Network Protocol based Power Management Architecture and Method in Always-On Home-Network devices

Chang-Sic Choi[1], Wan-Ki Park[2], and Kwang-Roh Park[3]
U-computing Research Department, ETRI
138 Gajeongno, Yuseong-gu, Daejeon, Korea
E-mail: [1]cschoi@etri.re.kr, [2]wkpark@etri.re.kr, [2]krpark@etri.re.kr

Abstract: Aggregated power consumption of home-network devices such as home-gateway, home-server, set-top box is rapidly increased because these devices are operated in powered-on state to support anyone, anywhere, anytime services. But power utilization of these devices is very low because there is much idle time under powered-on state. To reduce the overall power consumption in home-network, we are developing power-controlled home-gateway which could be changed to standby-state when there are no actvie services and traffics.

In this papare, we propose network-protocol based power management method and its architecture for our developing home-gateway. Proposed method maintains network informtion database at normal state, and set home-gateway into standby-state without loss of network connections or working contexts. Thus our proposed method and developing home-gateway can save power consumption dramatically in always-on home-network environments..

1. Introduction

In these days, more and more homes have high-speed internet connection through home-gateway or home-server and more household devices use the internet services at anytime. To support instantly internet services, the home-gateway is operated in always-on-state and most of the power consumption is wasted during idle times. Also there has been a great deal of work done on the design of power management technologies for PC (Personal Computer), Printer, Monitor and Mobile equipments [1]. Although these technologies cover wide range of hardware, bios, OS(Operating System), and application layers, but the power management technologies (such as ACPI) are not implemented on home-network environment.

Normally home-network devices such as home-gateway or home-server consume lower power than PC, Monitor, television, etc. But it's always power-on property results more wasted power consumptions [2]. To save power consumption for such a long-term and low-utilized network devices, we are developing power-controlled home-gateway system. Our method also could be applicable to home-server, set-top box, and the other networked household devices.

Fig. 1 shows the basic concept of power-controlled home-gateway which changes home-gateway into standby mode while preserving network information and connections when no effective user data requested.

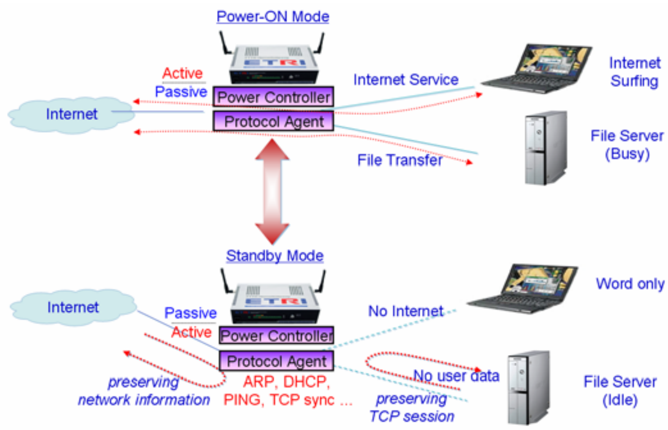

Fig. 1. The Concept of Power Controlled Home-Gateway System

To achieve this requirement, we are developing hardware-based Protocol Agent which generates acknowledge packets - control messages, keep-alive messages, TCP session control message, etc.

In this paper, we propose the power management architecture and implementation method of our power-controlled home-gateway. Our concept and operation mechanism are introduced into the following sections. In section 3 we describe our proposed power-management architecture and method. And section 4 shows overall operation flows and state transition. And performance of power management method is described in section 5. Finally, Section 6 is a summary

2. Power Controlled Home-Gateway System

Home-gateway is usually operated with fully powered-on state to support internet service immediately. And it is difficult to off the home-gateway's power because any other family maybe want to use internet at any time in the other room, Moreover home-gateway is usually located in corner or reclaimed in wall. Thus to save the wasted power of home-gateway during idle time, it is necessary to develop power-controlled home-gateway system which is capable of standby state [3][4].

As shown in Fig. 1, our power-controlled home-gateway adds two major components which named Power Controller and Protocol Agent. The Power Controller provides auxiliary power to Protocol Agent and off the main power of system in standby mode. Protocol Agent acts like a proxy generating acknowledge packets for control messages such as ARP(Address Resolution Protocol), ICMP(Internet Control Message Protocol), IGMP(Internet Group Management Protocol), TCP session control packets during idle time.

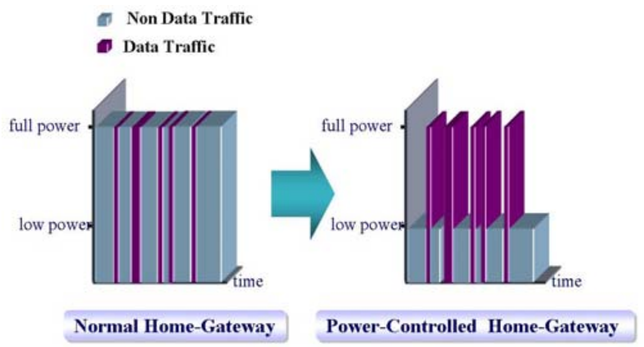

Fig. 2. Concept of saving power consumption in power-controlled system

As shown in Fig 2, at power-controlled home-gateway system, full power is only needed in data traffic transmission time. and most of time there are only transmitting non data traffic or control traffic. So power-controlled home-gateway can save total power consumption more and more in long time.

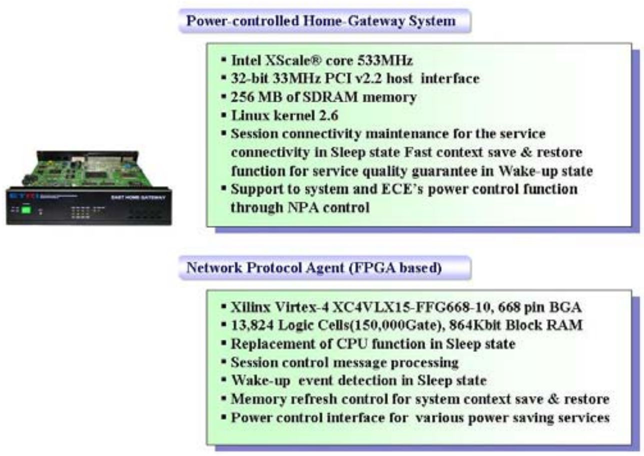

Fig 3. Power-Controlled Home-Gateway System

The detailed specification of our developing Power-Controlled Home-gateway system is described in Fig 3. It is xscale based embedded system and has FPGA based NPA(Network Protocaol Agent) to control power & network session state. Proposed Power Management Method interacts with this NPA hardware and support sleep & wakeup mechanism with SDRAM.

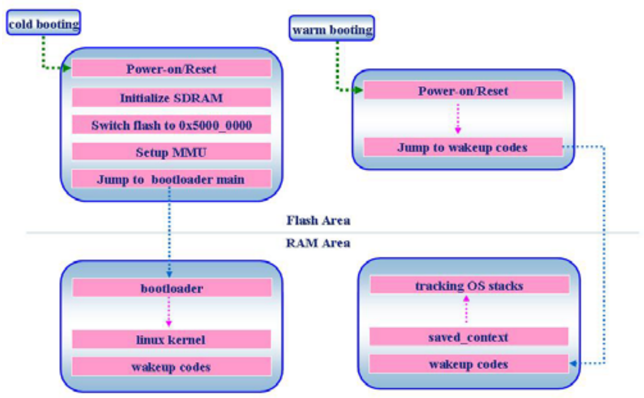

Fig. 4. Fast sleep and wakeup procedure

Fig 4 shows detailed procedure of fast sleep and wakeup function. when booting from power-on switch (cold booting), normal booting procedure executed from hardware initialization to linux kernel initialization. But booting from wakeup event (warm booting) only needs jump to wakeup codes which located in Self-Refreshed RAM area. In other words, there are no bootloader and linux kernel initialization.

To preserve continuance of services, power management method analyzes working context from OS, application, and network configuration data, and then it stores the context into RAM area before entering standby mode. This saved context is also quickly restored when requested wakeup interrupt from NPA hardware.

3. Proposed Power Management Method

Our proposed power-management method and its architecture are following in Fig. 5. There are three major modules named Power Control Module, Standby Decision Module, and Agent Control Module which interfaces to OS, Network Stack, Applications, and Hardware Components.

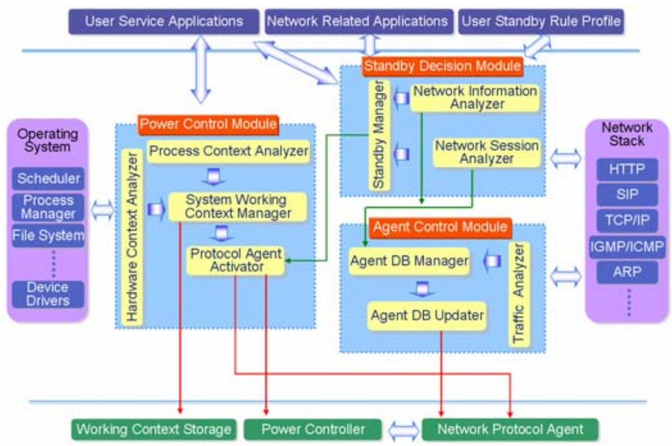

Fig. 5. Detailed Power Management Architecture and Method

Agent Control Module makes network information database called Agent DB(database) from network stack, activated network services, and received control packets. This Agent DB is written into NPA hardware by Agent Control Module and used to generate acknowledge packets by NPA in standby-state.

Power Control Module saves all effective working context to RAM area and changes NPA operation mode to active-state which generates acknowledge messages. Also Power Control Module should off the power of all components of home-gateway except NPA hardware and self-refreshed SDRAM in order to minimize the power consumption and to preserve service connections at standby-state. Power Control Module also interacts with Operation System and Power Controller through ACPI(Advanced Configuration and Power Interface) library

Working Context Storage, Power Controller, and Network Protocol Agent are hardware components interact with Power Management Method. Working Context Storage could be Flash, HDD or Memory, but in our home-gateway system, SDRAM memory is used to save working context through self-refresh mechanism which preserves memory data in very low power state. Power Controller and Network Protocol Agent control the power on-off operation of Home-gateway system. And these components receive

command by Protocol Agent Activator of Power Control Module.
As shown in Fig 5. Standby Decision Module determines sleep time to safely off the power of the home-gateway. This decision is derived from the idle duration of the network traffics and user applications' working state and power profiles which made by user.
Generally speaking, system wakeup procedure exhausts more power than normal operation. So sleep decision algorithm is important key of efficient power control strategy.
Detailed procedure of sleep decision algorithm in our first-stage is shown in Fig 6.

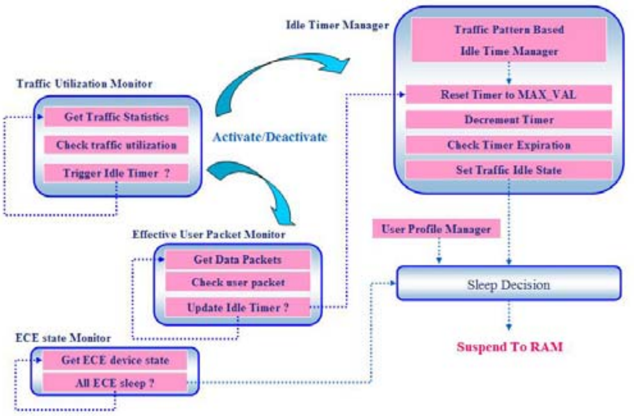

Fig. 6. Sleep Decision Procedure

Checking all send/receive packets is a heavy burden to home-gateway system. So it is very useful to monitor traffic utilization through statistic data from network interfaces. Whenever low utilization is detected, Traffic Utilization Monitor function activates Idle Time Manager function and Effective User Packet Monitor function. User data packets are checked in Effective User Packet Monitor function and it decides reset idle timer or not.
The Idle Timer Manager function maintains idle timer which used to determine entering sleep or not. This idle timer is reset to MAX_VAL when user data packet is detected. In conclusion, home-gateway can enter sleep state only if there are no user data packets exist in MAX_VAL duration.

4. Power Management Method Overall Flow

Fig. 7 shows the overall operation flow of our power-controlled home-gateway. It has circular state transition between Power-On state and Standby state. In Active Power-On state, Power Management Method executes active role of determining sleep time and In Active Standby state, NPA executes active operations to preserve network sessions.
Cold Booting State is similar to normal booting procedure of embedded devices except initializing Agent DB. This initialization about Agent DB is needed to set configuration of NPA hardware.
After completing cold booting procedure, our home-gateway goes into circulation transition state between Active Power-On State and Active Standby State. Active Power-On State is normal operation mode with full-power and it also analyzes network information and updates Agent DB which used to generate acknowledge packets by NPA hardware.
The other side, Active Standby State is standby state with low power. In this state, main components become power-off state and only NPA and self-refreshed DRAM are operating to preserve working context & network sessions.

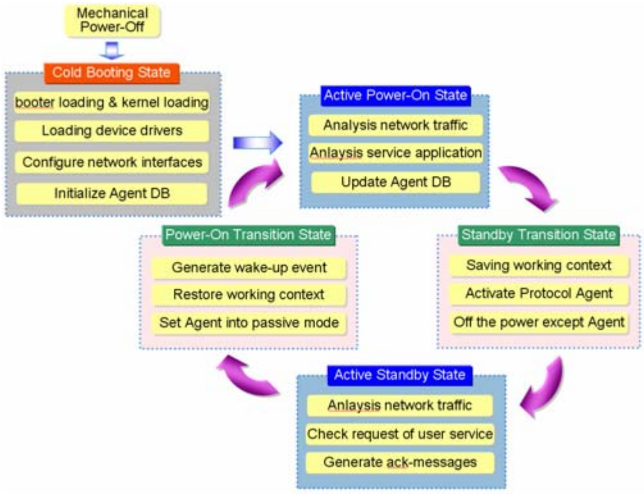

Fig. 7. Operation flow of the power management method

As shown in Fig 7, there are two Transition States which located between Active Power-On State and Active Standby State. Standby Transition State saves system working context -hardware, OS, Driver, and Application context – into unused low memory area. And it set NPA mode into active state and off the main components' power.
Power-On Transition State is called by NPA hardware through wakeup interrupt event which is generated as soon as user data packets received. This state restores system working context from low memory area and set NPA mode to passive state which bypass any packets.

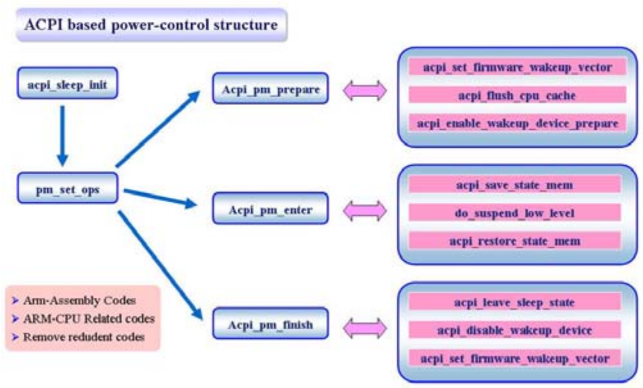

Fig. 8. ACPI compatible power control architecture

Fig 8 briefly shows sleep and wakeup function structure. It adopts ACPI structure to keep up with compatibility. Our sleep and wakeup codes are implemented in arm-assembly codes and optimized to achieve continuation of services. Only CPU or Hardware components dependent codes are modified or optimized and the others are compatible with ACPI library.

5. Performance of Power Control Method

Fig 9 shows the test-bed configuration for checking power saving performance of our power-controlled home-gateway.

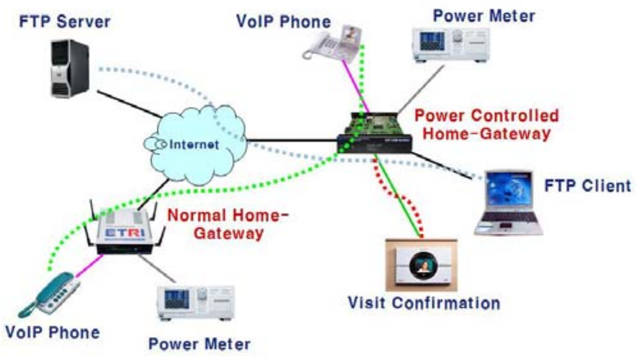

Fig.9. ACPI compatible power control architecture

As shown in Fig 9., there are two home-gateways in this test-bed, one is normal system and the other is power-controlled system. Session of FTP service is not disconnected though there are no transmitting data. But at this state, the power of home-gateway is not needed and it is very useful to enter standby state. And ftp session is preserved under standby state in our power-controlled home-gateway.

Our home-gateway system has many functions in addition to normal gateway function such as SIP based VoIP, Visit Confirmation Function, IEEE1394 interfaces, etc. So there more operation power is needed. As shown in Fig 10, the power consumption of normal state of home-gateway is about 18.7 watt. But when entering into standby state, power consumption is saved to 5.21 watt. It is about 72 % saving effect. Moreover, working context and network session is not lost at this low power state.

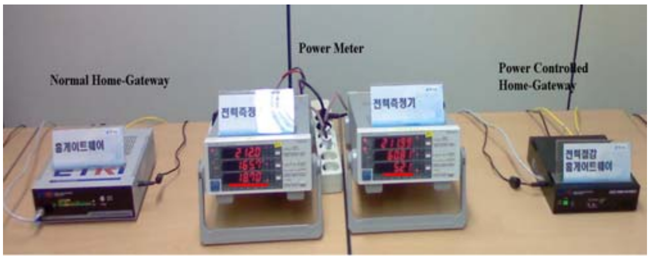

Fig.10. ACPI compatible power control architecture

6. Conclusion

In this paper, we propose the power-management architecture and method for our power-controlled home-gateway. Proposed power-management method can dramatically reduce the power-consumption during idle time. Moreover the proposed method preserves the network information and network sessions in standby state with minimized power with fast sleep and wake up algorithm.

ACKNOWLEDGEMENT

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