USB support in Zephyr OS

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What is it about today?

- USB support in Zephyr RTOS
- Continuation on the presenstation from ZDS2021
- Not about current USB device support
- ... which is not so bad
- ... but has few drawbacks and limitations

What is going on in USB development?

- New USB device controller (UDC) driver API
- New USB device stack implementation
- Current device support will stay maintained

Hot and new

- USB host controller (UHC) driver API
- Initial USB host stack implementation

USB device controller (UDC) API

- Support for multiple drivers (and instances)
- Support to query controller capabilities (FS, HS, rwup...)
- Support to check endpoint configuration
- Single asynchronous API to enqueue transfers
- ... (no direct read/write accesses to endpoint buffers)
- Uses net_buf for endpoint transfers
- Thin common layer between driver and device stack
- Implementation for nRF USBD and Kinetis USBFSOTG controllers

3. New USB device controller API

```c
/* Driver facing API */

struct udc_api {
        int (*ep_enqueue)(const struct device *dev,
                          struct udc_ep_config *const cfg,
                          struct net_buf *const buf);
        int (*ep_dequeue)(const struct device *dev,
                          struct udc_ep_config *const cfg);
        int (*ep_flush)(const struct device *dev,
                        struct udc_ep_config *const cfg);
        int (*ep_set_halt)(const struct device *dev,
                           struct udc_ep_config *const cfg);
        int (*ep_clear_halt)(const struct device *dev,
                             struct udc_ep_config *const cfg);
        int (*ep_enable)(const struct device *dev,
                         struct udc_ep_config *const cfg);
        int (*ep_disable)(const struct device *dev,
                          struct udc_ep_config *const cfg);
        int (*host_wakeup)(const struct device *dev);
        int (*set_address)(const struct device *dev,
                           const uint8_t addr);
        int (*enable)(const struct device *dev);
        int (*disable)(const struct device *dev);
        int (*init)(const struct device *dev);
        int (*shutdown)(const struct device *dev);
        int (*lock)(const struct device *dev);
        int (*unlock)(const struct device *dev);
};
```

3. New USB device controller API

```c
/* Upper layer facing API */

    int udc_init(const struct device *dev, udc_event_cb_t event_cb);
    int udc_enable(const struct device *dev);
...
    int udc_shutdown(const struct device *dev);
...
    int udc_set_address(const struct device *dev, const uint8_t addr);
    int udc_host_wakeup(const struct device *dev)
...
    int udc_ep_try_config(const struct device *dev,
                          const uint8_t ep,
                          const uint8_t attributes,
                          uint16_t *const mps,
                          const uint8_t interval);
...
    int udc_ep_enable(const struct device *dev,
                      const uint8_t ep,
                      const uint8_t attributes,
                      const uint16_t mps,
                      const uint8_t interval);
...
    int udc_ep_set_halt(const struct device *dev, const uint8_t ep);
...
    int udc_ep_enqueue(const struct device *dev, struct net_buf *const buf);
```

UDC drivers organization

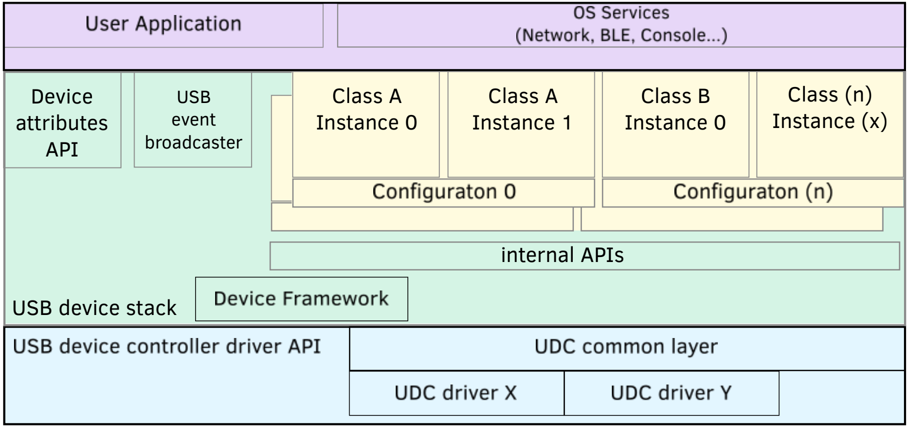
include/zephyr/drivers/usb/udc.h

```
drivers
└── usb
    ├── device
    │   └── ...
    └── udc
        ├── CMakeLists.txt
        ├── Kconfig
        ├── Kconfig.nrf
        ├── ...
        ├── udc_common.h ........................UDC common layer header
        ├── udc_common.c ..................................UDC common layer
        ├── udc_nrf.c .................................... nRF USBD driver
        └── ...
```

New USB device stack implementation

- Support for multiple UDC instances
- Support for multiple device configurations
- Interface to update/set device attributes at runtime
- Class/function assignment to a configuration at runtime
- Endpoint assignment by the stack
- Interface configuration by the stack
- Managed endpoint transfer events

USB device controller (UDC) API



4. New USB device stack

```
#include <zephyr/usb/usbd.h>
...
USBD_CONFIGURATION_DEFINE(config_foo, USB_SCD_SELF_POWERED, 200);
USBD_CONFIGURATION_DEFINE(config_baz, USB_SCD_REMOTE_WAKEUP, 200);

USBD_DESC_LANG_DEFINE(lang);
USBD_DESC_STRING_DEFINE(mfr, "ZEPHYR", 1);
...
USBD_DEVICE_DEFINE(uds_ctx, DEVICE_DT_GET(DT_NODELABEL(zephyr_udc0)),
                   0x2fe3, 0xffff);
...
        err = usbd_add_descriptor(&uds_ctx, &lang);
...
        err = usbd_add_descriptor(&uds_ctx, &mfr);
...

        err = usbd_add_configuration(&uds_ctx, &config_foo);
...

        err = usbd_register_class(&uds_ctx, "foobaz", 1);
...
        err = usbd_init(&uds_ctx);
...
        err = usbd_enable(&uds_ctx);
...
```

How does it work? (simplified)

- Device configurations are initialized by usbd_init()
- Device stack provides an event callback using udc_init()
- UDC submits an event (to stack's message queue) using callback
- Device is not recognized by the host until udc_enable()
- Finally device is enabled by usbd_enable()
- Host enumerates device, set configuration and interface alternate
- Stack configures endpoints according to class interface descriptors

USBD class API)

- Internal API used by the stack for the classes (functions)
- Looks like a driver API but much simpler
- Class instances use iterable section and a specific name to be recognizable
- Describes class configuration using (interface) descriptors
- API provides callbacks for configuration update,
- ... control and interface endpoint events,
- ... suspend and resume events

4. New USB device stack

```c
/* USBD class facing API */
struct usbd_class_api foobaz_api = {
        .update = foobaz_update,
        .control = foobaz_control,
        .request = foobaz_ep_request,
        .suspended = foobaz_suspended,
        .resumed = foobaz_resumed,
        .init = foobaz_init,
};

static struct usbd_class_data foobaz_data = {
        .desc = (struct usb_desc_header *)&foobaz_desc,
        .v_reqs = &foobaz_vregs,
};

USBD_DEFINE_CLASS(foobaz, &foobaz_api, &foobaz_data);

/* Stack facing internal class API (truncated) */
size_t usbd_class_desc_len(struct usbd_class_node *node);
...
struct usbd_class_node *usbd_class_get_by_ep(struct usbd_contex *uds_ctx,
                                             uint8_t ep);
...

/* Application facing USB device stack API (truncated) */
int usbd_register_class(struct usbd_contex *uds_ctx,
                        const char *name,
                        uint8_t cfg);
...
```

USB host support

- Similar in structure to new USB device support
- Asynchronous host controller driver API
- Simpler, initial host support
- Original driven by the need to test device support
- Should ideally map the device support features

Should ideally map the device support features

- Device CDC ACM <-> Host CDC ACM
- Device class-foo <-> Host class-foo

USB host controller (UHC) API

- Similar to UDC API
- Support for multiple driver (and instances)
- Support to obtain controller capabilities (FS, HS...)
- Single API for bus and transfer events
- Uses a container and net_buf for transfers
- Thin common layer between driver and host stack
- Implementation for MAX3421E host controller

USB testing

- The best way to test is on the hardware
- ... higher coverage and authenticity

Tests using Zephyr RTOS only (WIP)

- Closed loop using real host and device controller
- Closed loop using virtual host and device drivers

Tests using foreign host support or host stack

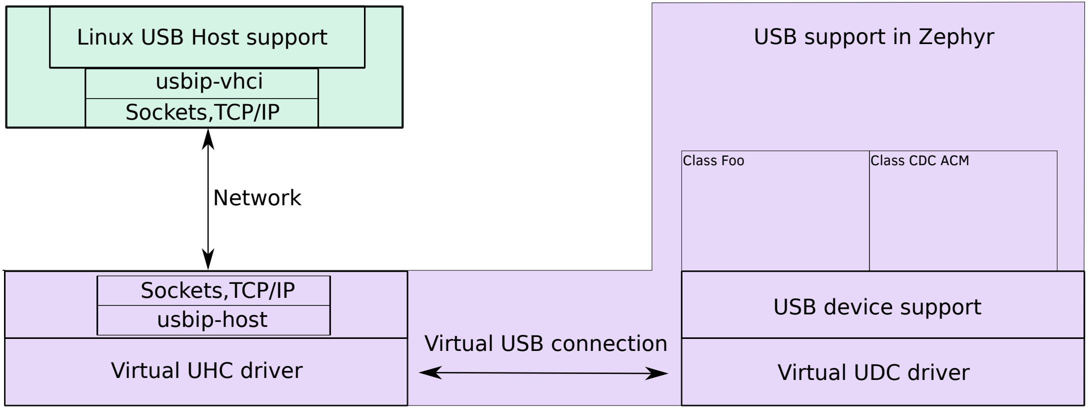
- Device support testing using testusb and Linux host
- Host controller testing using USBIP

- There are none emulated controller implemented yet (WIP)

USBIP

- Passes USB device from server to client over TCP
- ... actually exports a host controller over TCP
- Description and implementation available in Linux kernel[1] [2]
- New implementation based on USB host controller API is WIP
- Could be used to export a real host controller
- ... or virtual host connected to virtual device controller

USBIP support overview



Namespaces in USB support

- USB device controller driver API - udc_
- USB host controller driver API - uhc_
- current USB device controller driver API - usb_dc_
- USB device stack - usbd_
- USB host stack - usbh_
- Common Device Framework defines (Chapter 9) - usb_ and USB_
- current USB device stack - usb_

Questions?

9. References

[1] *USBIP Protocol*. https://elixir.bootlin.com/linux/latest/source/Documentation/usb/usbip_protocol.rst.

[2] *USBIP Tool*. https://elixir.bootlin.com/linux/latest/source/tools/usb/usbip/README.