Low Power Device Configuration Based On Battery Discharge Measurement

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Low Power Device Configuration Based On Battery Discharge Measurement

ABSTRACT

This disclosure describes techniques for the selection of suitable power-saving states when a device is placed in idle mode for an extended period of time. The device is placed in a low power state based on a comparison of the state of charge of the device battery with autonomously determined thresholds. The thresholds are determined based on battery discharge rates for various power-saving states. A remaining battery capacity at a time of entry into cutoff state or hibernation state and at a time of wake-up from the respective state is sampled by an embedded controller (EC) and stored in non-volatile (NV) memory. At a time of entry into a low power state, the time of entry is recorded by the application processor and/or the EC. Upon a time of wake-up from the low power state, a device real time clock (RTC) is synchronized with a network time in order to record a time of wake-up and determine an elapsed time.

KEYWORDS

- Battery Management
- Battery life
- Hibernate
- Embedded controller (EC)
- State of charge (SoC)
- Discharge rate
- Stay-up threshold
- Cut-off threshold
- Duration to survive (DTS)
BACKGROUND

Rechargeable batteries in portable computing devices such as laptops, mobile phones, etc. can be damaged permanently and become unrecoverable when completely drained. Power-saving states are utilized for power conservation and to prevent battery damage when a device is placed in idle mode for an extended period of time. In some power-saving states, an embedded controller (EC) is utilized to monitor a battery state of charge (SoC) and to electrically disconnect a battery upon detection of a battery charge state that is critically low to prevent permanent battery damage. However, in some other power-saving states such as cutoff and hibernation states, computing devices are placed in a state in which hardware components including the EC are shut down to conserve power and prolong battery life. Hibernation states are effective for computing devices that are in relatively frequent use, e.g., at least once a day, at least once a week, etc.

However, some computing devices can remain in a state of hibernation for a relatively long period. For example, laptop computers used in schools can be placed in hibernate mode at the beginning of the summer break and can stay in that state until the school reopens.

DESCRIPTION

This disclosure describes techniques to predict a duration of remaining battery life for a computing device battery when the computing device is placed in a cutoff state or a hibernation state. The prediction of expected battery life duration is based on a remaining battery capacity or battery state of charge (SOC) and respective battery discharge rates measured when the computing device is in the cutoff or hibernation state. The predicted duration is utilized to dynamically adjust thresholds that are used to determine a suitable power-saving state when the computing device enters an idle mode for an extended time period.
Per techniques of this disclosure, a device is placed in a suitable power-saving state based on a comparison of the state of charge (SoC) of the device battery with a stay-up threshold and a battery cut-off threshold. The thresholds are autonomously determined and adjusted by the device based on measured battery discharge rates for the respective power-saving states.

The power-saving state is selected such that the battery state of charge does not fall to a critical battery state for at least a specified period - duration to survive (DTS) - that the device may continue to remain in the idle state. The selected power-saving state is device-dependent and based on specific device capabilities and configuration.

![Battery state of charge (SoC) is divided into zones based on a prediction model](image)

**Fig. 1: Battery state of charge (SoC) is divided into zones based on a prediction model**

Fig. 1 depicts example zones utilized to characterize a battery state of charge based on a prediction model, per techniques of this disclosure. The prediction model is parameterized by a stay-up threshold $X_2$ and a battery cut-off threshold $X_1$. As depicted in Fig. 1, $X_F$ represents a 100% state of charge (e.g., full battery) and $X_0$ represents a 0% state of charge, a completely drained battery. Between the states of 100% SoC and 0% SoC, the SoC is divided into three zones (cutoff zone, warning zone, and safe zone, as seen in Fig. 1) by the stay-up threshold $X_2$ and the battery cut-off threshold $X_1$.

When a device enters an idle state in a safe zone (e.g., with a SoC value that is between $X_2$ and $X_F$), it is determined that the battery SoC is sufficient for the device to last more than an
expected DTS. The device is placed in a safe zone state, where the SoC is not monitored by an embedded controller (EC). For most devices, a hibernation state is utilized as the safe zone state.

When a device enters an idle state in a warning zone (e.g., with a SoC value between \( X_1 \) and \( X_2 \)), a warning zone state is selected whereby the EC monitors the battery SoC continuously or periodically. The warning zone state can be an S5 power-saving state wherein the battery SoC can be monitored by the EC. In devices that support a hibernation state where the EC can be activated by a timer periodically to monitor the SoC, such hibernation state is utilized.

When a device enters an idle state in a cutoff zone (e.g., with a SoC value between \( X_0 \) and \( X_1 \)), the device is placed in a battery cutoff state immediately after the execution of essential device tasks prior to disconnection of the battery.

![Diagram](https://www.tdcommons.org/dpubs_series/3650)

**Fig. 2: Selection of a suitable low power state based on battery state of charge**
Fig. 2 illustrates a flowchart of an example method for prediction of battery discharge rates in cutoff and hibernation states and selection of a suitable low power state for a battery-powered device, per techniques of this disclosure. It is detected that a computing device has entered an idle state (210). A battery cut-off threshold $X_1$ and a stay-up threshold $X_2$ are obtained (215). For example, the $X_2$ threshold can be determined based on the measured discharge characteristics of the battery and an expected period of disuse of the computing device.

The battery state of charge is measured (220). The battery SoC is compared (230) to the $X_2$ threshold. Based on the comparison, if the battery SoC meets the $X_2$ threshold, the computing device is placed in a safe zone state (240). For most devices, the safe zone state is a state of hibernation where the EC is shut down to conserve power. A battery capacity level at a time of the being placed in the safe zone state is recorded. Upon a subsequent wake-up of the device, the battery capacity is again measured and battery discharge rate in the safe zone state is determined (255) and the thresholds are updated (260).

If the battery state of charge does not meet the $X_2$ threshold, the computing device is placed into a warning zone state (250). As described earlier, the warning zone state is device specific and can be a hibernation state or a similar power state, as long as the battery SoC can be monitored. Periodically, the SoC is compared to a battery critical level (270). If the battery state of charge falls below the battery critical level, the battery is disconnected and the computing device is shut off (280) to prevent permanent battery damage.

A battery capacity level at a time of being placed in the warning zone state is recorded and subsequently utilized upon the next wake-up of the device to update the thresholds.
Table 1: Battery discharge rates are computed during cutoff and hibernation states

Table 1 includes example parameters utilized to determine the battery discharge rate when a computing device is placed in cutoff and hibernation states. The battery discharge rate (mAh/h) is based on a measured drop in battery capacity over a period of time (elapsed time). Battery capacity (mAh) at a time of entry into cutoff state or hibernation state and at a time of wake-up from the respective state is sampled by the EC and is stored in non-volatile (NV) memory.

At a time of entry into a cutoff or hibernation state, the time of entry is recorded by the application processor and/or the EC. Upon a time of wake-up from the cutoff or hibernation state, a device real time clock (RTC) is synchronized with a network time in order to record a time of wake-up and determine an elapsed time. This may be necessary, particularly during cutoff, since on many devices, the RTC is powered off during the time the device is in cutoff state. In devices where the RTC is powered on during cutoff, the time of wake-up can be directly obtained by the EC without a need for network synchronization.
The change in battery capacity upon entry and wake-up from a hibernation or cutoff state and the duration of time the device was placed in the respective state are utilized to determine the battery discharge rates and to update the $X_1$ and $X_2$ thresholds.

Dynamic adjustment of the $X_1$ and $X_2$ thresholds by utilizing measured battery discharge rates as described herein can improve prediction model performance for subsequent instances when the computing device is left idle since battery discharge rates are affected by factors such as operating temperature, battery age, battery charge cycle count, etc. Dynamically determining the thresholds based on measured battery discharge rates can provide more accurate results when compared to utilizing a fixed value for all devices.

CONCLUSION

This disclosure describes techniques for the selection of suitable power-saving states when a device is placed in idle mode. The device is placed in a low power state based on a comparison of the state of charge of the device battery with autonomously determined thresholds. The thresholds are determined based on battery discharge rates for various power-saving states. A battery capacity at a time of entry into cutoff state or hibernation state and a time of wake-up from the respective state is sampled by an embedded controller (EC) and stored in non-volatile (NV) memory. At a time of entry into a low power state, the time of entry is recorded by the application processor and/or the EC. Upon a time of wake-up from the low power state, a device real time clock (RTC) is synchronized with a network time in order to record a time of wake-up and determine an elapsed time.
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