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User Interrupts – A faster way to signal

Sohil Mehta
sohil.mehta@intel.com

Goals

- Motivation
- Use cases
- Software architecture
- Feedback / Opens
- Next steps

Motivation

- Deliver events directly to user space – bypass kernel
- Overcome limitations of existing IPC and I/O events
  - Synchronous, Asynchronous, Polling.
  - Signals, pipes, RPCs, hardware notifications, etc.
- Super fast and efficient alternative

First hardware implementation – x86

- Intel processor code-named Sapphire Rapids

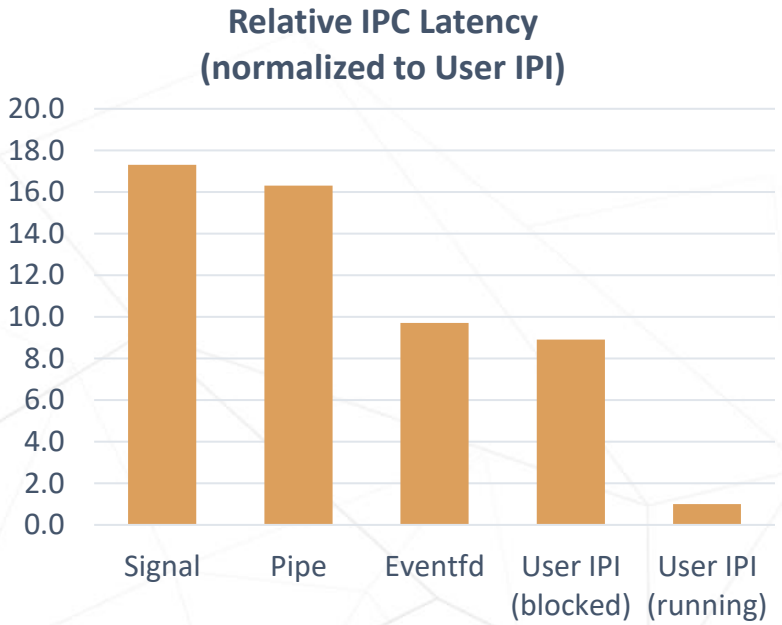
Sources of User Interrupts

- **Receiver infrastructure is common**
- Now - User to User IPC - SENDUIPI
  - RFC patches are out
- Soon - Kernel to User
  - Patches in development
- Later - Other sources
  - e.g. devices

https://lore.kernel.org/lkml/20210913200132.3396598-1-sohil.mehta@intel.com/

Use cases

- General purpose fast IPC
- User mode schedulers
- Event dispatch for I/O stacks
  - e.g. User space networking
- Abstractions
  - Libevent, Liburing, etc.
- Other suggestions?

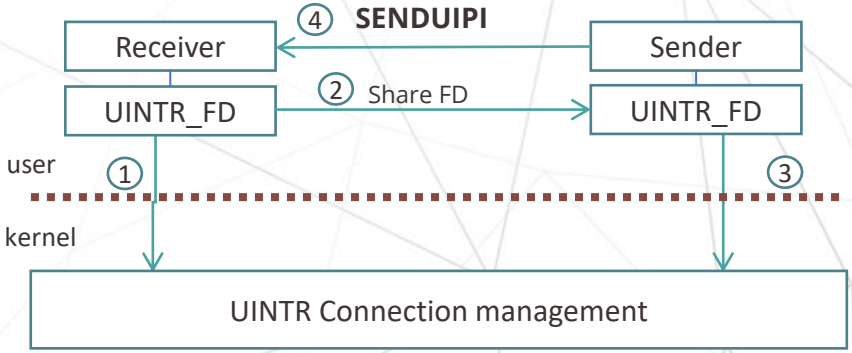


9x performance improvement

*details in backup

Software design

- Opt in – via system calls
- Sender – notifies the event
  - User application, kernel, others
- Receiver – waiting for events
  - User application
- Connection setup
  - File descriptor based
  - Closest equivalent is eventfd()



User IPI connection

Receiver APIs

- Register User Interrupt Handler

```
int uintr_register_handler(handler_func, flags);
int uintr_unregister_handler(flags);
```

- Create an fd representing the vector - priority

```
uintr_fd = uintr_create_fd(vector, flags);
```

- Share Connection with sender
  - Any existing fd exchange mechanism via inheritance or sharing via socket domain

Sender APIs

- Sender Connection Management using FDs
- Receive FD via inheritance or UNIX domain sockets

```
uipi_handle = uintr_register_sender(uintr_fd,flags);
int uintr_unregister_sender(uintr_fd, flags);
```

- x86 Instruction

```
void _senduipi(uipi_handle)
```

User IPI Sample

Receiver

```
void __attribute__ ((interrupt)) u_handler(struct __uintr_frame
                          *frame, unsigned long vector) {
    write(STDOUT_FILENO, “User Interrupt!\n”, 16);
    uintr_received = 1;
}
int main(int argc, char *argv[]) {
    int vector = 0;
    pthread_t pt;

    ret = uintr_register_handler(u_handler, 0);
    uintr_fd = uintr_create_fd(vector, 0);
    _stui();
    printf("Receiver enabled interrupts\n");

    pthread_create(&pt, NULL, &sender_thread, NULL)

    /* Do some other work */
    while(!uintr_received);

    pthread_join(pt, NULL);
    close(uintr_fd);
    uintr_unregister_handler(0);
    exit(EXIT_SUCCESS);
}
```

Sender

```
void *sender_thread(void *arg)
{
    int uipi_handle;

    uipi_handle = uintr_register_sender(uintr_fd, 0);

    printf("Sending IPI from sender thread\n");
    _senduipi(uipi_handle);

    uintr_unregister_sender(uintr_fd, 0);
    return NULL;
}
```

Compiler – GCC 11

```
gcc -muintr -mgeneral-regs-only uipi_sample.c -lpthread -o uipi_sample
```

Output

```
$./uipi_sample
Receiver enabled interrupts
Sending IPI from sender thread
            User Interrupt!
```

Feedback / Opens

Feedback

- Syscall and FD based approach
- Other architectures

Opens

- Interrupting blocking system calls like sleep(), read(), etc.
- Common `uipi_handle` across threads (and processes)
- Kernel page table isolation support
- Many more..

Next steps?

Any suggestion is appreciated!

Please review UINTR patches on LKML.

https://lore.kernel.org/lkml/20210913200132.3396598-1-sohil.mehta@intel.com/

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THANK YOU

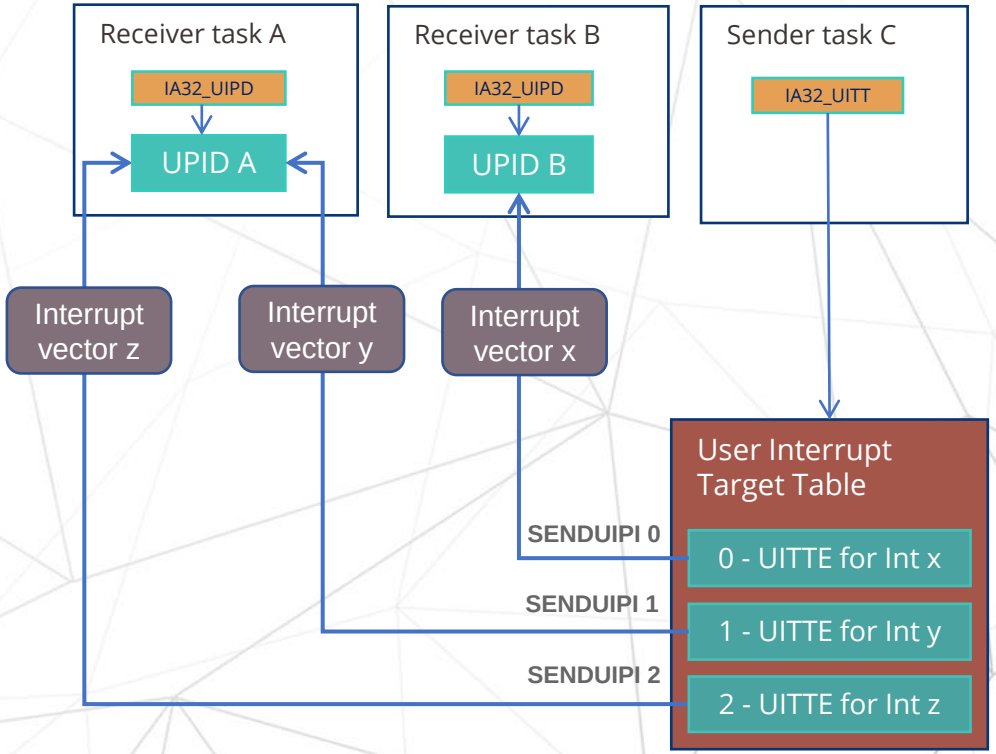
Special Thanks!

Ashok Raj, Dave Hansen, Jacob Pan Jun, Tony Luck.

Backup

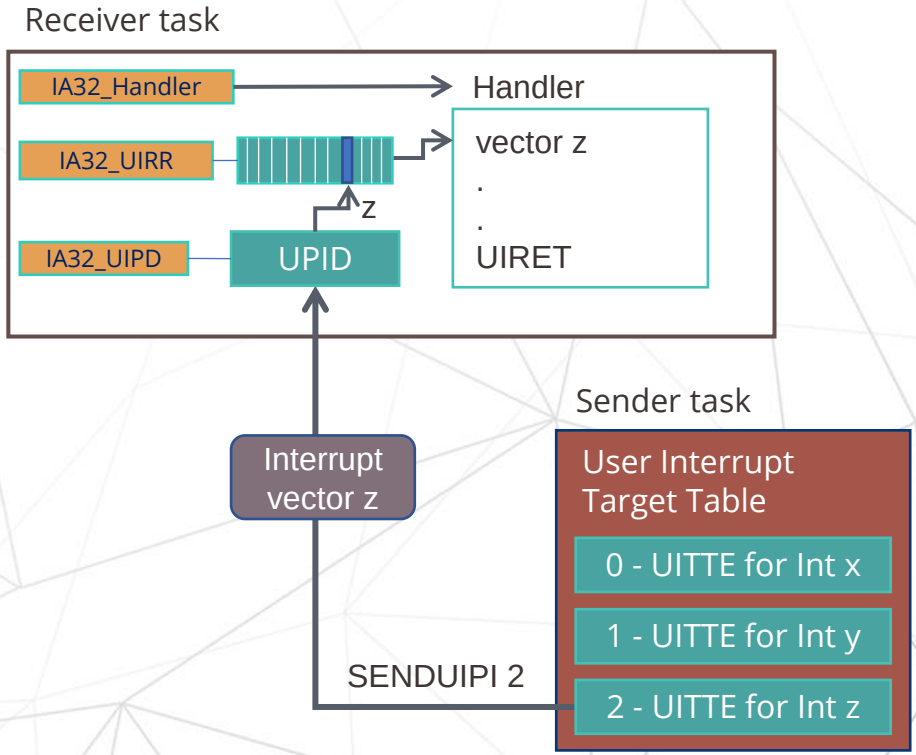
HW arch key elements

- UPID - Posted Interrupt descriptor
  - Pending interrupt vectors
  - Notification state – ON, SN.
  - Routing information
- UITT - Interrupt Target Table
  - UPID pointer
  - Vector information
- SENDUIPI <UITT index>



User Interrupt delivery

- Interrupt posting
  - Senduipi updates UPID
  - Generate notification interrupt
- Notification processing
  - Recognize interrupt
  - Move to UIRR
- Interrupt delivery
  - Push vector, invoke handler
- Return from handler - Uiret



x86 Instructions

- **senduipi <uipi_handle>** – send a user IPI to a target task based on the UITT index.
- **uiret** – Return from a User Interrupt handler
- **clui** – Mask user interrupts by clearing UIF (User Interrupt Flag).
- **stui** – Unmask user interrupts by setting UIF.
- **testui** – Test current value of UIF.

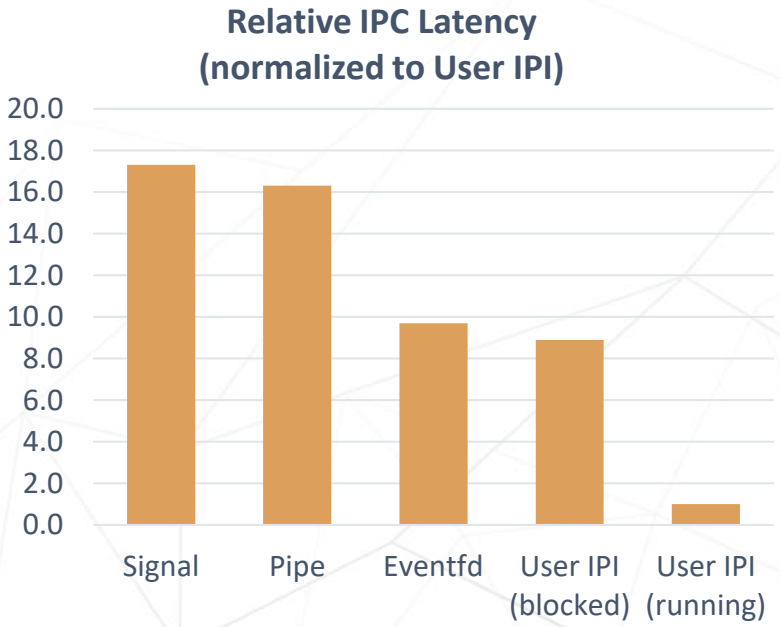
Kernel API for User Notification

- Exchange uintr_fd with kernel agent
- Post user interrupt from the kernel

```
int uintr_notify(int uintr_fd);
```

- Kernel identifies target, vector from uintr_fd

IPC Performance



9x performance improvement with User IPI (running)

Original workload: https://github.com/goldsborough/ipc-bench
Updated workload: https://github.com/intel/uintr-ipc-bench
Config: 1M ping-pong IPC notifications with message size=1

Results have been estimated based on internal tests with:
Kernel: Linux v5.14.0 + User IPI patches
System: Internal pre-production platform

*Performance varies by use, configuration and other factors.