling based on an activation pattern analysis: (a) Activation histories of several days, (b) Analysis of activation pattern, and (c) Controlling operation modes of the set-top boxes.

The remainder of this paper is organized as follows. Section II presents the operation modes and mode transitions for the set-top boxes using the adaptive-standby mode scheduling method. Section III described the procedure for this method. In Section IV, the simulation results are discussed. Finally, Section V provides some concluding remarks regarding this research.

II. Operation Modes and Mode Transitions for Low-Power Set-Top Boxes Using Adaptive Standby Mode Scheduling

Several standards and regulations for set-top boxes have been developed to define four operation modes: on-mode, active-standby mode, passive-standby mode, and off-mode [7]–[13]. A set-top box in off-mode deactivates all operational

Table 1. Activated modules depending on mode [12].

Mode STB module	On-mode	Active-standby mode	Passive-standby mode
RCU interface & front panel & RTC timer	○	○	○
Main memory	○	○	△
CPU & network interfaces	○	○	×
A/V decoder & processor & outputs	○	×	×

○: fully activated, ×: deactivated, △: low power mode.

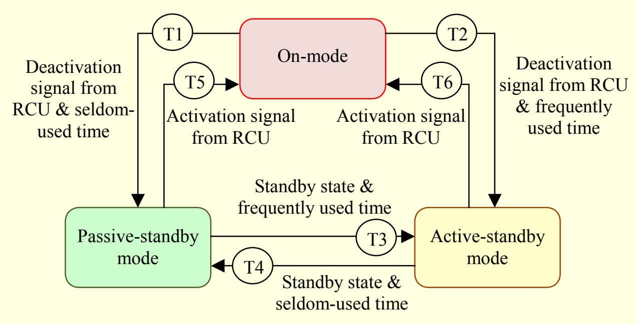


Fig. 2. Mode transitions of a low-power set-top box using daptive standby mode scheduling.

modules and takes several minutes for changing its mode to on-mode. Therefore, this paper focuses on on-mode, active-standby mode, and passive-standby mode.

Table 1 describes the activated operational modules of set-top boxes depending on the three operation modes [12]. A set-top box in on-mode operates all of its operational modules. Active-standby and passive-standby modes have been proposed as operation modes for a set-top box in a standby state. In active-standby mode, a set-top box activates almost all of the operational modules except for the A/V decoder (for example, an MPEG-2 decoder), processor (for example, an MPEG-2 transport processor), and outputs (for example, the high-definition multimedia interface (HDMI)). Therefore, a set-top box in active-standby mode can have a short activation latency of less than 5 s and update its EPG, software, and firmware [12]. A set-top box in passive-standby mode operates only the RCU interface, front panel, and RTC timer. A set-top box in passive-standby mode operates its main memory in low-power mode (for example, self-refresh mode) where the memory deactivates the data exchange with other operational modules and consumes power for only maintaining its data. The set-top box in passive-standby mode needs dozens of seconds to enter on-mode because it deactivates all processes. If the CPU (for example, BCM7241 of Broadcom) of the set-top box supports suspend-to-RAM (STR), the set-top box stores its processes before entering passive-standby mode, and thus reduces the activation latency from dozens of seconds to 7 s by resuming the processes stored in the main memory when entering on-mode [12].

Figure 2 describes the mode transitions of a low-power set-top box using adaptive standby mode scheduling. When receiving a deactivation signal, a set-top box in on-mode changes its mode to passive-standby mode (that is, transition T1) at a seldom-used time, or changes its mode to active-standby mode (that is, transition T2) at a frequently used time. In standby state, the set-top box changes its mode to active-standby mode (that is, transition T3) at a frequently used time or changes its mode to passive-standby mode (that is, transition T4) at a seldom-used time. When receiving an activation signal, a set-top box in passive-standby or active-standby mode changes its mode to on-mode, as shown in transitions T5 and T6 of Fig. 2.

III. Procedure for Adaptive Standby Mode Scheduling

This section describes the procedure for adaptive standby mode scheduling. Figure 3 shows the overall procedure for this scheduling type. In step 1, the set-top box records its activation histories by receiving signal inputs from the RCU, and accumulates the activation histories for several days. In step 2, the set-top box classifies the frequently and seldom-used times. The set-top box schedules active-standby mode during a frequently used time and passive-standby mode during a seldom-used time. In step 3, the set-top box controls its operation mode using the RCU's signal inputs and the standby mode schedule of step 2. In step 4, the set-top box calculates the standby power and prediction success rate, which indicates the probability for a set-top box to operate in active-standby mode for preparing for a transition to on-mode. The set-top box can adjust its activation threshold adaptively depending on its standby power and prediction success rate. In the following,

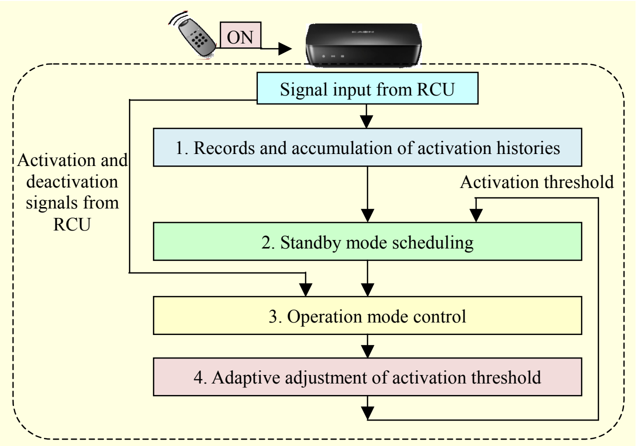


Fig. 3. Procedure for adaptive standby mode scheduling.

steps 1 through 4 are explained in greater detail.

1. Records and Accumulation of Activation Histories

In step 1 of Fig. 3, a set-top box using the proposed method records the activation histories each day and accumulates them for several days. The set-top box records its activation history by receiving activation and deactivation signals. These activation and deactivation signals are generated when the power button of the RCU is pushed. An activation history is recorded as a bit sequence. The set-top box accumulates the bit sequences of several days' worth of activation histories.

The set-top box records a bit sequence for the activation history per day. The history resolution is the time unit for recording the activation history and can be 10 m, 30 m, or 60 min. If the history resolution is 30 min, the set-top box records its activation every 30 min. This resolution is used for covering the time difference between activation histories. For example, activations of the set-top box at 11:01 and 11:05 have only a 4-min difference. When using a 10-min resolution, the set-top box can group 11:01 and 11:05 into the same time zone. In addition, if the set-top box records an activation history for a day by using such resolutions, the length of the bit sequences can be less than 200, and thus the set-top can save storage for recording the activation histories. The length of the bit sequence per day can be 144 (24 × 60 ÷ 10) for a 10-min resolution, 48 (24 × 60 ÷ 30) for a 30-min resolution, and 24 (24 × 60 ÷ 60) for a 60-min resolution.

The bit position of the bit sequence stands for the time when the set-top box operates in on-mode. For example, the 0th position of the bit sequence indicates the time from 00:00 to 00:10 for a 10-min resolution, from 00:00 to 00:30 for a 30-min resolution, and from 00:00 to 01:00 for a 60-min resolution. The value of each bit in the bit sequence indicates the state of activation at the time indicated by the bit positon. A bit value of 1 represents the operation of the set-top box in on-mode at the time indicated by the bit position. On the contrary, a bit value of 0 indicates that the set-top box is operated in passive- or active-standby mode.

Figure 4 shows example records of the *i*-th day's activation histories based on the history resolution. Figure 4(a) shows that the set-top box is operated from 06:03 to 06:17 in on-mode. Figures 4 (b) through 4(d) illustrate the bit sequences recorded using history resolutions of 10 min, 30 min, and 60 min, respectively. When the history resolution is 10 min, as shown in Fig. 4(b), the set-top box marks bits 36 and 37 with a value of 1 for the bit sequence of the *i*-th day's activation history (AH_i). When the history resolution is 30 min, as shown in Fig. 4(c), the set-top box marks bit 12 with a value of 1 for AH_i. When the history resolution is 60 min, as shown in Fig. 4(d), the set-top box marks bit 6 with a value of 1 for AH_i.

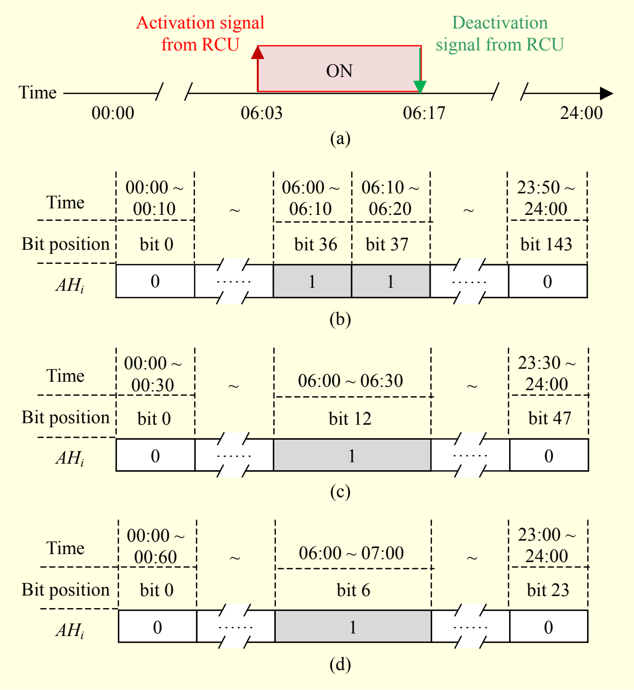


Fig. 4. Examples of bit sequences of the *i*-th day's activation histories: (a) a set-top box's activation between 06:03 and 06:17, (b) bit sequence of the *i*-th day's activation history (AH_i) recorded using a 10-min resolution, (c) AH_i recorded using a 30-min resolution, and (d) AH_i recorded using a 60-min resolution.

The set-top box accumulates bit sequences of activation histories recorded during a five-day period before the set-top box's current operation. Here, $AH_i(j)$ indicates the *j*-th bit of AH_i, and SH_N indicates the accumulated values of five days' worth of activation histories before the *N*-th day. For $N \geq 6$, the *j*-th value of SH_N ($SH_N(j)$) is calculated as follows:

$$SH_N(j) = \sum_{i=N-5}^{N-1} AH_i(j) . \tag{1}$$

When $N \leq 5$, the set-top box does not have sufficient bit sequences used for the activation history accumulations. The set-top box adds a value of 1 to the bits of those accumulated bit sequences made using fewer than five activation histories. Therefore, if $1 < N \leq 5$, $SH_N(j)$ is defined as

$$SH_N(j) = 4 - N + \sum_{i=1}^{N-1} AH_i(j) . \tag{2}$$

If $N = 1$, $SH_1(j)$ is defined as

$$SH_1(j) = 5 . \tag{3}$$

2. Standby Mode Scheduling

In step 2 of Fig. 3, before the day begins, the set-top box

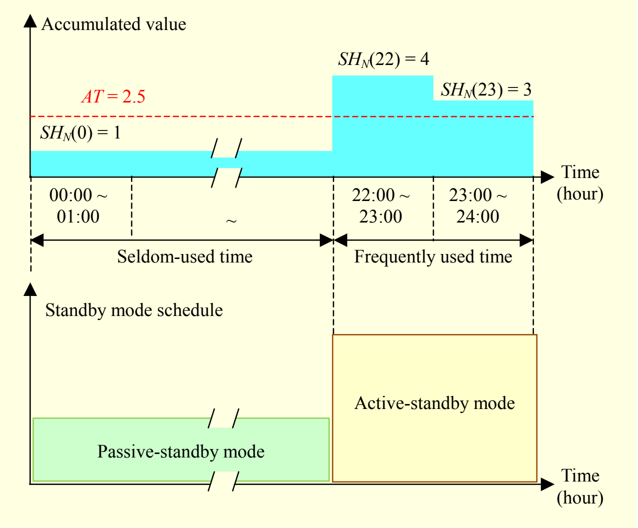


Fig. 5. Example of standby mode schedule when the history resolution is 60 min and the activation threshold is 2.5.

compares the activation threshold and accumulated values of the activation histories (SH_N), and then schedules the time for active- and passive-standby modes. By comparing the activation threshold and accumulated values, the set-top box can classify the frequently and seldom-used times. If the accumulated value is larger than the threshold, the time for the accumulated value is the frequently used time. If the accumulated value is less than the threshold, the time for the accumulated value is the seldom-used time. For the seldom-used time, the set-top box schedules passive-standby mode for reducing the standby power. For the frequently used time, the set-top box schedules active-standby mode for preparing the transition to on-mode and allowing it to be updated.

Figure 5 shows an example of the standby mode schedule when the history resolution is 60 min and the activation threshold (AT) is 2.5. The 22nd and 23rd accumulated values (that is, $SH_N(22)$ and $SH_N(23)$) are 4 and 3, respectively. In addition, $SH_N(22)$ and $SH_N(23)$ are larger than AT, and thus the time between 22:00 and 24:00 is the frequently used time period during which the set-top box schedules active-standby mode. For the other times, the set-top box schedules passive-standby mode.

3. Operation Mode Control

In step 3 of Fig. 3, the set-top box controls the operation mode using the signal inputs of an RCU and the standby mode schedule of step 2. When the set-top box receives an activation signal from an RCU, the set-top box changes its mode to on-mode, and the set-top box then operates in this mode until receiving a deactivation signal. After receiving a deactivation signal from the RCU, the set-top box operates in the standby mode scheduled in step 2.

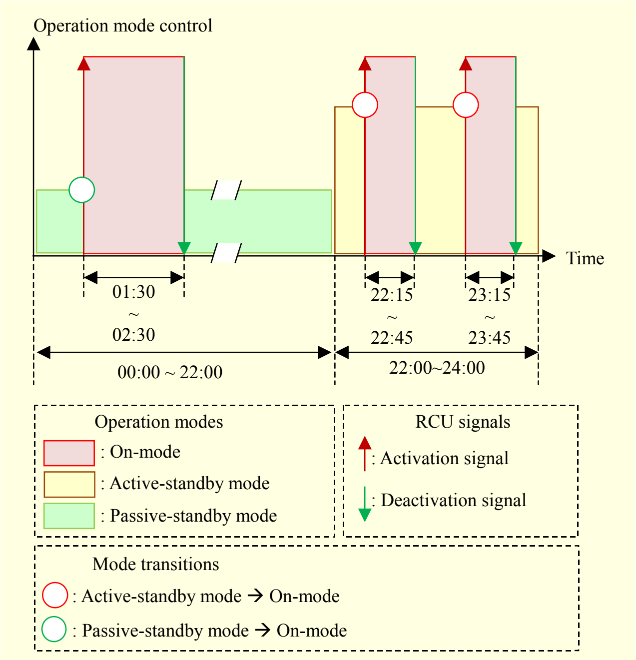


Fig. 6. Example of operation mode control.

In step 3, the set-top box also calculates the durations of active- and passive-standby modes, and the numbers of T5 and T6 transitions, which are described in Section II. The calculated durations are T_{AS} and T_{PS}, which indicate the durations of active- and passive-standby modes, respectively. The calculated numbers of mode transitions are N_{PO} and N_{AO}, which indicate, respectively, the numbers of T5 (transition from passive-standby mode to on-mode) and T6 (transition from active-standby mode to on-mode) transitions.

Figure 6 shows an example of the operation mode control. The set-top box begins operating in on-mode at 01:30, 22:15, and 23:15 by receiving an activation signal of an RCU, and begins to operate in the scheduled standby modes at 02:30, 22:45, and 23:45 by receiving the RCU's deactivation signal. In Fig. 6, TAS and TPS are 1 h and 21 h, respectively, and NAO and NPO are 2 and 1.

4. Adaptive Adjustment of Activation Threshold

In step 4 of Fig. 3, the set-top box adaptively adjusts its activation threshold for a tradeoff between the reductions of standby power and the activation latency. To reduce the standby power of the set-top box, T_{PS} needs to be increased. However, if T_{PS} increases, T_{AS} will decrease. In short, T_{AS} and N_{PO} tend to increase, and thus the activation latency of the set-top box may increase. Therefore, the set-top box requires a tradeoff between the reductions of the standby power and the activation latency by controlling T_{PS} and T_{AS}. To control T_{PS}

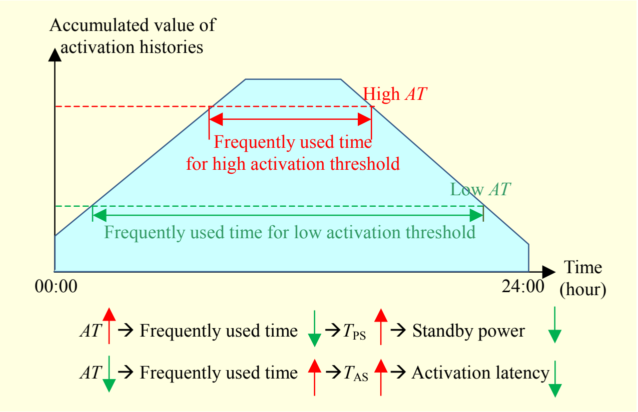


Fig. 7. Adjustment of activation threshold (AT) for tradeoff between standby power and activation latency.

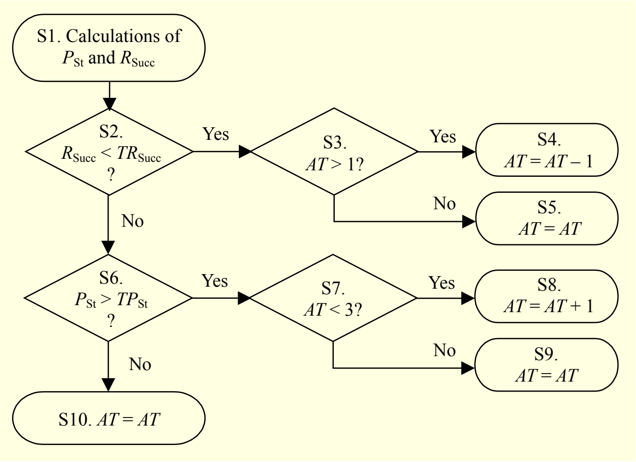


Fig. 8. Sequence for adjustment of AT.

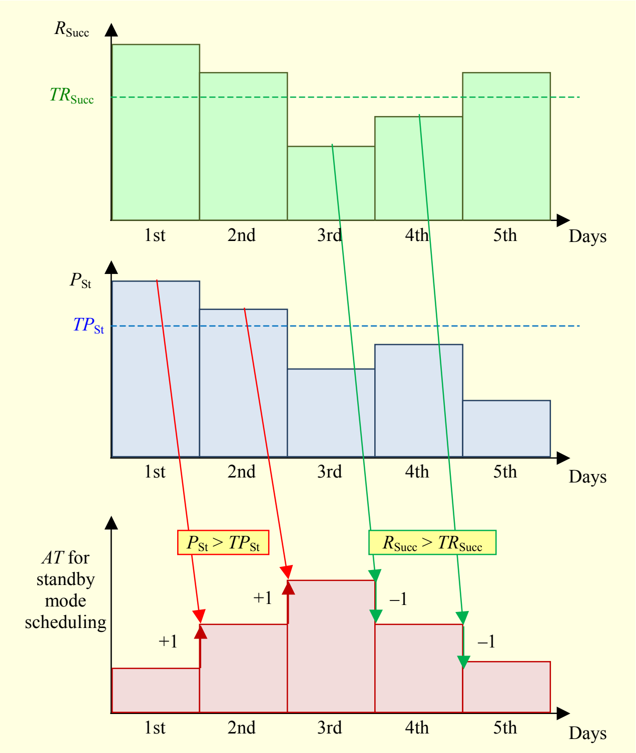


Fig. 9. Example of daily adjustment of AT.

and T_{AS}, an adjustment of the activation threshold is needed. As shown in Fig. 7, if the activation threshold (AT) increases, the amount of frequently used time decreases, T_{PS} increases, and the standby power can therefore decrease. If AT decreases, the frequently used time increases, T_{AS} increases, and thus the activation latency can decrease.

For the optimal activation threshold that can result in a tradeoff between the standby power and activation latency, the set-top box needs to calculate one day's worth of standby power (P_{St}) and the prediction success rate (R_{Succ}), which is related with the activation latency. Here, R_{Succ} indicates the probability of T6 (that is, the transition from active-standby mode to on-mode) during transitions to on-mode [13]. In addition, P_{St} and R_{Succ} can be calculated using T_{AS}, T_{PS}, N_{PO}, and N_{AO} in step 3, and P_{St} is calculated as

$$P_{St} = \frac{P_{AS}T_{AS} + P_{PS}T_{PS}}{T_{AS} + T_{PS}}, \tag{4}$$

where P_{AS} and P_{PS} are the power consumption of the set-top box in active- and passive-standby modes, respectively. Here, R_{Succ} is calculated as follows:

$$R_{Succ} = \frac{N_{AO}}{N_{AO} + N_{PO}}. \tag{5}$$

For example, P_{St} and R_{Succ} of the set-top box in Fig. 6 are $(P_{AS} + 21\,P_{PS})/22$ and 2/3, respectively.

In this paper, the set-top box has target values for the standby power and prediction success rate, and adjusts the activation threshold for achieving the target standby power (TP_{St}) and target prediction success rate (TR_{Succ}). Comparing the performances of the set-top box (P_{St} and R_{Succ}) and the target performances (TP_{St} and TR_{Succ}), the set-top box can adjust its activation threshold (AT). If the set-top box achieves a lower R_{Succ} than TR_{Succ}, it reduces its AT to increase R_{Succ}. In addition, if the set-top box achieves a higher P_{St} than TP_{St}, it increases its AT to reduce P_{St}.

Figure 8 shows a sequence for adjusting the AT of the set-top box. After the set-top box calculates its R_{Succ} and P_{St} (step S1), it compares its R_{Succ} with TR_{Succ} (step S2). If R_{Succ} is less than TR_{Succ} and AT is larger than 1 (step S3), the set-top box decreases AT (step S4). If R_{Succ} is not less than TR_{Succ}, the set-top box compares its P_{St} with TP_{St} (step S6). If P_{St} is less than TP_{St} and AT is less than 3 (step S7), the set-top box increases AT (step S8). In steps S5, S9, and S10, the set-top box does not increase or decrease its AT. The value of AT is between zero and 4.

The adjusted AT will be used for the standby mode scheduling of the next day. Figure 9 shows an example of a daily adjustment of AT. The set-top box has less R_{Succ} than TR_{Succ} on the third and fourth days, and thus the set-top box decreases AT for the standby mode scheduling of the fourth and fifth days. The set-top box has a larger P_{St} than TP_{St} on the first and second days, and thus the set-top box increases AT for the standby mode scheduling of the second and third days.

IV. Simulated Results of Adaptive Standby Mode Scheduling Method

This section shows the simulated results of the proposed adaptive standby mode scheduling method. For creating the general activation histories, we referred to the studies in [13], [16], and [17]. To acquire the general activation histories, we assumed that the set-top box transition to on-mode by following the rate of the switching-on events (that is, the set-top box's activation events caused by activation signals from RCU) in Fig. 10(a), and remains in on-mode during an average period of 1 h with an exponential distribution after activation [13]. Figure 10(b) shows simulated samples of the activation histories that are generated by the conditions of Fig. 10(a) and the exponentially distributed on-mode duration. The total simulation time is 1,000 days. The green bars in Fig. 10(b) indicate the operation of the set-top box in on-mode. Figure 10(c) shows the activation rate, and presents the normalized values of the accumulated activation histories.

We referred to our previous study [12] to acquire the power consumptions of the set-top boxes in passive- (P_{PS}) and active-standby modes (P_{AS}). In our previous work [12], we implemented a cable television (CATV) set-top box, where P_{PS} and P_{AS} of the CATV set-top box are 0.3 W and 10 W, respectively.

Under the conditions of the activation histories and power parameters, this section describes the set-top box's adaptive adjustment of AT and its effects on the standby power P_{St} and prediction success rate R_{Succ}. For the simulation, we set the history resolution to 60 min, TR_{Succ} to 0.9 W, and TP_{St} to 6 W. The set-top box sets the initial value of AT to 0.5 W. Figure 11 shows the relationship among R_{Succ}, P_{St}, and the adjustment of AT under the history resolution, against that of TR_{Succ}, TP_{St}, and the initial AT.

As shown in the simulation results of Fig. 11, the set-top box can obtain an average R_{Succ} of 0.9200 W and average P_{St} of 6.1506 W. These performances are attributed to the adaptive adjustment of AT, as shown in Fig. 11(c). To investigate the effects of the AT adjustment, this paper focuses on R_{Succ}, P_{St}, and AT from the 490th day to the 500th day. On the 494th, 495th, 497th, and 498th days, R_{Succ} is less than TR_{Succ}. The set-top box reduces its AT on the 495th, 496th, 498th, and 499th days, and thus can increase R_{Succ} on the 497th and 499th days. On the 490th, 491st, 493rd, 496th, and 499th days, P_{St} is larger than TP_{St}. The set-top box increases AT on the 491st, 493rd, and 496th days, and can thus reduce P_{St} on the 492nd, 494th, 497th, and 500th days.

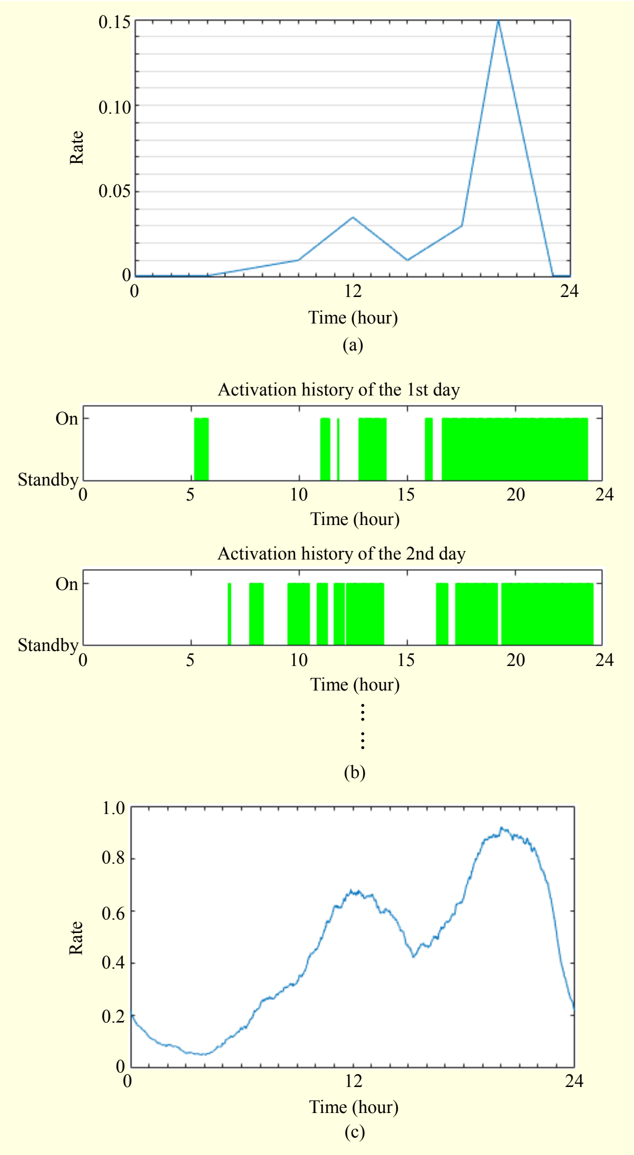
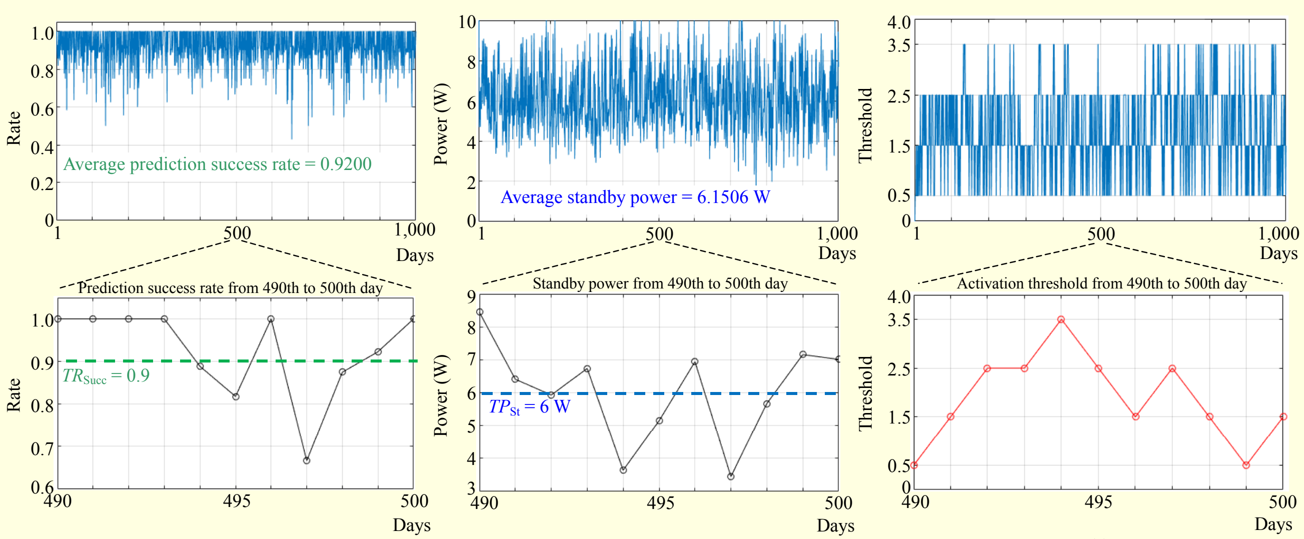


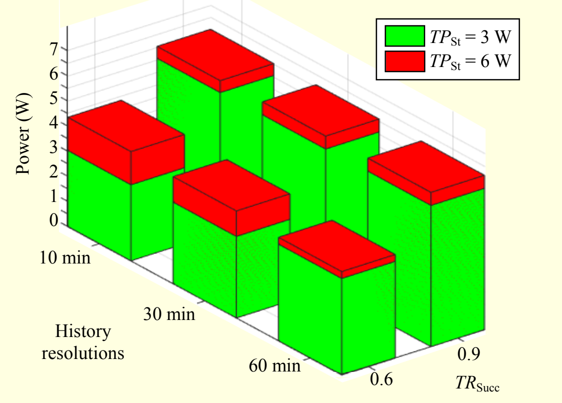
Fig. 10. Descriptions of the general activation histories in the simulations [13], [16], [17]: (a) switching-on event rate with 1-min granularity, (b) samples of the activation histories, and (c) activation rate of the activation histories.

We also conducted simulations by changing TR_{Succ}, TP_{St}, and the history resolutions, and compared R_{Succ} and P_{St} of the simulations, as shown in Figs. 12 and 13. For the simulations, we set 6 W and 3 W for TP_{St}, which are 60% and 30% of the power consumption of the set-top box in active-standby mode. The proposed set-top box also sets 10 min, 30 min, and 60 min



(a) (b) (c)

Fig. 11. Simulation of the set-top box using the proposed method for a history resolution of 60 min, TR_{Succ} of 0.9, TP_{St} of 6 W, and the initial AT of 0.5: (a) prediction success rate (R_{Suc}), (b) standby power (P_{St}), and activation threshold (AT).

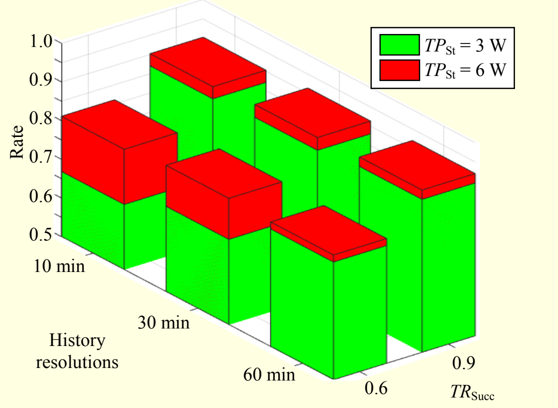


(a)

TR_{Succ} = 0.6			TR_{Succ} = 0.9		
TP_{St}	History resolutions	P_{St}	TP_{St}	History resolutions	P_{St}
3 W	10 min	3.0296 W	3 W	10 min	5.5670 W
	30 min	3.2515 W		30 min	5.5971 W
	60 min	3.8566 W		60 min	5.6307 W
6 W	10 min	4.3525 W	6 W	10 min	6.0416 W
	30 min	4.2682 W		30 min	6.1123 W
	60 min	4.1303 W		60 min	6.1506 W

(b)

Fig. 12. Average standby power (P_{St}): (a) graph and (b) values of P_{St} depending on TP_{Succ}, TP_{St}, and history resolutions.



(a)

TR_{Succ} = 0.6			TR_{Succ} = 0.9		
TP_{St}	History resolutions	R_{Succ}	TP_{St}	History resolutions	R_{Succ}
3 W	10 min	0.6687	3 W	10 min	0.8707
	30 min	0.7210		30 min	0.8802
	60 min	0.8050		60 min	0.8958
6 W	10 min	0.8113	6 W	10 min	0.9021
	30 min	0.8271		30 min	0.9132
	60 min	0.8231		60 min	0.9200

(b)

Fig. 13. Average prediction success rate (R_{Succ}): (a) graph and (b) values of R_{Succ} depending on TP_{Succ}, TP_{St}, and history resolutions.

for the history resolutions.

Figure 12 shows the simulation results for the average standby power (P_{St}). Here, TR_{Succ} is the most important parameter for controlling the standby power. When TR_{Succ} is 0.6, the set-top box consumes a low P_{St} that ranges from 3.0296 W to 4.3525 W.

In contrast, when TR_{Succ} is 0.9, the set-top box consumes a relatively high P_{St} that ranges from 5.5670 W to 6.1506 W. Moreover, if TR_{Succ} and TP_{St} are 0.6 W and 3 W, respectively, P_{St} varies from 3.0296 W to 3.8566 W. This shows that the low target prediction success rate (0.6) and low target standby power (3 W) enable the set-top box to consume low standby power.

Figure 13 shows the simulation results for the average prediction success rate (R_{Succ}). Here, TR_{Succ} is the most important parameter for controlling the prediction success rate. When TR_{Succ} is 0.6, the set-top box has a relatively low R_{Succ}, which ranges from 0.6687 to 0.8271. In contrast, when TR_{Succ} is 0.9, the set-top box has a relatively high R_{Succ}, which ranges from 0.8707 to 0.9200. Moreover, if TR_{Succ} and TP_{St} are 0.6 W and 3 W, respectively, R_{Succ} varies from 0.6687 to 0.8050. This shows that the low target prediction success rate (0.6) and low target standby power (3 W) reduces the prediction success rate of the set-top box.

The high prediction success rate leads to an improved user experience, which includes short activation latency and an update of a low-power set-top box. The high prediction success rate indicates that the set-top box can predict the frequently used time precisely. Therefore, as shown in Fig. 1, before users activate a set-top box, the set-top box operates in active-standby mode, prepares a full activation, and updates its EPG, software, and firmware. The proposed method enables the set-top box to be fully activated within a short time and the users to utilize the newly updated set-top box.

The prediction rate can be used for calculating the average activation latency (AL). If T_{AO} is the time required for the set-top box to transition from active-standby mode to on-mode, and T_{PO} is the time required for the set-top box to transition from passive-standby mode to on-mode, AL can be calculated as follows:

$$AL = T_{\mathrm{AO}} R_{\mathrm{Succ}} + T_{\mathrm{PO}}(1 - R_{\mathrm{Succ}}) . \tag{6}$$

Here, T_{AO} is less than T_{PO}, and thus a large R_{Succ} leads to a reduction in AL of the low-power set-top box. In the simulation of this paper, the maximum AL is given by

$$\text{Maximum } AL = 0.6687 T_{\mathrm{AO}} + 0.3313 T_{\mathrm{PO}} , \tag{7}$$

where R_{Succ} is 0.6687. The minimum AL is given by

$$\text{minimum } AL = 0.92 T_{\mathrm{AO}} + 0.08 T_{\mathrm{PO}} , \tag{8}$$

where R_{Succ} is 0.9200. In addition, T_{AO} is about 4 s, and T_{PO} varies depending on use of the STR method [15]. While T_{PO} of a set-top box without an STR is dozens of seconds (that is, about 30 s), T_{PO} of a set-top box with an STR is about 7 s [12]. Therefore, using (7) and (8), the AL of a set-top box without an STR ranges from 6.08 s to 12.61 s, and the AL of the set-top box with an STR can be calculated as a value ranging from 4.24 s to 4.99 s.

Table 2 shows comparisons of methods for saving the standby power of a set-top box. A set-top box using an adaptive standby mode scheduling method improves the user experience compared to a set-top box in passive-standby mode, and consumes less standby power than a set-top box in active-standby mode. The set-top box can be updated during a standby state by entering active-standby mode before the user activates it. It can also reduce its AL to 6.08 s without an STR method, and to 4.24 s with an STR method. Its P_{St} ranges from 3.03 (30.3% for a set-top box in active-standby mode) to 6.15 W (61.5% for a set-top box in active-standby mode). Passive-standby mode with an STR may be helpful to reduce P_{St} (0.3 W) and AL (7 s). However, set-top box service providers do not want set-top boxes in a standby state to operate only in passive-standby mode because the service providers cannot update the-set top boxes in this mode. A set-top box with adaptive standby mode scheduling meets the requirements of users and set-top box service providers, and will thus be welcomed by set-top box manufacturers.

Table 2. Comparisons of methods for saving standby power [12], [13].

	Update in a standby state	AL	Standby power (P_{St})
Adaptive standby mode scheduling	○ (update before a set-top box is activated)	• AL without STR: 6.08 s to 12.61 s • AL with STR: 4.24 to 4.99 s	3.03 W to 6.15 W
Passive-standby mode	× (network interfaces are deactivated)	• T_{PO} without STR: about 30 s (dozens of seconds) • T_{PO} with STR: 7 s	0.3 W
Active-standby mode	○ (update during standby state)	• T_{AO}: 4 s	10 W

V. Conclusion

We proposed an adaptive standby mode scheduling method based on an activation pattern analysis for improving the user experience of low-power set-top boxes equipped with passive-standby mode. A set-top box utilizing the proposed method analyzes its activation pattern by accumulating its activation histories. The set-top box can schedule its standby modes adaptively by following changes in the activation patterns. Through simulations, we proved that the proposed method is effective for a low-power set-top box to reduce its activation latency and be updated. In addition, the simulated results also indicate the need for finding the target performances (TP_{St} and TR_{Succ}) to support the optimal tradeoff between standby power and the prediction success rate. Future work will be conducted to find the target performances for supporting the optimal tradeoff between standby power and the prediction success rate.

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