Applying User-level Drivers on DTV System

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ELC, April 18, 2007

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Background

Background

- What is problem in developing Kernel-level device drivers in embedded Linux systems?
  - Hard to debug
    - Most of driver developers are not expert on Linux system.
    - ➔ Most of driver developers use only "**printk**".
  - Unstable
    - Bugs in the Kernel-level driver are critical for the system stability. (Kernel panic may occur)

❖ **User-level drivers can be a good choice…**

Background

- Merits of user-level drivers
  - Easy to develop…
  - Easy to debug…(GDB? or others)
- Risk: Real-time performance degradation
  - Real-time performance is very important in the DTV system.
  - What are the time constraints required by the DTV drivers?
  - Recent improvements on real-time performance in Linux Kernel 2.6 provide good environments for user-level drivers.

Requirements of DTV Device Drivers

Device Drivers on DTV System

- Basic DTV system consists of devices below…
  - SDEC : System Decoder (or demux)
  - VDEC : Video Decoder
  - ADEC : Audio Decoder
  - VDP : Video Display Processor (scaler)
  - OSD : On Screen Display
  - GFX : Graphic acceleration engine
  - I2C : Inter-Integrated Circuit
  - GPIO : General Purpose I/O
  - and Etc…

❖ **Each device has control registers.**

❖ **Some devices have large buffer memory.**

Features of Kernel-level DTV Drivers

- Memory access
  - Provide accessibility to the registers.
  - Provide accessibility to the large buffer memory.
- Interrupt handling
  - Provide ISR. (interrupt service routine)
  - Provide control over IRQ. (enabling/disabling)
- Real-time responsibility
  - Some DTV drivers require real-time responsibility.
    - ISR should finish job within a guaranteed latency.

Real-time Requirements

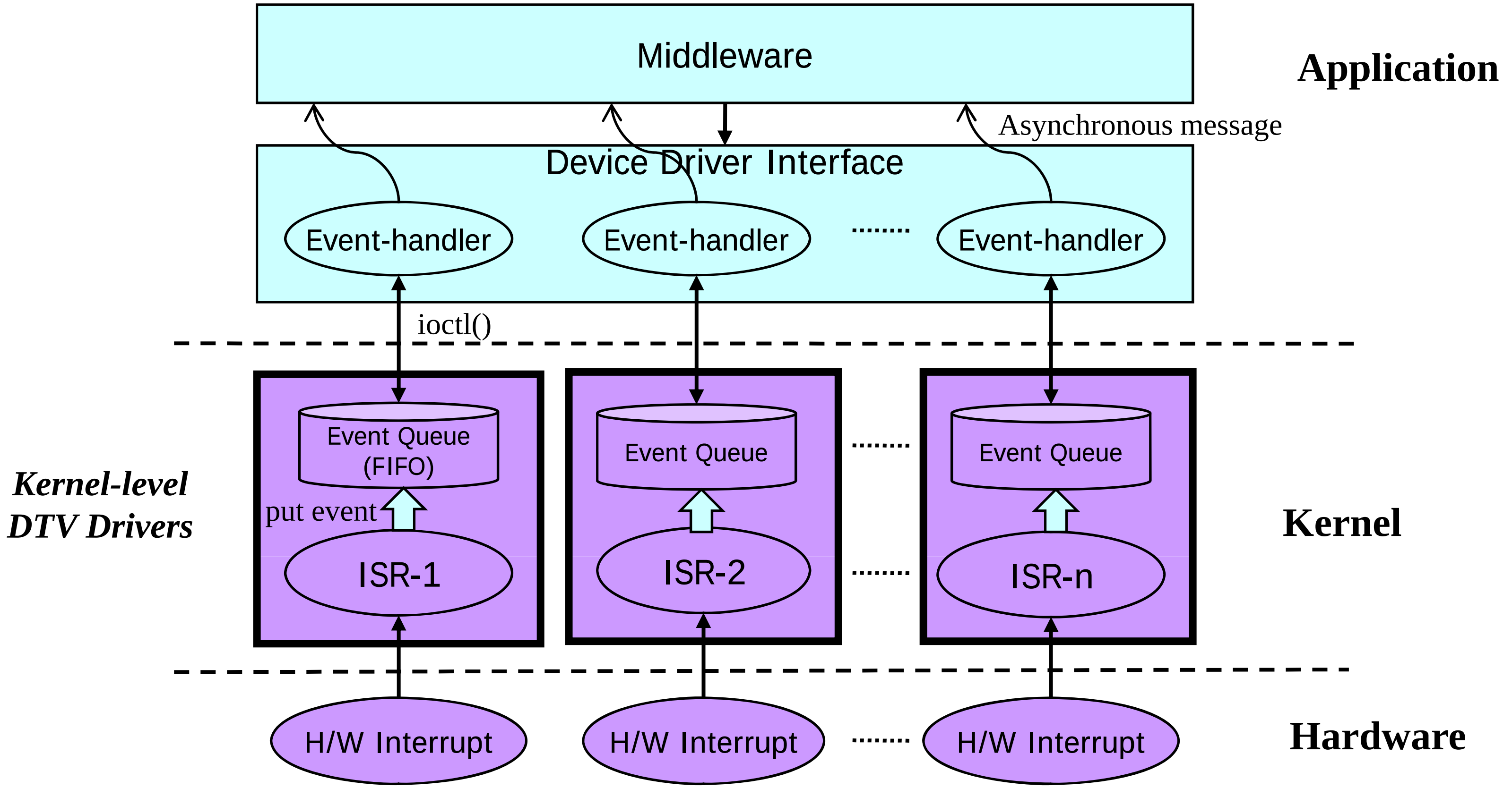
◆ Representative real-time requirements of DTV drivers

Drivers	Requirements	Constraints
SDEC	PAT (Program Association Table) section filtering (interval of PAT section is 10msec)	10 msec
	PCR (Program Clock Reference) recovery	< 1 msec
VDEC	Caption data processing (interval of V-sync is 16msec)	16 msec
VDP	Frame error correction (complete during blank lines of frame)	1.39 msec
For all	Interrupt pending clear	At the Kernel ISR

Design of LG DTV User-level Drivers

How Kernel-level Drivers are Used in LG DTV

- All drivers existed in the Kernel.
- Event (= outcome of ISR) was delivered to the event handler task.
- Each driver has an ISR, event queue and event handler task.
- Interrupt pending clear and status clear are done in the ISR.



Principles in Converting to User-level Drivers

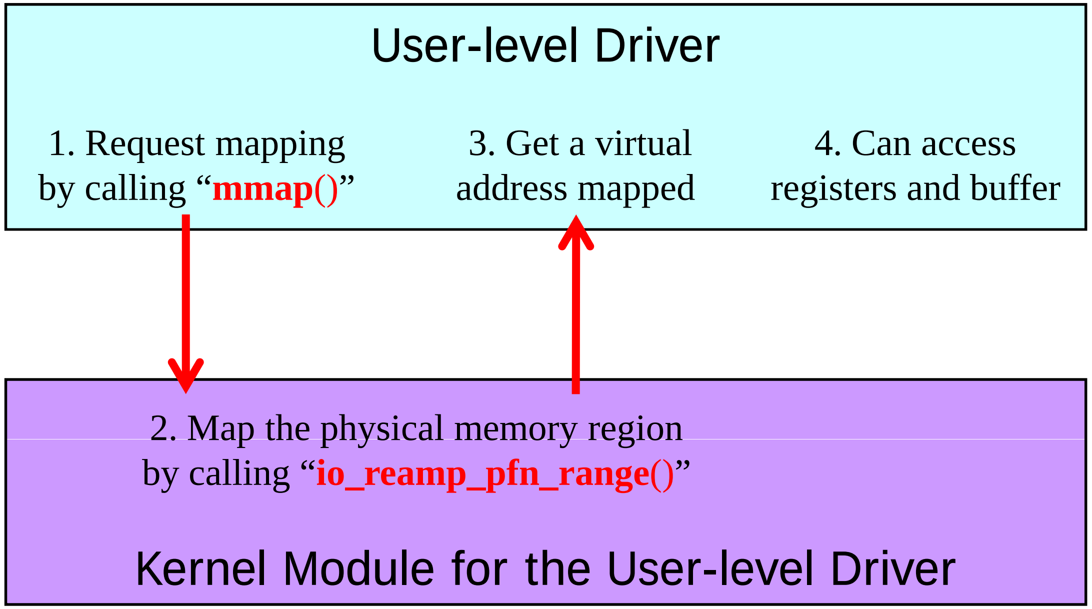
- Minimize Kernel-level codes
  - Implement drivers in user-level, except some time critical codes.
- Minimize overhead
  - Simple and compact structure to reduce performance degradation.
- Easy to develop
  - DTV SW developers should adapt to new environments easily.

Requirements

- Memory access: same as Kernel-level drivers…
  - Provide accessibility to the registers.
  - Provide accessibility to the large buffer memory.
- Interrupt handling: ISR in the user-level
  - Provide interface to deliver Kernel IRQ to user task (U-IRQ)
  - Provide interface for user-level ISR (U-ISR, awaken by U-IRQ)
  - Provide control over IRQ & UIRQ (enabling/disabling)
- Real-time performance
  - Minimal time critical codes in the Kernel-level.
  - Minimize and guarantee the U-ISR latency.

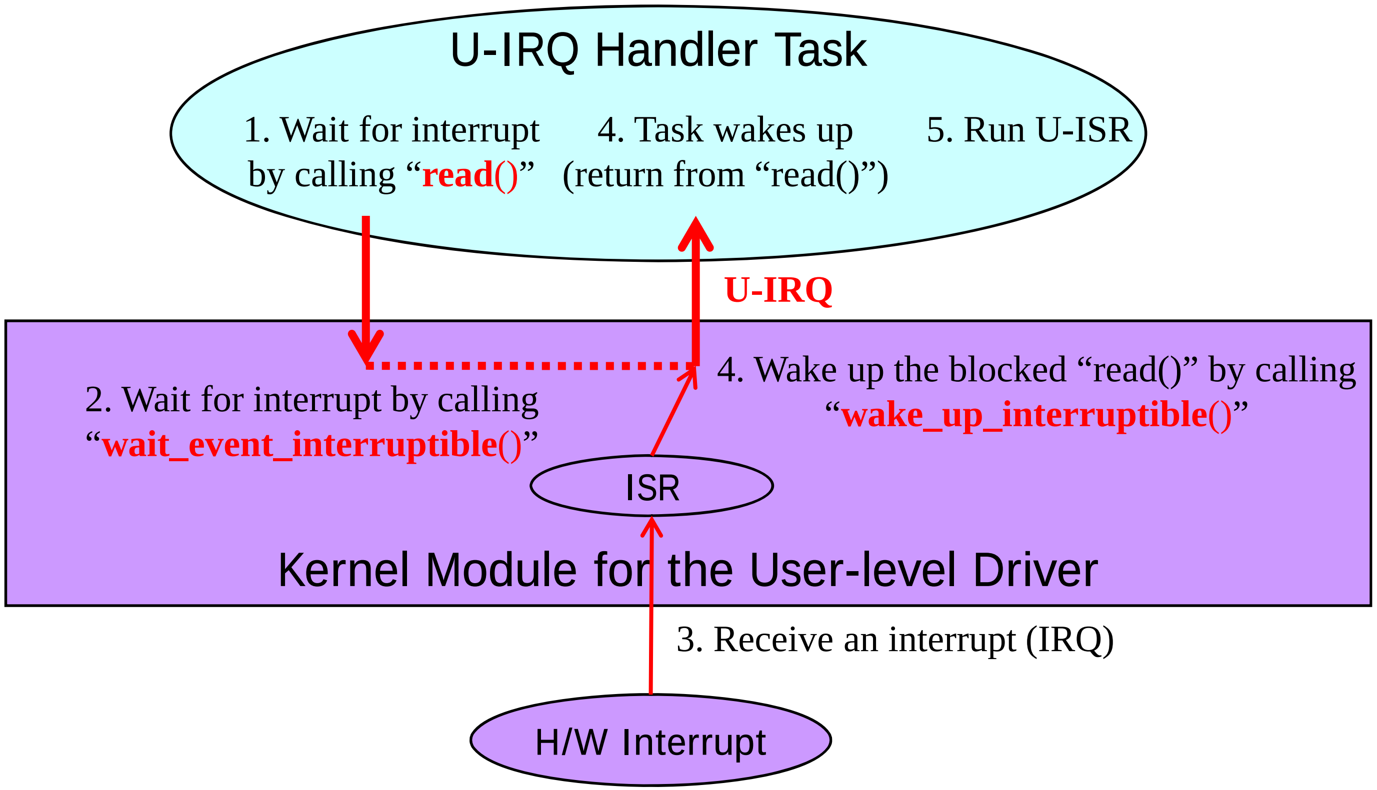
Memory Access

- User-level drivers can access control registers and buffer memory by mapping the physical memory.



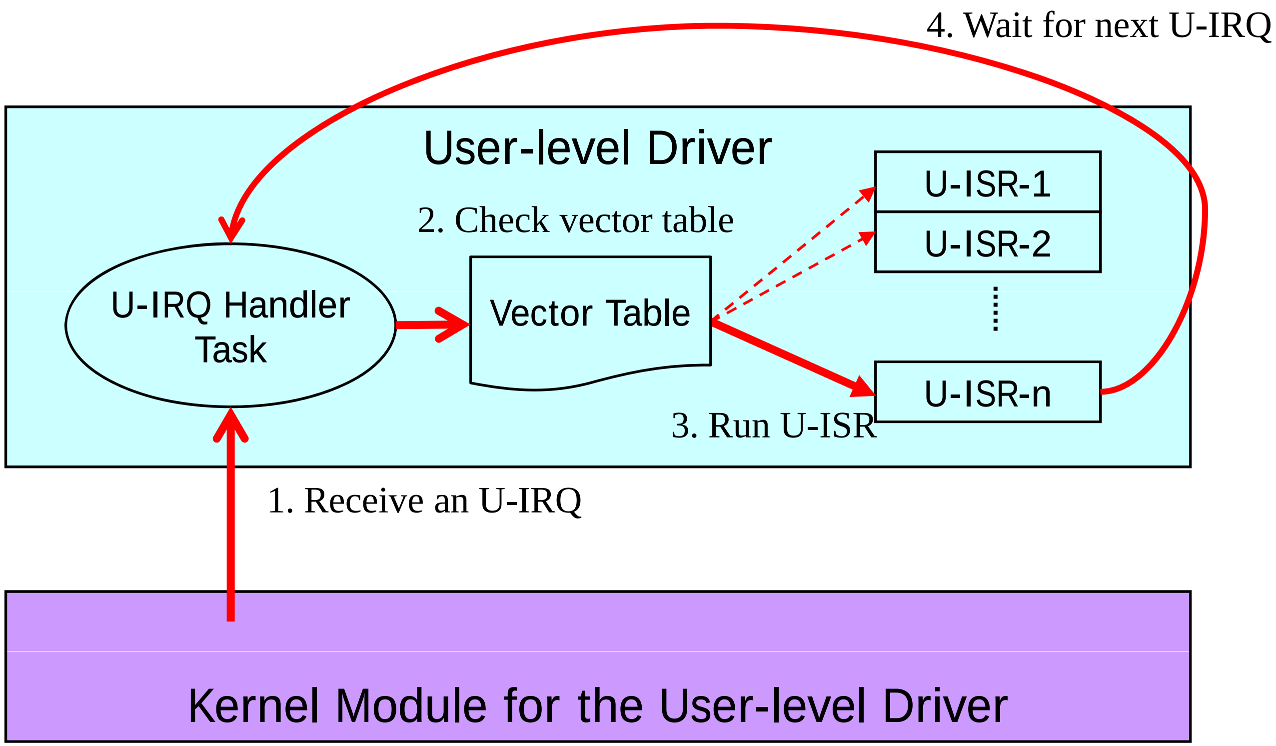
Interrupt Handling: U-IRQ

- Methodology to deliver Kernel IRQ to user task (U-IRQ)
  - Use synchronous file I/O (system call "**read**()")



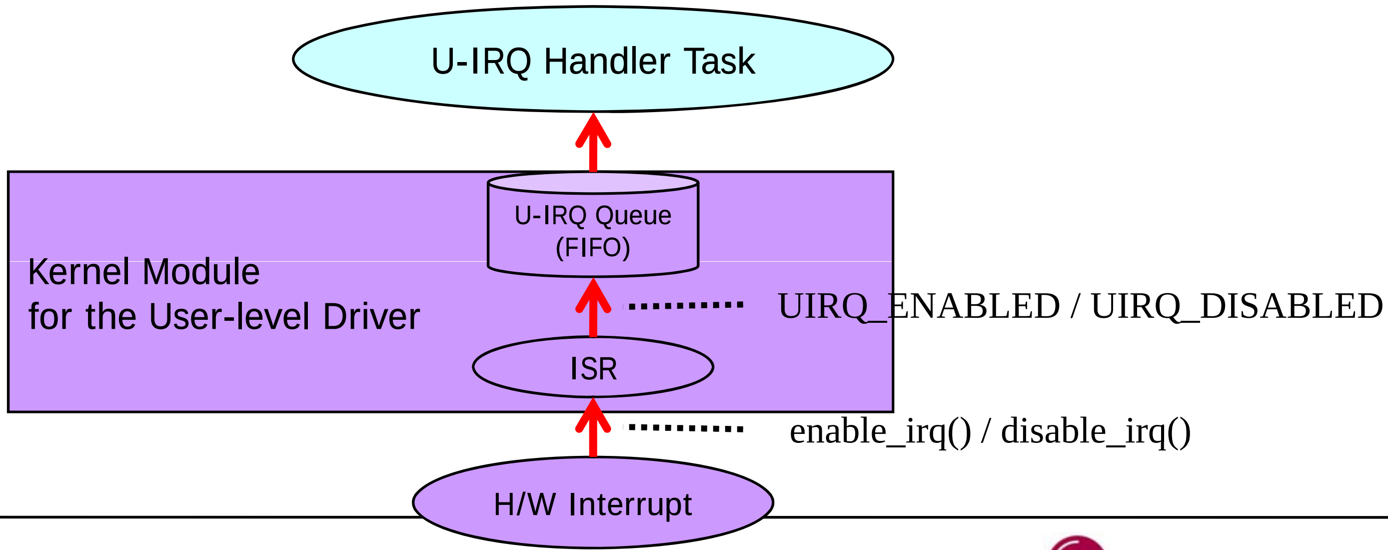
Interrupt Handling: U-ISR

- Implementation of U-ISR (waken up by U-IRQ)
  - U-IRQ handler task is a real-time thread with maximum priority. It will run dominantly.



Interrupt Handling: Controlling IRQ

- To enable and disable IRQ
  - Use the file I/O (system call “**ioctl**()”)
  - This controls the HW interrupt in the Kernel module (using api “**enable_irq**()” and “**disable_irq**()”)
- To enable and disable U-IRQ
  - Also use the file I/O (system call “**ioctl**()”)
  - This controls the U-IRQ queue (FIFO) in the Kernel module (using flags “**UIRQ_ENABLED**” and “**UIRQ_DISABLED**”)



Real-time

- Following time critical codes should be implemented in the Kernel-level.

Drivers	Time critical codes	Constraints
SDEC	PCR recovery	< 1 msec
For all	Interrupt pending clear	At the Kernel ISR

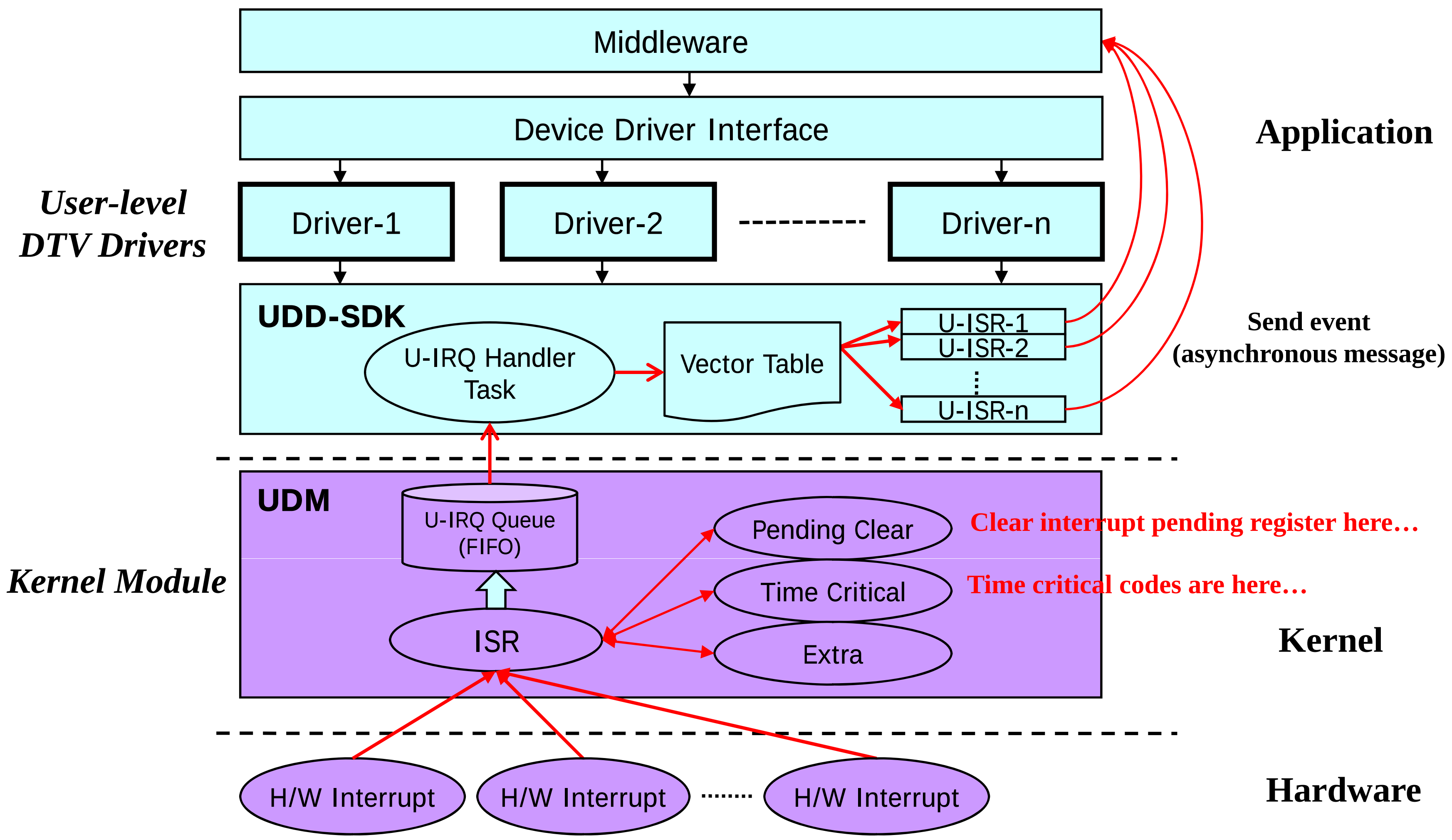
- Minimize and guarantee the IRQ delivery latency.
  - Use linux 2.6 Kernel.
  - Use real-time thread with maximum priority.

Implementation of User-level Drivers

Kernel Module & SDK for User-level Drivers

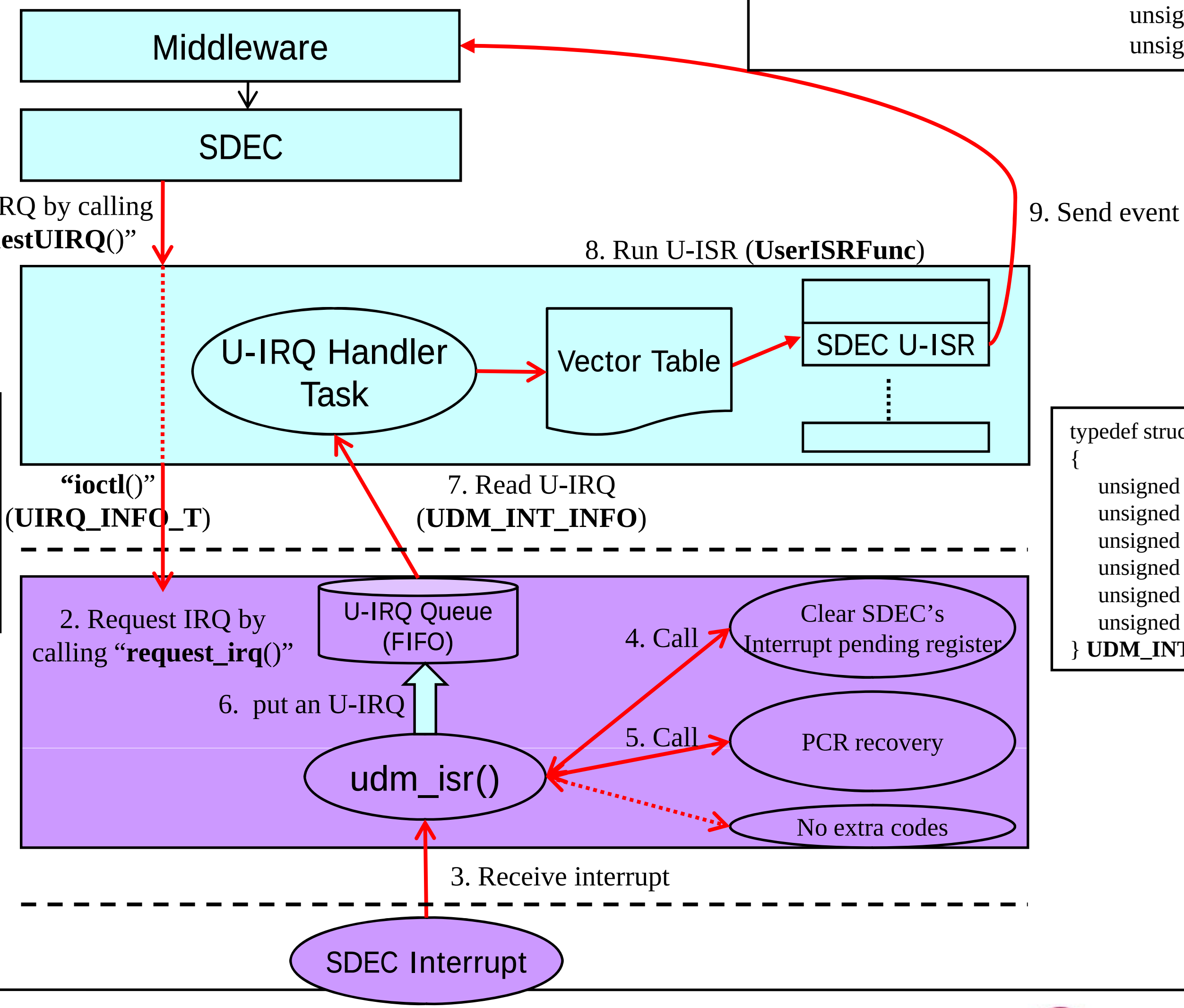
- User-level Driver Module (**UDM**)
  - Kernel module to provide…
    - map physical memory region to user memory space.
    - enable/disable IRQ & U-IRQ.
    - deliver Kernel IRQ to user handler task.
    - run time critical codes in Kernel-level.
- User-level Driver SDK (**UDD-SDK**)
  - Provides user-level APIs by calling UDM.
    - get user memory space mapped with physical memory region.
    - request U-IRQ and register U-ISR for it.
    - enable/disable IRQ & U-IRQ.

Structure of User-level Drivers



Interrupt Handling Flow: SDEC Driver

```
typedef void (*UserISRFunc) (   int uirqn,
                                unsigned int irq_status_h,
                                unsigned int irq_status_l,
                                const char * dev_name,
                                unsigned int latency,
                                unsigned int count);
```




```
typedef struct
{
    int             uirqn;
    int             usage;
    unsigned int    irq_status_h_addr;
    unsigned int    irq_status_l_addr;
    char            name[16];
} UIRQ_INFO_T;
```

```
typedef struct _UDM_INT_INFO
{
    unsigned int    uirq;
    unsigned int    uirq_status_h;
    unsigned int    uirq_status_l;
    unsigned int    uirq_wait_count;
    unsigned int    kirq_sec;
    unsigned int    kirq_usec;
} UDM_INT_INFO;
```

UDD-SDK APIs

- UDD_SDK_STATE **UDD_SDK_Init**(void)
  - Initialization function
- UDD_SDK_STATE **UDD_SDK_Release**(void)
  - Release function
- UDD_SDK_STATE **UDD_SetLogLevel**(UDD_LOG_LEVEL **loglevel**)
  - Set logging level (run-time changeable)
- UDD_SDK_STATE **UDD_RequestUIRQ**(UIRQ_INFO_T **uirqInfo**, UserISRFunc **uisrFunc**)
  - Request IRQ and register U-ISR
- UDD_SDK_STATE **UDD_EnableIRQ**(unsigned int **uirq**)
  - Enabe IRQ in Kernel
- UDD_SDK_STATE **UDD_DisableIRQ**(unsigned int **uirq**)
  - Disable IRQ in Kernel
- UDD_SDK_STATE **UDD_EnableUIRQ**(unsigned int **uirq**)
  - Enable U-IRQ in user-level
- UDD_SDK_STATE **UDD_DisableUIRQ**(unsigned int **uirq**)
  - Disable U-IRQ in user-level
- UDD_SDK_STATE **UDD_MemMap**(int **nLength**, int **nProt**, int **nFlags**, unsigned int **PhysAddr**, int * **pVirtAddr**)
  - Request mapping of physical memory region

Memory Access

- In the user-level driver

```
{
        …
        UDD_MemMap(SDEC_SIZE, PROT_READ | PROT_WRITE,
                        MAP_SHARED, SDEC_BASE_ADDR, &SdecBase)
        …
        /* can access physical memory directly through SdecBase */
        …
}
```

- In the UDD-SDK (user-level)

```
int UDD_MemMap(int nLength, int nProt, int nFlags, unsigned int PhysAddr, int * pVirtAddr)
{
        …
        nMemMapped = (int) mmap(0, nLength, nProt, nFlags, g_fdMem, PhysAddr);
        …
        * pVirtAddr = nMemMapped;
        …
        return UDDSDK_OK;
}
```

Memory Access

- In the UDM (Kernel-level)

```
static int udm_mmap(struct file *file, struct vm_area_struct *vma)
{
        …
        if (io_remap_pfn_range(vma,
                        vma->vm_start,
                        vma->vm_pgoff,                  /* Physical address     */
                        vma->vm_end - vma->vm_start,    /* Size                 */
                        vma->vm_page_prot))
        {
                return -EAGAIN;
        }

        return 0;
}
```

Requesting IRQ & U-IRQ

◆ In the UDD-SDK (user-level)

```
int UDD_RequestUIRQ(UIRQ_INFO_T * puirqInfo, UserISRFunc uisrFunc)
{
        …
        /* request IRQ & U-IRQ from UDM (Kernel) */
         ioctl(g_fdUDM, CMD_REQUEST_IRQ, (unsigned int) puirqInfo))
        …
        /* register U-ISR function in the U-IRQ vector table*/
        UIRQVectT.uirq[uirqn].UISRFunc     = uisrFunc;
        …
```

◆ In the UDM (Kernel-level)

```
static int udm_ioctl(struct inode *inode, struct file *file, unsigned int cmd, unsigned long param)
{
        switch (cmd)  {
        case CMD_REQUEST_IRQ: {
                …
                copy_from_user(&uinfo, (void *) param, sizeof(UIRQ_INFO_T));
                irqn = uinfo.uirqn;
                /* request IRQ */
                request_irq (irqn, udm_isr, IRQF_DISABLED, uinfo.name, NULL);
                …
                /* enable U-IRQ */
                uirqInfo[irqn].usage        = UIRQ_ENABLED;
```

Controlling IRQ & U-IRQ

- In the UDM (Kernel)

```
static int udm_ioctl(struct inode *inode, struct file *file, unsigned int cmd, unsigned long param)
{
        switch (cmd)  {
        …
        case CMD_ENABLE_IRQ:  {
                …
                enable_irq(irqn);
        }
        case CMD_DISABLE_IRQ:  {
                …
                disable_irq(irqn);
        }
        …

        case CMD_ENABLE_UIRQ: {
                …
                uirqInfo[irqn].usage        = UIRQ_ENABLED;
        }
        case CMD_DISABLE_UIRQ: {
                …
                 uirqInfo[irqn].usage       = UIRQ_DISABLED;
        }
        …
```

U-IRQ Handler Task (1)

- In the UDD-SDK (user-level)

```
#deifne  UISR_HANDLER_TASK_PRIORITY        99

int CreateUIRQHandlerTask
{              …
               pthread_attr_getschedparam(&attr, &sched);
               sched.sched_priority = UISR_HANDLER_TASK_PRIORITY;     /* set priority */
               pthread_attr_setschedparam(&attr, &sched);

               /* create RT task */
               if ((ret = pthread_create(pthd, &attr, (void *) UIRQ_HandlerTask, NULL)) != 0)
               …
}

/* This is RT task with maximum priority. This task will run dominantly. */
int UIRQ_HandlerTask(void)
{
               while (1)
               {
                              /* wait for interrupt. */
                              ret = read(g_fdUDM, &g_UIRQ, sizeof(UDM_INT_INFO));
                              …
                               UIRQVectT.uirq[irqn].UISRFunc(…);              /* run U-ISR */
                              …
               }
```

U-IRQ Handler Task (2)

◆ In the UDM (Kernel)

```
ssize_t  udm_read( struct file *file, char __user *buffer, size_t count, loff_t *offset)
{
        …
        /* blocked here */
        ret = wait_event_interruptible(&udm_int_waitq, udm_fifo_count > 0);

        if (ret == 0)  /* success, condition (udm_fifo_cound > 0) is true */
                return fifo_copy_to_user(buffer);
        …
}

irqreturn_t  udm_isr(int irq, void* dev_id, struct pt_regs *regs)
{
        …
        if (uirqInfo[irqn].usage  ==  UIRQ_ENABLED)     /* check U-IRQ usage */
                fifo_put(&uint_info);                   /* add U-IRQ to FIFO */
        …
        /* wake up the blocked udm_read() */
        wake_up_interruptible(&udm_int_waitq);
        …
}
```

Performance Evaluation

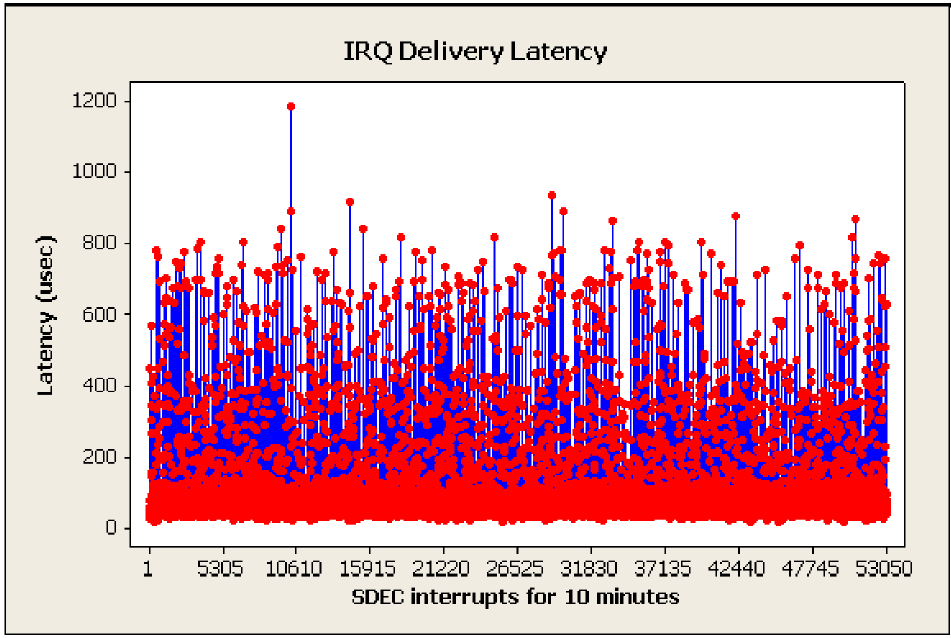
Environments

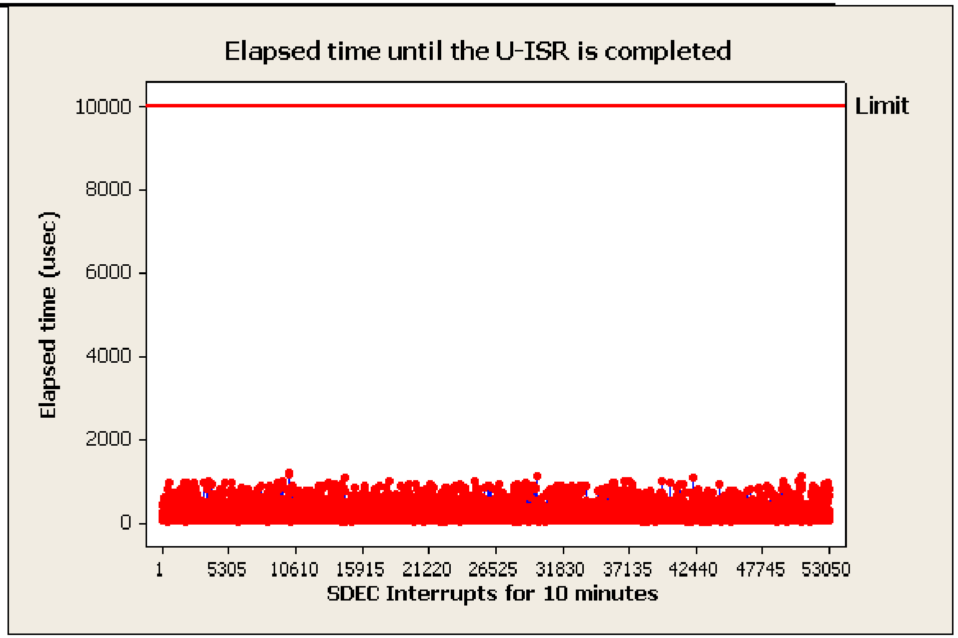
- Implement and test user-level drivers on LG’s own DTV chipset board.
  - H/W
    - 333 MHz core
    - 128MB DDR2 & 32MB flash
  - Kernel-level Drivers
    - Ethernet, uart, pci, sata, usb,…
  - **User-level Drivers (8 drivers)**
    - **SDEC, VDEC, ADEC, VDP, OSD, GFX, I2C, GPIO**
- Bootloader & Kernel & rootfs
  - U-boot-1.1.4
  - Linux 2.6.20.2 Kernel
  - uClibc 0.9.28
  - Squashfs-3.2

Measurement

- Measured the …
  1. **IRQ delivery latency** from Kernel interrupt to the U-IRQ handler task.
  2. **Elapsed time until the U-ISR is completed** from the Kernel interrupt occur.
- Test conditions
  - Kernel : **Non-preemptible** Kernel
  - Stress : With lightweight stress (channel change)
- Functions to get time
  - Kernel : "**do_gettimeofday**()"
  - User-level : "**gettimeofday**()"
- Test targets
  - **SDEC**, **VDEC** and **VDP** driver (they have real-time requirements)
- Test time
  - **For 10 minutes**

SDEC

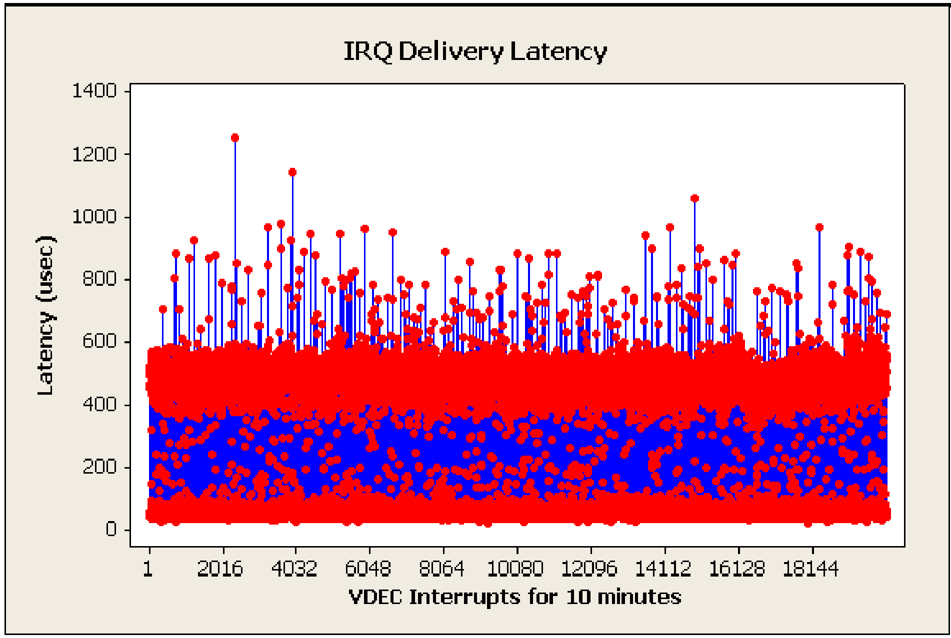


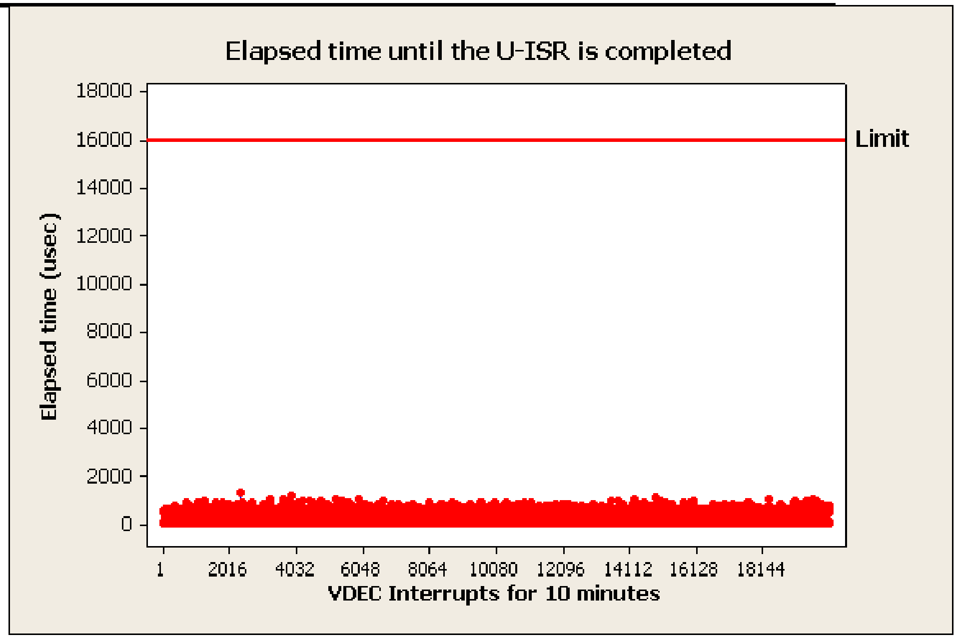


- Statistics
  - Average = 69.1 usec
  - Minimum = 19 usec
  - Maximum = 1,183 usec

- Statistics
  - Average = 150.4 usec
  - Minimum = 33 usec
  - Maximum = 1,199 usec
- Real-time requirement of SDEC
  - Under of **10,000 usec**

VDEC

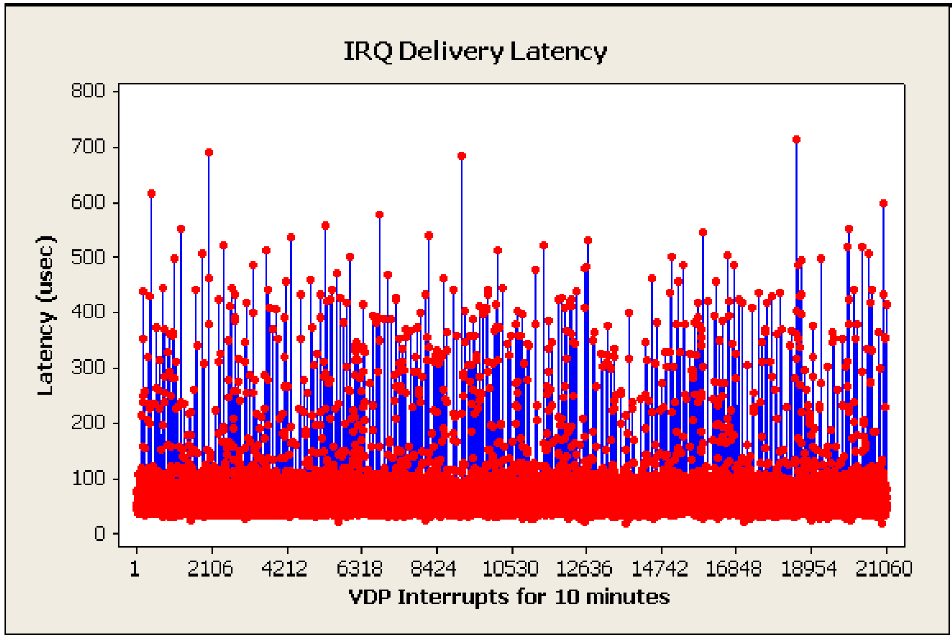


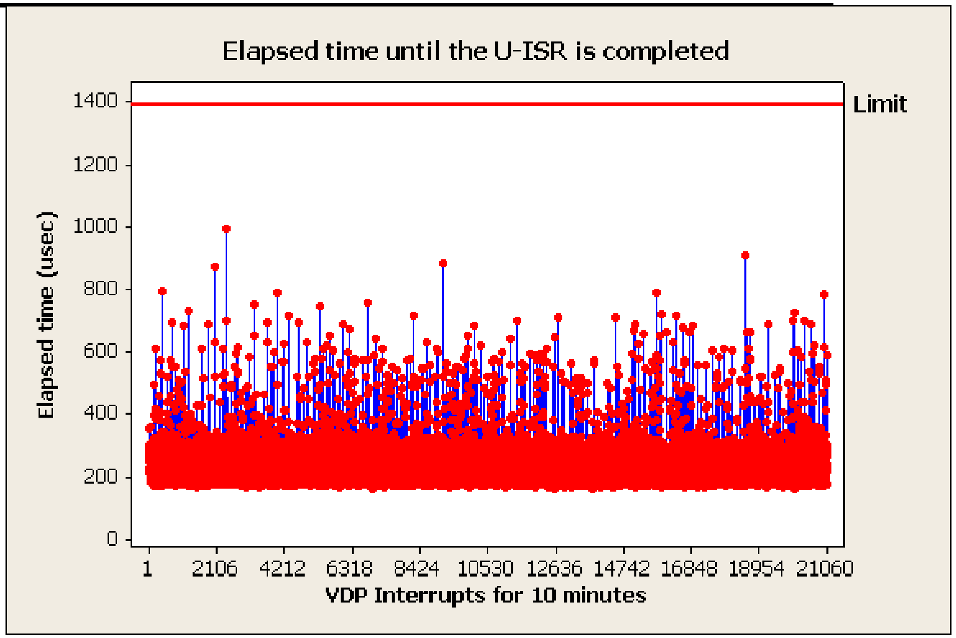


- Statistics
  - Average = 270.6 usec
  - Minimum = 20 usec
  - Maximum = 1,255 usec

- Statistics
  - Average = 312.4 usec
  - Minimum = 35 usec
  - Maximum = 1,331 usec
- Real-time requirement of VDEC
  - Under of **16,000 usec**

VDP





- Statistics
  - Average = 67.4 usec
  - Minimum = 18 usec
  - Maximum = 716 usec

- Statistics
  - Average = 229.3 usec
  - Minimum = 157 usec
  - Maximum = 993 usec
- Real-time requirement of VDP
  - Under of **<u>1,390 usec</u>**

Conclusion

- Implemented all DTV drivers in user-level.
- User-level drivers satisfied the requirement of LG DTV.
- Built general architecture of user-level drivers (UDM, UDD-SDK)

Future Works

- Evaluate trade-offs between real-time performance and throughput.
- Evaluate the Ingo Molnar’s “Real-Time Preemption” Kernel.
- Extend UDM and UDD-SDK to apply on other embedded Linux systems.

Reference

- Katsuya Matsubara, “Analysis of User Level Device Driver usability in embedded application - Technique to achieve good real-time performance”, CELF ELC 2006. (http://tree.ceLinuxforum.org/CelfPubWiki/ELC2006Presentations?action=AttachFile&do=get&target=uldd060411celfelc2006.pdf)
- Real-time resources of CE Linux Forum, (http://tree.ceLinuxforum.org/CelfPubWiki/RealTimeResources)
- Real-time preemption patches (http://redhat.com/~mingo/realtime-preempt/)

Thank you !