The Power Management Model for Hitachi 32-bit CPU Based Handheld PC “Himalia”

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ABSTRACT

This paper proposes a state transition model for the power consumption estimation of the handheld computer “Himalia”, which can receive information from networks sporadically. To process intermittently arriving information under a certain throughput, we need a power management mechanism that can control some modules of handheld computers on and off to save power consumption. The power saving is possible due to the existence of the “sleep” and “suspend” states of handheld computers. From the state probability transition of the state transition diagram for a tri-state power managed mechanism of the platform “Himalia”, we obtain the state probabilities of “sleep”, “suspend” and “normal” states, respectively, and obtain the average power consumption which is lower than the same platform without power management mechanism. We also provide an estimate bound for the power consumption based on the tri-state power managed mechanism. The estimation also shows that the tri-state design can save 50% of power consumption at the homogeneous machine state probability.

Keywords: power management, power consumption, handheld computer, state probability.

1. Introduction

Recently, research has been done on power management in handheld computers at different levels of computing systems [1-3]. The purpose of power management is to save power consumption for extending the recharge period of handheld computers. Obviously, for mobile users, the longer the recharge period in a mobile computer, the more convenient its operation [4,5]. Usually, the power management mechanism of the handheld computer can detect the machine status and decide if the system is in “idle state” or “busy state”. During idle state, the system can turn off some subsystems in order to save power consumption.

Traditionally a handheld computer can switch the machine states based on a timing counter [6]. When the counter counts to a preset value, the machine will decide that the state should be switched in order to save power consumption. Recent handheld computers can switch the machine states based on event driven. When an event happens, the machine decides which state should be switched to. A couple of methods have been proposed, including stochastic prediction methods equipped with power management mechanism [7-10]. Most of the power management methods provide a couple of machine states with specific ratio of computing performance and power consumption. Usually, one low power machine state will be designed in order to save power consumption. But, more machine states can provide a better scalable ratio of computing performance and power consumption. In other words, if a machine has more states, it can have more potential in saving power consumption. In this paper we propose the handheld computer with three machine states as an example of having a better potential in power saving in comparison with one and two machine states, based on the homogeneous probability distribution of machine states [11-15].

The rest of this paper is organized as follows. In section 2, we discuss the state probability distribution of a typical handheld computer. In section 3, we present the average power consumption of a handheld computer and show some special cases in which we can succeed in power consumption saving. In section 4, we show the power managed circuits and their latency. The last section draws some conclusions.

2. The State Probability

In a mobile computing environment, the users issue the commands to the handheld computer intermittently and the computer receives information sporadically from networks. Besides, a handheld computer has to provide enough information processing power to meet the specification requirement of a certain application. To save power consumption and fulfill this requirement, often, there is a power management mechanism in the handheld computer. Commonly, there exists a few machine states such as: normal, sleep, suspend and no power state

[14,15].

Usually, handheld computers work in the normal state. Their states can be transferred between run state and sleep state, depending on software implementation and operation characteristics. While the application software is not using some hardware modules or is waiting for some hardware event to happen, it is possible to switch these hardware modules into standby mode. Later, these hardware modules can be waken up by an event trigger. Module sleep state will return to system run state when the pre-defined system events appear or specific situation such as, power failure. When the system detects the main power supply is not available or a low battery alarm, the system should stop all application executions and turn off possible hardware modules to ensure system information saved by limited power resources.

The handheld computer will switch into the suspend state when the system power is available for first time. If the main power is removed, the system will be turned off. While the machine states of a handheld computer go into system suspend state, all system modules will stay in the standby mode with a very low power consumption. The last machine state is a zero power state with neither backup battery nor main battery or AC adapter being available in this system. New machines or accidental removal of the battery will force the system into this state.

In a typical design, the working situation of a handheld computer, usually depends on the information or task arriving patterns which can be a Poisson distribution based on the random combination of transmission characteristics of computer networks or the random characteristics of user operation patterns. From the definition of the Poisson arrival process, we learn the probability of K arrivals in an interval T sec. is as follows:

$$P(k) = P(K \text{ arrivals in T sec.}) = \frac{(\lambda \mathrm{T})^{k} e^{-\lambda T}}{\mathrm{K}!} \qquad (1)$$

K=1,2,3,4,…, λ : the average task arrival rate

For example, from equation(1), we assume λT=1 , then $P(0)$=0.38, $P(1)$=0.18, $P(0)$=0.38 means the probability of no task arrived in T sec. At that interval T, we can turn off some modules in order to save power consumption.

The average and variance of task or packet arrival in the interval T are given as

$$E(K) = \sum_{K=0}^{\infty} KP(K) = \lambda \mathrm{T} \qquad (2)$$

The variance

$$\sigma_K^2 = E[K - E(K)]^2 = E(K^2) - E^2(K) = E(K) = \lambda \mathrm{T} \qquad (3)$$

Equations (2) and (3) will eventually effect the power consumption of the receiver module. These arrival characteristics also effect the state probability of machine operation that provide a guideline for managing the power consumption.

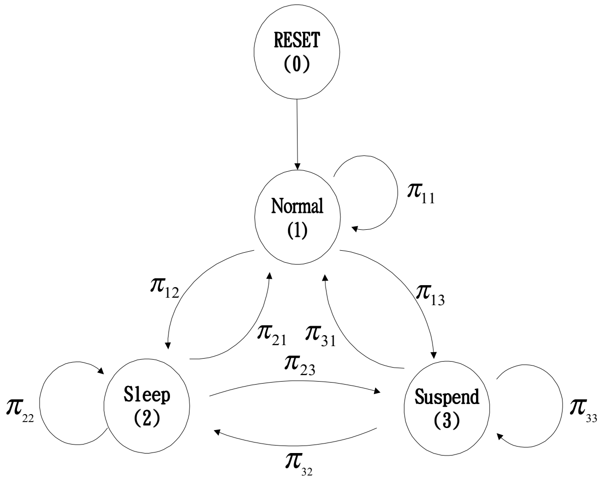


Fig 1. The state transition diagram of Hitachi 32-bit handheld PC.

Figure 1 shows the state transition diagram of Hitachi 32-bit handheld PC with three machine operation states. π_{ij} represents the state transition ratio from state i to state j. In case of a stationary, non-time-varying system, the balance equation for each state of Figure 1 can be shown as follows:

$$\text{State 1}: P_1(\pi_{12} + \pi_{13}) = P_2\pi_{21} + P_3\pi_{31} \qquad (4)$$

$$\text{State 2}: P_2(\pi_{21} + \pi_{23}) = P_1\pi_{12} + P_3\pi_{31} \qquad (5)$$

$$\text{State 3}: P_3(\pi_{31} + \pi_{32}) = P_1\pi_{13} + P_2\pi_{23} \qquad (6)$$

$$0 \le \pi_{ij} \le 1$$

$$P_1 + P_2 + P_3 = 1 \qquad (7)$$

The exact solutions for the state probability of Figure 1 are shown in equations (8) to (11)

$$P_1 = \frac{\pi_{21}\pi_{31} + \pi_{21}\pi_{32} + \pi_{23}\pi_{31}}{\pi_{21}\pi_{31} + \pi_{21}\pi_{32} + \pi_{23}\pi_{31} + \pi_{12}\pi_{31} + \pi_{12}\pi_{32} + \pi_{13}\pi_{32} + \pi_{12}\pi_{23} + \pi_{13}\pi_{21} + \pi_{13}\pi_{23}} \qquad (8)$$

$$P_2 = \frac{\pi_{12}\pi_{31} + \pi_{12}\pi_{32} + \pi_{13}\pi_{32}}{\pi_{21}\pi_{31} + \pi_{21}\pi_{32} + \pi_{23}\pi_{31} + \pi_{12}\pi_{31} + \pi_{12}\pi_{32} + \pi_{13}\pi_{32} + \pi_{12}\pi_{23} + \pi_{13}\pi_{21} + \pi_{13}\pi_{23}} \qquad (9)$$

$$P_3 = \frac{\pi_{12}\pi_{23} + \pi_{13}\pi_{21} + \pi_{13}\pi_{23}}{\pi_{21}\pi_{31} + \pi_{21}\pi_{32} + \pi_{23}\pi_{31} + \pi_{12}\pi_{31} + \pi_{12}\pi_{32} + \pi_{13}\pi_{32} + \pi_{12}\pi_{23} + \pi_{13}\pi_{21} + \pi_{13}\pi_{23}} \qquad (10)$$

3. Average Power Consumption

The exact solutions, equations (8) to (10) are very complicated in terms of real algebra representation. To simplify the explanation, we discuss three typical cases.

Case 1.

If the state transition ratio between states are all equal, i.e.,

$$\pi_{11} = \pi_{22} = \pi_{33} = \pi_{12} = \pi_{21} = \pi_{32} = \pi_{23} = \pi_{13} = \pi_{31} = \frac{1}{3}$$

Then from equation (8) to 10 we have

$$P_1 = P_2 = P_3 = 1/3 \qquad (11)$$

With this set of state probability, the average power consumption $POWER_{average}$ can be represented as the weighted summation of power consumption of each machine state as shown in equation (12)

$$\begin{aligned} POWER_{average} &= P_1 \cdot POWER_{normal} + P_2 \cdot POWER_{sleep} \\ &\quad + P_3 \cdot POWER_{suspend} + POWER_{extra} \end{aligned} \qquad (12)$$

where

$$POWER_{normal} \approx 100\,\% \qquad POWER_{sleep} \approx 50\,\%$$
$$POWER_{suspend} \approx 0.05\,\% \qquad POWER_{extra} \approx 0\%$$

$$POWER_{average} \approx \frac{1}{3} \cdot 100\% + \frac{1}{3} \cdot 50\% + \frac{1}{3} \cdot 0.05\% \approx 50\% \qquad (13)$$

Equation (13) shows that, when the task arrival is equal to 1/3 in the time interval T sec., about 50% of the average power consumption can be saved.

Case 2.

If the palmtop computer is operated in a very busy situation, the task arrival probability will be close to 1. The machine state of the handheld computer is almost in the "normal state", hence, there is no power saving in this case.

$$P_1 \approx 1, P_2 \approx P_3 \approx 0,$$

POWER $_{average}$ in equation (12) can be simplified

$$POWER_{average} = 1 \cdot (100\%) + 0 \cdot (50\%) + 0 \cdot (0.05\%) \qquad (14)$$

Case 3.

If the task arrival probability is smaller than 1/3, the machine state of the palmtop computer often is in the "sleep" and "suspend" states. Hence, the average power consumption can be saved with an amount between cases 1 and 2.

To examine the overall characteristics of the average power consumption, we can rewrite Equation (7) and obtain Equation (15). Hence, by combining Equation (12) and (15), we can obtain Equation (16)

$$P_3 = 1 - P_1 - P_2 \qquad (15)$$

$$\begin{aligned} \mathrm{POWER}_{\mathrm{average}} &= P_1 \cdot POWER_{normal} + P_2 \cdot POWER_{sleep} \\ &\quad + (1-P_1-P_2) \cdot POWER_{suspend} + POWER_{extra} \end{aligned} \qquad (16)$$

If we use the conditions of Equation (12), we can obtain Equation (16) and (17). Their 3D figure is shown in Figure 2. Point B in Figure 2 is the situation case 2 that we discussed previously. In this case, the handheld computer is operated in very busy situation, then the probability of "normal state" is equal to 1 and there is no power saving at this operation situation. In addition, Point A in Fig. 2 represents the machine staying in sleep state which can have 50% potential power reduction. Overall, the plane on the triangular ABC represents the average power consumption $POWER_{average}$ which is smaller than the power consumption without power management shown in Equation (17).

$$\begin{aligned} \mathrm{POWER}_{\mathrm{average}} &\le \mathrm{POWER}_{\mathrm{normal}} \\ &= \mathrm{POWER}_{\mathrm{without\ power\ management}} \end{aligned} \qquad (17)$$

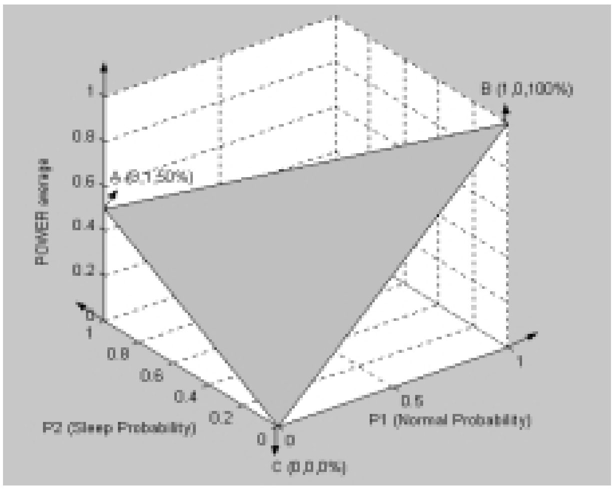


Fig 2. The average power consumption of the tri-state power management model

4. The Power Managed Circuits

The Hitachi handheld computer, Himalia, supports several wakeup events to the system run state from suspend state, including: dedicated keypad press event, internal PS/2 pointing data receive, cover lid operation, modern ring detection and power switch input. When the system is off and the main battery (smart battery) retains power, all of the system device modules stay in the standby mode. Power management unit is able to wake the system up by receiving the above wakeup event sources. To fulfill the wake up function or state transition mechanism, a typical power managed circuit will be designed. First, we simplify and redraw Fig.1 with the event input and state assignment S_1, S_2 and S_3.

From state transition diagram in Figure 3, we derive the state table as shown in Table 1. With state encoding, $S_0 = 00$, $S_1 = 01$, $S_2 = 10$ and $S_3 = 11$, we can obtain the state table as shown in Table 2 with the state codes assigned.

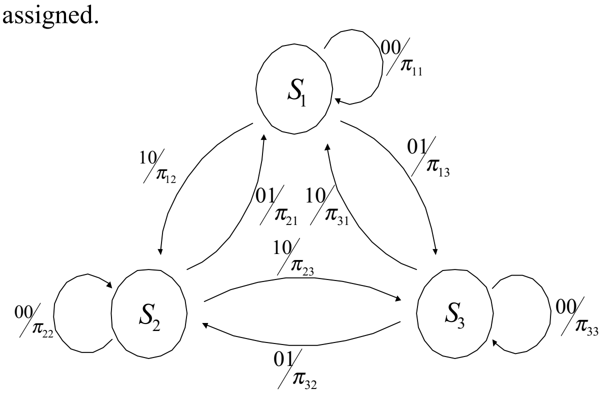


Fig 3. The state transition diagram with the even inputs

Table1. State table for the tri-state machine

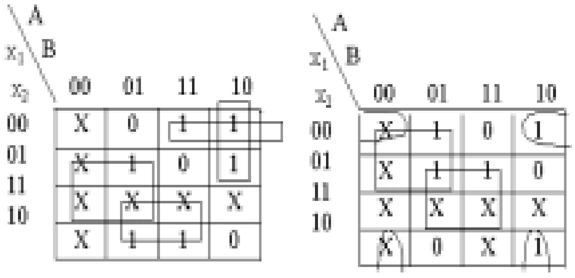
Present State	Next State			
	Input 00	Input 01	Input 10	Input 11
S_0	×	×	×	×
S_1	S_1	S_3	S_2	×
S_2	S_2	S_1	S_3	×
S_3	S_3	S_2	S_1	×

Table2. State table with state encoding for the tri-state machine

Present State		Next State A B							
		Input 00		Input 01		Input 10		Input 11	
A	B								
0	0	×	×	×	×	×	×	×	×
0	1	0	1	1	1	1	0	×	×
1	0	1	0	0	1	1	1	×	×
1	1	1	1	1	0	0	1	×	×

By using the logic design procedure, the flip-flop input equations are obtained from the next-state values as listed in Table2. They are simplified by means of the plot in Figure 4.

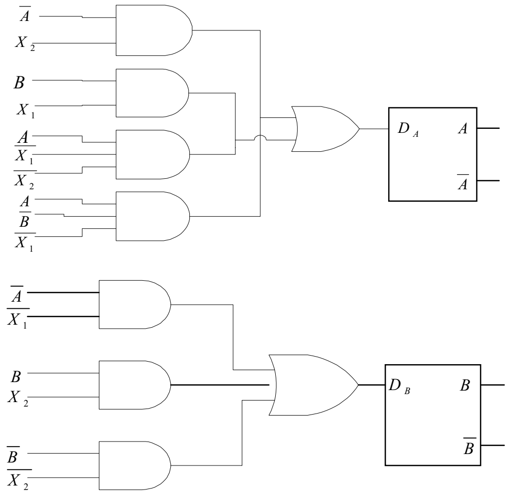
$$D_A = \bar{A}X_2 + BX_1 + A\overline{X_1}\,\overline{X_2} \qquad D_B = \bar{A}\overline{X_1} + BX_2 + \bar{B}\overline{X_2} + A\bar{B}\overline{X_1}$$



x_1x_2 \ AB	00	01	11	10
00	X	0	1	1
01	X	1	0	1
11	X	X	X	X
10	X	1	1	0

x_1x_2 \ AB	00	01	11	10
00	X	1	0	1
01	X	1	1	0
11	X	X	X	X
10	X	0	X	1

Fig 4. Maps for input equations of the power managed circuits



X_1, X_2 : task arrival

Fig 5. Logic diagram for the power managed circuit of the tri-state machine

Fig. 5 is a single layer D-type flip-flop implementation for the power managed circuit of the tri-state machine, the circuit has only one clock cycle latency and very limited power consumption in comparison with the power that we can save by turning off some subsystems.

5. Conclusion

This paper has presented a tri-state power management model for a Hitachi handheld computer. Due to the information arriving sporadically from a mobile network, providing the reasonable state transition probability, the state probability of a handheld computer shows the system can stay in “sleep”, “suspend” and “normal” states. Usually, the system can turn off modules during “sleep” state and “suspend” state in order to save power consumption. In a tri-state machine design, for the state transition probability value of 1/3, we can have the potential to 50% power saving due to the state probability being 1/3. To fulfill the state transition mechanism of the tri-state machine, we also provide a single layer D-type flip-flop design for the power managed circuit with a minor increase in latency and power consumption.

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