LINUX PLUMBERS CONFERENCE
August 24-28, 2020

Using Zephyr, Linux and Greybus for IoT

Chris Friedt
chris@friedt.co

FRIEDT
Professional Engineering Services

LINUX PLUMBERS CONFERENCE
August 24-28, 2020

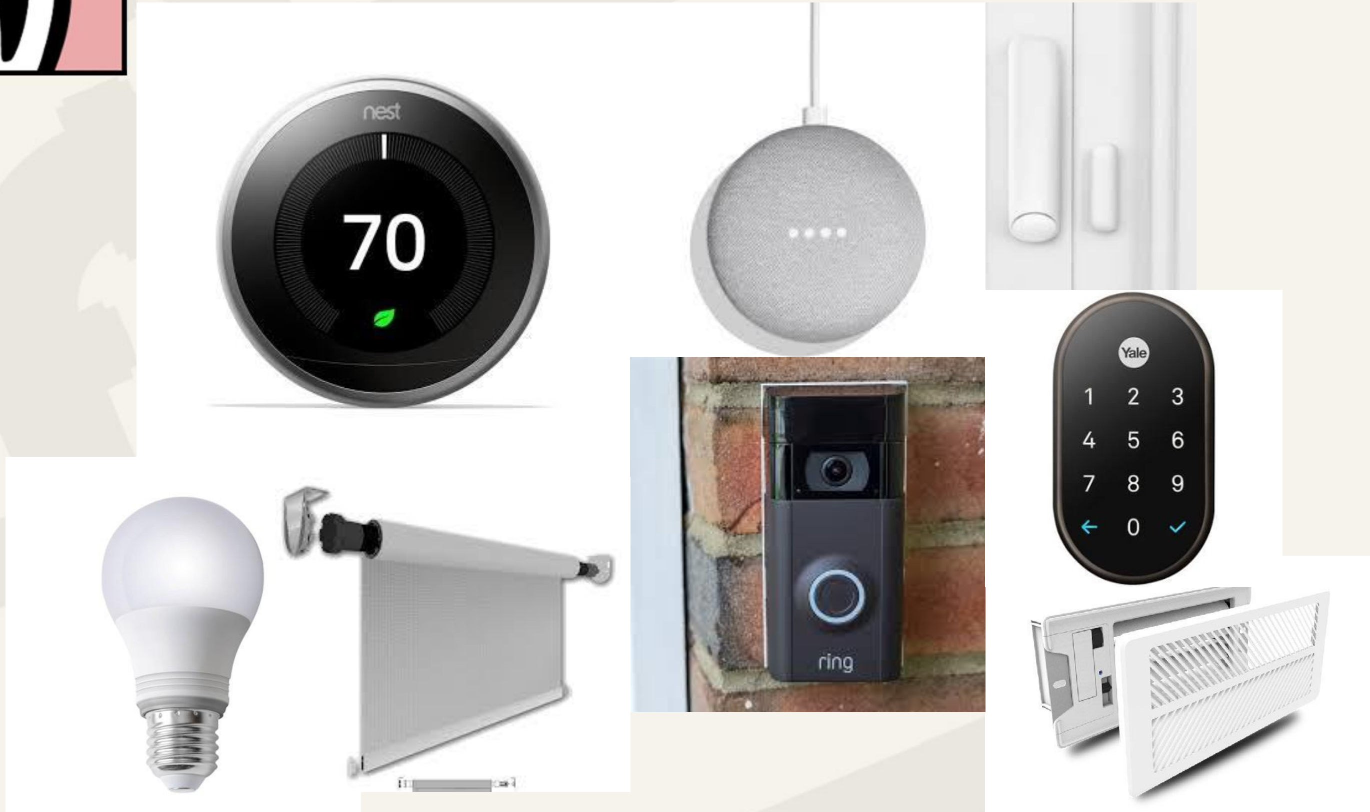
The Internet of Things

“A system of interrelated computing devices, mechanical and digital machines provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.”

-- Wikipedia

LINUX PLUMBERS CONFERENCE
August 24-28, 2020

Popular IoT Devices



beagleboard.org

FRIEDT
Professional Engineering Services

LINUX
PLUMBERS
CONFERENCE
August 24-28, 2020

~~Popular IoT~~ Devices

- /dev/gpiochipN
- /dev/i2cN
- /dev/videodevN
- /sys/bus/iio/devices/iio:deviceN

  ...

beagleboard.org

FRIEDT
Professional Engineering Services

LINUX PLUMBERS CONFERENCE
August 24-28, 2020

Discoverable Buses

1. Must be able to query devices attached to the bus
2. Services provided by each device must be categorized
3. Services should use a standard protocol

PCIe, USB, Ethernet are discoverable
GPIO, I2C, SPI are non-discoverable

beagleboard.org

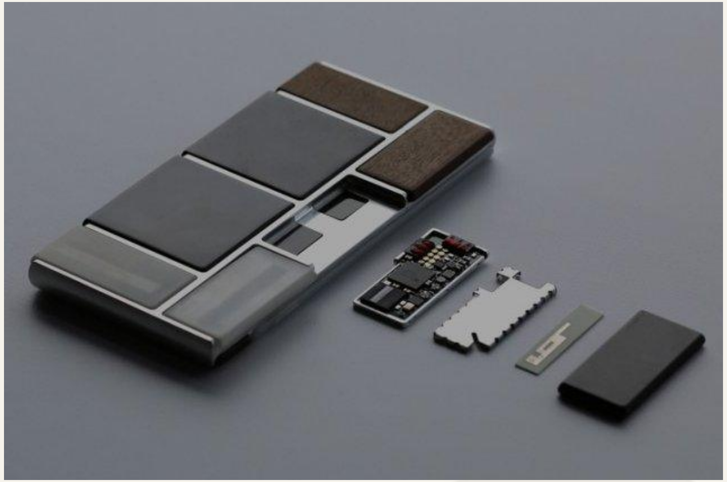
FRIEDT
Professional Engineering Services

Project Ara

- Motorola Advanced Technologies and Projects (ATAP)
- Former DARPA
- Acquired by Google

Project Ara

- Modules could use GPIO, I2C, SPI, MIPI, etc.
- UniPro High-speed Interconnect
- Shelved in 2016

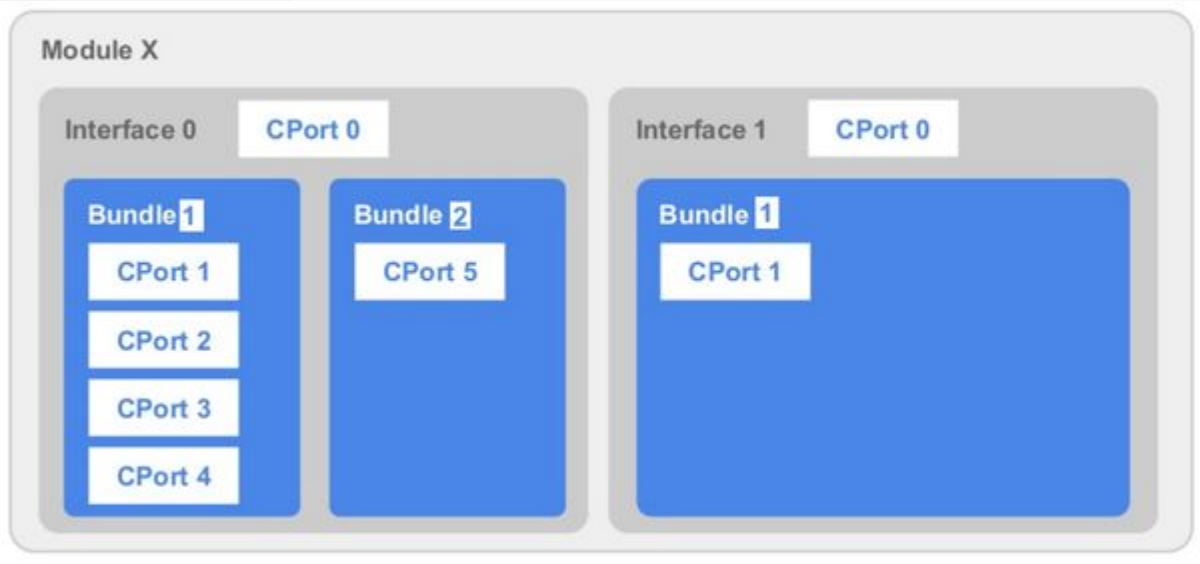


Project Ara

Due to the application-layer protocol being used on top of UniPro for Project Ara, all of those non-discoverable buses that we had been using in embedded for so long had suddenly become discoverable*.

*with some exceptions

Greybus



LINUX PLUMBERS CONFERENCE
August 24-28, 2020

beagleboard.org

FRIEDT
Professional Engineering Services

Greybus Manifest

```
[manifest-header]
version-major = 0
version-minor = 1

[interface-descriptor]
vendor-string-id = 0x1
vendor-product-id = 0x2

; Interface vendor string
[string-descriptor 0x1]
string = Zephyr Project RTOS

; Interface product string
[string-descriptor 0x2]
string = Greybus Service Sample Application

; 'Control' class on Bundle 0
[bundle-descriptor 0x0]
class = 0x0

; 'Bridged PHY' class on Bundle 1
[bundle-descriptor 0x1]
class = 0xa

; 'Bridged PHY' class on Bundle 2
[bundle-descriptor 0x2]
class = 0xa

; 'Bridged PHY' class on Bundle 3
[bundle-descriptor 0x3]
class = 0xa

; 'Control' protocol on CPort 0
[cport-descriptor 0x0]
bundle = 0x0
protocol = 0x0

; 'GPIO' protocol on CPort 1
[cport-descriptor 0x1]
bundle = 0x1
protocol = 0x2

; 'I2C' protocol on CPort 2
[cport-descriptor 0x2]
bundle = 0x2
protocol = 0x3

; 'SPI' protocol on CPort 3
[cport-descriptor 0x3]
bundle = 0x3
protocol = 0xb
```

Greybus Special Entities

AP (Applications Processor)

- Lives inside the Linux kernel
- Communicates via UniPro using AP Bridge
- Administrates the Greybus network

SVC (Supervisory Controller)

- Notify AP when modules are inserted or removed
- Configure and Control the transport (e.g. UniPro)

LINUX PLUMBERS CONFERENCE
August 24-28, 2020

Gbridge: Greybus for IoT

- Alexandre Baillon, BayLibre
- ELCE 2016, Berlin
- Plumbers 2019, Lisbon
- Implement SVC in software
- Communicate with AP (Linux kernel) via Netlink
- gb-netlink kernel module

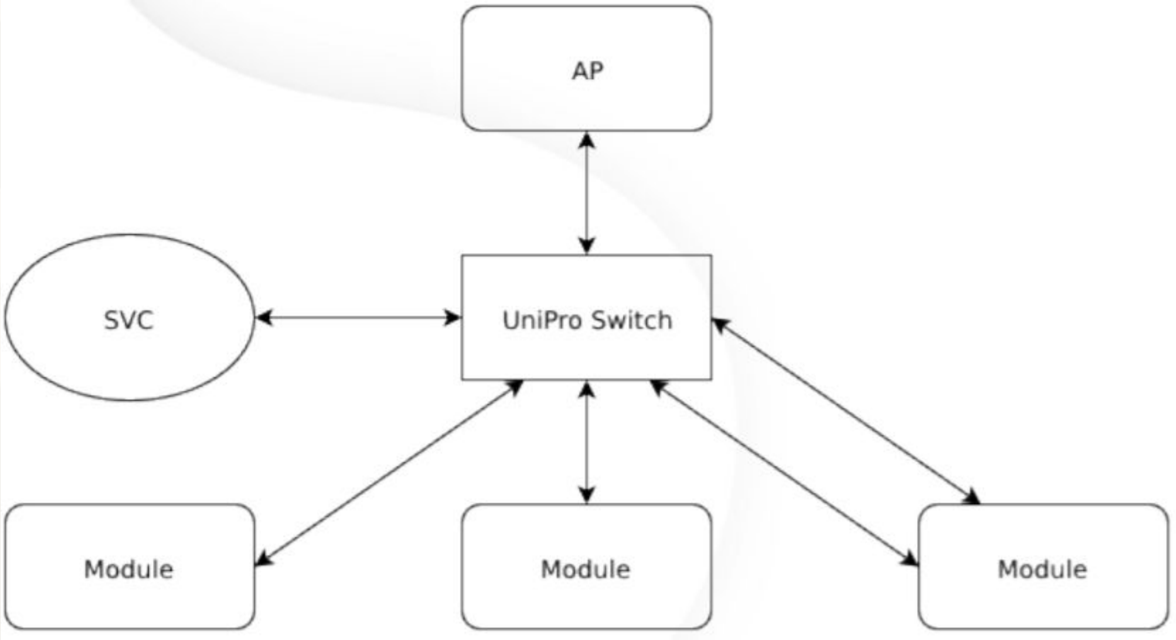
beagleboard.org

FRIEDT
Professional Engineering Services

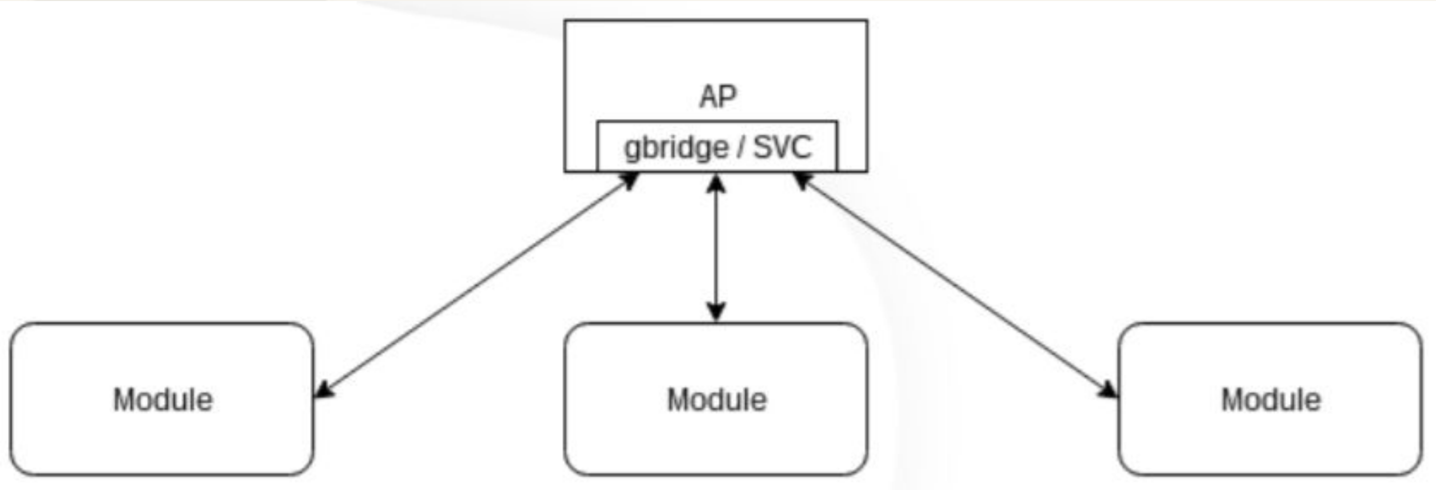
https://github.com/anobli/gbridge

https://github.com/anobli/greybus/tree/gb_netlink

Project Ara Topology



Gbridge Topology



Gbridge Host Controllers

- UART (CPort buried in reserved bits)
- BLE (using Generic Attribute Profile?)
- GB Sim (simulated Greybus module using BBB)
- TCP/IP (mDNS discovery, CPorts as seq TCP ports)

LINUX PLUMBERS CONFERENCE
August 24-28, 2020

beagleboard.org

FRIEDT
Professional Engineering Services

Gbridge Host Controllers

- ~~UART (CPort buried in reserved bits)~~
- ~~BLE (using Generic Attribute Profile?)~~
- ~~GB Sim (simulated Greybus module using BBB)~~
- TCP/IP (mDNS discovery, CPorts as seq TCP ports)

focus on TCP/IP for the simple reason, that all Greybus requires is a reliable transport

Features:

- BSD Sockets API
- Network protocols
- 6LowPAN
- IP over everything
- POSIX threads
- Device Tree

- Kconfig
- Menuconfig
- Shell!
- Documentation!
- Community!

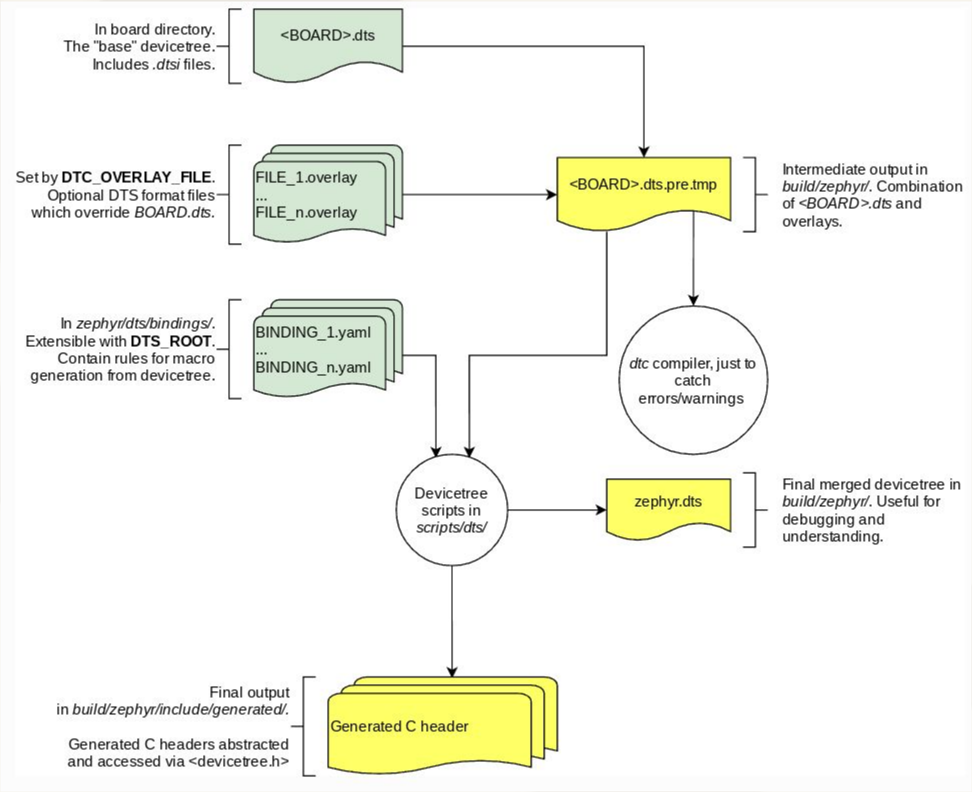
Zephyr Menuconfig

- $ ninja -C build menuconfig
- familiar look & feel
- easily find Kconfig symbols and info

```
(Top)
                                                                       Zephyr K
    Modules  --->
    Board Selection (TI CC1352R SensorTag)  --->
    Board Options  ----
    SoC/CPU/Configuration Selection (TI SimpleLink Family CC13x2 / CC26x2)  --->
    Hardware Configuration  --->
    ARM Options  --->
    General Architecture Options  --->
    Floating Point Options  --->
    General Kernel Options  --->
    Device Drivers  --->
    C Library  --->
    Additional libraries  --->
[ ] Bluetooth  ----
[*] Console subsystem/support routines [EXPERIMENTAL]  --->
[*] Greybus  --->
[ ] C++ support for the application  ----
    System Monitoring Options  --->
    Debugging Options  --->
[ ] Enable Thread analyzer  ----
[ ] Disk Interface  ----
    File Systems  --->
-*- Logging  --->
    Management  --->
    Networking  --->
-*- Shell  --->
[ ] DFU image manager  ----
    Random subsystem  --->
    Storage  --->
[ ] Enable settings subsystem with non-volatile storage  ----
    Testing  --->
[ ] Enabling Tracing
[ ] Character framebuffer for dot matrix displays  ----
[ ] Enable JSON Web Token generation  ----
    Controller Area Network (CAN) bus subsystem  --->
    Build and Link Features  --->

[Space/Enter] Toggle/enter   [ESC] Leave menu           [S] Save
[O] Load                     [?] Symbol info            [/] Jump to symbol
[F] Toggle show-help mode    [C] Toggle show-name mode  [A] Toggle show-all mode
[Q] Quit (prompts for save)  [D] Save minimal config (advanced)
```

Zephyr & Device Tree



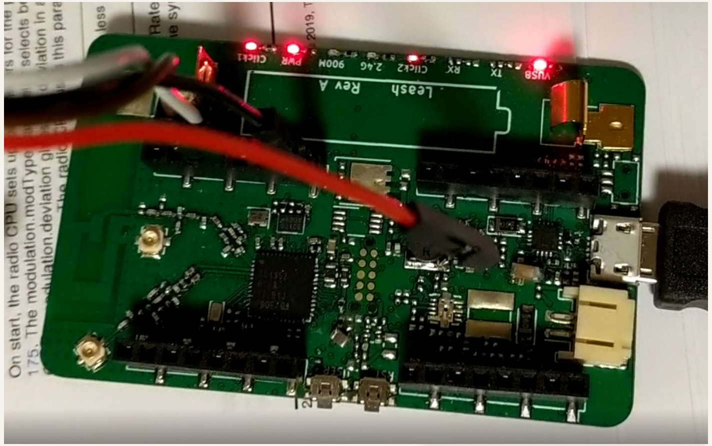
Porting Greybus to Zephyr

The original NuttX Greybus implementation had relatively few runtime and OS requirements:

- POSIX threads
- malloc / heap allocation
- unistd.h sleep routines
- qsort
- atomics
- linked-lists

Porting Greybus to Zephyr

- Port done last year
- Sneak preview of Leash PCB
- Blinking LEDs
- UART only
- Demo hardcoded a lot of things



Zephyr & Device Tree

- DT is the single source of all hardware configuration
  - Includes virtual hardware
- DT bindings compatible with Linux & other OS’s
- Preprocessed DT used to generate C header
  - All DT information is compile-time const
  - Unused DT nodes occupy 0 bytes in ROM
  - Cannot parse DT at runtime

Zephyr Devices

- Devices instantiated by macro

```
#define DT_DRV_COMPAT my_dt_label
#include <devicetree.h>
#define MY_FUN(_num) ...
DT_INST_FOREACH_STATUS_OKAY(MY_FUN)
```

- All Zephyr devices have
  - Mandatory init function (ro)
  - optional config (ro), data (rw), api (ro)

Zephyr Devices + Greybus

Integration Options:

1. 👎require users to maintain a Greybus Manifest AND Device Tree AND ensure that the two are consistent

2. 👍somehow generate Manifest from Device Tree or vice-versa

Greybus Manifest ≠> Device Tree 👎

- Insufficient platform metadata to go in this direction
  - Implies that 10’s (100’s?) of board-specific init functions exist
- Possibly requires runtime parsing of DT
  - Not possible in Zephyr
- Possibly requires handling permutations of enabled device instances
  - Undesired ROM footprint

Device Tree => Greybus Manifest 👍

- DT is a Superset of what is required for Manifest
- Conveniently handles nested relationships
  - Possibility of supporting multiple, isolated Greybus instances
- Handle the base case for a given platform
  - Allow User Manifests (e.g. in EEPROM) to override default given a fixed pinmux / pinconf

Greybus (DT)

```
#include <dt-bindings/greybus/greybus.h>
/ {
	greybus0: greybus0 {
		compatible = "zephyr,greybus";
		label = "GREYBUS_0";
	};
};
&greybus0 {
	status = "okay";
	version-major = <GREYBUS_VERSION_MAJOR>;
	version-minor = <GREYBUS_VERSION_MINOR>;
	/* … interfaces …  */
};
```

Greybus String (DT)

```
&greybus0 {
	/* ... */
	gbstring1: gbstring1 {
		status = "okay";
		compatible = "zephyr,greybus-string";
		/* string id 0 is invalid */
		id = <1>;
		greybus-string = "Zephyr Project RTOS";
	};
	/* ... */
};
```

LINUX PLUMBERS CONFERENCE
August 24-28, 2020

beagleboard.org

FRIEDT
Professional Engineering Services

Greybus Interface (DT)

```
&greybus0 {
	/* ... */
	gbinterface0 {
		status = "okay";
		compatible = "zephyr,greybus-interface";
		/* give phandle rather than integer */
		vendor-string-id = <&gbstring1>;
		product-string-id = <&gbstring2>;
		greybus-interface;
	};
	/* ... */
};
```

Greybus Bundle (DT)

```
&greybus0 {
	/* ... */
	gbbundle0 {
		status = "okay";
		compatible = "zephyr,greybus-bundle";
		id = <42>; /* 0 is reserved for the Control Bundle */
		bundle-class = </* fixed based on child CPorts */>;
		/* … CPorts nested inside of bundles … */
	};
	/* ... */
};
```

GPIO CPort (DT)

```
&greybus0 {
	gbbundle0 {
		/* ... */
		bundle-class = <BUNDLE_CLASS_BRIDGED_PHY>;
		gbgpio0 {
			status = "okay";
			compatible = "zephyr,greybus-gpio-controller";
			greybus-gpio-controller = <&gpio0>;
			id = <1>;
			cport-protocol = <CPORT_PROTOCOL_GPIO>;
		};
	};
};
```

LINUX PLUMBERS CONFERENCE
August 24-28, 2020

I2C CPort (DT)

```
&greybus0 {
	gbbundle0 {
		/* ... */
		bundle-class = <BUNDLE_CLASS_BRIDGED_PHY>;
		gbi2c0 {
			status = "okay";
			compatible = "zephyr,greybus-i2c-controller";
			greybus-i2c-controller = <&i2c0>;
			id = <1>;
			cport-protocol = <CPORT_PROTOCOL_I2C>;
		};
	};
};
```

beagleboard.org

FRIEDT
Professional Engineering Services

LINUX PLUMBERS CONFERENCE

August 24-28, 2020

SPI CPort (DT)

```
gbspi0 {
    status = "okay";
    compatible = "zephyr,greybus-spi-controller";
    greybus-spi-controller = <&spi0>;
    id = <1>; /* CPort ID */
    cport-protocol = <CPORT_PROTOCOL_SPI>;
    /* Entries for struct gb_spi_master_config_response */
    bpw-mask = <0xff>;
    min-speed-hz = <2000000>;
    max-speed-hz = <6000000>;
    mode = <0>;
    flags = <0>;
    /* greybus spi devices */
```

beagleboard.org

FRIEDT Professional Engineering Services

SPI Device (DT)

```
gbspi0 {
    gbspidev0 {
        status = "okay";
        compatible = "zephyr,greybus-spi-peripheral";
        cs = <0>; /* used as gpio array index in spi phandle of parent device */
        /* Entries for struct gb_spi_device_config_response */
        mode = <0>;
        bpw = <8>;
        max-speed-hz = <8000000>;
        device-type = <GB_SPI_SPI_DEV>;
        device-name = "ADXL362";
    };
};
```

Fake GPIO, I2C, & SPI

Another core philosophy of Zephyr is to test everything

Development of DT bindings was mostly driven via test cases using “fake” device interfaces.

```
tests/subsys/greybus/gpio/boards
├── native_posix_64.conf
├── native_posix_64.overlay
├── native_posix.conf
└── native_posix.overlay
tests/subsys/greybus/i2c/boards
├── cc1352r1_launchxl.overlay
├── native_posix_64.conf
├── native_posix_64.overlay
├── native_posix.conf
└── native_posix.overlay
tests/subsys/greybus/spi/boards
├── cc1352r1_launchxl.overlay
├── native_posix_64.conf
├── native_posix_64.overlay
├── native_posix.conf
└── native_posix.overlay
```

Greybus System Service

- Leveraged Device Tree to automatically generate the manifest.
- Leveraged Device Tree to automatically create virtual
- Why not also automatically start a Greybus Service?
- Not a single line of code required
  - Declare GB resources in Device Tree
  - Support for drivers in Kconfig

Linux Driver Ecosystem

- Keep the intelligence in the host
- Vaishnav Ma has done a great job of re-using existing Linux drivers
- Same driver works regardless of Wireless SoC
- Drivers get updated & maintained in the Linux kernel

Greybus in Linux: a Proposal

- Currently with the Gbridge Topology, the SVC lives in userspace and effectively routes messages between AP and other Greybus devices
- By using a connected socket (or really any file descriptor), we can move the SVC into the kernel
- Gbridge would then stay in userspace as mainly an auth + session broker

LINUX PLUMBERS CONFERENCE
August 24-28, 2020

Linux: WPANUSB

- being developed further as more of a generic interface to IEEE 802.15.4 USB hardware
    - Enable Linux & RTOS devs, as well as HW manufacturers
    - Originally developed by Andrei Emeltchenko (Intel)
    - Already supported in Zephyr (less extensions below)
    - Commitment to add support in RIOT OS (Koen Zandberg)
- Add GET_EXTENDED_ADDR command
- Add GET_CAPABILITIES command
- Set LBT in USB
- Set frame retries in USB (for controllers lacking auto-ack)

beagleboard.org

FRIEDT
Professional Engineering Services

Open Problems: Greybus

- authentication: support multiple mechanisms
  - public key auth (in progress)
- encryption: standardize on one or two methods
  - aes-128 (in progress)
- auth negotiation
- commissioning, joining, rejoining
- cloud: management of devices at scale

Open Problems: Zephyr

- pthread: dynamic stack allocation (in progress)
- dt-bindings: greybus: mask for fixed pin direction
- dt-bindings: greybus: pwm, adc, camera, ..
- ieee802154: cc1352r: TI RF driverlib (in progress)
- ieee802154: cc1352r: subghz (in progress)
- ble: cc1352r: split-stack driver (in progress)
- proper Zephyr module repo for Greybus
- init: dt: deterministic module loading (in progress)

Open Problems: Linux

- gbridge: discovery should be ip-version agnostic
- gbridge: move svc in-kernel
- greybus: pass fd + session key to kernel post auth
- wpanusb: feature implementation, test, & lkml patch
- opt3001: specify i2c bus / addr with modprobe

Additional Resources

Current development branch for Greybus in Zephyr
https://github.com/cfriedt/zephyr (branch greybus-service-lpc2020)
Zephyr Getting Started Guide / Slack
https://docs.zephyrproject.org/latest/getting_started/index.html
BeagleConnect (Hardware Rev C) / Slack

https://github.com/jadonk/beagleconnec

Board	Topic(s)	Instructions	Video
nRF52840 DK	GPIO LED BLE	https://bit.ly/2NR0NCI	https://youtu.be/Y_6y6gpZ2GA
CC1352R1 LaunchXL	GPIO LED IEEE 802.15.4	https://bit.ly/31FQNV4	https://youtu.be/hd60CbiUN1g
CC1352R SensorTag	GPIO LED I2C SPI IEEE 802.15.4	https://bit.ly/3aZK7ne	https://youtu.be/6SNkjiDJ3KY

Conclusion

- Now is the time to start contributing!
- Developers Wanted!! - Zephyr, Linux, Cloud, BeagleConnect
- Greybus itself may well begin to evolve very soon..

Q & A

LINUX
PLUMBERS
CONFERENCE
August 24-28, 2020

beagleboard.org

FRIEDT
Professional Engineering Services

Thank You!