Intelligent IoT Gateway on OpenWrt

Andrzej Wieczorek **Bartosz Markowski**

Introduction

IoT

gateways

standards

IoT home alone

concept

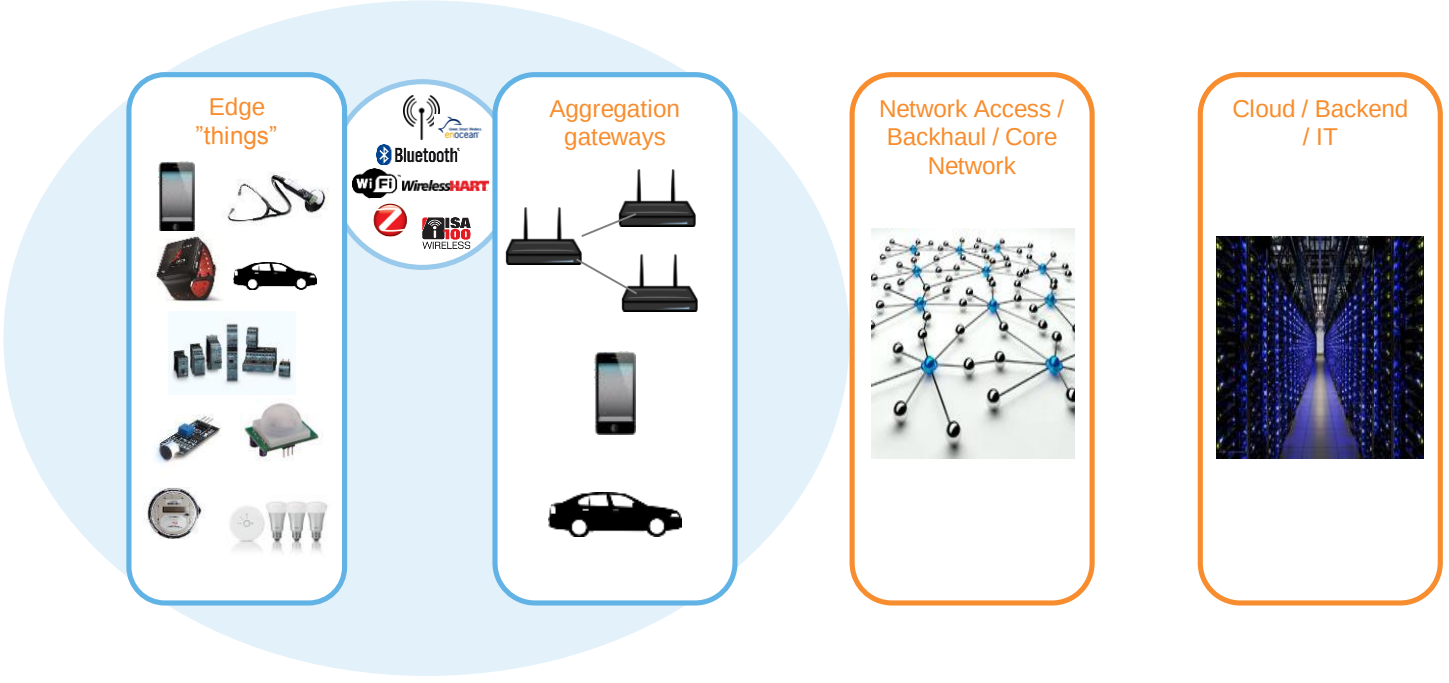
replacement of standard IoT intro ☺

IoT is big! Infinite!

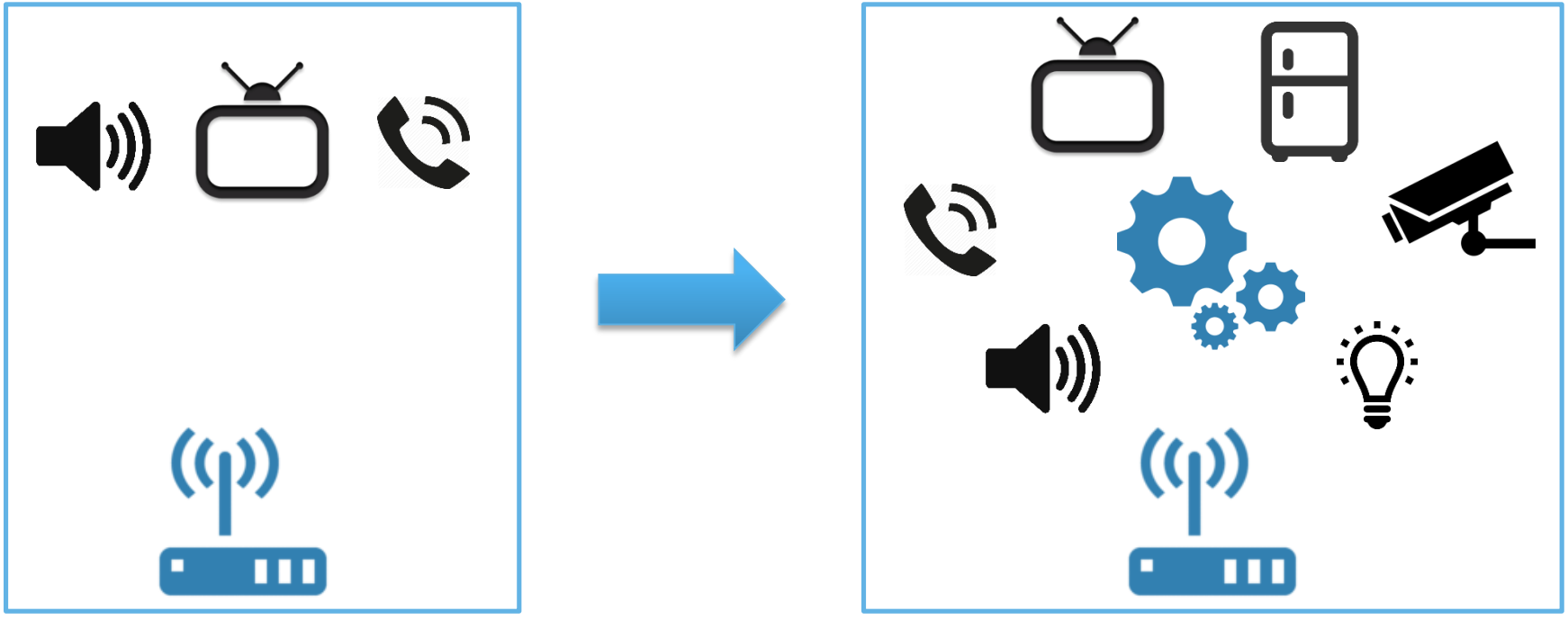
„Bigger than the biggest thing ever and then some. Much bigger than that in fact, really amazingly immense, a totally stunning size, "wow, that's big", time. Infinity is just so big that by comparison, bigness itself looks really titchy.”

[Douglas Adams, *The Restaurant at the End of the Universe*]

IoT structure

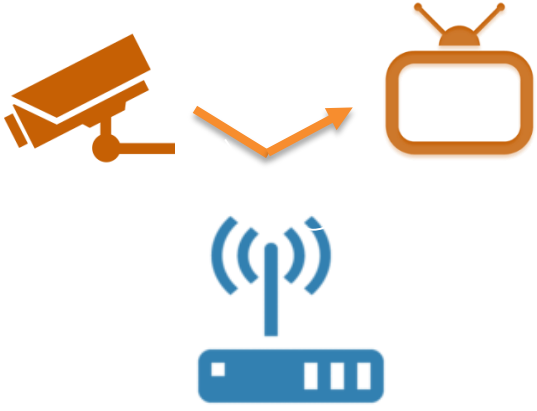


Gateways role evolves (home)

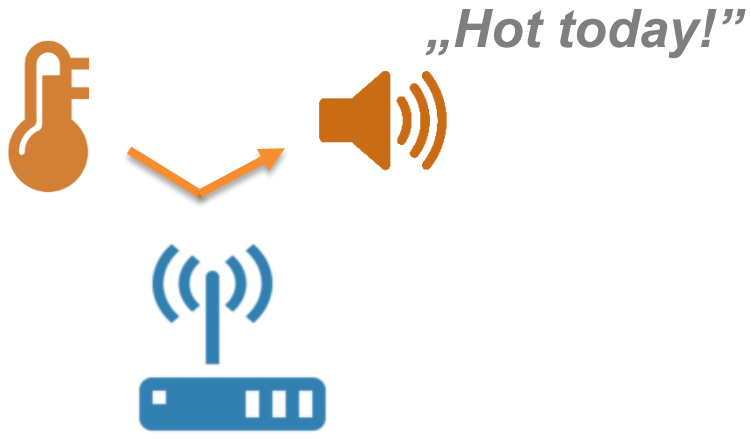


From single application to ecosystem enabler

Ecosystem applications



Purpose build apps
[Vertical]

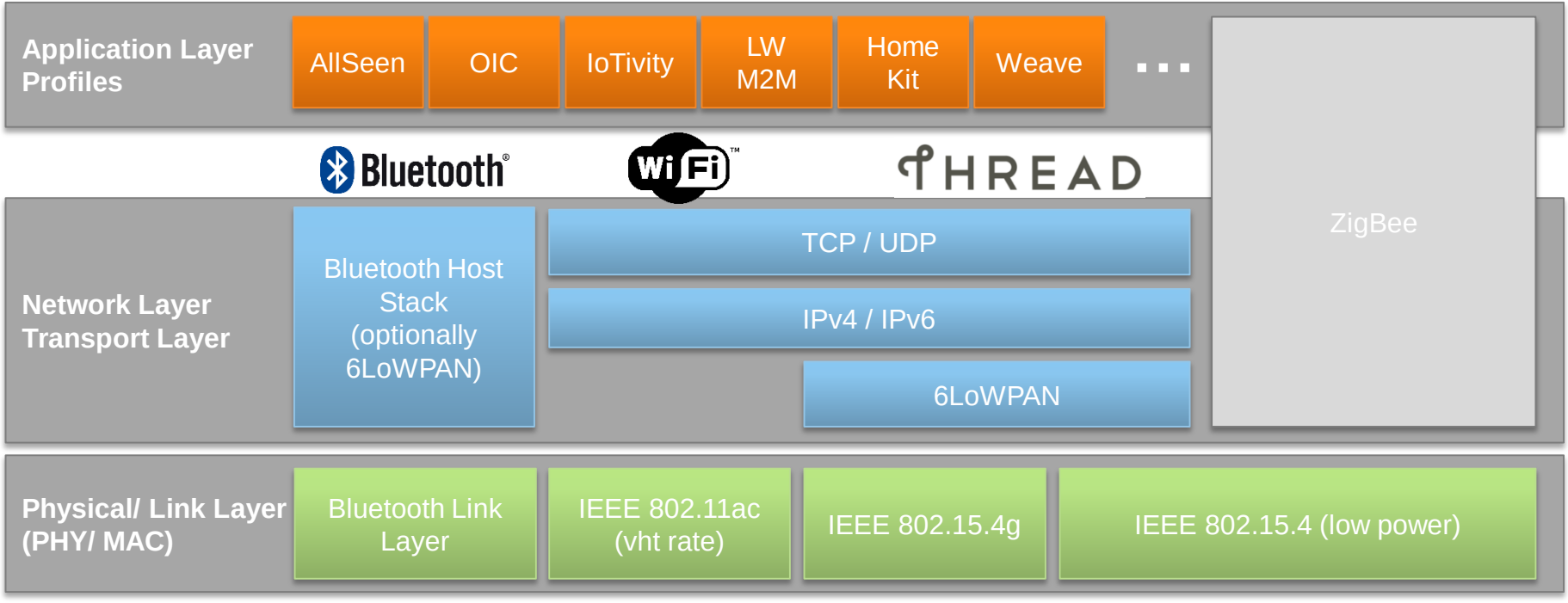


Ecosystem enabled apps
[Horizontal]

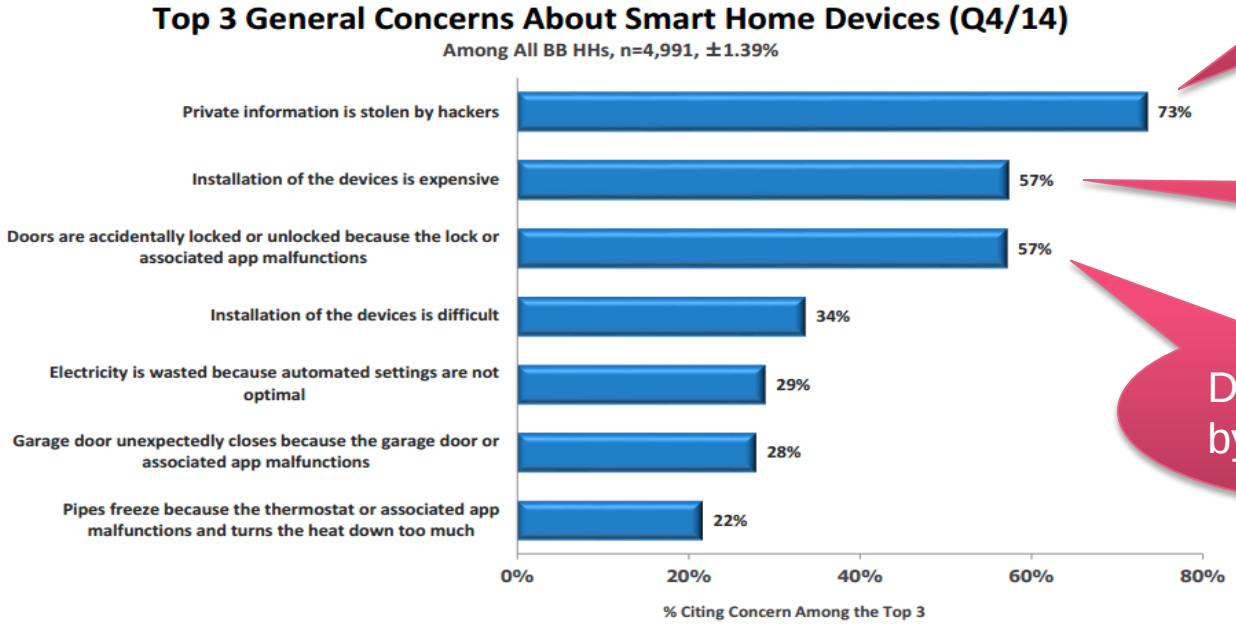
IoT Alliances and Consortia

Connectivity complexity

Smart home applications



Smart Home – concerns



"Q2911. What are your greatest concerns about connecting these types of devices to the Internet?" | Source: American Broadband Households and Their Technologies Q4 2014 | N=10,000, ±0.98% | © 2015 Parks Associates

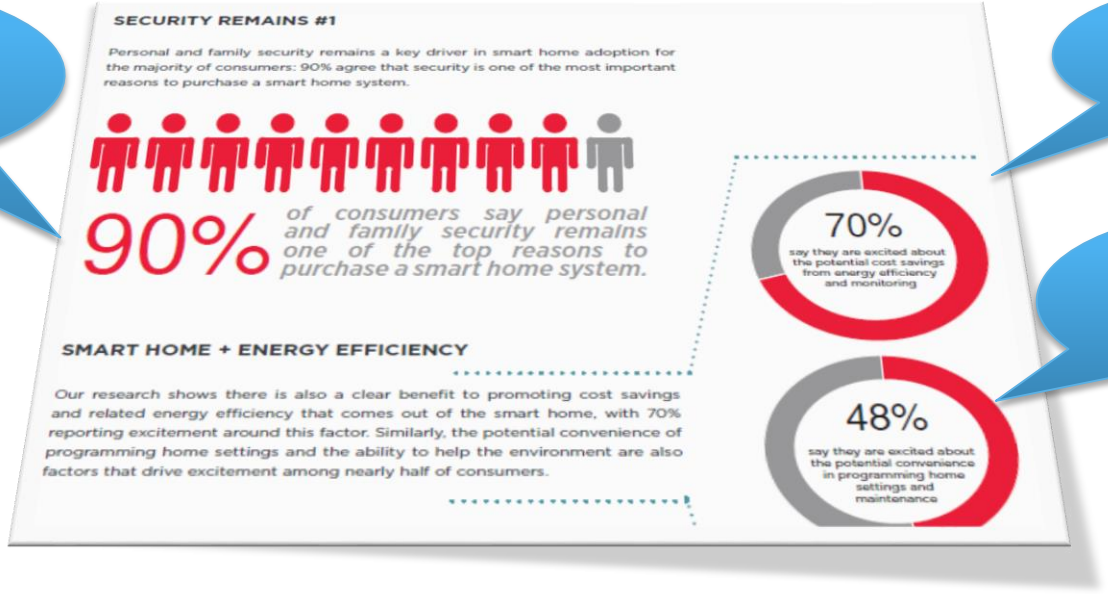
Information hacked

Expensive

Door [un]locked by a bug

Smart Home – key drivers

Personal and family security

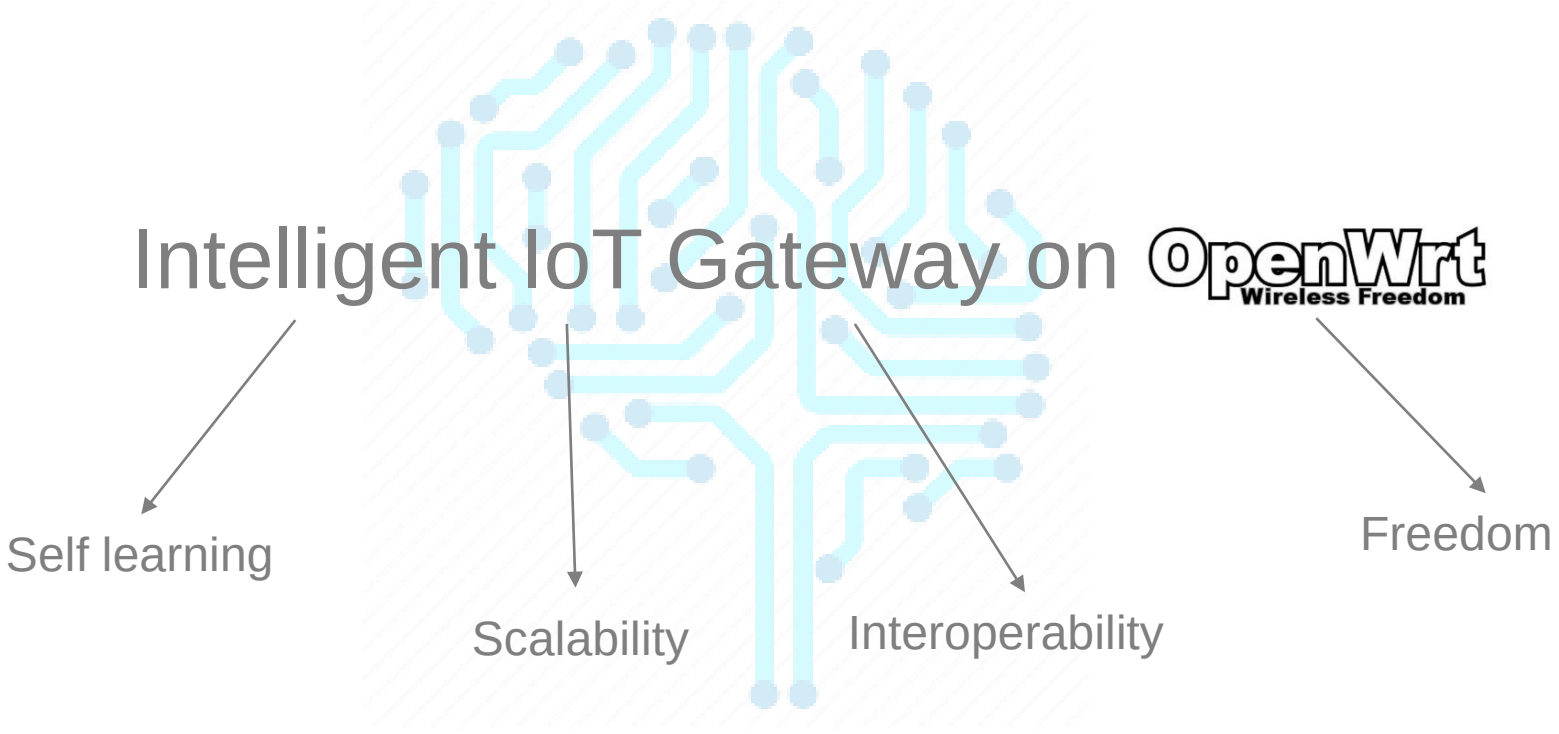


Cost savings

Programming (yes!)

Source:
http://www.icontrol.com/blog/2015-state-of-the-smart-home-report/

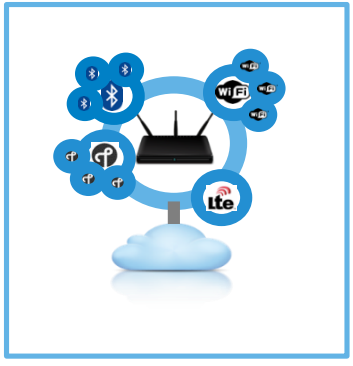
„One to rule them all”



Intelligent IoT Gateway concept

Ecosystem enabler for horizontal applications

Multiradio Linux/ mbed Gateway



+

Intelligence

+

Virtualization

Implementation

platform

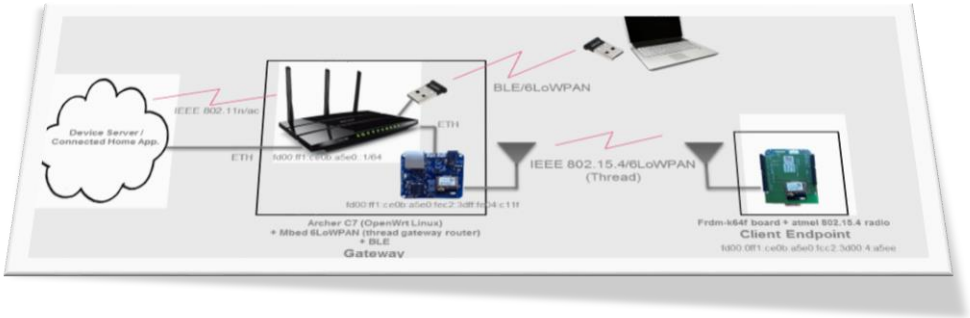
radio(s)

layers

security

apps

demo



Platform

Specification

- Platform: mid-range router / ~$100 / + we have it at home
  - HW: TP-LINK Archer C5 v1.20
  - CPU: Qualcomm Atheros QCA9558 (720 MHz) / mips arch
  - RAM: 128 MiB / 16MiB Flash
  - Networking: Wi-Fi (dual-band / 2.4GHz 11n + 5GHz 11ac) + eth switch
  - USB ports

- OpenWrt ready:
  - Target System (Atheros AR7xxx/AR9xxx)
  - Target Profile (TP-LINK Archer C5/C7)
  - Chaos Calmer, trunk r46693

Platform

Deploying OpenWrt

OpenWrt Wireless Freedom

1. Prepare development environment

- git clone trunk OpenWrt sources (git clone git://git.openwrt.org/openwrt.git)
- from menuconfig pick target system/profile + utilities at your own preference

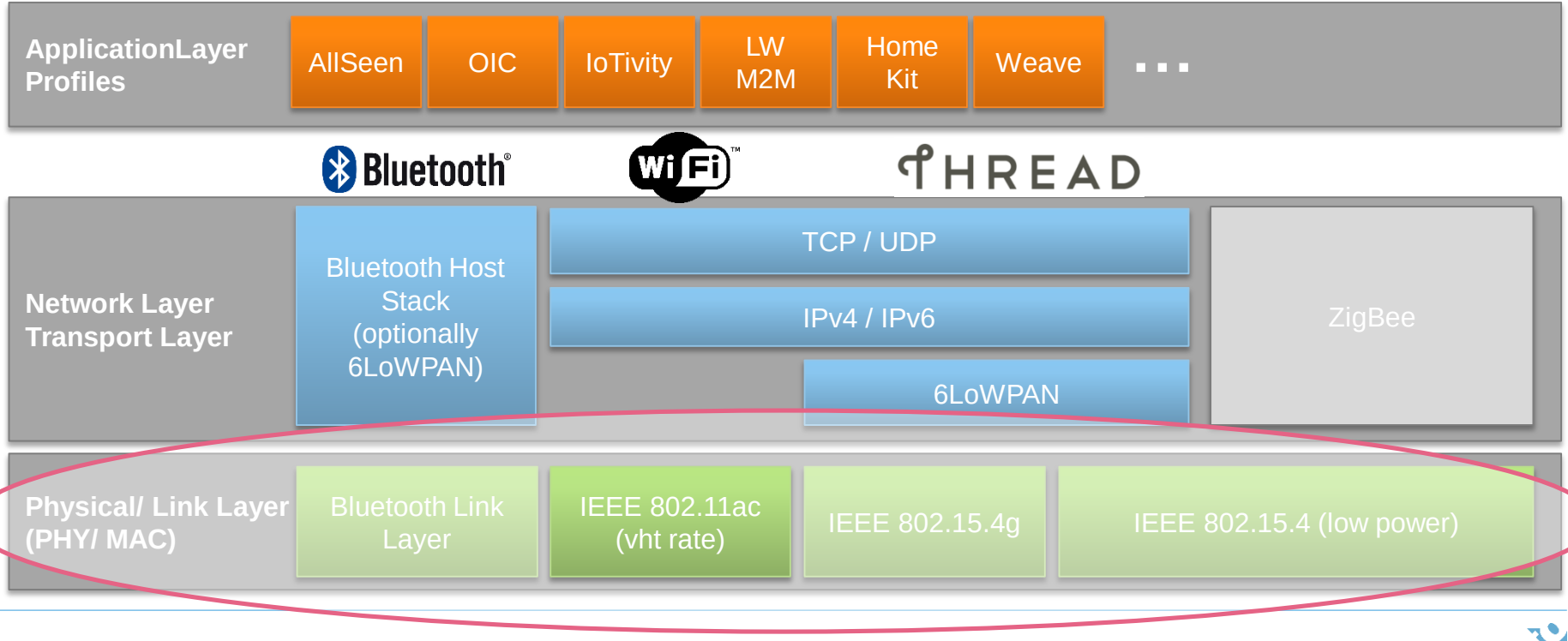
```
Target System (Atheros AR7xxx/AR9xxx)
Target Profile (TP-LINK Archer C5/C7)
```

2. Reflash the router from the TP-LINK web UI

- for later easy-use it's good to enable luci feeds in OpenWrt

```
luci-mod-admin-full. LuCI Administration - full-featured for full control
```

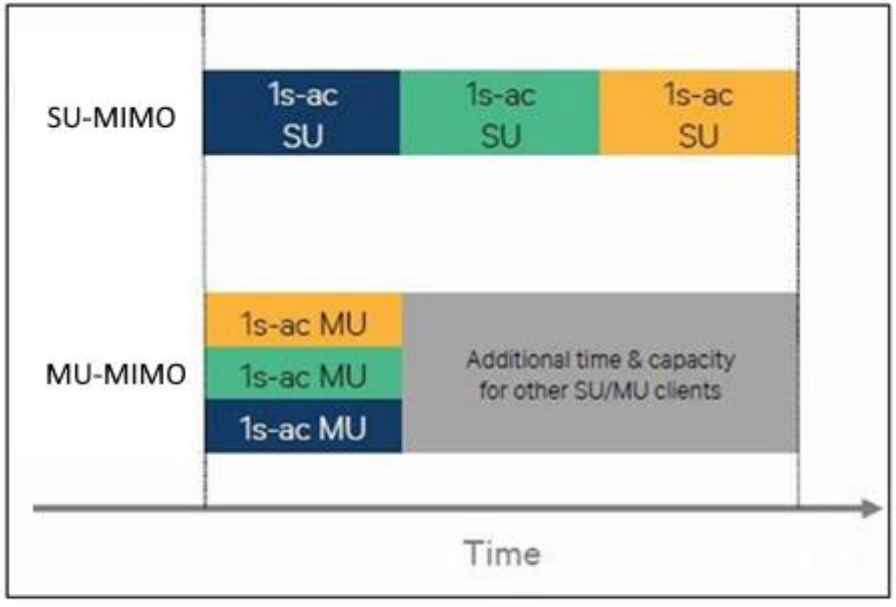
Adding PHY/MAC



Boosting WiFi

MU-MIMO

- „Wave 2” devices
- Spatial Division Multiplexing (SDM)
- Advanced form of beamforming
- Simultaneous AP-to-multiple-clients transmission



Single User vs. Multi User MIMO Throughput
Image credit: Qualcomm Atheros

Boosting WiFi

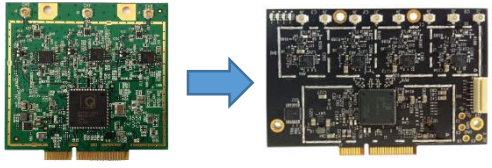
MU-MIMO

- Benefits
  - Spectrum efficiency
    - improved combined DL throughput
  - Lower latencies

- Limitations?
  - Clients also have to support MU-MIMO (beamformees)
  - Downstream only – From AP to clients (sophisticated antenna systems and signal processing)
  - Limited number of clients can be supported (NSS-1)

PCIe

802.11ac



CUS223 -> CUS239 (Compex WLE1200V5-22)

802.11ac

Boosting WiFi

MU-MIMO – upgrading router

- PHY: Replace wifi NICs hardware
  - CUS223 (3x3 11ac) ---> WLE1200V5-22 CUS239 (4x4 11ac + mu-MIMO)
- SW: Upgrade ath10k driver (QCA99X0 support in 4.3-rc1)
- FW: ath10k 10.4.1.00007-1

Boosting WiFi

MU-MIMO – how to

- Create your own backports package from e.g. ath.git / linux-next or …*
  - It's just important to make sure the QCA99X0 support is there
- Cross-compile the backports to get the wireless LKMs

```
toolchain-mips_34kc_gcc-4.8-linaro_musl-1.1.10/initial/bin/mips-openwrt-linux-musl-
```

- Upload (replace) the backports *.ko modules and firmware to FS, depmod etc.

- Problems?
  - Firmware for QCA99X0 crashes during bootup on BE mach with ath10k… (under investigation)
  - Processing power of the QCA9558 platform (do not expect maximum performance)

Adding BLE

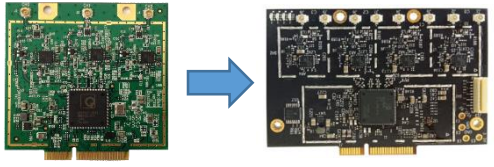
- One of the most popular local connectivity protocols
- Many small cheap multi-purpose devices
- Low and ultra-low energy
- Easy for building various use cases

- 6LowPAN supported
  - IPv6 networking over BLE link
  - BT SIG: ISPS 1.0
  - Since kernel 3.17 (OpenWrt trunk for ar71xx has 4.1 now)

PCIe

USB

802.11ac



CUS223 -> CUS239 (Compex WLE1200V5-22)

LogiLink Bluetooth 4.0 (BT0015)

Adding BLE support

How to do it

- HW: Extend AP by plugging in BLE USB dongle
- SW:
  - Fetch and install: bluez-utils, bluez-libs, ip feeds
  - Enable kernel modules: kmod-bluetooth, kmod-bluetooth_6lowpan
- Compile new *openwrt-ar71xx-generic-archer-c5-squashfs-*.bin* and flash the router

Adding BLE support

How to enable it


```
root@OpenWrt:# modprobe bluetooth_6lowpan
root@OpenWrt:# echo 1 > /sys/kernel/debug/bluetooth/6lowpan_enable
root@OpenWrt:# hciconfig hci0 reset
root@OpenWrt:# hcitool lescan
root@OpenWrt:# echo "connect 00:1B:DC:07:32:7E 1" > /sys/kernel/debug/bluetooth/6lowpan_control}
```

- Consider btmgmt ctrl tool (new tool)
- Check for bt0 interface now
- Play around with networking interface and firewall settings for packet forwarding

Adding BLE support

Debugging

- use dynamic_debugs for bt kernel messages
  - enable it from menuconfig:
  - Global build settings ---> [*] Compile the kernel with dynamic printk

- check readlog –f
- check if you have all required crypto modules

Extending with Thread

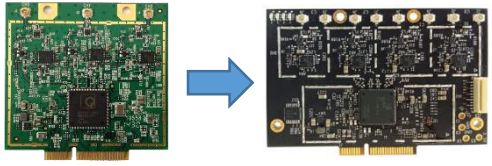
- New standard designed for Smart Home/ IoT, all-in-one
  - mesh
  - IPv6
  - low energy
  - security
- First devices coming soon (beginning 2016)
- Same radio as in ZigBee
- Thread Group with big names: Nest, Samsung, Freescale, Qualcomm, …

PCIe

USB

Eth

802.11ac



CUS223 -> CUS239 (Compex WLE1200V5-22)

Bluetooth 4.0 Low Energy

LogiLink Bluetooth 4.0 (BT0015)

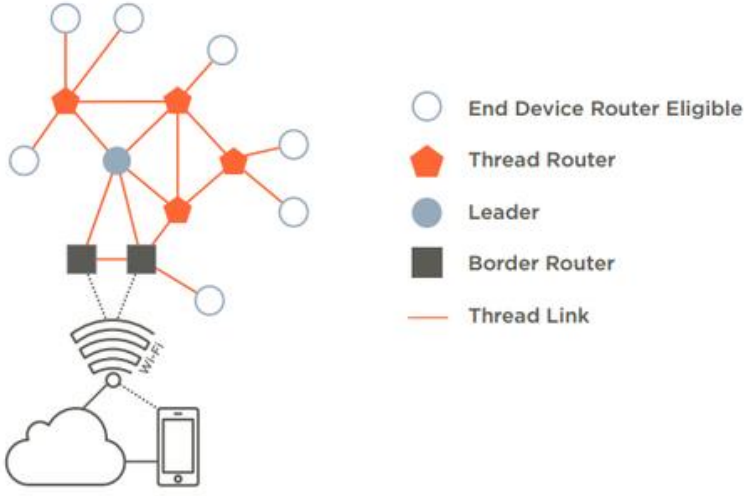
THREAD

Freescale Freedom-K64F +
Atmel 802.15.4 radio (at86rf233)

Extending with Thread

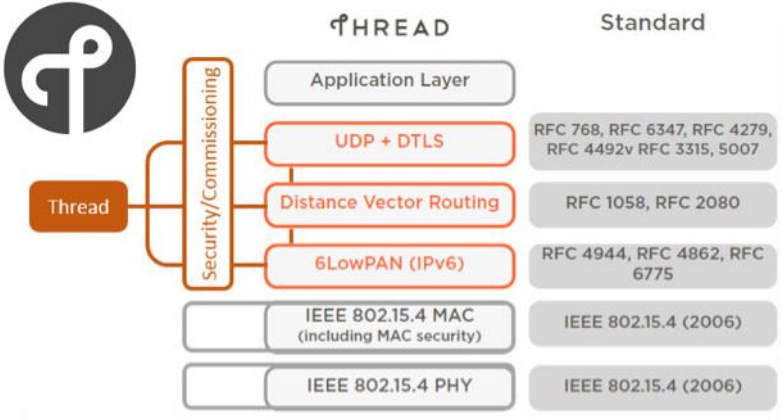
How to do it

- Add **Thread Border Router** (mbed OS) over Ethernet
- Static IPv6 addressing to communicate with OpenWrt br-lan interface
- *Alternative way: implement Thread stack and Border Router in Linux/ OpenWrt + connect 802.15.4 radio*

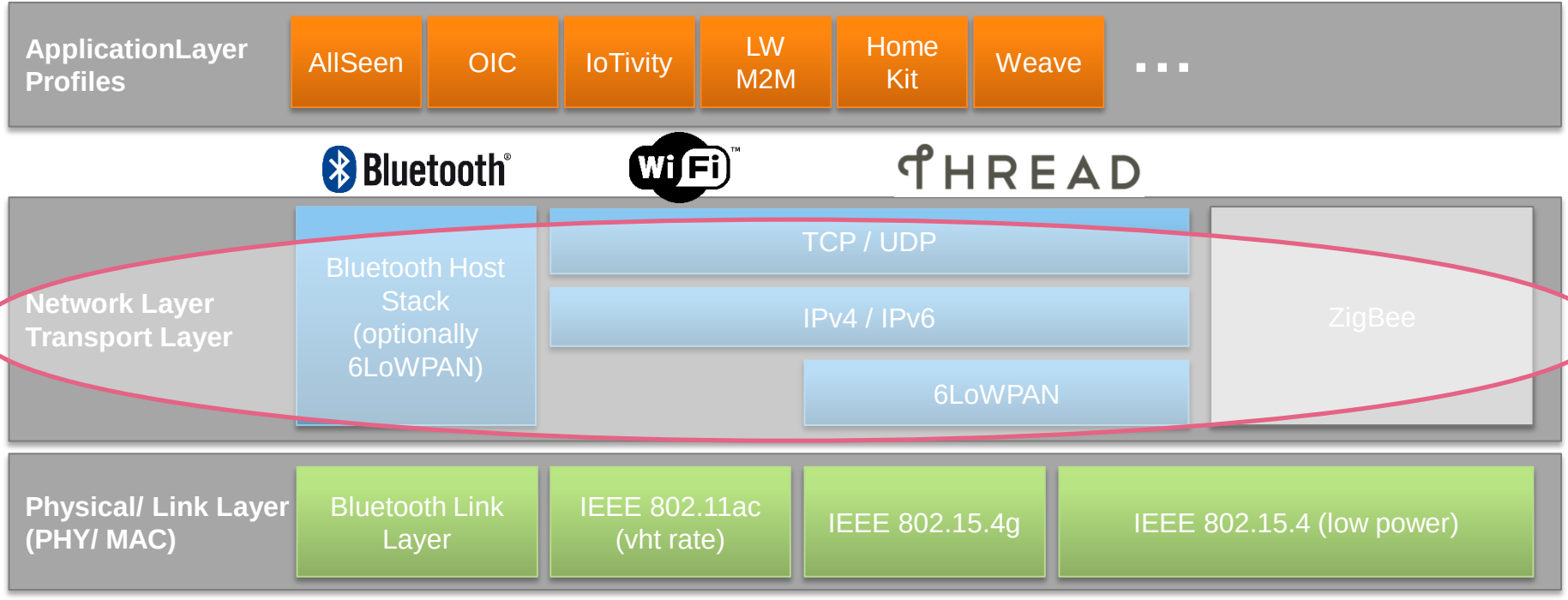


About Thread

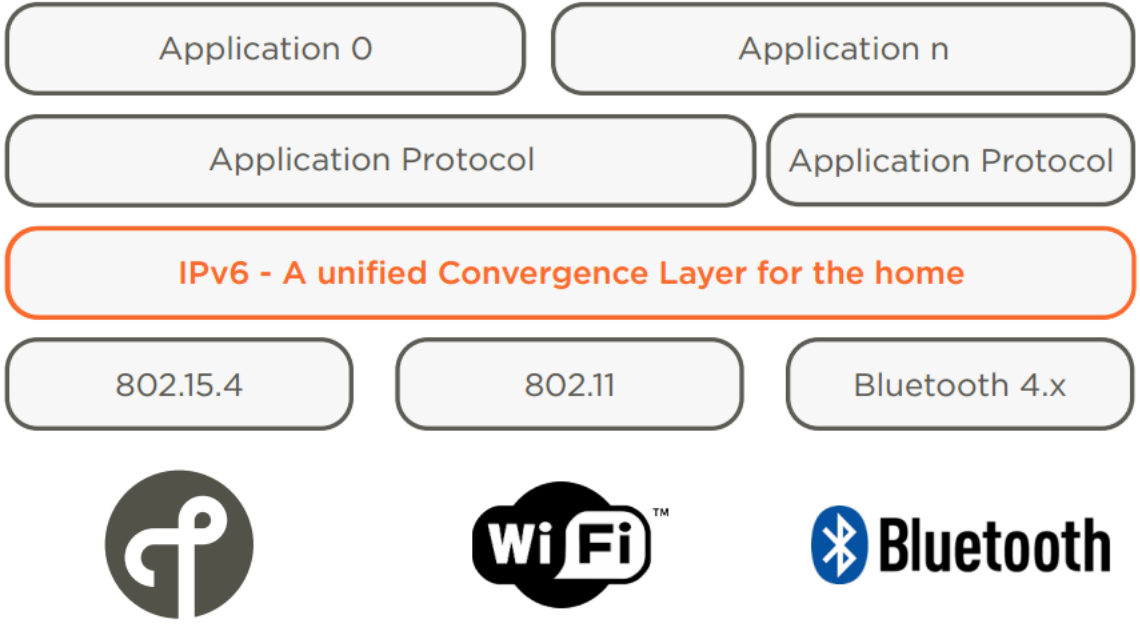
- Based on 802.15.4 radio, IPv6 and low power networking (6loWPAN) standard (existing IEEE and RFC documents)
- Designed mainly for Connected Home apps with high impact on security aspects.
- Mesh topology with No Single Point of Failure to guarantee reliability
- Device types: Boarder Router, Router, REED (router-eligible end device), End Device



Unifying transport

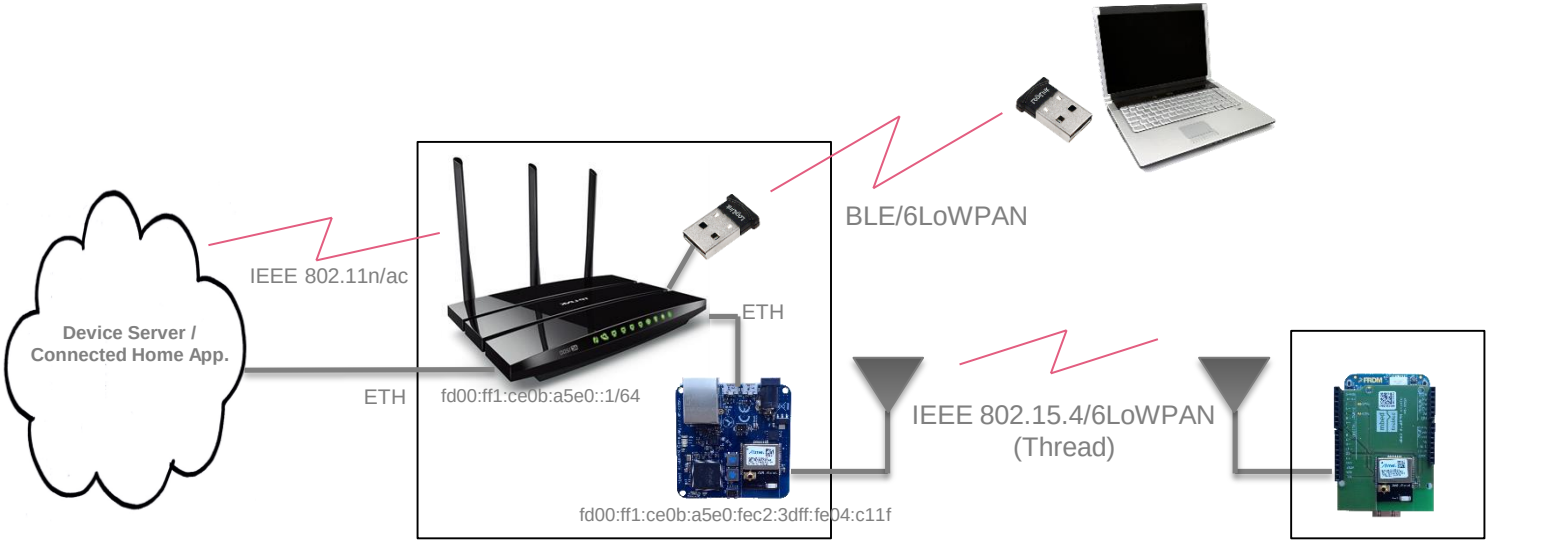


IPv6 to unify



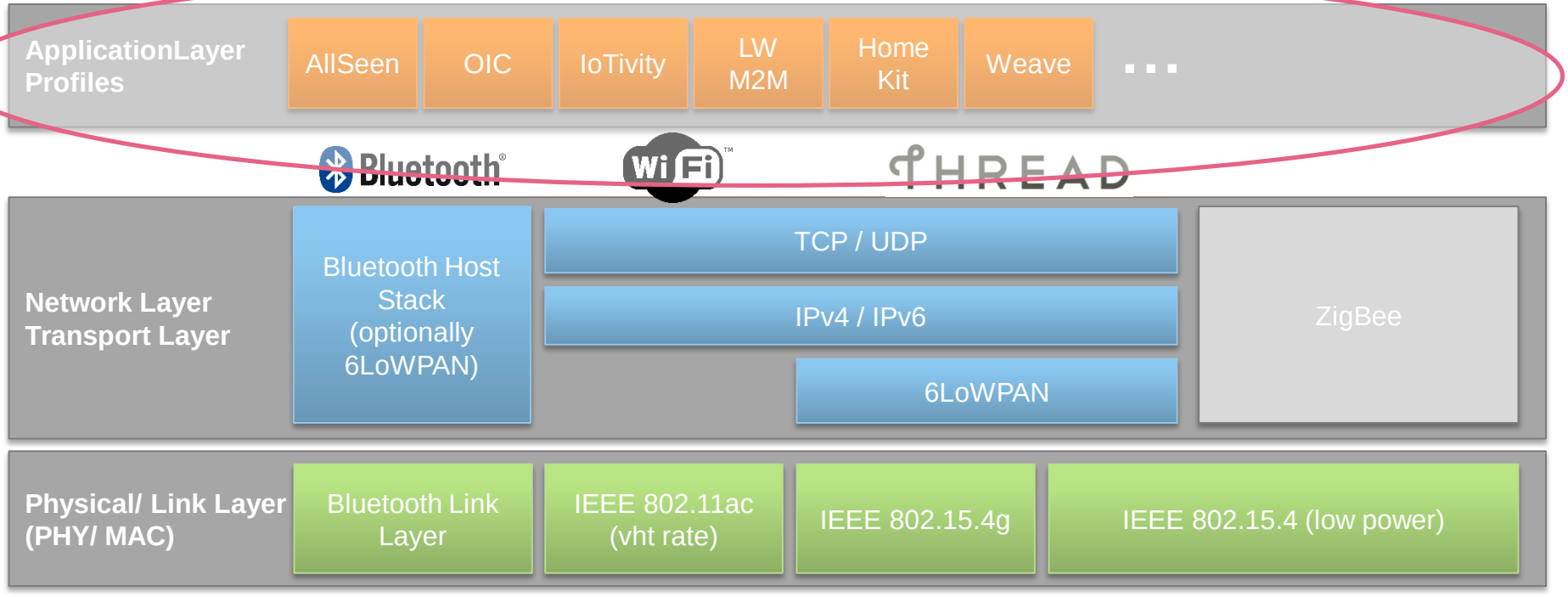
6LoWPAN - focus on low energy

- Fragmentation and reassembiling
  - 1280 bytes IPv6 packets fragmented to fit into 127 bytes 802.15.4 frames
- Header compression mechanism
  - IPv6 header is 40bytes long! – reducing transmission overhead
- Link layer packet forwarding
  - Thread is using IP layer routing with link layer packet forwarding

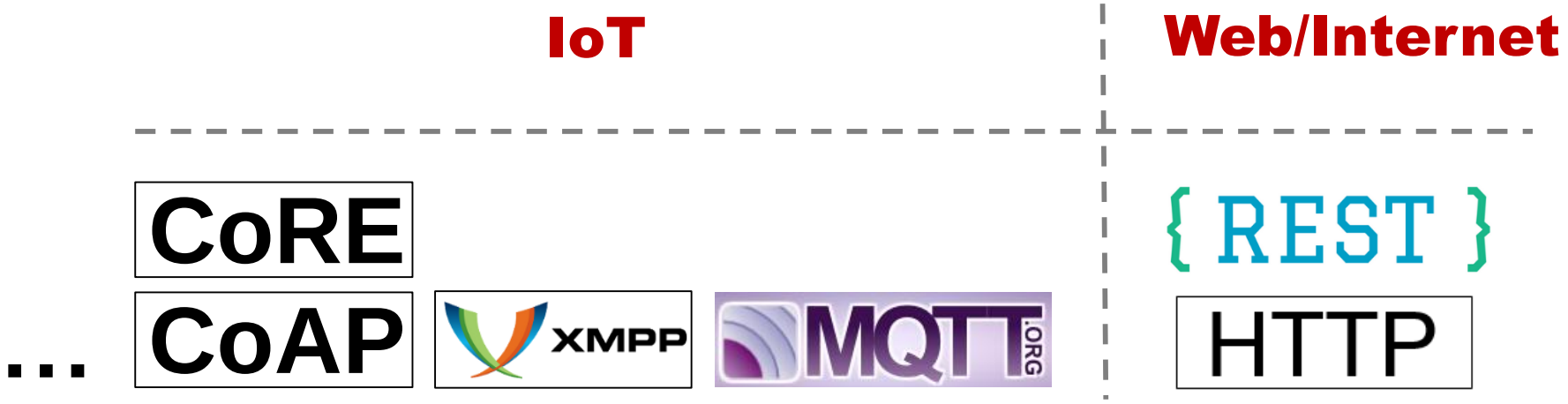


IPv6 networking

Selecting application layer



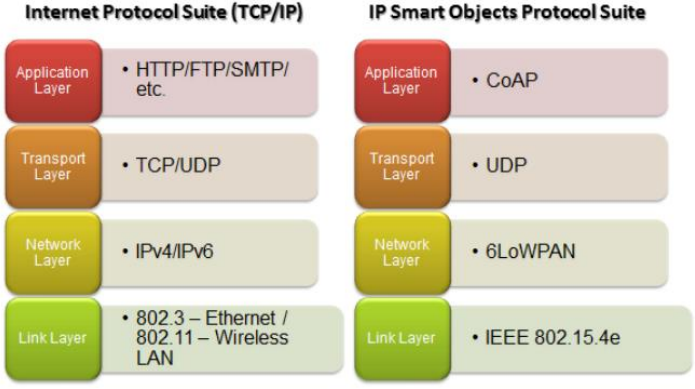
App transfer protocols



What is CoAP?

"The Constrained Application Protocol (CoAP) is a specialized web transfer protocol for use with constrained nodes and constrained networks in the **Internet of Things.**

The protocol is designed for machine-to-machine (M2M) applications such as smart energy and building automation." (res. http://coap.technology/)



- Open standard
- REST model (resource access)
- GET, PUT, POST, DELETE, …methods to

CoAP over Thread – demo

IEEE 802.11

IEEE 802.15.4/6LoWPAN
(Thread)

console

Router – „Device Server”
libcoap-client
libcoap-server

Thread Border Router

Thread Node
CoAP_service_app

POST

LED

CoAP ACK

coap-client -m post coap://[fd00:0ff1:ce0b:a5e0:fcc2:3d00:4:a5ee]/resources/led

GET

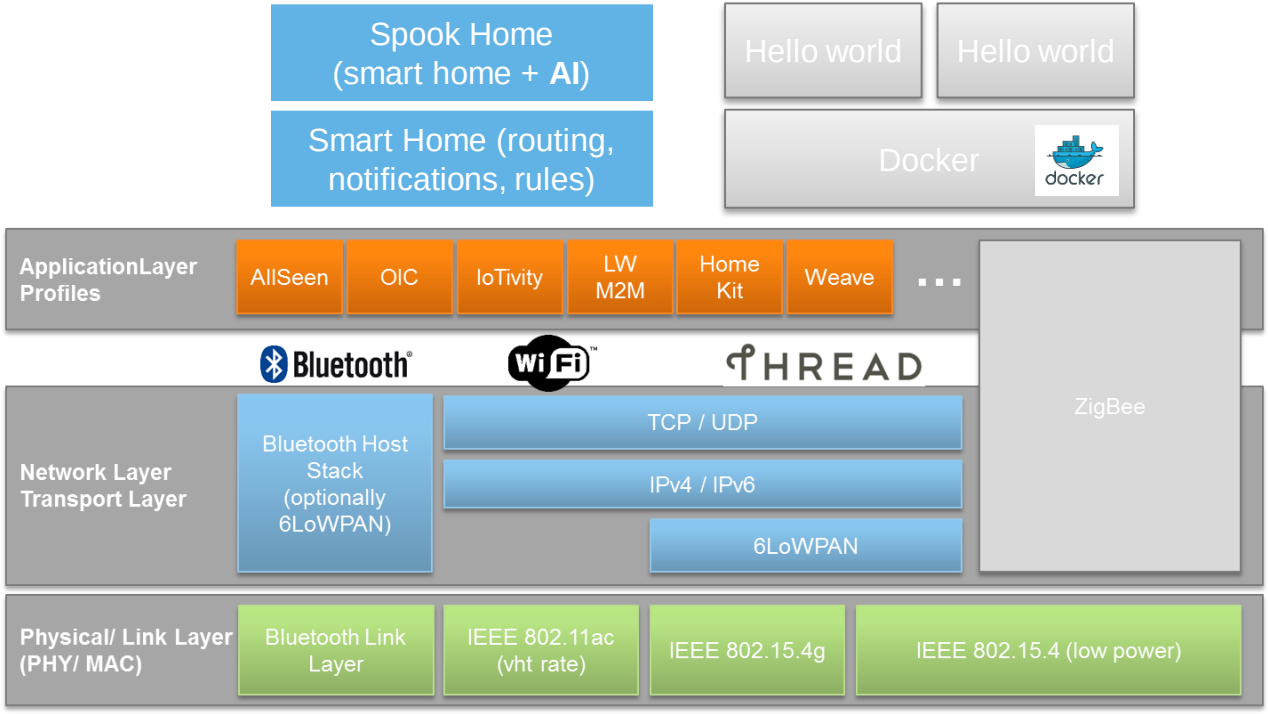
BUTTON Counter

RESP (counter)

cnt=$(/root/coap-client coap://[fd00:0ff1:ce0b:a5e0:fcc2:3d00:4:a5ee]/resources/button)

Applications and containers

Examples

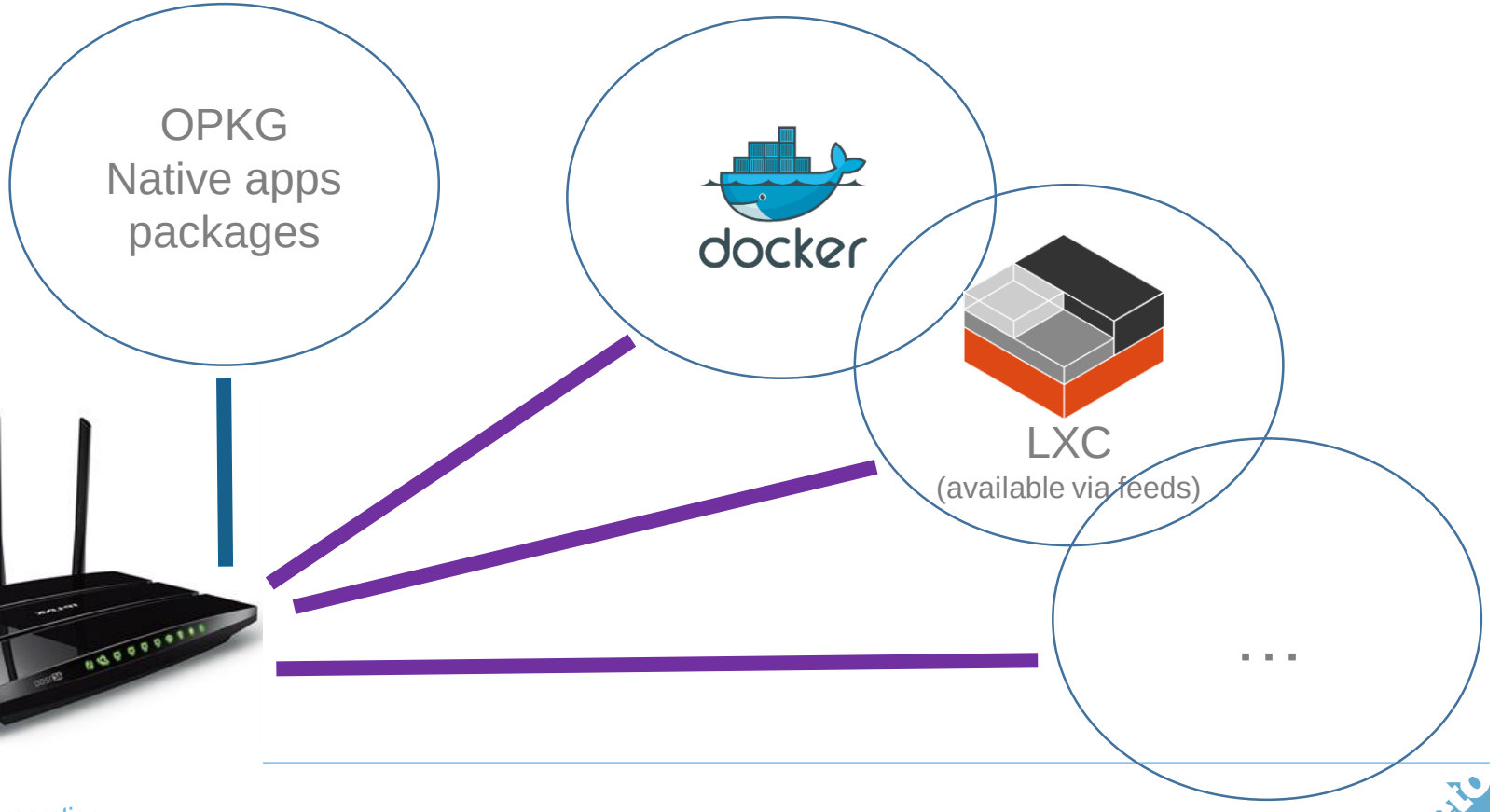


AI in applications

- Mining and analysis for aggregated data
- Learning trends = habits
- Levels of notifications based on probability
- Fuzzy logic
- Cost saving (water, electricity)
- Security improvement
- Feedback based learning

- Example below

Containers



Security

Application	Fine grained security Data aggregation and privacy protection (for cloud) Information integrity check by AI (data correlation, trends analysis etc)
System	Security holes like Heartblead, ShellShock or backdoors in devices Keep your system up to date - security on the level of last patch Open source
Protocol	Security services for link layer (auth, data integrity, confidentiality, reply protection) IP networking based security mechanisms (access control, firewalls, …) Keep to standards, e.g. DTLS (RFC6347 v1.2)

Demo - „Spook House”

example smart application for lighting

- Light control system
- Learning light usage trends
- Notifications based on deviations and likeliness
- Focused on cost saving (i.e. recommendations) and security (notifications when out of trend)

Demo - „Spook House”

Description

- running on IOT Gateway and receives data from the IoT network sensors
- monitor usage of home lights and detect unusual events. For instance if someone forgets to turn off the light.
- Application gathers statistical information about how often and how long light are turned on.
- Since users activity changes during the week (for instance on weekends) the algorithm takes into account not only time of day but also day of week.
- Application will notice if lights in some room are turned on for unusually long time.

Demo - „Spook House”

Internals

- StateTracker
  - Receives data in form of events about state change

```
{"Device": "light3", "EventType": "SHStateChange", "State": "On", "Timestamp": 122848.71204376257}
{"Device": "light3", "EventType": "SHStateChange", "State": "Off", "Timestamp": 123907.1497501683}
```

  - Communiate with TrendMonitor and external modules
- TrendMonitor (learning)
  - Keeps a data base with statistics
  - Implements algorithm to calculate and detect unusual situations (deviations) and notify ActionManager about such.
- ActionManager (learning)
  - Receives ‚SHActionRequests’ about deviations and makes decission on what to do with it (e.g. notify user)
  - Options: User feedback loop
- Clock or internal interrupt to throw ‚SHtimer’ event – check the House state.

Wrap-up

Q&A

Intelligent IoT Gateway on OpenWrt

Thank you!

Andrzej Wieczorek Bartosz Markowski