Regular Paper

Personal Mobile DTV Terminal Designed for Service Trial of Digital Terrestrial Broadcasting with Full Use of Internet Connectivity

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In digital terrestrial broadcasting, a service profile for personal mobile terminals such as PDA or cellular phones is specified in addition to conventional TV services for typical home STB (Set Top Box) terminals. The mobile DTV service is quite attractive as new services with sufficient functionality and flexibility are becoming more available in taking advantage of network connectivity. In order for experimental evaluation of new services, a prototype terminal was developed. This paper describes assumed application images of the integrated service and the technical architecture of the prototype terminal with regard to the hardware and software respectively. Performance evaluations were conducted from results of the CPU load average, particularly on software modules.

1. Introduction

In digital terrestrial broadcasting, a broadcasting bandwidth is utilized for three service profiles as shown in the following.

- Home terminal service
  This service corresponds to conventional TV services for typical home STB (Set Top Box) terminals.
- Mobile terminal service
  The typical mobile terminal assumed in this service is car navigation equipment. For this service, the channel coding scheme should be selected to maintain robustness of the terminal moving speed.
- Personal mobile terminal service
  The personal mobile terminal includes a PDA and a cellular phone which moves much slower compared to automobiles.

In those service profiles, the DTV service for personal mobile terminals is quite attractive because new services with enough functionality and flexibility become available by utilizing its network connectivity [1),2)]. In recent years, 'integrated service', a new service enabled by utilizing both a DTV function and Internet connectivity is studied world-wide [3),4)]. Toward the field trial for exemplifying integrated services, a prototype terminal was developed [5)]. In this paper, assumed application images of integrated services were first described, and technical architecture of the terminal was introduced with regard to hardware and software respectively. In addition, experimental results were presented in order to evaluate software performance embedded on the hardware.

2. Network Configuration

Figure 1 shows the network configuration where the integrated service is provided. The service network is composed of several server equipments. The main role of each server is summarized below.

2.1 DTV Content Server

The DTV content server distributes DTV contents in an MPEG-2 TS format. The server is located in a broadcasting station. DTV content consists of the four following media components. The DTV content is transmitted based on the standard protocol stack shown in **Fig. 2**.

- Video stream of DTV programs
- Audio stream of DTV programs
- BML data content dependent on DTV programs

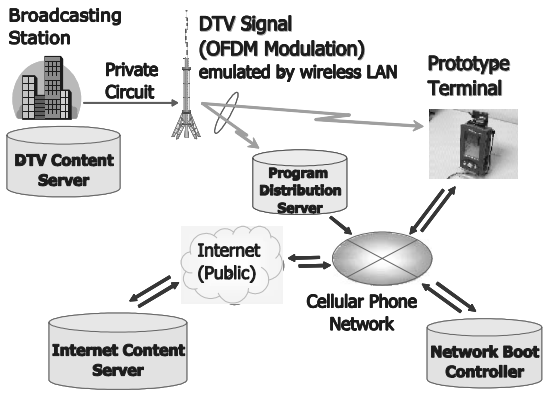

Fig. 1 Network configuration where integrated service is provided.

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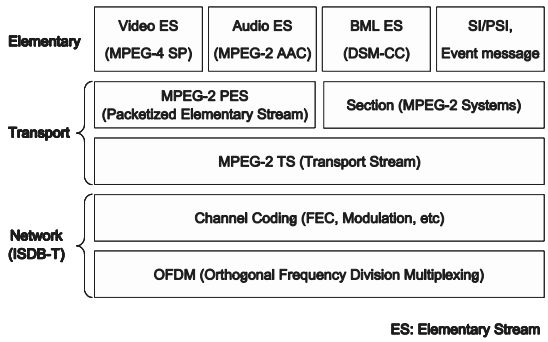

Fig. 2 Transmission format of DTV contents.

- BML data content independent of DTV programs (weather news, traffic information, etc.)

2.2 Internet Content Server

The Internet content server provides video streaming contents as well as typical web contents prepared for cellular phone terminals. Those contents can be accessed directly via an Internet connection, and are also accessible from the DTV BML content which includes a hyperlink to the corresponding URL.

2.3 Program Distribution Server

The program distribution server receives DTV signals and extracts MPEG-2 TS (Transport Stream) packets. Those packets are converted in a video streaming format preparing for the program redistribution according to user demands.

2.4 Network Boot Controller

The network boot controller manages a user profile for each mobile terminal, and sends a trigger messages to an arbitrary terminal. This message is utilized in order to switch the terminal operation mode (stand by mode, DTV mode, etc.) automatically based on user requests.

3. Proposed Application Images

The prototype terminal was developed to be utilized for inventing new integrated services and clarifying technical problems to realize those services at the commercial level. Proposed GUI layout of the prototype terminal is shown in **Fig. 3**. The display area is divided into two areas under the TV mode operation. The top area is allocated to display video content of a DTV program. The bottom area is allocated to display the browser output, and this area is commonly used by DTV BML contents and Internet web contents.

The terminal operation mode is switched by

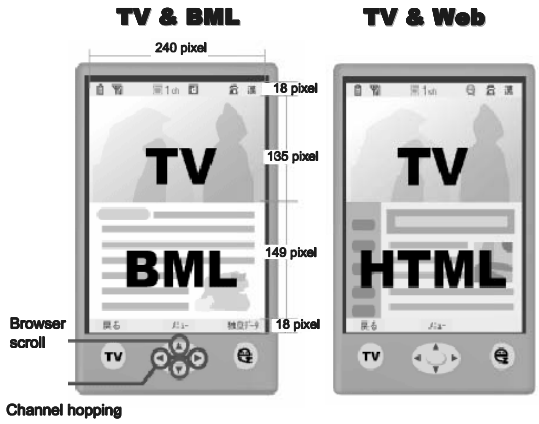

Fig. 3 GUI layout of prototype terminal.

the TV button on the left and the Internet button on the right. When the TV button is pressed, the TV mode is selected and received DTV programs are displayed on the screen. Pressing the Internet button initiates the Internet web access, and presents a top menu with materials on guidance. In addition, the left/right arrow button and the up/down arrow button are used for channel hopping and scrolling the browser screen respectively. For the terminal, typical examples of assumed application images are introduced in the following.

(a) Emergency warning system
The terminal operation mode can be switched depending on a trigger message received from a network boot controller. By using this mechanism, an emergency warning system can be achieved. This system notifies a user of special news programs that appear when a disaster occurs. As a general use, this mechanism is applicable for TV program reservation services where the TV play operation is automatically started in synchronization with the timeline of the program requested by the user in advance.

(b) Pin-point GPS information service
By utilizing the GPS service of a cellular phone, regional information can be properly selected and provided from Internet web contents, depending on the current terminal position calculated by GPS. Based on the mechanism, intelligent weather information service for the target area is automatically determined by adapting to the terminal position.

(c) Assistance for minority users
Narration texts for the selected TV program can be obtained in many languages as Internet web contents. In Japanese DTV service,

inserting subtitles written in Japanese and English are mandatory for any on-air program. However, further detailed information can be obtained with regard to the currently distributed program from the Internet web server. This application contributes to assisting minority users who require narration text data to understand the program content.

(d) TV chat service
When more than two users are watching an identical TV program, so called TV chat service is available by mutually submitting short messages to a chat server located in Internet. This application provides users communication space where a common topic can be achieved on a DTV program.

(e) TV program navigation
An exclusive TV guide, so called web EPG is provided as Internet web contents. Web EPG includes program guides of all available TV channels just like the TV guide in the newspaper. The user can jump to the TV play mode for selected program by clicking the hyperlink described in the web EPG document. Furthermore, reserved TV programs are recorded in the program distribution server, which users can access on demand. The distribution server also enables the TV program archive services by which users can access distributed TV programs over the past several days.

4. Prototype Terminal

In this section, the system architecture is described for hardware and software, and software performance is evaluated from experimental results.

4.1 System Architecture

The detailed system architecture of the prototype terminal is described in the following. In terms of the terminal, the outline of the prototype terminal is shown in **Fig. 4**, while the principal system parameters are summarized in **Table 1**. T-engine is an open standard platform for developing mobile embedded terminals [6),7)]. For the T-engine platform, CPU is selectable, and we adopted SH4 whose CPU performance was about 400 MIPS (highest at that time). In the terminal, the OFDM transmission of DTV signals is emulated by the RTP streaming over wireless LAN. The transport stream format and coding syntax of each media component conform to the Japanese DTV standard specified in ARIB STD-B24 [8)]. **Figure 5** shows the hardware configuration of the prototype terminal. On the main board, three PCMCIA sockets are equipped, where one socket is allocated for application program storage, and others are

Fig. 4 Outline of prototype terminal.

Table 1 Principal system parameters of prototype terminal.

Hardware			
	Main Board	T-engine	
	Ext. Board	PCMCIA Socket (x3)	
	PCMCIA	Compact Flash (Application module), Wireless LAN (IEEE802.11b), PHS (AirH")/CDMA (Rapira)	
	CPU	SH7751R (SH4)	
	Memory	64 MB	
	LCD	QVGA (320 pixels × 240 lines), 16 bit depth, Touch Panel	
	Dimension Weight	144 × 91 × 59 (mm) 660 g (including battery pack)	
Software			
	OS	Realtime OS (T-kernel)	
	DTV Receiver	MPEG-2 TS Demux	
		A/V Decoder	MPEG-4 Visual SP, MPEG-2 AAC LCP
		BML Browser	HTML4.0 (XHTML Basic +CSS2+ECMA Script)
	Web Browser	HTML4.0 (XHTML Basic+CSS2 +ECMA Script)	

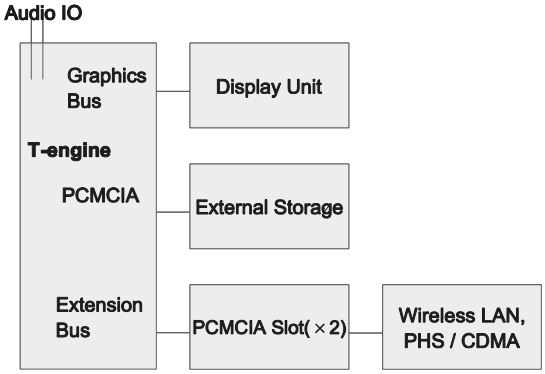

Fig. 5 Hardware configuration of prototype terminal.

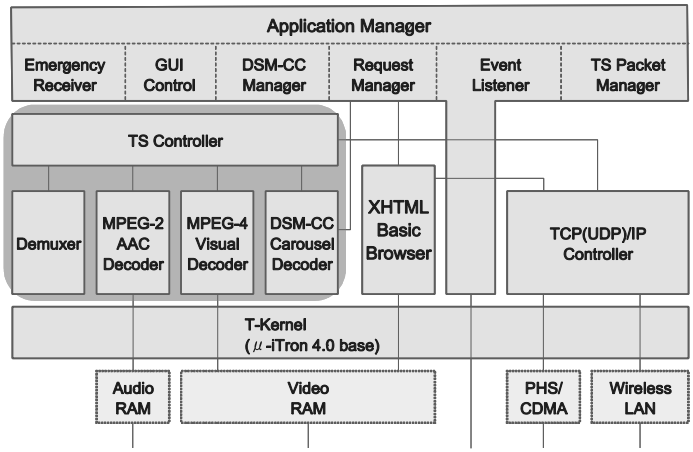

Fig. 6 Software configuration embedded on prototype terminal.

allocated for inserting network interface cards.

With regard to software, **Fig. 6** shows the configuration of software modules embedded on the hardware described above. In the figure, the meshed region corresponds to specific software modules for receiving DTV programs. In the meshed region, TS controller module controls each media decoder module to maintain the media synchronization.

The application manager provides a user interface and controls subsidiary modules whose functions are introduced in the following. A browser module is commonly used for DTV BML contents and Internet web contents.

(1) Application Manager Module

The application manager module controls all software tasks including low level software engines. This main module is comprised of the tasks listed below.

- TS Packet Manager
  The TS packet manager task provides the packet scheduling mechanism for the TS control module in order to eliminate the network jitter from a received transport stream. This task also provides a buffering mechanism for Internet web content such as HTML documents received from a TCP/IP control module.
- GUI Control
  The GUI control task provides a GUI framework, and manages user events and application status transition according to the respective application image.
- DSM-CC Manager
  The DSM-CC manager task manages BML data objects according to instructions from a DSM-CC carousel decoder module. The main function is a content cache and a data delivery for the XHTML browser module by which the browsing performance improvement can be achieved.
- Emergency Receiver
  To realize the emergency warning system, a trigger message is emitted for selected terminals. The emergency receiver task receives and interprets the trigger message, and activates the appropriate DTV function.

(2) TS Control Module

The TS control module provides MPEG-2 TS and MPEG-2 PES (Packetized Elementary Stream) protocol stacks, and maintains media synchronization of real time contents (audio stream and video stream). **Figure 7** shows the employed synchronization mechanism. In the figure, L_{APU} and L_{VPU} indicate the buffer occupancy level with regard to the audio PU (Presentation Unit) and video PU respectively. The presentation timing for an audio frame and video frame is managed in the following way.

- Audio stream
  Digital audio data reconstructed from an audio PES is stored in an audio PU buffer. When the occupancy level reaches the threshold value TH_L, audio play is started, and the current local STC (System Time Clock) time is set at the same value with the first audio PTS (Presentation Time Stamp) value PTS_{A0}. Then, STC time is adjusted based on the system clock frequency (27 MHz) calculated from the received PCR (Program

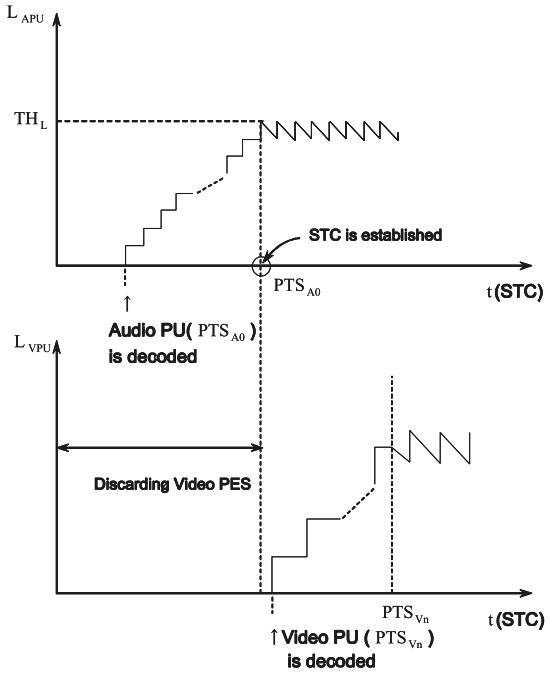

Fig. 7 Synchronization mechanism for audio and video presentation units.

Clock Reference) value.

- Video stream
  Video frame output is conducted by directly refreshing the VRAM when corresponding to PTS time. As long as local STC time has not been established by the audio initialization process, received video PES packets are discarded because presentation timing of video PU can not be resloved.

(3) Demuxer Module
The demuxer module extracts media elementary streams (MPEG-4 Visual, MPEG-2 AAC, DSM-CC) from a transport stream received from TS control module.

(4) MPEG-2 AAC Decoder Module
The MPEG-2 AAC decoder module reconstructs digital audio data from the MPEG-2 AAC elementary stream.

(5) MPEG-4 Visual Decoder Module
The MPEG-4 visual decoder module reconstructs image data from the MPEG-4 visual elementary stream.

(6) DSM-CC Carousel Decoder Module
The DSM-CC carousel decoder module extracts BML objects from the DSM-CC elementary stream, and notifies the application manager of an event whereby new BML objects have been detected.

Table 2 Operation parameters for performance evaluation.

Network	protocol	RTP (UDP/IP)
	RTP payload	1,316 Byte
	bit-rate	∼400 kbps
Transport	stream format	MPEG-2 TS
	bit-rate	350 kbps
Video	image size (coding domain)	(A) 176 × 112 (B) 240 × 144
	frame-rate	15 fps
	bit-rate (ES)	192 kbps
Audio	sampling-rate	24 kHz, stereo
	bit-rate (ES)	64 kbps
BML	stream format	DSM-CC carousel
	bit-rate (ES)	100 kbps

(7) XHTML Basic Browser Module
The XHTML Basic browser module presents XHTML contents received from the application manager. This module is composed of XHTML1.1/Basic Profile, CSS2 subset and ECMA Scripts. However, this browser does not conform to the basic BML module specified in ARIB STD-B24 [8] exactly.

(8) TCP (UDP)/IP Control Module
The TCP (UDP)/IP control module provides TCP/IP and UDP/IP protocol stacks on the network interface (wireless LAN, PHS, CDMA2000), while extracted payload data units are delivered to the application manager module.

4.2 Performance Evaluation

The software performance was evaluated under service parameters particularly for terminal operations under the TV mode as shown in **Table 2**. With regard to the image size in the video coding domain, two types (A) and (B) were assumed. In both cases, active vertical size is smaller than the value in the table so that the aspect ratio in active video samples can be kept at 16 : 9. As experimental results, the CPU usage ratio of each internal task is summarized in **Table 3** and **Table 4**. Tables 3, 4 are results under the image size of (A) and (B) respectively. In those tables, evaluated software modules are categorized as shown in **Table 5**, and the CPU usage ratio is represented by a percentage.

From these results, it was confirmed that the occupancy ratio using a system control task increased when initializing the receiving process of DTV programs. The result only includes the averaged value, while the result for the A/V decoder task was confirmed to have a fluctuation that depends on image characteristics such as the distribution of moving vectors. In addi-

Table 3 CPU usage ratio of each internal task in case of image size (A).

Task No.	Status				
	Power ON	Stand-by	TV Mode	TV Play	Channel Hopping
#1	45.553	0.632	34.566	6.349	33.492
#2	2.120	0.005	0.538	0.000	0.678
#3	17.887	1.309	7.899	7.566	8.641
#4	0.000	0.000	33.979	32.870	29.561
#5	0.002	0.000	0.275	0.055	0.422
#6	0.000	0.440	1.009	1.055	1.117
Total	68.562	2.386	78.266	47.895	73.911

Table 4 CPU usage ratio of each internal task in case of image size (B).

Task No.	Status				
	Power ON	Stand-by	TV Mode	TV Play	Channel Hopping
#1	47.228	0.676	34.557	6.106	34.971
#2	2.006	0.009	0.650	0.000	0.706
#3	18.926	1.227	7.271	7.803	8.203
#4	0.000	0.000	38.334	45.486	34.593
#5	0.001	0.000	0.277	0.047	0.389
#6	0.000	0.457	1.153	1.169	1.172
Total	68.161	2.369	82.242	60.611	80.034

Table 5 Definition of sotware module category.

Task No.	Software modules
#1	System Control (LCD/Sound Manager, Network Manager, etc.)
#2	Application Manager
#3	XHTML Basic Browser
#4	TS Controller, Demuxer, A/V Decoder
#5	DSM-CC Carousel Decoder
#6	Others (Clock Manager, etc.)

tion, the occupancy by XHTML browser task was concentrated only for a relatively short period while BML or XHTML data objects were updated.

From the comparison between Table 3 and Table 4, it was confirmed that only occupancy by A/V decoder was largey changed dependent on the image size. Under the status of TV play, the occupancy by video decoder was confirmed to be increased in proportion to the number of macroblocks from further experiments.

With regard to averaged CPU usage ratio, 15% safety margin was always kept even for the considerably large image size of 240 pixels $\times$ 144 lines. Therefore, it was concluded that proposed DTV terminal design where all media processing units were implemented by software was appropriate and reasonable for the representative mobile terminal architecture based on SH4 and μ-iTron.

5. Conclusions

In this paper, the technical architecture of a prototype terminal for a personal mobile DTV service was introduced. The terminal was developed in order to create new services and clarify technical problems to realize those services at the commercial level.

In further studies, user tests and field trials will be conducted to evaluate the usability of proposed system. Furthermore, the next generation prototype terminal will be developed in typical cellular phone packages equipped with the DTV tuner module, which must enable field trials to be conducted over actual DTV infrastructures.

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