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Analysis of Energy Consumption in SET TOP BOX: A survey and Opportunities for Energy Saving

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Abstract: Researchers across the globe have been concerned about the power consumption as a major issue. In set-top-box, many hardware devices and software solutions are used, leading to reasonable power consumption. Nowadays, nearly 90% of world households subscribe to pay TV-television or cable/satellite services. Today's set-top boxes use more energy whether the user is watching TV, recording or not. The use of set-up box is rapidly moving to the boxes called set top box with High Definition (HD) and Digital Video Recording (DVR). Approximately, 1000 million set-top boxes are used worldwide, leading to a lot of energy consumption. In this paper, the approaches for power-mode in setup boxes are discussed. Energy Saving opportunities have been explored in this paper. There are many possibilities through which energy can be saved. These methods include using various modes like sleep mode, on mode and active mode in set-up boxes. Less heat and low temperature on working devices leads to lower power consumption. Nowadays, set-top boxes use new and innovative designs and features which consume less power like on-demand video recording, home networking for connecting set-top box with other boxes and remote programming with mobile phones. Sky broadcasting is one example of energy saving set top box. Analysis of various test-cases shows that energy savings in the explored opportunities are 30-40 percent more. In this paper, various techniques are used to show that less power is consumed when device is in standby mode or in sleep mode.
Keywords: Low Power mode, Energy consumption, set-top-box, energy-efficiency

I. Introduction:

This preliminary study of set-top-box is carried out in order to support ongoing research for energy-efficiency and implementing standard techniques and program to reduce power consumption. The STB market development is increasing rapidly as many companies have started DTH (Direct-to-home) devices manufacturing. Analysis shows that DTH (Direct-to-home) product runs many players in background along with satellite viewer. The objective of this paper is to analyze how energy efficiency can be improved in Set Top Boxes (STB).

Focus of this paper is on energy saving options for set-top-box devices. In current era, set-top-boxes show steady gain in energy-efficiency. Initially, set-top-boxes used scrambling and de-scrambling process, zapping and fast-channel change. But now set-top-boxes use the latest design concepts, technologies and features to meet consumer demands like:

- HD, 4K resolution
- multiple tuners for watching simultaneous channels
- on demand video broadcasting
- advanced applications like Wi-Fi set-top-box which is used for network connectivity [2]
- direct service using IP on Android or iPad device
- security purpose for smart card user

Hence, for fulfilling the above mentioned requirements, advanced hardware and complex software are required which in turn would consume additional power.

Energy consumption by various types of set-top-boxes vary due to different make and model. In this paper, majority of energy consumption is measured from cable and satellite receiver and multifunction DVR and pay-TV. Service providers provide services like High Definition and video recording which requires different kind of STB units. Hardware and software services used for set-top-boxes like CPU, SOC (system-on-chip), memory and hard-drives consume more energy. To analyze the energy-consumption [10], AC power of cable used in satellite set-top-boxes is measured. Moreover, HD and DVR devices are also analyzed. The results show that, whether power is off or on, the set-top-box data is already set in either ready mode or sleep mode. During this process also, it will consume power for the internal processing.

Video providers and TV broadcasters have introduced various approaches for saving energy in efficient ways:

- Use home-hold devices or home network to enable other devices and perform various operations like Pause, Forward-trick and maintain it in DVR.
- Try to make a network where energy is consumed on shared basis.
- Move program guide into the Cloud environment so that, it can be accessible from home and doesn't need installation.
- Customers have devices like iPad and Android Tablets, so services can be directly delivered to that device.

II. Types of set-top-boxes:

A set-top-box takes radio frequency signal from tuner like satellite or cable feed, and converts that signal into a signal which can be displayed on TV. Set-top-box acts as a gateway between Televisions to tuner feed. From tuner to TV display, modulation and demodulation techniques, de-multiplexer, De-scramble, decoder and CA system are used for performing variety of functions. Here, MPEG compression technique is used for decoding signals which take commands from user and transmit it back to network operator.

Cable:
This service is provided between VHF to UHF range. Quadrature Amplitude Modulation (QAM)[3] technique is used for modulating digital signal.

Satellite:
In this type of STB, tuner is set as frond end. It receives signals from satellite network and forwards them into Quadratic Phase Shift Keying (QPSK) for Modulation and Demodulation.

Terrestrial or Off-Air:
This service is provided in UHF range. Coded Orthogonal Frequency Division Multiplexing (COFDM) is used for modulation. In geographical areas like mountain or large buildings, this type of signal is robust for easy signal propagation. So customers require specifically designed antenna.

IPTV:
Internet Protocol Television (IPTV) uses packet switched network like LAN and Internet over Internet protocol suite for delivering their services. These services are mainly classified in VOD (Video on Demand), live television and time-shifted television.

Digital video recorder (DVR):
Digital video recorders take input from cable or satellite converter and record video in digital format in any hard-drive, flash-drive or SD card attached with device [1].

When television signal broadcasting started, signals were broadcasted through the medium of air and customer needed only one antenna to pick up the signal and transmit on Display TV. In the last decade, these policies and customer requirements have changed. So there has been need to change hardware and software design of STB and accordingly, complex chips and larger memory are added. These changes necessitate providers to offer programming in High Definition (HD) and Standard Definition (SD), thereby providing accurate resolution and picture quality. Facilities like multiple channels recording at a given time makes use of mail access through Internet, DVR, etc. So these new functionalities affect the cost of STB and further complicate power consumption issues. As functionality is added, requirement for more chips and other services increase thereby increasing power consumption of that device. Analysis of increasing power requirement by incorporating newer functionalities to device is as shown in figure 1.

III. STB power saving modes:

The set-top-box providers nowadays are continuously enhancing the capabilities of these devices to provide state-of-the-art services to the customers. When compared with other devices, the results show that set-top-box is spending more efforts for distributing video and audio signals from one component to other and consumes more energy than typical hardware devices. Set-top-boxes that offer more services and features in day-to-day life consume more processing power with higher memory requirements [9]. Pay-TV television is used to access video content from the service providers. As the consumers pay for what they see, so it will

consume less energy resource. Pay-TV service providers control installation, refurbishment, configuration, software updates of set-top-boxes. Television viewing power in India is changing with implementation of Conditional Access System (CAS) and DTH (Direct-To-Home) [7]. They are used to transfer signal in the encrypted form and a viewer needs to buy set-top-box to receive and decrypt that signal and display it on the TV. This whole process is used for security purpose and it consumes more energy. Set-top-box add new functionalities like video recording, DTV, pay-per-view programming, Wi-Fi support and Internet access. These facilities with an energy penalty. This energy compounded with some hardware and software configuration is designed with STB. So it is necessary to reduce power and use certain energy-efficient techniques for low power consumption.

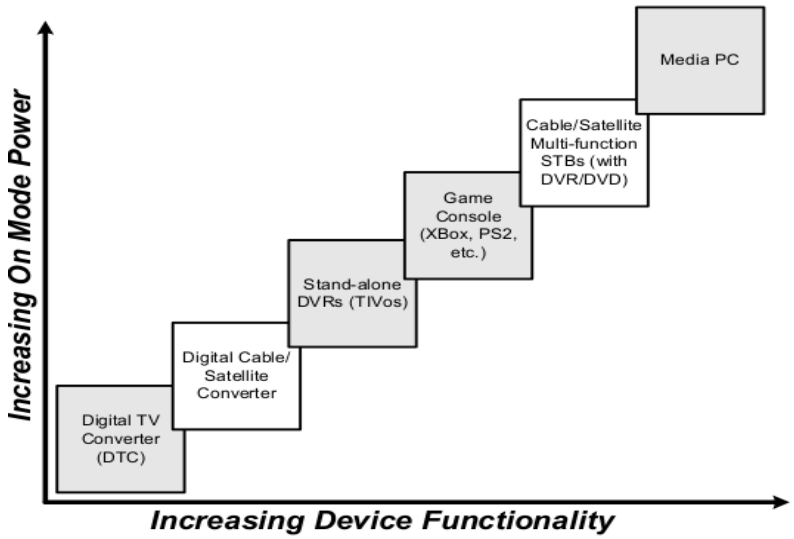

Figure 1: On mode power vs. Device functionality

Whether watching TV or not, cable and satellite set-top-boxes never completely shut down. Here set-top-box is constantly delivering their software updates and other services like bug fixes, new functionalities and current channel navigation information through network. The program guide is also delivering its schedules; network is continuously delivering security keys using CAS. Low power consumption means to reduce energy or heat generated by the device, which increase system performance, reliability, re-usability and consistency. So here, the newer mode for set-top-box like lower sleep mode is analyzed which is available for other consumer Electronics products [8] such as Printers, Computers, and Fax Machines etc.

i) Power Modes:

STB has many modes for measuring power. There are number of ways to define various modes of STB [1]. There are basically three modes of power: sleep mode, active mode and standby mode. However, the power level of individual STB is different from others because of difference in functionalities. The ready mode usually consumes 1 to 2 Watts less energy than the active mode, and active mode of one STB might be 11 Watts and others might be approximately 20 watts. In home based devices, ready mode is used for watching TV and programming and recording shows. When a user uses remote control to turn-off the television, it goes into sleep mode. So for these two scenarios, assumption is that this multi-functionality works like active mode. If both these modes use relatively low power, the difference between these two functionalities is very minor. So there is need to develop sufficiently great low power mode than ready mode, where the aim is to save energy and also create more energy efficient protocols for sleep mode.

ii) STB modes of operation:

Here the details of power modes are elaborated as given in table I. The results mentioned in the table are based on the literature and practical analysis.

Mode category	Mode name	definition	Mode observed in recent STBs	Power used by mode
On	Active	Whenever user is watching TV or recording show it is on mode. STB is plugged in and perform many functionality like recording, playing, video signal processing.	YES	30 W
	Ready	STB is off in this mode but actually a form of on. STB is plugged in and exchanging data with service provider. A signal from remote will move it into active mode, and after some time it automatically goes into sleep mode when no action from remote control.	YES	30 W
Sleep	sleep	It is non-existent in today's STB but can be called a standby mode operation. STB is plugged in but all services are disconnected like signal processing, recording, services from service providers. When STB turned with ready mode or active mode using remote control or switch on it wake up all signals. It is standby passive mode.	YES	0 to 5 W
Off	Unplug ged	STB is unplugged and consumes no power, not able to communicate with service provider, and when plugged in it take hours to download programs from service provider.	NO	None

Table 1: modes of power

IV. Implementing low power module in set-top-box:

Various key components are taken into consideration while implementing low power mode like design changes, functionality, test-cases etc.

Hardware changes required: The facts pertaining to required hardware changes as per [5] is mentioned as below:

- Build hardware in such a way so that circuits and chips which are not in use will automatically go in shut down mode and wake up as and when required for any services.
- For memory solution, it is observed that program guide is stored with desktop when it is in low power mode.

Software changes required: Following software changes are desirable for reducing power consumption [5]:

- Intelligent Software design also opens demand for low power mode.
- Put energy saving option for DVR which allow hard-disk or pen-drive to spin down if user choose not to record a program.
- Design reliable communication protocols so that it can enable security like CAS and directly download all services from head end.
- Develop technology using which multiple STBs can communicate in one home using network protocols.

- Properly designed software help to detect and select essential part from MPEG[4] stream which will reduce load of processor resulting in low power mode.
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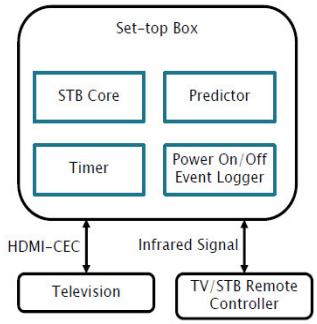

Figure 1: Architecture of energy saving system

For analysis and implementing low power mode, various power modes are developed and discussed. Here, some test-cases and use cases are used to check power consumption by device. There are basically three types of modes we use as shown below:

1) **Active mode:**
Active mode is the standard mode when the Set Top Box is in use. Based on dynamic power management mechanisms, drivers may be "active/on" or in "low power". However, CPU is active. Based on dynamic power management mechanisms, some of the drivers are in low power mode, some in reduced function mode and others are in normal mode. This implementation is done by using Linux power management frameworks. Dynamic Power Management stands for the fact that hardware and software drivers are enough intelligent while consuming the needed power for the current use case realization.

2) **Controller Passive Standby mode (CPS) / Standby mode:**
System-on-chip (SOC) is not powered. Wake-up triggers are handled by a separate controller (Standby Controller - SBC). This controller is internal to SOC and is in the "always ON" power domain. After detecting a valid wake-up trigger, controller will repower the SOC and the Host CPU will execute its restoration procedure. During restoration, Host CPU will resume from where it has stopped when entering CPS mode. Later, SBC will inform the wake-up reason to Host CPU.

3) **Deep Controller Passive Standby mode (DCPS) / Sleep mode:**
SOC is not powered. LMI state during DCPS is a hardware configuration. To have it powered off during DCPS mode, LMI power supply should be controlled by the SBC power control line. Wake-up triggers are handled by a separate controller (Standby Controller - SBC). This controller is internal to SOC and is in the "always ON" power domain. After detecting a valid wake-up trigger, controller will re-power the SOC and the Host CPU will execute its cold boot procedure.

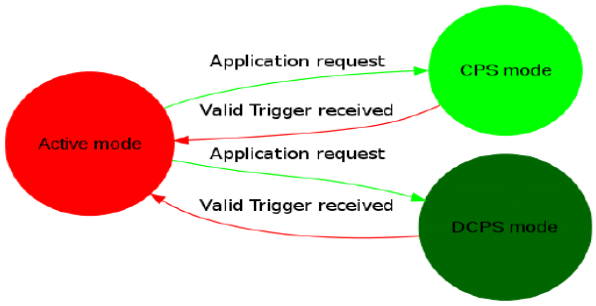

Figure 2: Flow of Power in different modes

This flow shows that, there are mainly three supported modes in the study of implementing low power mode: Active mode, CPS mode and DCPS mode (sleep mode). Here, many test-cases and triggers are created for testing and analysis. Test-cases cover the specific test in form of video and audio to check whether functionality is working correctly or not. These video-audio files are stored in pen-drive that is attached with STB.

Here, various triggers for CPS and DCPS mode are defined. This trigger means they include various modes of operation and functionalities for power saving. The detailed description of trigger is discussed in the following section.

i) Power Management Implementation:

This section describes how to write a driver to properly connect to the Linux Kernel Power Management framework in order to achieve both the supported Power Management (PM) mechanisms:

Static Power Management:
It allows putting the device in a low power mode when entire system enters in low power mode. To register a driver to the PM framework, create suspend and resume API.

Dynamic power management:

It allows to automatically calling low power APIs when device is no longer active. Several APIs exist to control device's behavior regarding its state. Many devices are able to dynamically power down while it is in still running mode. This is also known as Runtime PM.

CPU IDLE:
When CPU is idle, it can switch to CPS and DCPS modes, consuming less power. When system is in idle state, CPU power is saved in terms of battery lifetime and heat generated by system is less, etc. [4].

Common Clock Framework:
This clock framework gives drivers the opportunity to control board or SOC clocks. This allows to switch off a clock source when it is no longer in use by any device.

DVFS:
Dynamic Voltage and Frequency Scaling is related with CPU Frequency (CPUFREQ) framework. It provides support to change frequency of processor on run. This again helps to save processor power.

ii) Supported wake-up triggers:

Trigger is an event that has the ability to wake-up the STB. Triggers are detected by the SBC mainly through interruption. A trigger needs to be enabled and may be configured (like RTC alarms) prior to entering standby mode in order to be able to wake-up the system. Different triggers have different power saving modes. Following list of triggers are used in the Set Top Box:

Infrared trigger:
An Infrared (IR) key from the remote control is used to wake up system from standby mode. In this configuration, press the ON or OFF switch from the remote control towards TV and measure power consumed by that operation. For enabling IR as wake-up trigger, there is a need to update some Linux drivers that open the reading channel.

RTC/Time trigger:
RTC (real-time-clock) works as wake-up alarm. In RTC configuration it will wake-up system from standby mode; here some time-limit like 30 to 60 second is kept. If in this time no alarm is ringing means system should not wake up then it expires and enter into DCPS mode which is totally shut down.

PIO trigger:
Programmable input output trigger is controlled by a button which is set on the device to wake up system from standby mode. Here in configuration we need to change hardware design like put an extra button on STB board to wake-up trigger.

HDMI plug detector:
Plug of HDMI is also used to wake-up from standby mode. Here HDMI is plugged in and unplugged as requirement. If no HDMI is available then it will enter in DCPS mode.

Board wake-up:
This is new type of configuration in which remote control is used to make board wake-up from standby mode, for this a key is pressed towards the board and the power is measured [6].

All trigger mentioned above give result in watts for power measurement. The process of calculating power from trigger to various mode is given below.

- Select one of the triggers
- Entering standby mode
- Exiting from standby mode

Once the STB is in a standby mode, user just have to either generate a trigger to wake it up (e.g.: IR remote control key press), or wait for the trigger to happen (e.g.: alarm).

V. Results and analysis:

Graph in figure 5 shows the results and analysis of the methods discussed earlier and amount of power that can be saved through these techniques. Here, the power supply given to all triggers is constant i.e. 12V and current is rising between 0 to 1 Amp.

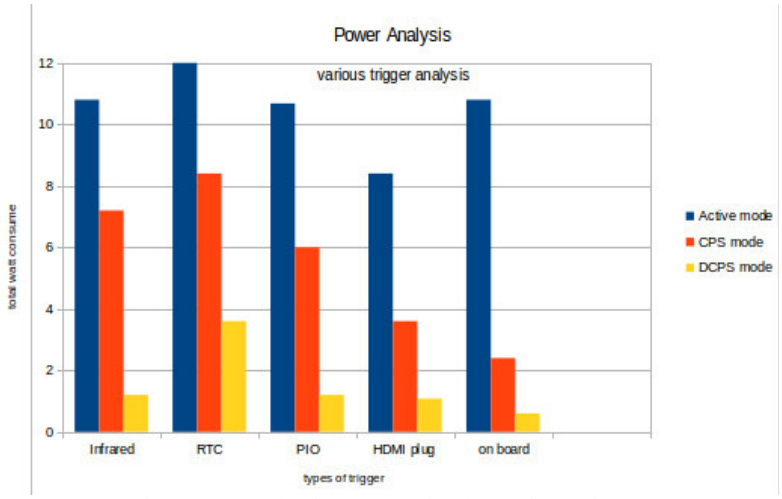

Figure 3: Graph of power saving by various trigger

Analysis of triggers using equation P=VI:

Table 5 shows that in DCPS mode, the level of power consumption of set-top-box goes to 1W. An energy saving system for set-top boxes with passive standby mode is proposed to fully utilize the passive standby mode.

Name of trigger	Active mode			Standby mode (CPS)			Sleep mode (DCPS)		
	V	I	P	V	I	P	V	I	P
Infrared	12	0.9	10.8	12	0.6	1.2	12	0.1	0.96
RTC	12	1	12	12	0.7	8.4	12	0.3	3.6
PIO	12	0.89	10.68	12	0.5	6.0	12	0.1	1.2
HDMI plug	12	0.7	8.4	12	0.3	3.6	12	0.09	1.08
On board	12	0.9	10.8	12	0.2	2.4	12	0.05	0.6

Table2: Power consumed by different triggers

VI. Conclusion:

Consumers and Green Environment activists demand products with low power consumption for making environment healthy by reducing the greenhouse effect [11]. These hardware and software changes when applied properly during design can make set-top-box platform more energy-efficient.

From the above analysis it can be concluded that a large amount of energy can be saved from this implementation in both standby mode and active mode. The study concludes that, by using the methods and techniques discussed above, the set top box consumes about 30% of its energy requirement while in passive standby mode, the STB consumes about 50% less energy.

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