FAST RADIO TECHNOLOGIES FOR UNINTERRUPTED TRAIN
TO TRACKSIDE COMMUNICATIONS

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Deliverable D2.1
Report on the selection of the hardware and software development platform and tools

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Abstract

The aim of this deliverable is to report the outcomes from the selection of the hardware and software development platform and tools suitable to implement the FAST-TRACKS radio, in close cooperation with architecture definition and the list of functional and non-functional requirements, as defined in WP1.

Starting from the FASTTRACKS architecture, the approach we followed in this deliverable is based on the selection of hardware components, software components and firmware components useful to implements the basic features of the FASTTRACKS radio. For each section, when meaningful, we have provided a comparative analysis between the different componets motivating also the choices made.

Table of Contents

Figure Summary

Table Summary

1 Introduction

FAST-TRACKS project is a disruptive innovation based on the development of a low cost re-programmable radio infrastructure that implements simultaneously different radio propagation standard allowing efficient planning of the network, redundancy techniques, automatic-adaptive reconfiguration, able to support the constrained requirements of the railway telecommunications. The proposed telecommunication infrastructure permits to support both vital and not vital data on separate networks and independent radios.

This technique allows the increase of the life time of the hardware (both of the radio base station that the user terminal) removing the risk of obsolescence; the re-programmability of the radio allows also the reuse of the hardware in case of new services or new generation systems will make their entry into the field, thus reducing OPEX and CAPEX.

This deliverable, conceived to describe the hardware and software building blocks of the FAST-TRACKS platform, is organized as follows: In Chapter 2, we show the high-level FAST-TRACKS architecture, focusing on FCP, RCP and MCP layers. Chapter 3 describes the FAST-TRACKS Hardware Development Platform (HDP) describing all the hardware modules involved in the FAST-TRACKS radio, as result of the T2.3 task. Chapter 4 presents the Firmware Development Patform. Chapter 5 finalizes the deliverable discussing Software Development Platform, connected with the T2.4 task.

The following member organizations have allocated manpower in Task T.2.3 and T2.4:

ID	Short Name	Full Partner Name
1	COM	Comesvil

Table 1-1 – Member organizations in Task T.2.3 and T2.4

2 FAST-TRACKS reference architecture

This section introduces the FAST-TRACKS high-level architecture, a novel wireless architecture able to seamlessly and efficiently support train-to-ground communications. FAST-TRACKS layering structure is shown in Figure 1. It comprises (bottom-up view):

1. The Mobile Communication Plane (MCP)
2. The Fixed Communication Plane (FCP)
3. The Radio Control Plane (RCP)
4. The Radio Monitoring Plane (RMP)

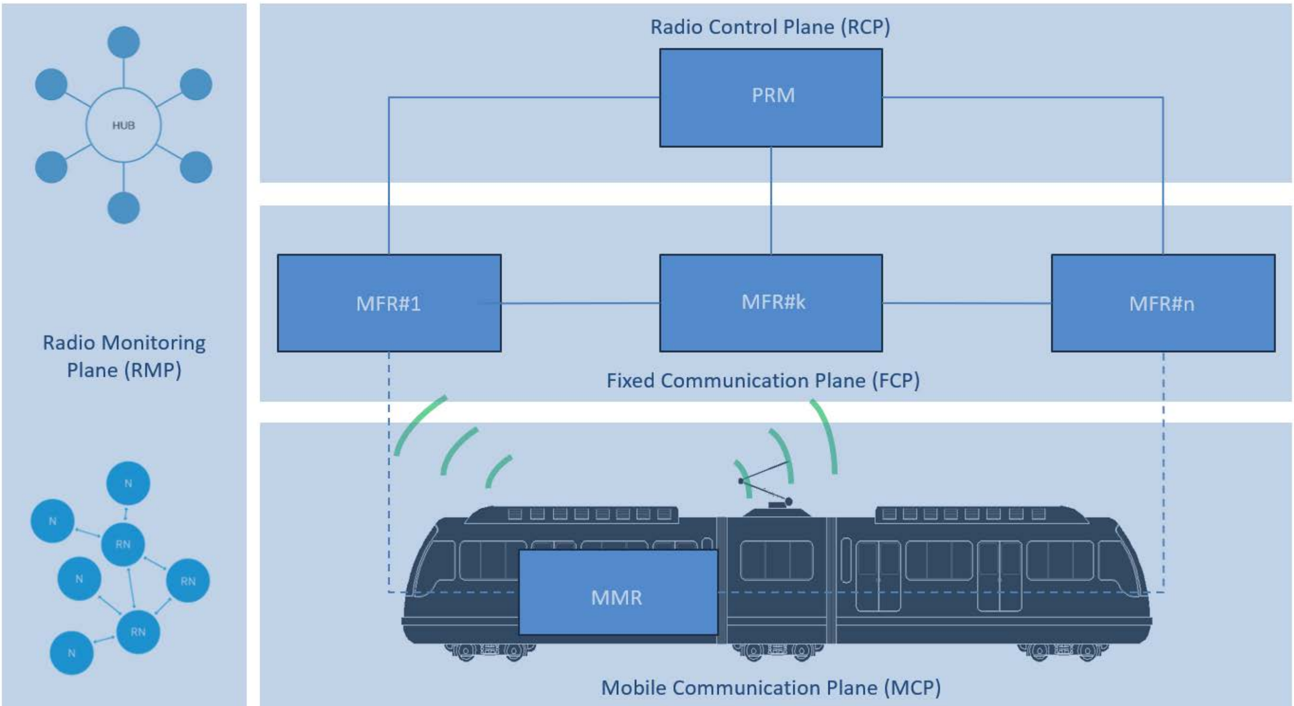


Figure 1 – Reference model for FAST-TRACKS high-level architecture

MCP is the mobile communication plane devoted to the transmission over the air of vital and non-vital data between train and wayside. This layer comprises hardware, firmware and software and involves mainly the train side of the network infrastructure (mobile radio).

FCP is the fixed communication plane devoted to the transmission over the air of vital and non-vital data between wayside and train. This layer comprises hardware, firmware and software and involves a plurality of fixed radio installed on the wayside.

RCP is the control plane devoted to the the implementation of protocols to connect radio dynamically, using both mesh and hub-spoke configurable patterns, to provide advanced transport services.

RMP is the infrastructure responsible for the realtime collection, management and monitoring of the wireless network data and parameters by means of resource abstraction and partitioning.

The novelty in the FAST-TRACKS architecture lies in the combination of the following three layers: Mobile Communication Plane (MCP), the Fixed Communication Plane (FCP) and the the Radio Control Plane (RCP).

Mobile radio and Fixed radio, basic elements of the MCP and FCP, are based on the concept of Cognitive Radio (CR) and Multi-Transport Radio (MTR), introduced for the first time by Comesvil within the FAST-TRACKS phase 1 project [1]. Currently the concept is enhanced adding a set of distruptive ideas and special features, designed for railway infrastructure and covered by the European Patent [2] filed to the EPO [3]. The advantages of the CR and MTR, within the train to ground communication are the high adaptability of the radio to the continuous evolution of wireless standards and the development of an innovative and not yet on the market product. The proposed infrastructure, due to the high-speed capacity, dual embedded radio and configurable approach, permits to integrate vital and non-vital services on the same wireless backbone, simply dedicating different radio to different services operating with a “full mesh” redundant network architecture. Thus, the system proposed will contribute to:

- Establish a high speed, reliable and continuous communication between a train in motion and the trackside, allowing capacity enhancement
- Support Communication Based Train Control (CBTC) services
- Collect data of CCTV (Close Circuit TV)
- Provide support for VoIP and Personal Information Systems (PIS) services
- Enable preventive maintenance
- Ensure passengers’ safety and security during their journey
- Improve travel comfort

The following sections shows the basic technologies involved at each layer of the FAST-TRACKS architecture. In details:

- Software Defined Radio
- Software Defined Networks
- Protocols for high performance wireless communications
- Cloud Computing
- Virtualization

3 The FAST-TRACKS Hardware Development Platform (HDP)

The FAST-TRACKS Hardware Development Platform is composed by a set of hardware devices conceived to create the building blocks of the FAST-TRACKS physical architecture. Three main types of devices compose the HDP:

- FAST-TRACKS Mainboard
- FAST-TRACKS Embedded Modules
- FAST-TRACKS Controller

With reference to the FAST-TRACKS architecture (described in the above chapter) the FAST-TRACKS Mainboard and Embedded Modules implements the hardware of the Fixed Communication plane (wayside radio) and Mobile Communication plane (train radio). The FAST-TRACKS controller instead is the building block of the Radio Control Plane. The next sections present the different hardware solutions analyzed, to cover the functional and non-functional requirements of the FCP and MCP, selected in the D1.2.

3.1 The Fast-Tracks Mainboard

As reported in the D1.1, FastTracks is based on the development of a low cost re-programmable radio infrastructure that implements simultaneously different radio propagation standard allowing efficient planning of the network, redundancy techniques, automatic-adaptive reconfiguration, and able to support the constrained requirements of the railway telecommunications. This technique allows the increase of the life time of the hardware (both of the radio base station that the user terminal) removing the risk of obsolescence; the re-programmability of the radio allows also the reuse of the hardware in case of new services or new generation systems, reducing OPEX and CAPEX.

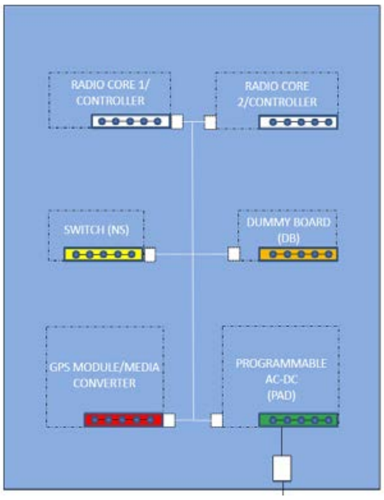


Figure 2 – FastTracks mainboard: logical architecture

The **first component** of the FT hardware development platform is the mainboard, which hosts all the radio modules and components through a standard set of PIN connectors based on the Mini PCIe standard. The above figure illustrates the logical composition of the mainboard.

The modular architecture proposed is a disruptive innovation in the field of railway telecommunicatoions. It permits to achieve benefits from a manufacturer point of view, allowing within the same product line, the implementation of Mobile radio, Fixed radio and Controller. The following image reports the customizations for the Fixed and the Mobile radio:

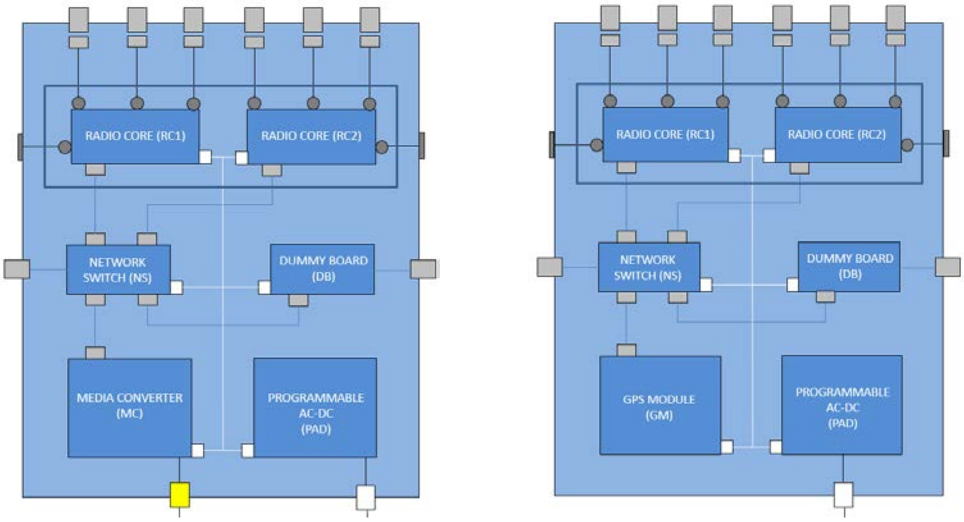


Figure 3 – Fixed (left Side) and Mobile (right Side) Radio

This chapter presents the description of the different mainboard analyzed, as possible candidate to develop the basic hardware of the radio equipment, matching the requirements reported in the deliverable D1.2.

All the boards are equipped with one or more Mini PCIe card connectors, in order to enable the integration of the mainboard with embedded modules, implementing the different radio standards we have selected: WiFi 802.11abg/802.11n/802.11ac, LongTerm Evolution (LTE), Long Range (LoRa), Tetra and Software Defined Radio.

The next section introduces different OEM products, analysed to create the first building block of the FASTTRACKS radio: the mainboard.

3.1.1 Compex WPJ344

The Compex WPJ 344 is a robust wireless embedded board, based on the Qualcomm Atheros AR9344 CPU. The board is equipped with a 560MHz network processor and integrates two radio modules (802.11 - 2.4Ghz 2x2 MiMo - 23dbm) and a miniPCIe slot that supports high power radio modules (802.11a/b/g/n, or 802.11 ac 3x3). Embedded with a memory capacity of 128MB and 8MB Flash, the WPJ344 represents the ideal platform for basic network applications. It includes an integrated Power over Ethernet (PoE) connector, that allows the WPJ344 to be used in areas where power outlets are not readily available. The next figure, shows more physical details of the board:

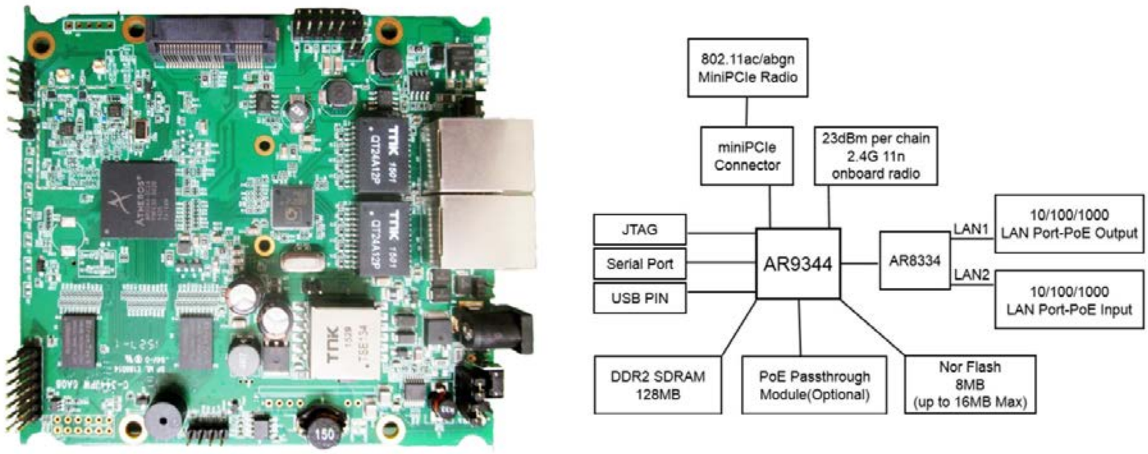


Figure 4 – The Compex WPJ344 board – The WPJ344 Block Diagram

The WPJ344 board can be easily integrated to develope the following applications:

- Standard 802.11b/g/n/ac Access Point
- Point-to-Point High Capacity Wireless Bridge
- Point-to-Multipoint High Capacity Wireless Bridge
- Wireless Base Station
- Wireless Customer-Premises Equipment (CPE)

Main features of the WPJ344 are the following:

Product Type: WPJ344	**Main features**
Chipset	AR9344
CPU Frequency	560MHz
Architecture	MIPS 74Kc
System Memory	128MB
Flash Memory	8-16MB
Wireless Standard	802.11n, 802.11g, 802.11b
MIMO Channels	2×2
Frequency Range	2.412 ~ 2.472 GHz

Output Power (Per Chain)	23dBm
Wireless Speed	300Mbps
MiniPCI-e Slot	v1.1
Interface	1x JTAG 14 Pin Connector, 1x MiniPCI-e Slot 9.2mm, 1x Serial Port 4 Pin Connector, 2x Gigabit Ethernet Port, 2x U.FL Connectorr
LED	14 PIN Connector, 7x LED Indicator
Power over Ethernet	IEEE 802.3af, IEEE 802.3at
DC Jack	12 – 24V, 24 – 56V
Reset Button	Yes
Operating System	CompexWRT or OpenWRT/LEDE
Certification	CE, FCC, RoHS Compliance
Power Consumption	7 Watts
Extra	Surge Suppressor, Watchdog Timer
Temperature Range	Operating: -20ºC to 70ºC, Storage: -40ºC to 90ºC
Humidity	Operating:5% to 95% (non-condensing)
Dimension	117 x 105 x 17mm (W x H x D)

Table 1 – Technical Specification WPJ344

3.1.1.1 Equipment Description

The WPJ344 board offers the following physical interfaces.

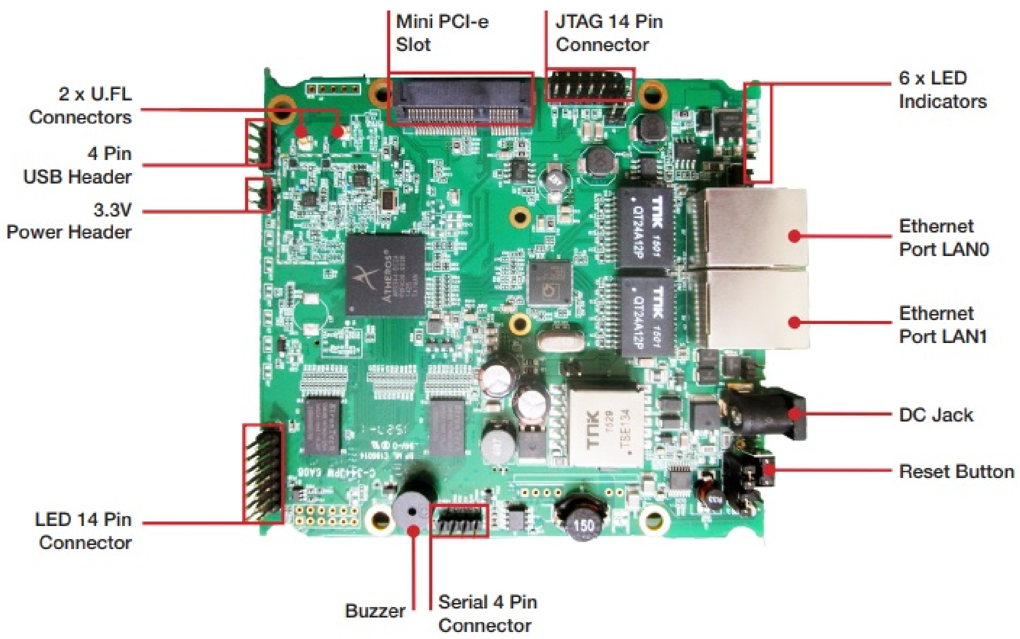


Figure 5 – Equipment Description WPJ344

Feature	Description
Reset button	For board reset and startup mode control
DC Jack	(HV) 24V~48V DC Supply (LV) 9V~24V DC
LAN port	① 10/100/1000BASE-T Ethernet port - PoE Output with PoE Passthrough. ② Can change to WAN port in CompexWRT firmware.
LAN port	① 10/100/1000BASE-T Ethernet port - PoE Input. ② Can change to WAN port in CompexWRT firmware.
5V Pin	① After connecting these two pins with Jumper, the board can provide on- board 5V to the radio card. ② Plug 5V cable to the 5V pin, the cable can provide external 5V power. Refer to RMF.
JTAG port	JTAG jumper header for programming
Mini PCIe slot	9.2mm height Mini PCIe slot
Radio	2.4GHz On-board Radio
USB Pin	Support USB Port and USB Extension
AR9344	Main Chipset
Serial port	Serial port connection header

Table 2 – Interface Description of the WPJ344 board

3.1.1.2 Mechanical details

The mechanical details of the WPJ344 board are the following:

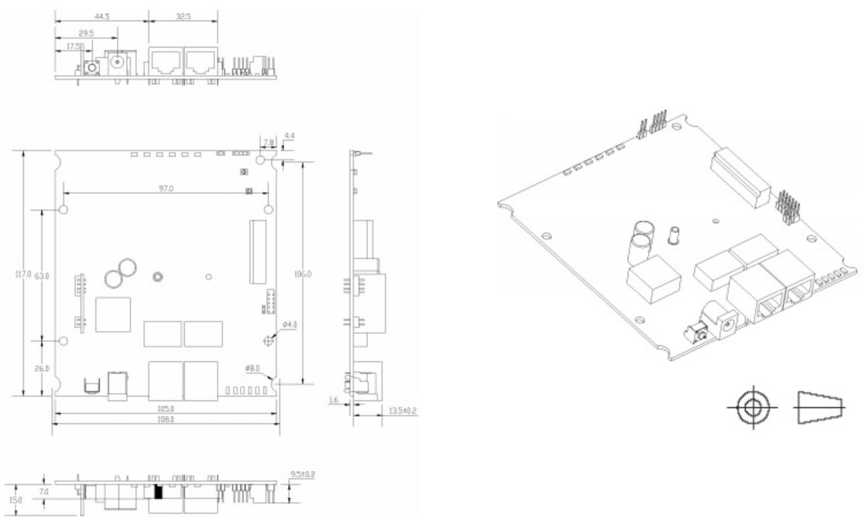


Figure 6 – Mechanical details of the WPJ344

3.1.2 Compex WPJ558

The Compex WPJ558 is a robust wireless embedded board, based on the Qualcomm Atheros QCA95558 WiSoC CPU. The board is equipped with a 700MHz network processor and integrates two radio modules (802.11 - 2.4Ghz 2x2 MiMo - 23dbm) and a miniPCIe slot that supports high power radio modules (802.11a/b/g/n, or 802.11 ac 3x3). Embedded with a memory capacity of 128MB 16MB Flash, the WP558 represents a good compromise for network applications with professional features and low costs. The WP588 includes an integrated 48V Power over Ethernet (PoE) connector, that allows to be used in areas where power outlets are not readily available. The next figure, shows more physical details of the board:

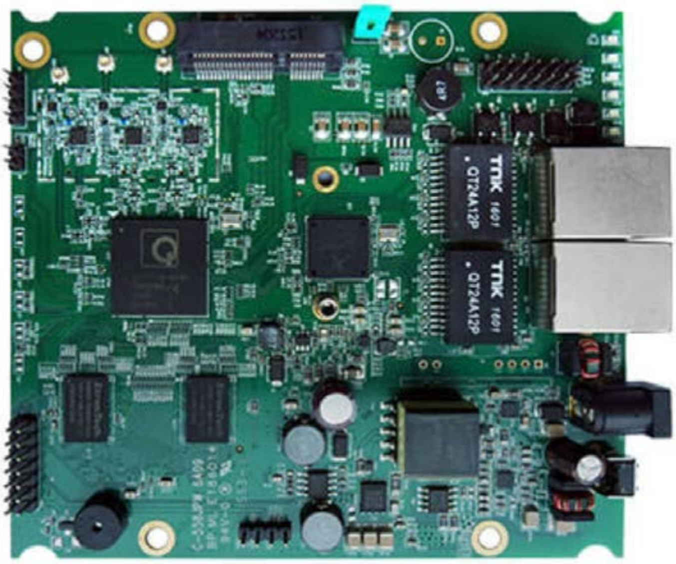


Figure 7 – The WPJ558 board

The WPJ344 board can be easily integrated to develope the following applications:

- Tri Band MU-MIMO 802.11b/g/n/ac Access Point
- Dual Concurrent MU-MIMO 802.11a/n/ac Access Point
- Wireless Base Station with optimized 4x4 MU-MIMO 802.11ac Module Support
- 3G/LTE Access Point

The key feature of the WPJ558 board, respect of WPJ344, is the support to the 3G/LTE modulation-demodulation third party module, which permits the implementation, on top of the same board, of WiFi-3G-LTE technologies. Main features of the WPJ344 are the following:

Product Type: WPJ588	**Main features**
Chipset	QCA9558
CPU Frequency	700MHz
Architecture	MIPS 74Kc
System Memory	128MB
Flash Memory	16MB
Wireless Standard	802.11n, 802.11g, 802.11b

MIMO Channels	3×3
Frequency Range	2.412 ~ 2.472 GHz
Output Power (Per Chain)	23dBm
Wireless Speed	450Mbps
MiniPCI-e Slot	v1.1
Interface	1x JTAG 14 Pin Connector, 1x MiniPCI-e Slot 9.2mm, 1x Serial Port 4 Pin Connector, 2x Gigabit Ethernet Port, 3x UFL Connectorr
LED	14 PIN Connector, 7x LED Indicator
Power over Ethernet	IEEE 802.3af, IEEE 802.3at
DC Jack	24 – 56V
Reset Button	Yes
Operating System	CompexWRT or OpenWRT/LEDE
Certification	RoHS Compliance
Power Consumption	8.6 Watts
Extra	Surge Suppressor, Watchdog Timer
Temperature Range	Operating: -20ºC to 70ºC, Storage: -40ºC to 90ºC
Humidity	Operating:5% to 95% (non-condensing)
Dimension	117 x 105 x 17mm (W x H x D)

Table 3 – Technical Specification WPJ558

3.1.2.1 Equipent Description

The following image reports the details of the physical interfaces of the board:

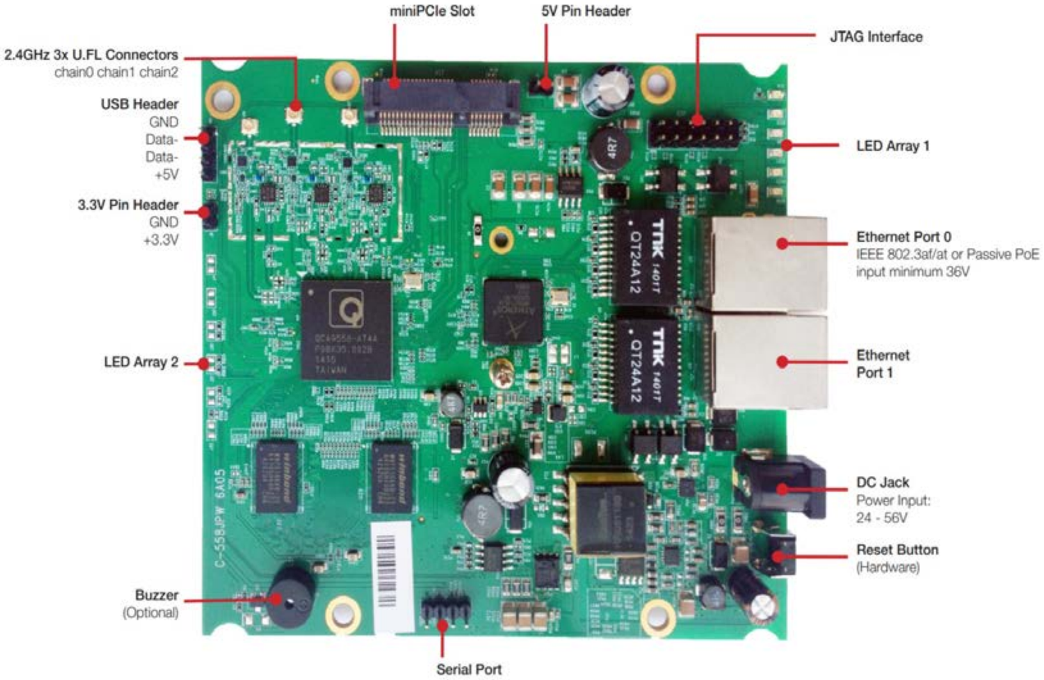


Figure 8 – Hardware Description WPJ558

3.1.2.2 Mechanical details

The mechanical details of the WPJ558 board are the following:

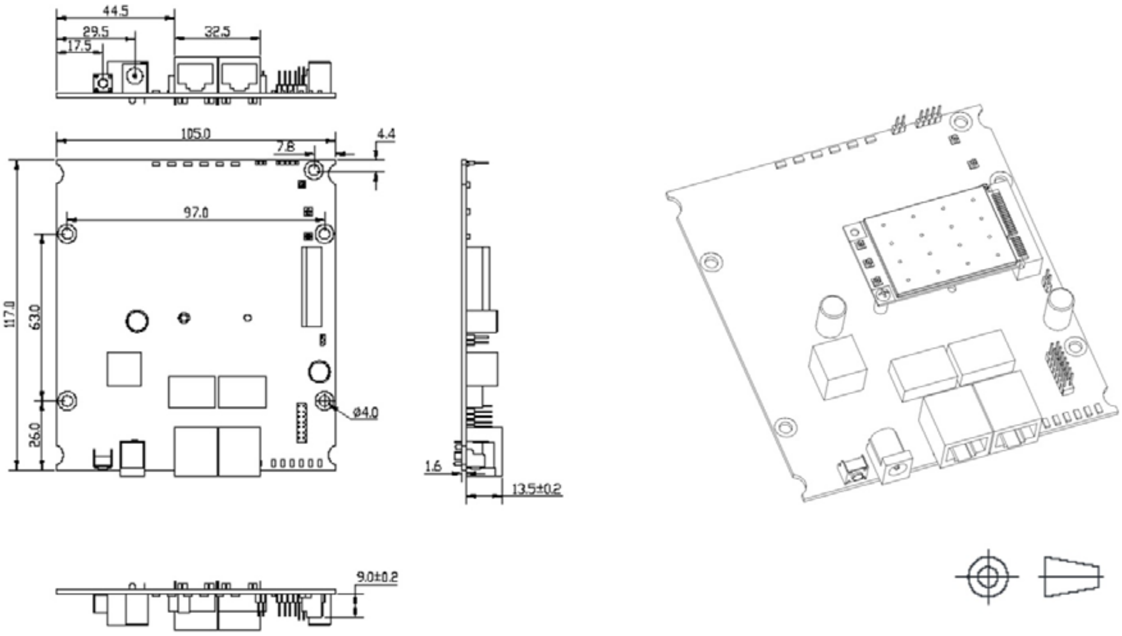


Figure 9 – Mechanical details of the WPJ558 board

3.1.3 Compex WPQ864

The Compex WPQ864 6A02 is a very powerful wireless embedded board, based on the Qualcomm Atheros IPQ8064 ARM Dual core CPU. The board is equipped with a 1.4GHz network processor and integrates three Mini PCI Express v2.0 Slots supporting high power 802.11/ac radio. Embedded with 1GB DDR3 memory and 256MB NAND Flash, it provides the ideal platform for the first prototype of the FASTRACKS mainboard. WPQ 864 includes 1x IEEE 802.3af/at POE Standard Port, 48~57V, up to 70W (4-pair power feed) on LAN4 and one DC Jack Connector with 12V, 4A input. The next figure, shows more physical details of the board:

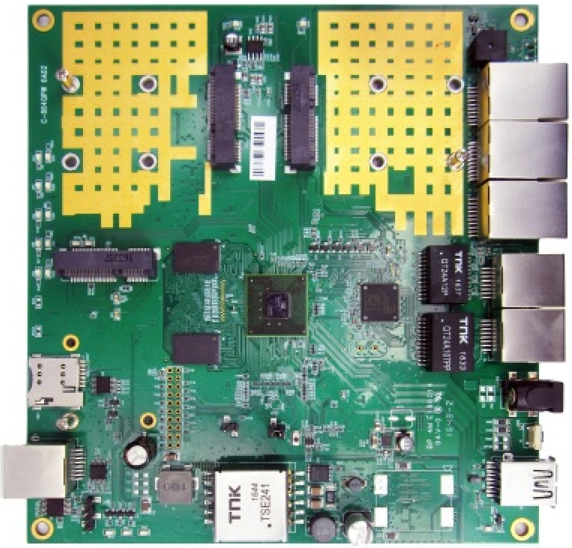


Figure 10 – WPQ864

The WPQ864 board can be easily integrated to develope the following applications:

- 802.11b/g/n + 802.11a/n/ac Access Point
- Point-to-Point High Capacity Wireless Bridge
- Point-to-Multipoint High Capacity Wireless Bridge
- Wireless Base Station optimized with 802.11ac Module Support
- Wireless Customer-Premises Equipment (CPE)
- 3G/LTE AP (Support Third Party 3G/LTE Module)

Main features of the WPQ864 are the following:

Product Type	**Main features**
Chipset	Qualcomm Atheros Dual Core Krait ARMv7 IPQ8064 1.4GHz CPU
Reference Design	Qualcomm Atheros AP148
System Memory	2x 512MB = 1GB DDR3
NOR Flash	32MB
NAND Flash	256MB
Expansion	3x Mini PCI Express v2.0 Slot at 9.2mm Height
Interface	5x Gigabit Ethernet LAN RJ45 Port1 (Auto MDI-X)

	1x RJ45 Serial Console Port 1x Serial Port 4 Pin Connector2 1x JTAG 20 Pin Connector3 (optional)
Reset Button	1x H/W Reset Button
LED	12x LED Indicators
Power Over Ethernet	1x IEEE 802.3af/at POE Standard Port, 48~57V, up to 70W (4-pair power feed) on LAN4
DC Power	1x DC Jack Connector: 12V, 4A (Optional, absent by default)
Power Consumption	TBA
Supported Operating System	CompexWRT or OpenWRT/LEDE4
RoHS Compliance	Yes
Environmental	Temperature: Operating: -20ºC to 70ºC, Storage: -40ºC to 90ºC Humidity (non-condensing): Operating: 5% to 95%, Storage: Max. 90%
Dimensions (W x H x D)	159 x 168 x 15.1 mm
Other Features	Surge Suppressor, Watchdog Timer, Buzzer, Heat Sink with Heat Pads on Bottom Side

Table 4 – Technical SPecification WPQ864

3.1.3.1 Equipent Description

The following image reports the physical interfaces details of the board:

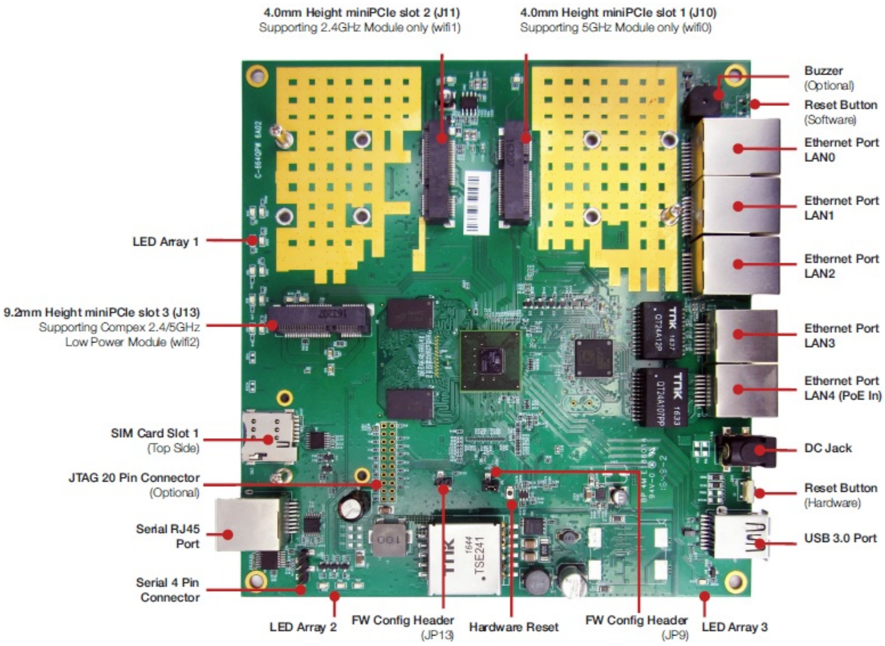


Figure 11 – Hardware Description WPQ864

3.1.3.2 Mechanical details

The mechanical details of the WPQ864 board are the following:

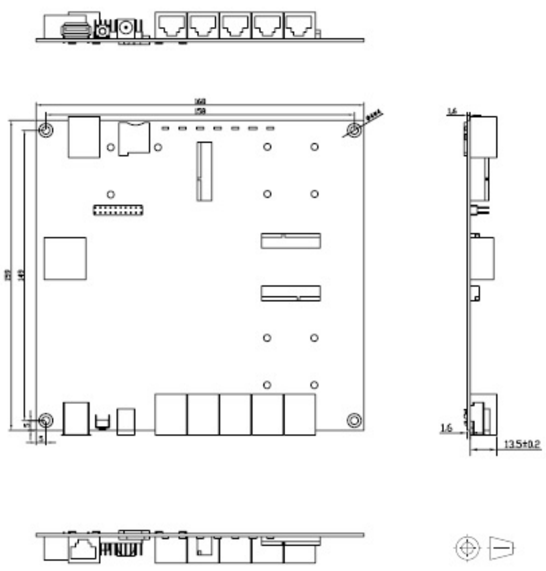


Figure 12 – Mechanical Dimensions WPQ864

3.1.4 Acksys WLn-LINK-OEM

The Acksys WKn-LINK-OEM is an embedded module working at 2.4/5 GHz, implementing IEEE 802.1a/b/g/n standards and designed to quickly and easily add wireless LAN to a wide range of wired Ethernet OEM products. More than just a radio adapter, WLn-LINK-OEM features a fully integrated IEEE 802.11a/b/g/n radio and a powerful PowerPC processor that provides a complete wireless connection (AP/brigde/repeater/Mesh) in a single small footprint. WLn-LINK-OEM reduces the design time and eliminates the risk associated in wireless chipset-based designs by providing all of the WiFi network protocols and processing needed to quickly implement embedded wireless solutions; its industrial-grade performance makes it ideally suited for harsh environments. Main features of the WKn-LINK-OEM are the following:

Product Type	Main features
Ethernet interface	1-port Gigabit Ethernet 10/100/1000 Base TX auto-sensing, plug & play mode & auto MDI/MDIX cross-over, RJ45 or TTL Ethernet interface (HE10 connector)
Serial interface	One serial port (TTL level)
WiFi interface	1 radio IEEE 802.11 a/b/g/n, MIMO 3T3R, 2.4 / 5 Ghz
WiFi radio data rate	802.11a: 6, 9, 12, 18, 24, 36, 48 and 54 Mbps 802.11b/g: 1, 2, 5.5, 6, 9, 11, 12, 18, 24, 36, 48 and 54 Mbps 802.11n: MCS0-23, 3 streams (6.5 to 450 Mbps)
Operating frequencies	ISM: 2.4-2.483 GHz (up to 14 channels) UNII: 5.15-5.25 GHz (up 4 channels) UNII-2: 5.25-5.35 GHz (up to 4 channels) UNII-2 ext: 5.470-5.725 GHz (up to 11 channels) UNII-3: 5.725-5.825 GHz (up to 4 channels) Supports DFS and TPC
Output power	Up to 24dBm (aggregate), depending on radio card model
Antennas	3 UFL connectors
Security	IEEE 802.1x (RADIUS authenticator & supplicant), WPA2-PSK, WPA-PSK, WEP
WiFi Modes	Access point, client, repeater, MESH point (IEEE 802.11s), infrastructure, AD-HOC, client router, WMM QoS, multicast, dynamic routing and firewall modes fully supported, fast roaming (less than 30 ms), redundancy (VRRP)
Administration	Built-in WEB interface, SNMP agent, administration software for Windows/Linux (ACKSYS NDM)
LEDs Signaling	Radio: quality and activity | Ethernet: link 10/100/1000 and activity | Power: on-off | Product diagnostic
Power supply	+5VDC (+/- 5%), 8 Watts typical
Dimensions & weight	Small sized PCB, L: 103 x l: 57 x H: 20 mm, approx. 50g
Standards	Radio module CE and FCC certified. WLn-LINK-OEM has to be certified in the final product.
Environment	Operating temperature: -20°C to +70°C or -40°C to +85°C (for extended temperature range model) Storage: -65°C to +100°C, Humidity: 5% to 95% (non-condensing)

Table 5 – Technical Specification WPQ864

The following figure, shows the equipment analysed.

Figure 13 – Acksys WKn-LINK-OEM Equipment

3.1.5 Abicom International's Scorpion 450

Abicom International's Scorpion 450 is an unparalleled wireless platform, offering a wealth of features that enable the creation of high performance, flexible wireless installations. The Scorpion 450 has been optimised for a range of high performance wireless applications including wireless bridges, last mile access and mixed hotspot/backbone applications. The Scorpion 450 combines an enterprise level, 3 streams, 802.11an based radio with a gigabit Ethernet interface and SFP Fibre module port.

Scorpion 450 supports 5GHz 802.11a/n operation through a highly integrated single chip solution enabling 3x3 Spatial Stream MIMO configurations. Enhanced features include, DFS selection in all required bands, 5, 10, 20 & 40MHz channelisation, cyclic-delay diversity (CDD), low density parity check (LDPC), maximal ration combining (MRC), Space Time Block Code (STBC), TX Beamforming (TxBF) and 8-bit spectral analysis resolution. Data rates of 216.7 Mbps for 20MHz channels and 450Mbps for 40MHz channel can be achieved.

Additionally, Scorpion 450 includes a SFP Fibre module port and a PCIe expansion port to allow a second radio module to be used. Inbuilt hardware encryption provides an unparalleled level of security. Scorpion 450 supports all mandatory and optional modes specified in 802.11i.. A 128-entry Key Cache holds both shared and unique keys on a per-station basis. WPA and WPA2 are offered as standard, along with hardware support for FIPS140 AES certification.
The following image, shows the Scorpion 450 board:

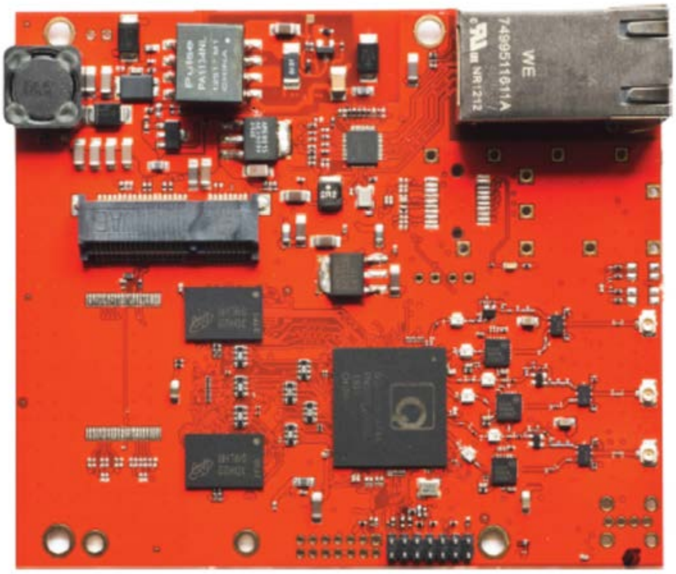


Figure 14 – Abicon Scorpion 450

Main features of the board analysed are:

- Connects to any 5GHz 802.11 Client
- 450Mbps Data Rate
- Extended Tuning Range for Worldwide Use
- Hardware Encryption For WPA and 802.11i, AES TKIP and WEP
- DFS/TPC For International Operation
- Support for 802.11e,h and i standards
- WDS, AP and Client functionality for hotspot and bridging applications
- OpenWRT support
- +27dBm output power

Hardware Configuration

- Board-Level Product Suitable for OEM's
- Full-Duplex gigabit ethernet port
- SFP Fibre module port
- PCIe expansion port
- Integrated 32-bit 700MHz MIPS Processor
- 256MB DDR2 SDRAM, 16MB Flash
- x USB2.0 Ports
- Gigabit Power over Ethernet (802.3at) eases installation in confined and remote sites
- Optional 12Vdc power supply
- Multipurpose IO port with support for 3.3V GPIO and SPI interfaces
- Industrial temperature options (- 40 - 110°C)

3.2 The Fast-Tracks Embedded Modules

The FASTTRACK modules are conceived to implement the Modulation-Demodulation features for each kind of supported radio standard, as described in the D1.1 and D1.2 deliverables. In this section we present the possible set of embedded radio modules selected for the Fast Tracks Hardware Development Platform. In details, by using the PCI Express Mini Card interface, universally used to interface mainboards with modulation and demodulation modules, in this chapter we analyze all the radio modules in charge to implements radio protocols meaningful for the FAST-TRACKS environment.
PCI Express Mini Card (also known as Mini PCI Express, Mini PCIe, and Mini PCI-E) is a replacement for the Mini PCI form factor based on PCI Express. It is developed by the PCI-SIG. In our scenario, the FAST-TRACKS Mainboard supports both PCI Express and USB 2.0 connectivity, and each Embedded Module uses whichever radio technology appropriate to the railway context.

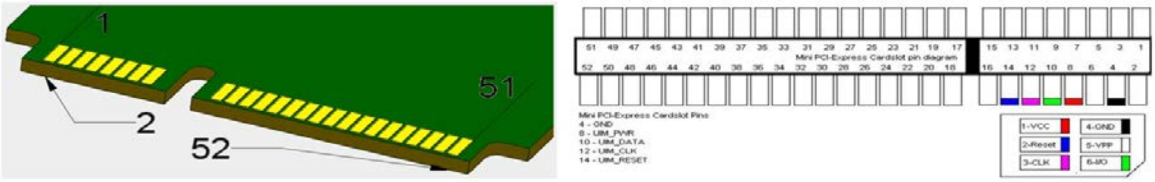


Figure 15 – PCI Express Mini Card - Pinout

In details, the radio technologies we want to add to the FAST-TRACKS mainboard are:

- Wi-Fi 802.11 a/b/g/n/ac
- Long Term Evolution (LTE)
- Terrestial trunked Radio (TETRA)
- Long Range (LORA)
- GSM
- GPS

The logical slots of the radio core impacted by the Embedded modules are the RC1, RC2 and the dummy slots.

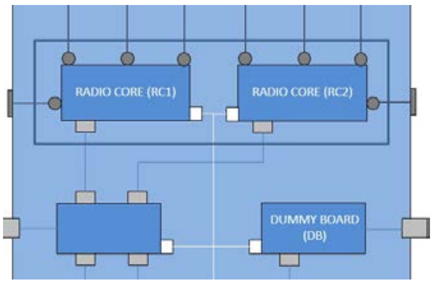


Figure 16 – Logical slots for Embedded modules

The modular architecture proposed permits the full implementation of the Software Defined Radio concept, where the modulation-demodulation devices are pluggable and decoupled by the software drivers and tools. During the FAST-TRACKS project, the implementation of this concept is pursued in two directions. The first, using different modules described in the next section, each one implementing a different media protocol. The second, very innovative, based on the usage of only one SDR module, where is possible to implements different media protocols only changing the control and application software. This solution is described in the Software Defined Radio section.

3.2.1 Wi-Fi modules

Wi-Fi modules are pre-programmed devices implementing one or more 802.11 standards, the most popular technology today that allows electronic devices to connect to the internet or exchange data wirelessly using RF radio waves. Wi-Fi refers specifically to ability for interoperability with other WLAN devices. Wi-Fi technology may be used in a variety of scientific, industrial, commercial and consumer applications. Many devices can use Wi-Fi, and these devices can all connect to a network resource via a wireless network access point.

To achieve a stable wireless connection between the train and wayside, the first objective is to learn how to add wireless capability to the FASTRACKS mainboard presented in the above chapter. The most common way to add wireless capability is to use a prepackaged WLAN module. While this approach greatly simplifies the process, it still has many challenges. The following paragraph shows a possible hardware set, developed by Compex and compatible with the mainboard presented above.

3.2.1.1 *Compex WLE600VX 7AA*

This module implements a MIMO 2x2 802.11 a/b/g/n/ac (working on both 2.4Ghz end 5.8Ghz frequencies) with maximum speed of 867Mbps. The physical interface is based on a standard PCIExpress slot.

Figure 17 – Wireless Module - WLE600VX

Product Type	*Wireless Module*
Chipset	QCA9882
Wireless Standard	802.11n, 802.11g, 802.11b, 802.11ac, 802.11a
MIMO Channels	2×2
Output (Per Chain)	21dBm
Frequency Range	2.412 ~ 2.472 GHz, 5.180 ~ 5.825 GHz
Wireless Speed	867Mbps
Interface	1x MiniPCI-e Pin
MiniPCI-e Pin	v1.1
Power Consumption	3.5 Watts
Temperature Range	Operating: -20ºC to 70ºC, Storage: -40ºC to 90ºC
Humidity	Operating:5% to 95% (non-condensing)
Certification	CE, FCC, RoHS Compliance
Dimension (W x H x D)	50.95 x 30 x 3.2 mm (W x H x D)

Table 6 – Technical Specification WLE600VX

3.2.1.2 Compex WLE600V5-27

This module implements a MIMO 2x2 802.11 a/n/ac (working only on 5.8Ghz frequencies) with maximum speed of 867Mbps. The physical interface is based on a standard PCIExpress slot.

Figure 18 – Wireless Module - WLE600V5

Product Type	Wireless Module
Chipset	QCA9882
Wireless Standard	802.11n, 802.11ac, 802.11a
MIMO Channels	2×2
Output (Per Chain)	27dBm
Frequency Range	5.180 ~ 5.825 GHz
Wireless Speed	867Mbps
Interface	1x MiniPCI-e Pin, 2x MMCX Connector
MiniPCI-e Pin	v1.1
Power Consumption	7.5W (Max)
Temperature Range	Operating: -20ºC to 70ºC, Storage: -40ºC to 90ºC
Humidity	Operating:5% to 95% (non-condensing)
Certification	IC, CE, FCC, RoHS Compliance
Dimension (W x H x D)	50 x 50.95 x 8.5 mm

Table 7 – Technical Specification WLE600V5

3.2.1.3 Compex WLE900VX

This module implements a MIMO 3x3 802.11 a/b/g/n/ac (working on both 2.4Ghz end 5.8Ghz frequencies) with maximum speed of 1300Mbps. The physical interface is based on a standard PCIExpress slot.

Figure 19 – Wireless Module – WLE900VX

Product Type	*Wireless Module*
Chipset	QCA9880
Wireless Standard	802.11n, 802.11g, 802.11b, 802.11ac, 802.11a
MIMO Channels	3×3
Output (Per Chain)	21dBm
Wireless Speed	1300Mbps
Frequency Range	2.412 ~ 2.472 GHz, 5.180 ~ 5.825 GHz
Interface	1x MiniPCI-e Pin, 3x U.FL Connector
MiniPCI-e Pin	v1.1
Power Consumption	5 Watts(Max)
Temperature Range	Operating: -20ºC to 70ºC, Storage: -40ºC to 90ºC
Humidity	Operating: 5% to 95% (non-condensing)
Certification	CE, FCC, RoHS Compliance
Dimension (W x H x D)	50.95 x 30 x 3.2 mm (W x H x D)

Table 8 – Technical Specification WLE900VX

3.2.1.4 Compex WLE900V5-27

This module implements a MIMO 3x3 802.11 a/n/ac (working only on 5.8Ghz frequencies) with maximum speed of 1300 Mbps. The physical interface is based on a standard PCIExpress slot.

Figure 20 – Wireless Module – WLE900V5

Product Type	*Wireless Module*
Chipset	QCA9880
Wireless Standard	802.11n, 802.11ac, 802.11a

MIMO Channels	3×3
Output (Per Chain)	27dBm
Frequency Range	5.180 ~ 5.825 GHz
Wireless Speed	1300Mbps
Interface	1x MiniPCI-e Pin, 3x MMCX Connector
MiniPCI-e Pin	v1.1
Power Consumption	10W (Max)
Temperature Range	Operating: -20ºC to 70ºC, Storage: -40ºC to 90ºC
Humidity	Operating:5% to 95% (non-condensing)
Certification	RoHS Compliance
Dimension (W x H x D)	50 x 50.95 x 8.5 mm

Table 9 – Technical Specification WLE900V5

3.2.2 LTE Module

To receive the highest possible data rate or/and the most reliable connection, the FASTTRACKS equipment is enhanced with additional modules, to use in different contextual networks. In this paragraph will be described one of possible LTE modules that could be used to enhance the FASTRACKS radio with LTE client functionalities. With LTE (Long Term Evolution), is possible to achieve higher speed and lower latency. The use of diversity or MIMO antennas also ensures better reception. All the presented modulation and dempodulation modules are downward compatible in the mobile radio standard. So, each analyzed device supports 3G (HSPA+, HSUPA, HSDPA, UMTS) and 2G (EDGE, GPRS, GSM). If the network with the highest standard is not available or the reception is too weak, it is automatically changed to the next-best network. The next section analyses some of the LTE modules analysed for the FASTRACKS project.

3.2.2.1 NaviSys WW-4161 4G

NaviSys WW-4161 4G PCI Express Mini Card supports the latest 4G LTE with seamless fallback to 2G networks. It is designed based on Gemalto/Cinterion LTE Cat1 and 2G GSM/GPRS wireless WAN technologies. The module not only exhibits excellent hardware/radio frequency performance, it also supports rich software for fast product development. Following the PCI Express Mini Card standard, it could be easily applied in devices with PCI express architecture. It is an ideal solution for the vast number of M2M and industrial IoT applications that are not dependent on speed but that requires the longevity of LTE networks, while still providing 2G connectivity to ensure complete population and geographic coverage as LTE rolls out.

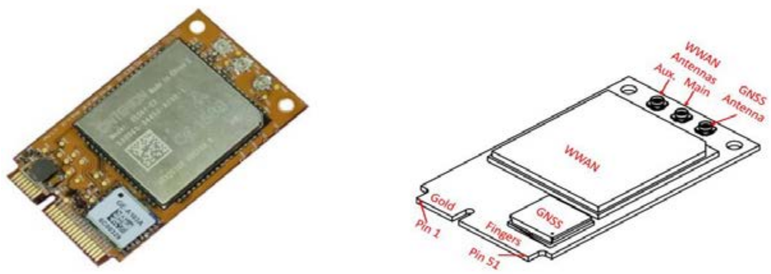


Figure 21 – LTE Module – WW4161 AG

In addition to WWAN, features of (a) ultra-sensitive GNSS (GPS & GLONASS), (b) SIM card holder, and (c) modem control via UART TTL/RS232 are available for increasing your product value in just one card.

Features

- Both 4G LTE and 2G GSM/GPRS/EDGE support
- PCI Express Mini Card standard V1.2 compliant
- Communication via USB
- Network status indication
- Airplane mode support
- Remote host wakeup support
- Powered by Gemalto LTE Cat 1 module
- ELS61-E2 (4G LTE bands 1, 3, 8, 20, 28; 2G bands 3,8) for Europe/APAC
- Approvals: R&TTE (CE), GCF
- USB 2.0 High Speed (480Mbit/s) device interface, Full
- Speed (12Mbit/s) compliant
- Onboard SIM card holder (for Micro-SIM)
- Customer IMEI/SIM-Lock as variant
- RLS Monitoring (Jamming detection)
- Rich driver/RIL support for various platforms
- Rich internet communication protocol support
- Internet Services TCP/UDP server/client, DNS, Ping, HTTP, SMTP, FTP client
- The latest TLS/SSL engine provides secure and reliable TCP/IP connectivity.
- eSIM support, BIP (Bearer Independent Protocol)
- SIM Access Profile (SAP)
- Abnormal temperature protection of module board (out of -40~90℃)
- Option of UART TTL or RS232 modem control
- Option of high performance GNSS (GPS&GLONASS)
- GNSS antenna short circuit protection

3.2.2.2 AirPrime EM7565 LTE-Advanced Pro Module

The EM7565 module is part of the EM Series offering global 4G coverage, unprecedented LTE speeds, bandwidth, and network performance on the M.2 form factor commonly used in networking equipment. Leveraging LTE-LAA and CBRS unlicensed bands and carrier aggregation, this LTE-Advanced Pro Cat-12 embedded module delivers up to 600Mbps downlink speed and 150Mbps uplink speed, offering global 4G coverage on a single module. With automatic fallback to 3G networks and integrated GNSS receiver (GPS, GLONASS, Beidou, and Galileo satellite systems supported), the EM7565 is ideal for mobile computing, networking, and industrial M2M applications. Coupled with the most operator certifications in the industry and network switching capability, EM7565 allows customers to change their network provider anytime, providing more flexibility in manufacturing.

Figure 22 – LTE Module – Airprime EM7565

Sierra Wireless is building the Internet of Things with intelligent wireless solutions that empower organizations to innovate in the connected world. We offer the industry's most comprehensive portfolio of 2G, 3G and 4G embedded modules and gateways, seamlessly integrated with our secure cloud and connectivity services. OEMs and enterprises worldwide trust our innovative solutions to get their connected products and services to market faster.

3.2.2.3 Huawei ME909s-120

ME909s-120 Mini PCI express is the first LTE cat4 module based on Hi-Silicon chipset. Which is high-quality designed LTE module in small size and standard mPCIe form factor, especially for industrial-grade M2M applications such as vehicle telematics, tracking, mobile payment, industrial router, safety monitor and industrial PDAs.

ME909s-120 Mini PCI express supports eight bands (B1/B2/B3/B4/B5/B7/B8/B20) in the EMEA region. It also have the form factor LGA if it suits your need better. ME909s-120 Mini PCI express supports 150Mbps downlink data rate, including enhanced features like FOTA, USSD and Huawei enhanced AT commands.

Figure 23 – LTE Module – Huawei ME909s-120

This is the mPCIe form factor of the module ME909s-120.

3.2.3 Tetra Module

TETRA, Terrestrial Trunked Radio, is a professional mobile radio and two-way transceiver specification defined by European Telecommunications Standards Institute (ETSI) standard, first version published 1995. TETRA was specifically designed for use by government agencies, emergency services, (police forces, fire departments, ambulance) for public safety networks, rail transport staff for train radios, transport services and the military. The main advantages of TETRA in over other technologies (such as LTE) are:

- The much lower frequency used gives longer range, which in turn permits very high levels of geographic coverage with a smaller number of transmitters, thus cutting infrastructure costs.
- During a voice call, the communications are not interrupted when moving to another network site (handover). This is a unique feature, which dPMR networks typically provide, that allows a number of fall-back modes such as the ability for a base station to process local calls. So called 'mission critical' networks can be built with TETRA where all aspects are fail-safe/multiple-redundant.
- In the absence of a network, mobiles/portables can use 'direct mode' whereby they share channels directly (walkie-talkie mode).
- Gateway mode - where a single mobile with connection to the network can act as a relay for other nearby mobiles that are out of range of the infrastructure.
- TETRA also provides a point-to-point function that traditional analogue emergency services radio systems did not provide. This enables users to have a one-to-one trunked 'radio' link between sets without the need for the direct involvement of a control room operator/dispatcher.
- Unlike cellular technologies, which connect one subscriber to one other subscriber (one-to-one), TETRA is built to do one-to-one, one-to-many and many-to-many. These operational modes are directly relevant to the public safety and professional users.
- Rapid deployment (transportable) network solutions are available for disaster relief and temporary capacity provision.
- Network solutions are available in both reliable circuit-switched (telephone like) architectures and flat, IP architectures with soft (software) switches.
- Further information is available from the TETRA Association (formerly TETRA MoU) and the standards can be downloaded for free from ETSI.

3.2.3.1 PMR-R BDM313L

The PMR-D BDM313L implements microprocessor and storage logic "on-board" to develop TETRA capabilities. Basic interfaces are PEI (Peripheral Equipment Interface) and debug Interface. Additional interfaces for the connection of sensors are available. The moduie is based on latest energy-saving components in the smallest version.

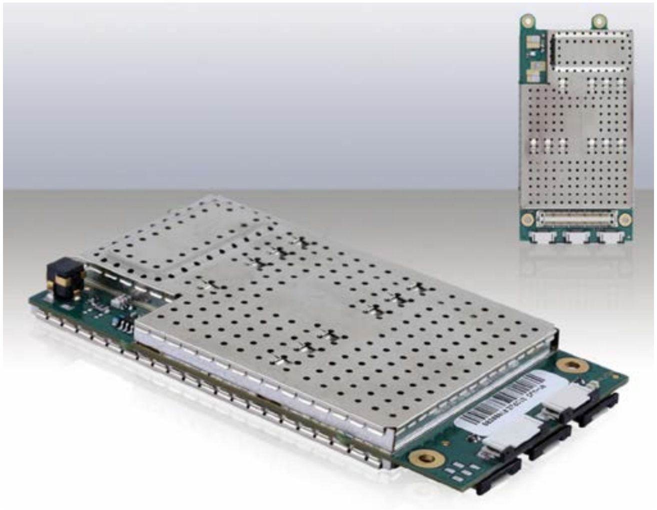


Figure 24 – TETRA Radio Modem – PMR-R BDM313L

The following list of characteristics are implemented by Tetra Radio Modem:

- Transmission method: TDMA
- Modulation method: π/4 DQPSK
- Channel spacing: 25 kHz
- TX/RX separation ETSI TS 100 392-15
- (10 MHz and user defined)
- RF power output: 1.8 W (class 3L), RF power control
- Transmitter characteristics: ETS 300 392-2, ETS 300 396-2
- Receiver: Class A (TU 50)
- Tetra messages: Status, SDS Type 1, 2, 3 and 4
- (with or without TL)
- PEI - ETSI EN 300 392-5
- Voice call: (on request)
- Operation Modes:
- TMO - Trunking mode
- Frequency ranges:
- 360 - 400 MHz
- 380 - 400 and 410 - 430 MHz
- 410 - 430 and 445 – 470 MHz

Specifications

- Antenna connector: MMCX
- Power supply: 3.7 VDC @ 3.0 A (TX burst)
- Dimensions: 86 x 43 x 8 mm (L x B x H)
- Weight: 35 g
- Operation temperature: -20 °C to +49 °C
- Interfaces: 80 pin interface (service and application) power connector
- Status-LED, RTC, one serial interface (6 pin's) and two RS232 (4 pin's) i.e. for the connection of sensors
- (other interfaces on request)
- Calibration: no calibration required after production check
- Maintenance: no maintenance required after production check
- Options: Integration of costumer application on the board possible

3.2.4 LORA Module

LoRa (Long Range) is a wireless technology that has been developed to enable low data rate communications to be made over long distances by sensors and actuators for M2M and Internet of Things, IoT applications. LoRaWAN™ is a Low Power Wide Area Network (LPWA) protocol based on Semtech LoRa Technology for IoT devices and LoRaWAN networks. The LoRaWAN specification provides interoperability among smart devices without the need of complex local installations. LoRaWAN network architecture is based on a star-of-stars topology with gateways as a transparent bridge relaying messages between end-devices and a central network server in the backend. Gateways are connected to the network server via standard IP connections while end-devices use single-hop wireless communication to one or many gateways. All end-point communication is generally bi-directional, but also supports operation such as multicast enabling software upgrade over the air or other mass distribution messages to reduce the on-air communication time. Communication between end-devices and gateways is spread out on different frequency channels and data rates. The selection of the data rate is a trade-off between communication range and message duration. Due to the spread spectrum technology, communications with different data rates do not interfere with each other and create a set of "virtual" channels increasing the capacity of the gateway. LoRaWAN data rates range from 0.3 kbps to 50 kbps. To maximize both battery life of the end-devices and overall network capacity, the LoRaWAN network server is managing the data rate and RF output for each end-device individually by means of an adaptive data rate (ADR) scheme.

3.2.4.1 GlobalSat LD-11

LD-11 series are low power-consuming, half-duplex dongle with mini PCIe interface. It can wirelessly transmit data to long-distance. It is built-in high speed and low power-consuming MCU and SX1276 modulation chipset. This chipset is applied with the forward error correction technique which greatly improves interference immunity and advances sensitivity. The coding can detect errors and automatically filter out errors and false data. It can work as the end-node devices in the LoRaWANTM infrastructure or in GlobalSat proprietary M.O.S.T. mode. LD-11 series are suitable for long-distance transmission or harsh environments.

Figure 25 – GlobalSat LD-11

Product Features

- LoRa Alliance™ certified module inside, support Class A/ Class C

- Compliant with LoRaWAN™ FW and proprietary M.O.S.T. FW
- Mini PCI Express Form Factor
- Micro USB Interface
- u.F.L antennas to support EU 868, US 915 and AS 923MHz
- Range 10km (@ 980bps)
- Support Windows® 7/ 8/ 10, x86 Linux® Ubuntu 12.04, MacAir OS 10.7 (later)

3.2.4.2 *LyaTech LRM001*

The LRM001 with Microchip's RN2483 is an Low-Power Long Range LoRa Technology Transceiver module. It provides an easy to use, low-power solution for long range wireless data transmission. The advanced command interface offers rapid time to market. The RN2483 module complies with the LoRaWAN Class A protocol specifications. It integrates RF, a baseband controller, command application programming interface (API) processor, making it a complete long-range Solution. The RN2483 module is suitable for simple long-range sensor applications with external host MCU.

Figure 26 – LyaTech LRM001

Product Features

- Mini PCI express interface /USB
- Support 868 and 915MHz
- X86 Linux / Ubuntu, Debian driver support
- Win 7, Win 8 and Win 10 driver
- Freescale Linux OS driver
- Raspberry Pi Linux driver support

3.2.5 Other Modules

To complete tha hardware architecture proposed and fully implements the features described based in D1.2, another set of pluggable or external modules are needed. These modules will be analyzed and selected in a next phase of the project:

- GPS module (Mini PCI card)
- GSM Module (Mini PCI card)
- Media Converter (external module)
- AC/DC power converter (external module)
- Wayside antenna

3.3 FAST-TRACKS Software Defined Radio

For small-scale laboratory testbed setups, commercially available SDR platforms offer low-cost hardware and software solutions for rapid prototyping and experimental assessment of programmable wireless networks. In the following section, we discuss the strength and limitations of both software frameworks and hardware architectures with respect to rapid prototyping and testing of the FAST-TRACKS wireless systems. In details, the following SDR technologies are explored:

- Universal Software Radio Peripherial (USRP)
- Hack RF One
- The Fairwaves XTRX

We also provide a compatibility overview between the available software tools and heterogeneous SDR platforms at the end of the chapter.

3.3.1 Universal Software Radio Peripherial (USRP)

The Universal Software Radio Peripheral, or USRP was designed as a low-cost board solely for the purpose of running GNU radio applications and allowing general purpose computers to function as high bandwidth software radios. Fully developed by Matt Ettus [3], it is a very flexible platform and can be used to implement real time applications. In essence, it serves as a digital baseband and IF section of a radio communication system. It is the bridge between the software world and the RF world. The basic design philosophy behind the USRP has been to do all of the waveform specific processing, like modulation and demodulation, on the host CPU. All of the high-speed general-purpose operations like digital up and down conversion, decimation and interpolation are done on the FPGA. The true value of the USRP is in what it enables engineers and designers to create on a low budget and with a minimum of effort. A large community of developers and users have contributed to a substantial code base and provided many practical applications for the hardware and software. The powerful combination of flexible hardware, open-source software and a community of experienced users make it the ideal platform for your software radio development. Figure 27 shows a typical graph for USRP Motherboard.

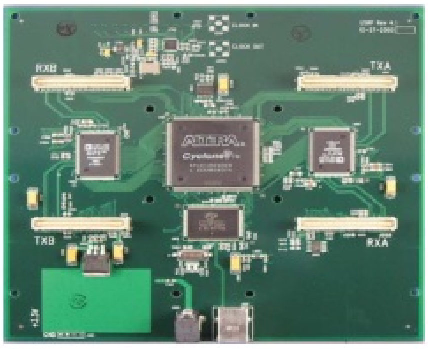


Figure 27 – USRP Motherboard

The USRP has four highspeed analog to digital converters (ADCs), each at 12 bits per sample, 64MSamples/sec. There are also four high-speed digital to analog converters (DACs), each at 14 bits per sample, 128MSamples/sec. These four inputs and four outputs channels are connected to an Altera Cyclone EP1C12 FPGA. The FPGA, in turn, connects to a USB2 interface chip, the Cypress FX2, and on to the computer. The USRP connects to the computer via a high speed USB2 interface only and will not work with USB1.1. So, in principle, we have four inputs and four outputs channels if we use real sampling. However, we can have more flexibility (and bandwidth) if we use complex (IQ) sampling. Then we have to pair them up, so we get 2 complex inputs and 2 complex outputs. The USB controller contains the firmware that defines its behavior and the USB endpoints. The firmware also takes care of loading the FPGA bit stream. The FPGA handles the high bandwidth computations and reduces the data rate to something we can send over the USB 2.0. The Analog Device chip is a mixed signal processor that takes care of the conversion between analog and digital signals, digital up conversion in the transmit path and interpolation/decimation of the signals. The motherboard can have up to 4 daughterboards, two for receive and two for transmit to achieve wireless communication at different frequencies. They consist of the RF front end where the signal is up converted from the intermediate frequency to the carrier frequency or vice versa for the received signal. Following the success of of the USRP (or USRP1), the USRP 2 has been realized, but it is not meant to replace USRP1. New features added to the USRP2 are:

- Gigabit Ethernet interface
- 25 MHz of instantaneous RF bandwidth
- Xilinx Spartan 3-2000 FPGA
- Dual 100 MHz 14-bit ADCs
- Dual 400 MHz 16-bit DACs
- 1 MByte of high-speed SRAM
- Locking to an external 10 MHz reference
- 1 PPS (pulse per second) input
- Configuration stored on standard SD cards
- Standalone operation
- The ability to lock multiple systems together for MIMO
- Compatibility with all the same daughter boards as the original USRP
- Configuration: flash SD-card

Today Ettus Research is the leader in the market SDR’s with the following products:

- USRP X Series
- USRP N (Network) Series
- USRP E (Embeded) Series
- USRP B(Bus) Series

3.3.1.1 Ettus URRP N210 and E310

The USRP N210 and USRP E310 series are widely used in many scientific and open source context like Open BTS and Open LTE.

Figure 28 – N210 and E310 Ettus boards

The USRP N210 (architecture in figure 29) provides high-bandwidth, high-dynamic range processing capability and is intended for demanding communications applications requiring rapid prototyping. The device architecture includes a Xilinx Spartan 3A-DSP 3400 FPGA, 100 MS/s dual ADC, 400 MS/s dual DAC and Gigabit Ethernet connectivity to stream data to and from host processors. A modular design allows the USRP N210 to operate from DC to 6 GHz, while an expansion port allows multiple USRP N210 series devices to be synchronized and used in a MIMO configuration. An optional GPDSO module can also be used to discipline the USRP N210 reference clock to within 0.01 ppm of the worldwide GPS standard. The USRP N210 can stream up to 50 MS/s to and from host applications.

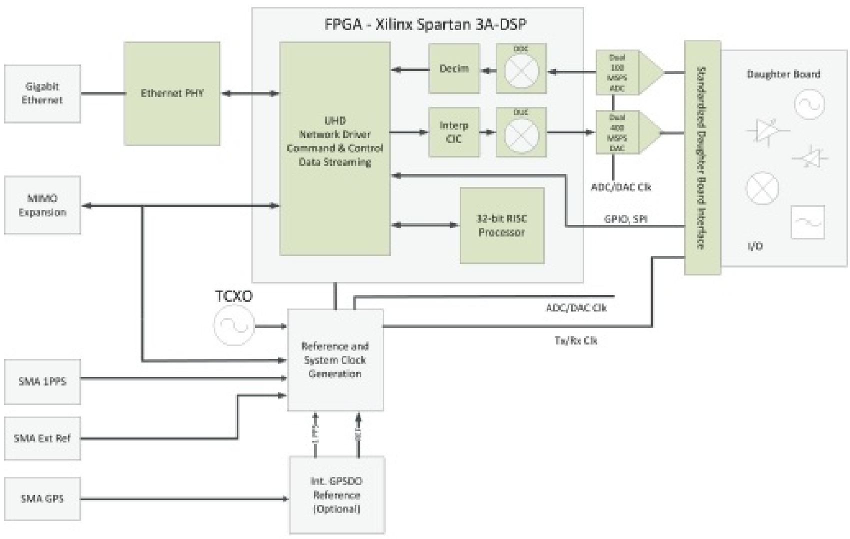


Figure 29 – N210 Architecture

Users can implement custom functions in the FPGA fabric, or in the on-board 32-bit RISC softcore. The USRP N210 provides a larger FPGA for applications demanding additional logic, memory and DSP resources. The FPGA also offers the potential to process up to 100 MS/s in both the transmit and receive directions. The FPGA firmware can be reloaded through the Gigabit Ethernet interface.

The USRP E310 is a stand-alone software defined radio and pocket size. Using the AD9361 RFIC from Analog Devices, the USRP E310 provides 2x2 MIMO support covering 70 MHz – 6 GHz and up to 56 MHz of instantaneous bandwidth. At roughly the footprint of a mobile phone, with a typical power consumption of 2-6 watts, the USRP E310 is ideal for mobile and embedded applications with limited size, weight, and power requirements. A lighter weight, partial-enclosure version is available for custom and volume deployments. Baseband processing is performed in the Zynq 7020 IC which combines a reconfigurable Xilinx 7 series FPGA and integrated dual-core ARM A9 processor running a Linux operating system. The E310 platform (architecture in figure 30) uses the OpenEmbedded framework to create custom Linux distributions tailored to application specific needs. The default operating system is pre-installed with the UHD software API and a variety of third party development tools such as GNU Radio. Support for the RFNoC FPGA development framework enables deterministic computations for real-time and wideband signal processing.

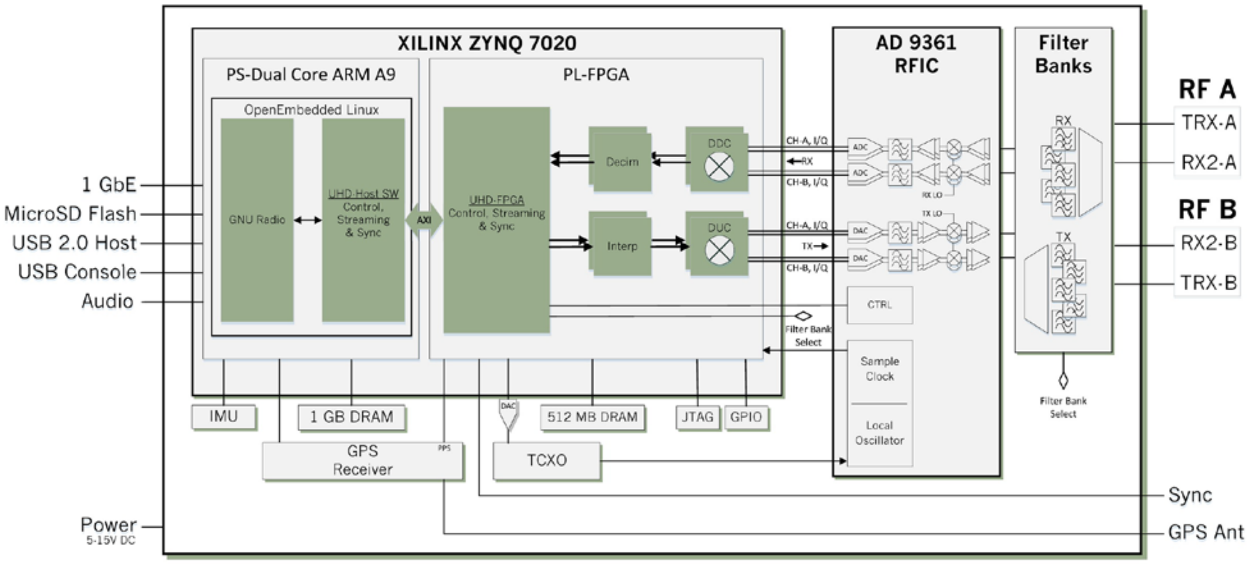


Figure 30 – E310 Architecture

The open-source software architecture, common to all USRP devices, provides cross-platform support with the USRP Hardware Driver (UHD). UHD allows a large selection of applications and frameworks, such as GNU Radio. A summary of the main characteristics of the boards is shown in next table.

USRP Model	Interface	FPGA	Total Host BW (MSPS 16b/8b)	Daughterboard Slots	ADC Resolution (bits)	ADC Rate (MSPS)	DAC Resolution (bits)	DAC Rate (MSPS)
N210	GigE	Xilinix Spartan 3A DSP	50/100	1	14	100	16	400
E310	Embedded	Xilinix Zynq-7000	61.44	N/A	12	61.44	12	61.44

Table 10 – Main features of Ettus N210 and E310 Boards

3.3.2 HackRF One

HackRF One is a software Software Defined Radio peripheral capable of transmission or reception of radio signals from 1 MHz to 6 GHz. Designed to enable test and development of modern and next generation radio technologies, HackRF One is an open source hardware platform that can be used as a USB peripheral or programmed for stand-alone operation.

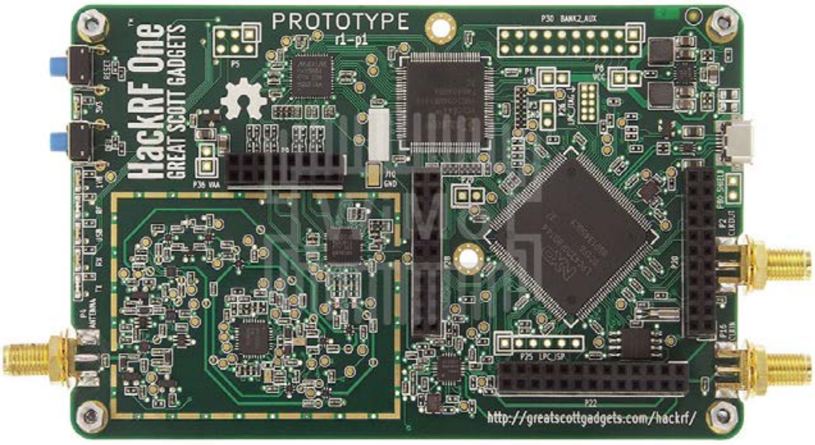


Figure 31 – HackRF One Board

The board is equipment with the following features:

- 1 MHz to 6 GHz operating frequency
- Half-duplex transceiver
- Up to 20 million samples per second
- 8-bit quadrature samples (8-bit I and 8-bit Q)
- Compatible with GNU Radio, SDR, and more
- Software-configurable RX and TX gain and baseband filter
- Software-controlled antenna port power (50 mA at 3.3 V)
- SMA female antenna connector
- SMA female clock input and output for synchronization
- Convenient buttons for programming
- internal pin headers for expansion
- Hi-Speed USB 2.0
- USB-powered
- Open source hardware

For MiMo applications (LTE, WiFi 802.11 n/ac) at least two boards are needed.

During the first phase of the project, all the presented boards are used. In particular Ettus N210 will be used for laboratory test. The Ettus E310 and Hack RF One instead will be used to develop the first prototype of SDR boards. Finally, a Mini PCI Express Card with SDR capability will be integrated in the FAST-TRACKS mainboard.

3.3.3 The Fairwaves XTRX

The XTRX is a high performance/high bandwidth Software Defined Radio board that is specifically designed to support innovations around high data rate applications like 4G/5G and massive MIMO. The XTRX is a compact Mini PCIe card SDR based around the Lime Microsystems LMS7002M FPRF. It has 2× 2 MIMO and has a tuning range of 10 MHz — 3.7 GHz, down to 100 kHz with some degradation, with a sample rate of up to 120 MSPS. It has a built-in GPSDO and an onboard FPGA, a Xilinx Artix 7 35T, which can be used to accelerate DSP tasks.

The XTRX's main features are the integrated GPSDO (GPS Disciplined Oscillator), the compact size (just 30x51mm) and the 120MHz max RF bandwidth. Such a wide bandwidth generates a very large volume of data, so only a high-speed low-latency port like the PCIe can handle it. The FPGA used in conjuction with the LMS7002M is the 33k cell, low power Xilinx Artix-7 35T.

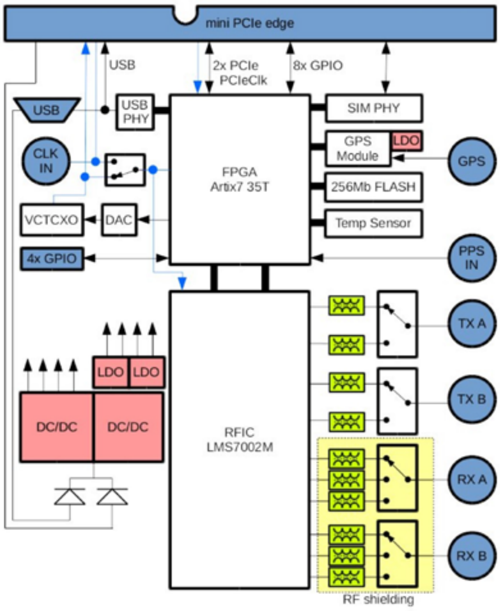


Figure 32 – FairWaves XTRX Architecture - FairWaves XTRX Mini PCIe card

The figure above shows the SDR designed to be a component, a black box to be slotted into a bigger build, rather than a build itself. LTE modems and GPS receivers are commodity parts but integrating them together takes time.

Features and specifications of the XTRX SDR device are described in the following table:

Features & Specifications	Description
RF Chipset	Lime Microsystems LMS7002M FPRF
FPGA Chipset	Xilinx Artix 7 25T/35T/50T
Channels	2 × 2 MIMO
Tuning Range	30 MHz – 3.8 GHz
Rx/Tx Range	10 MHz – 3.7 GHz 100 kHz – 3.8 GHz with signal level degradation
PCIe Bandwidth	PCIe x2 Gen 2.0: 8 Gbit/s PCIe x1 Gen 2.0: 4 Gbit/s PCIe x1 Gen 1.0: 2 Gbit/s
Sample Rate	~0.2 MSPS to 120 MSPS
Reference clock	Frequency: 26 MHz Stability: <10 ppb stability after GPS/GNSS lock, 500 ppb at start up
Form Factor	full-size miniPCIe (30 × 51 mm)
Bus Latency	<10 µs, stable over time
Synchronization	synchronize multiple XTRX boards for massive MIMO
GPIO	4 lines @ miniPCIe connectors, 3 lines @ FPC edge connectors
Accessories	miniPCIe-USB3 converter, miniPCIe-PCIe converter

Table 11 – XTRX Features

Software support

Platform	PCIe/TB3	USB3
Linux x86_64	full	full
Linux i386	needs testing	needs testing
Linux arm (32bit)	needs testing	full
Linux Aarch64 (ARM 64bit)	needs testing	needs testing
Windows i386	planned	needs testing
Windows x86_64	planned	full
Other	no	no

- GNU Radio
  - Native gr-osmosdr
  - gr-osmosdr via SoapySDR
- gqrx (via gr-osmosdr)
- SoapySDR (limited features)
- osmo-trx
- Amarisoft LTE (only FDD for now)
- kalibrate
- srsUE/srsLTE (in progress)

Figure 33 – FairWaves XTRX - Software support

The following table report a comparative analysis between the differen technologies analysed:

	USRP B2x0	USRP B3x0	Hacker RF One	XTRX
Tuning range	70 MHz - 6 GHz	30 MHz - 3.8 GHz	10 MHz - 6 GHz	30 MHz - 3.7 GHz
Duplex	Full MIMO	Full MIMO	Full SISO	Full MIMO
Max sampling rate	61.44 MSPS	61.44 MSPS	30.72 MSPS	120 MSPS SISO / 90 MSPS MIMO
ADC/DAC resolution	12-bit	12-bit	12-bit	12-bit
Max RF bandwidth	56 MHz	61.44 MHz	30.72 MHz	120 MHz
Channels	1 (2 for B210)	2	1	2
Transmit power	10dBm+	0 to 10dBm (depending on frequency)	0 to 10dBm (depending on frequency)	0 to 10dBm (depending on frequency)
RF chipset	AD9364 or AD9361	LMS7002M	LMS7002M	LMS7002M
Embedded	no	no	no	yes
Industrial temperature range	no	no	no	Optional
Temperature sensors	no	yes	no	yes
Frequency stability	±2 ppm	±2.5 ppm	±2.5 ppm	±0.5 ppm initially, <±0.01 ppm after GPS lock
GPS synchronization	Addon (+$636)	no	no	on board
Bus/interface	USB 3	USB 3	USB 3	PCIe x2, USB 3 adapter, and more (FPGA based)
Raw bus bandwidth	5 Gbit/s	5 Gbit/s	5 Gbit/s	10 Gbit/s
Dimensions	97 x 155 mm	87 x 131 mm	100 x 60 mm	69 x 31.4 mm
Extra features	GPIO	GPIO	GPIO	GPIO

	USRP B2x0	USRP B3x0	Hacker RF One	XTRX
Multiple boards synchronization	Sample clock and timestamps	Sample clock and timestamps	Sample clock	Sample clock
Price	$686 - $1,119 + $636 (for GPSDO)	$415	$299	$139
Price per channel	$560 - $715 + $636 (for GPSDO)	$415	$150	$139

Table 12 – SDR Comparative analysis

As outcome of the comparative analysis, the ETTUS represents the bes lab solution and the XTRX the best solution for integration in the FAST Radio PCIe slot, due to the high-speed, low-latency bus that is both physically compact and widely used (high-performance and easily embeddable).

3.4 The Fast-Tracks Controller

The FAST-TRACKS Controller in charge to manage the dynamic coupling of the local and remote radio, in order to achieve the best performance during the data transmission and guarantee the reliability and security of the whole infrastructure. From the hardware point of view the controller is based on the same building blocks of the wayside radio, except the radio cores which are changed with the radio network controller cores.

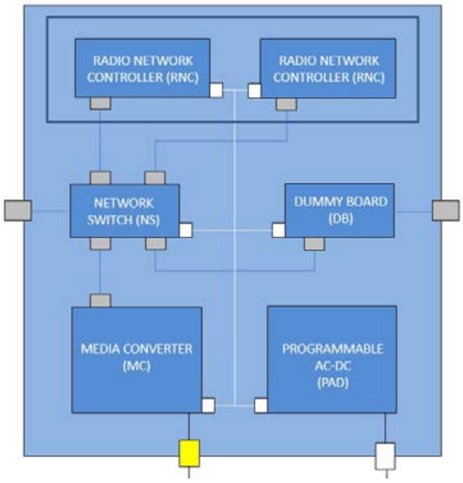


Figure 34 – Radio Network Controller detailed architecture

The standard configuration of the FAST-TRACKS controller is composed by a mainboard, two radio network controllers, a network switch, a dummy board (optional), a programmable AC/DC and a media converter.

This chapter presents the description of the different controllers analyzed, as possible candidate to develop the basic hardware of the Radio Control Plane, matching the requirements reported in the deliverable D1.2.

The next section introduces different OEM products, analysed to create the last building block of the FASTTRACKS radio.

3.4.1 Mini Pc Linux Ubuntu Mi3215C4

The Mini Pc Linux Ubuntu Mi3215C4 is an aluminium fanless PC box with high performance, based on Intel Celeron Processor 3215U (2M Cache, 1.70 GHz, Broadwell), Dual-Core, Space saving and low energy consumption. The memory configuration is 4G DDR3 Ram 64G Msata SSD WIFI (2*Antennas). Rich I/O Peripherials set based on 2*HDMI, 4 *COM, 2*Lan, 2*USB2.0, 4*USB3.

Figure 35 – Radio Network Controller implemented via Mini PC Linux

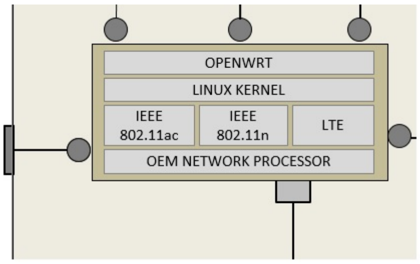
Hardware Specification:

Dimension:156*128*48mm (L*H*W)
Weight:1Kg
Color: black
Material: aluminum alloy
Power Consumption: TDP 15W
Onboard CPU: Intel Celeron Processor 3215U (2M Cache, 1.70 GHz, Broadwell)
Memory: Support DDR3L 1333/1600 MHz,1.35V 1 x DDR3 DIMM Memory Slot Max. Support up to 8GB Memory
Hard Disk: support SSD (MSATA / SATA) and support HDD (2.5-inch SATA HDD)
Onboard VGA: Intel HD Graphics
Onboard LAN:2 * Realtek 8111E 10/100/1000 Controller
Audio Solution: Realtek ALC662 6-Channel HD Audio
USB:4*USB3.0,2*USB2.0
Display:2 *HDMI
COM: 4*COM port

At the time of writing of this document, no mini-PCIe board was selected yet to be integrated on the mainboard of the system.

4 The FAST-TRACKS Firmware Development Platform

The Firmware architecture of the FAST-TRACKS project is based on a GNU Radio/GNU Linux suite equipped with ethernet and networking driver devices. The approach followed in the FAST-TRACKS project is the customization and extension of the basic suite especially re-designed and customized for the hardware used.



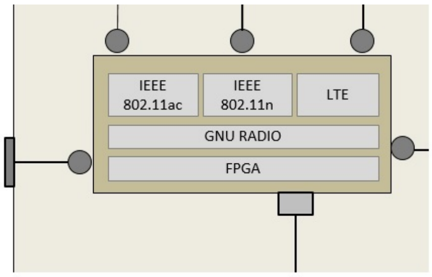


Figure 36 – Detailed architecture of the two development approach proposed

The first figure shows the Radio firmware stack, implemented on top of the OEM product (Original Equipment Manufacturer) presented in the hardware section. Since the board is equipped with a MiniPCI card connector, it permits the integration of different modules implementing the standards 802.11abg/802.11n/802.11ac and LongTerm Evolution (LTE). The whole system is managed via linux-kernel extended to support additional drivers and multiple transport technologies.

The second of the two figures shows the Radio firmware stack, implemented using a powerful Software Defined Radio based on ARM Cortex-M4 microcontroller. The board is completely programmable in GNURadio environment and permits to implements each kind of radio device working in the frequency range 1 MHz to 6 GHz. In this context the implementation of the standards 802.11abg/802.11n/802.11ac and Long-Term Evolution (LTE) is fully developed via software. The next section shows the principal firmware platforms were identified as starting point to create the firmware for the FAST-TRACKS radio.

4.1 OpenWRT

OpenWrt [4] is a highly extensible GNU/Linux distribution for embedded devices. Unlike many other distributions for these routers, OpenWrt is built from the ground up to be a full-featured, easily modifiable operating system for wireless Access Points. In practice, this means that is possible to have all the features needed with none of the bloat, powered by a Linux kernel that's more recent than most other distributions. Instead of trying to create a single, static firmware, OpenWrt provides a fully writable filesystem with optional package management. This frees the developers from the restrictions of the application selection and configuration provided by the vendor and allows to use packages to customize an embedded device to suit any application. For developers, OpenWrt provides a framework to build an application without having to create a complete firmware image and distribution around it. For users, this means the freedom of full customization, allowing the use of an embedded device in ways the vendor never envisioned. Main advantages.

- Free and open-source. The project is entirely free and open-source, licensed under the GPL. The project is intended to always be hosted at an easily accessible site, with full source code readily available and easy to build.
- Easy and free access. The project will always be open to new contributors and have a low barrier for participation. Anyone shall be able to contribute. We, the current developers, actively grant write access to anyone interested in having it. We believe people are responsible when given responsibility. Just ask and you will be able to acquire the access rights you need.
- Community driven. This is not about 'us' offering 'you' something, it is about everyone coming together to work and collaborate towards a common goal.

OpenWrt has long been established as the best firmware solution in its class. It far exceeds other embedded solutions in performance, stability, extensibility, robustness, and design. It is the clear-cut goal of the OpenWrt developers to continue to expand development and ensure that OpenWrt is the foremost framework for innovative and ingenuitive solutions. The development architecture of OpenWRT is composed of 4 blocks, as described in the following figure:

Figure 37 – OpenWRT development architecture

The lower layer represents the CPU on which the compiling process has to be performed. The Linux Kernel layer is referred to the operating system, such as CentOS or Debian, intended to host the selected SDK. The SDK is the software that enables the custom image generation. This software could include a Graphic User Interface to set up the firmware generation process. Some examples of SDK will be described in the following section. The last release of OpenWRT was ChaosCalmer v15.05, after that the project was not fully updated. Figure 3 show the main menu of ChaosCalmer firmware configuration tool.

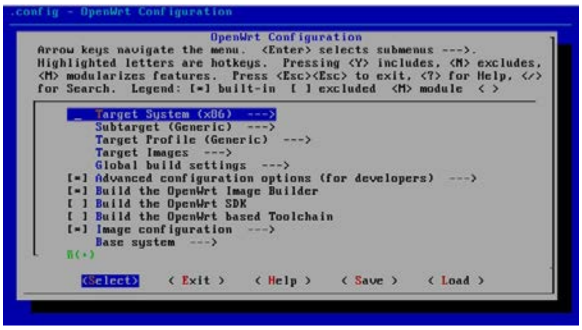


Figure 38 – OpenWRT firmware configuration

OpenWRT ChaosCalmer SDK also includes LuCi packages which provides a free, clean, extensible and easily maintainable web user interface for embedded devices.

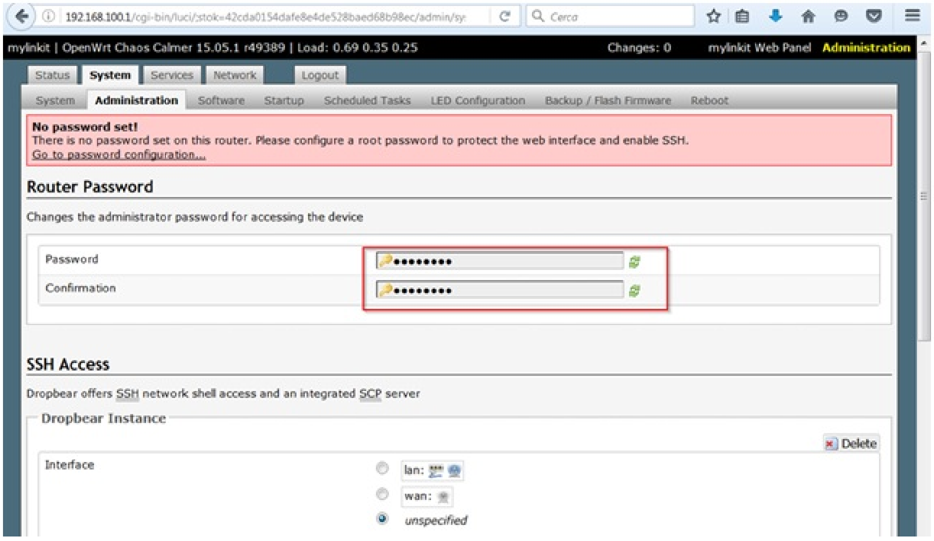


Figure 39 – Luci administration page

The above figure shows the LUCI administration web page.

4.2 LEDE

The LEDE Project [5] (“Linux Embedded Development Environment”) is a Linux operating system based on OpenWrt. It is a complete replacement for the vendor-supplied firmware of a wide range of wireless access points and non-network devices. People install LEDE because they believe it works better than the stock firmware from their vendor. They find it is more stable, offers more features, is more secure and has better support. Extensibility: LEDE provides many capabilities found only in high-end devices. Its 3000+ application packages are standardized, so it’s possible to easily replicate the same setup on any supported device, including two (or even five) year old routers.

- Security: LEDE's standard installation is secure by default, with Wi-Fi disabled, no poor passwords or backdoors. LEDE's software components are kept up-to-date, so vulnerabilities get closed shortly after they are discovered.
- Performance and Stability: LEDE firmware is made of standardized modules used in all supported devices. This means each module will likely receive more testing and bug fixing than stock firmware which can be tweaked for each product line and never touched again.
- Strong Community Support: LEDE team members are regular participants on the LEDE Forum, LEDE Developer and LEDE Admin mailing lists, and LEDE's IRC channels. You can interact directly with developers, volunteers managing the software modules and with other long-time LEDE users, drastically increasing the chances you will solve the issue at hand.
- Research: Many teams use LEDE as a platform for their research into network performance. This means that the improvements of their successful experiments will be available in LEDE first, well before it gets incorporated into mainline, vendor firmware.
- Open Source/No additional cost: LEDE is provided without any monetary cost. It has been entirely created by a team of volunteers: developers and maintainers, individuals and companies. If you enjoy using LEDE, consider contributing some effort to help us improve it for others! All of the above is possible because LEDE is part of the Open Source community and powered by Linux kernel.

Because LEDE is a true Linux-based system, the developers have the full control over all functions of base router/device. In details:

- LEDE provides both command-line interface (via SSH) and a web-based user interface for configuration
- Configuration information is stored in plain-text files to ease the editing and/or copying
- Configure the external LEDs and buttons/switches to suit your needs

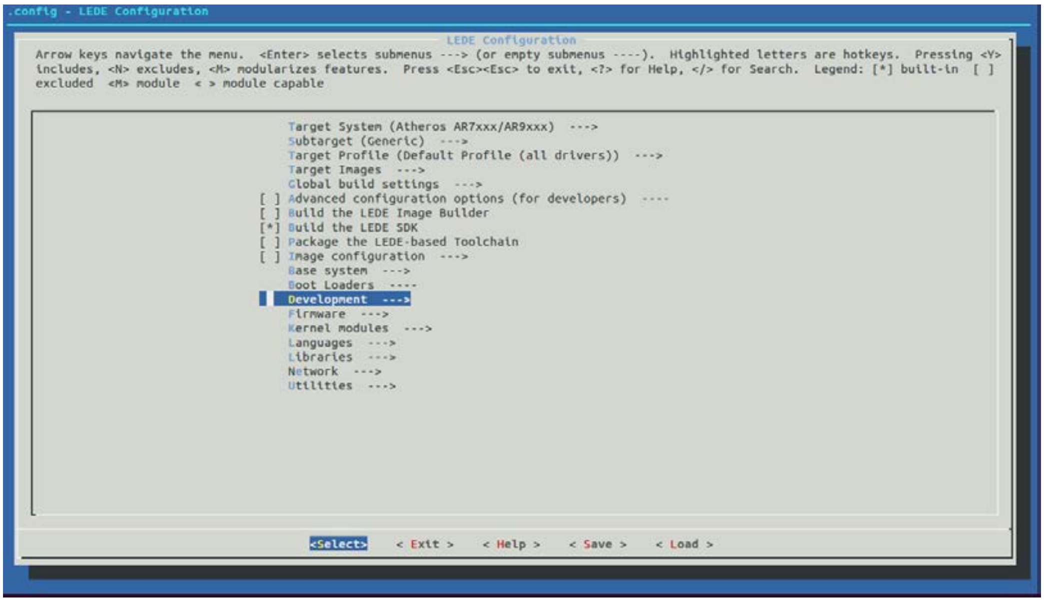


Figure 40 – LEDE firmware configuration tool

The figure above shows the main menu of LEDE firmware configuration tool where is possible to observe that the interface is very similar to the OpenWRT ChaosCalmer one.

4.3 CompexWRT

CompexWRT [6] is an operating system powering our Wireless Embedded Boards and Access Points. It is engineered with Qualcomm Atheros latest QSDK fused with Qualcomm's propriety Wireless Driver, CompexWRT is the ultimate operating system to deploy WiFi far and wide. CompexWRT is the operating system used on Compex's embedded boards. Based on OpenWRT platform paired with LuCI web interface embedded with QCA proprietary Wireless Drivers, it come with all the necessary networking features routing, firewall, wireless access point and many more. CompexWRT is an enterprise grade OS, featuring Mesh networking, native SNMP support, 802.11ac Wave 2 support and UI branding. It offers many level of customization. CompexWRT is the ultimate operating system to deploy WiFi far and wide.

4.4 DDWRT

DD-WRT [7] was known as the most feature rich firmware of them all until Openwrt came along. Since this particular Linux based firmware has been in development for several years, stability is not usually a problem, but having a multitude of configuration options that are often left unused does come at a price. Compared to Tomato, DD-WRT is reported to have more bugs. Additionally, the interface, being cluttered with options, can be intimidating and harder to navigate. Overall, it provides immense improvement to consumer routers, turning them into a network geek's dream. In addition to having the most options, DD-WRT is also the most compatible of the bunch. It should also be noted that DD-WRT is not the easiest to flash to and can sometimes become frustrating for beginners. The graphical user interface is logically structured, and it is operated via a standard Web browser, so even non-technicians can configure the system in only a few simple steps. DD-WRT provides the following features:

- supports more than 200 different devices
- comprehensive functionality
- supports all current WLAN standards (802.11a/b/g/n*)
- supports outdoor deployment*
- supports enhanced frequencies *
- VPN integration
- supports various Hotspot systems
- bandwidth management
- multilingual user interface

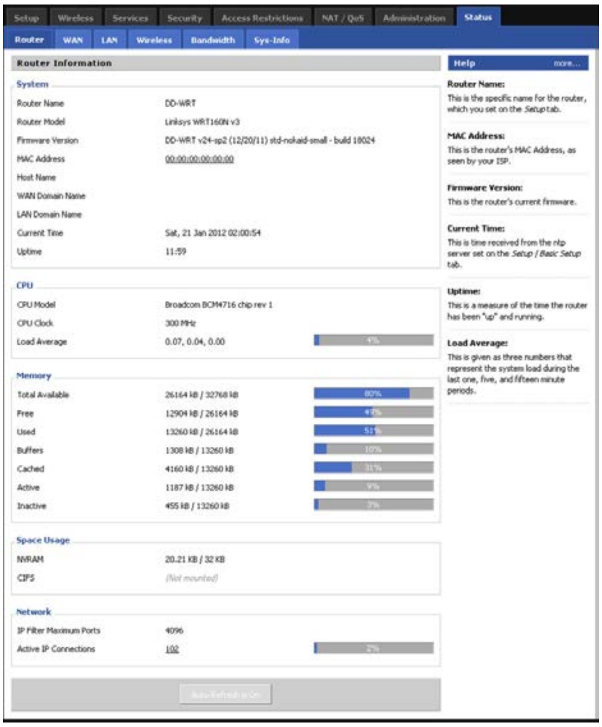


Figure 41 – DD-WRT administration page

4.5 Tomato

Tomato [8] is a small, lean and simple replacement firmware for Linksys' WRT54G/GL/GS, Buffalo WHR-G54S/WHR-HP-G54 and other Broadcom-based routers. It features a new easy to use GUI, a new bandwidth usage monitor, more advanced QOS and access restrictions, enables new wireless features such as WDS and wireless client modes, raises the limits on maximum connections for P2P, allows you to run your custom scripts or telnet/ssh in and do all sorts of things like re-program the SES/AOSS button, adds wireless site survey to see your wifi neighbors, and more. Tomato SDK provides the following key features:

- Interactive Ajax based GUI using SVG and CSS-based color schemes (allowing GUI look and feel changes)
- CLI access (BusyBox) via Telnet or SSH (using Dopbear);
- DHCP server (with static allocation of IP addresses);
- Bandwidth statistics and graphing;
- Wireless modes:
  - Access point (AP)
  - Wireless client station (STA)
  - Wireless Ethernet (WET) bridge
  - Wireless distribution system (WDS also known as wireless bridging)
  - Simultaneous AP and WDS (also known as wireless repeating)
- JFFS;
- Wireless LAN Adjustment of radio transmit power, antenna selection, and 14 wireless channels
- 'Boot wait' protection (increase the time slot for uploading firmware via the boot loader)
- Advanced port forwarding, redirection, and triggering with UPnP and NATP-PMP
- Advanced user access restrictions
- Init, shutdown, firewall, and WAN Up scripts
- uptime, load average, and free memory status
- Minimal reboots - Very few configuration changes require a reboot
- wireless survey page to view other networks in your neighborhood
- More comprehensive dashboard than stock firmware: displays signal strengths of wireless client devices, reveals UPnP mappings
- Configuration persistence during a firmware upgrade

The following figure shows the Tomato Control Panel

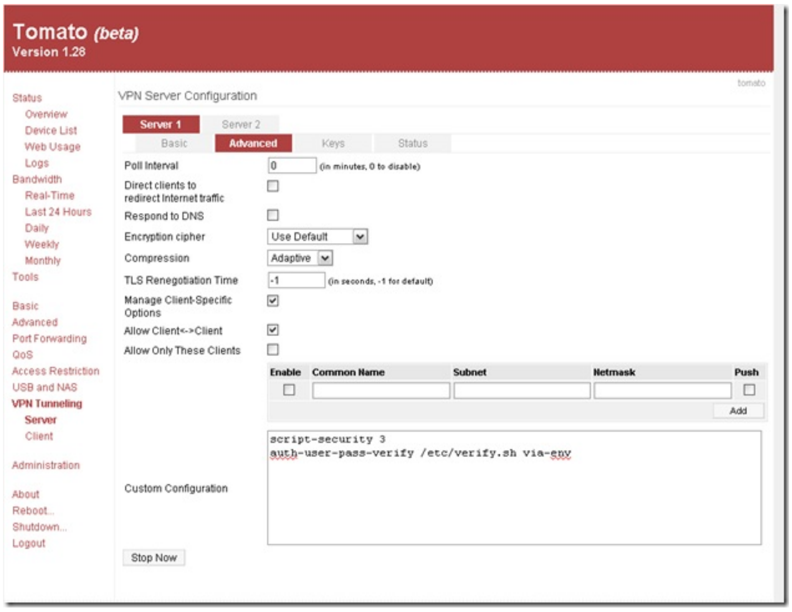


Figure 42 – Tomato control panel

4.6 Comparative analysis

In the previous sections some firmware SDKs were briefly described by introducing their main features.

DD-WRT was known as the most feature rich firmware of them all until Openwrt came along. Since this particular Linux based firmware has been in development for several years, stability is not usually a problem, but having a multitude of configuration options that are often left unused does come at a price. Compared to TOMATO, DD-WRT is reported to have more bugs. Additionally, the interface, being cluttered with options, can be intimidating and harder to navigate. Overall, it provides immense improvement to consumer routers, turning them into a network geek's dream. In addition to having the most options, DD-WRT is also the most compatible of the bunch. It should also be noted that DD-WRT is not the easiest to flash to and can sometimes become frustrating for beginners.

TOMATO firmware is similar to DD-WRT, and also based off Linux, but opts for a better balance between performance and features and does so very efficiently. Tomato has a simple, graphically rich interface, making it easy for even beginners to pickup. If your router is not supported by the DD-WRT firmware, your best alternative is undoubtedly Tomato. It might not be as featured rich as the DD-WRT firmware, but it will still open up the best config options required to supercharge your router. Tomato also offers certain capabilities not found on DD-WRT, specifically live 'visual' traffic monitoring, allowing easy visibility on inbound/outbound traffic in real-time. Being that its' lighter in features, it is also often said to be more stable and offer better overall performance. If you're a beginner, or simply want better firmware with no bells and whistles, Tomato probably still scores as the best option when available.

OpenWRT has quite a different approach to customizing your router. Instead of having a one-solution-fits-all approach, as seen in DD-WRT, OpenWRT only provides an environment in which other packages can be added. This means that other than providing the bear minimum, it also is a fully customizable firmware that allows the user to only pick the features they like. It too is built around Linux and even contains a package manager. OpenWRT is more attractive because it is a totally free SDK but it is not always user-friendly so that OpenWRT is preferred by experienced users such as network administrators. However, over the times, the platform has come a long way in making itself more accessible to all user levels.

SDK	Pros	Cons
OpenWRT	✓ Completely customizable, include or exclude packages to build firmware tailored to your needs. With time a multitude of add-ons has been made available to OpenWRT, including existing network software apps, allowing for full integration all in a single place	✓ Not always user-friendly, best reserved for software developers, network admins, or advanced users
DD-WRT	✓ Offers multitude features and configurations ✓ Compatible with more routers than any other third-party firmware	✓ Bit more difficult to Setup. Advanced features make it harder to use
Tomato	✓ Offers better stability and performance than DD-WRT ✓ Unique features for real-time traffic monitoring, with graphic charts ✓ Easiest to setup and use	✓ Less features available than DD-WRT ✓ Smaller router compatibility list

Table 13 – SDK comparison

From this analysis it can be deduced that OpenWRT SDK best fits our project purposes. Many versions of OpenWRT SDK project have been released over the time. The last release of OpenWRT, ChaosCalmer, was merged into the new LEDE project, which support more network devices than ChaosCalmer. Unlike OpenWRT, CompexWRT is a custom operating system that cannot be further customized. We choose LEDE SDK because it supports more devices than ChaosCalmer SDK, for example it includes COMPEX WPQ864 board.

5 The FAST-TRACKS Software Development Platform

This chapter introduce a set of tools and platforms useful to develop the FASTTRACKS software applications. The section starts with GNU Radio, a software tool running in Linux environment, specially tailored to develop Software Defined Radio applications. A second tool presented is Zeoshell, a toolkit meaningful for the development of the controller. Finally, the tird tool presented is Compex Access Point, an opensource tool devoted to the network management and control of wireless access points.

5.1 GNU Radio

GNU Radio is an open source software toolkit [9] which provides a library of signal processing blocks and the glue to tie these blocks together for building and deploying software defined radios. Using GNU Radio, a radio can be built by creating a graph where the vertices are signal processing blocks and the edges represent the data flow between them. The signal processing blocks are implemented in C++ and the graphs are constructed and run in Python. Conceptually, a signal processing block processes an infinite stream of data flowing from its input ports to its output ports. A block attributes include the number of input and output ports it has as well as the type of data that flows through each. Some blocks have only output ports or input ports. Input and output ports serve as data sources and sinks in the graph. For instance, there are sources that read from a file or ADC, and sinks that write to a file, digital-to-analog converter (DAC) or graphical display. More than 100 blocks are currently implemented in GNU Radio. Using a generic RF front end and few other hardware components like the ADC and DAC, GNU Radio code implements radio functionalities as shown in next figure.

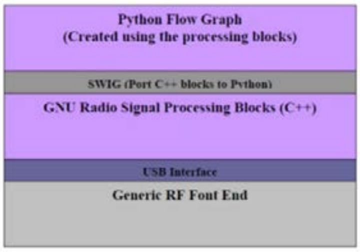


Figure 43 – Block diagram of GNU Radio components

GNU Radio Companion (GRC)

GNU Radio programming has a steep learning curve, due to its command line interface. To aid beginners, Josh Blum of Johns Hopkins University, has developed a graphical interface for GNU Radio. This GUI termed GNU Radio Companion (GRC) allows users to interact with GNU Radio signal blocks in a manner similar to Labview or Simulink. The entire interface is completely designed with GNU Radio in mind and encompasses over 150 blocks from the GNU Radio Project. Blocks are manually integrated into GRC via descriptive python definitions. The definitions are very flexible and allow multiple GNU Radio blocks to be grouped into a single GRC super-block (Figure 44 shows an example of algorithm developed with GRC). The components of GRC are:

- **Flow Graph**: A flow graph is an interconnection of signal processing blocks. GRC provides a scrollable window to place and connect various signal blocks.
- **Signal Blocks**: Signal blocks perform all of the processing in a flow graph. For example, a signal block can be a filter, an adder, a source, or a sink. GRC represents signal blocks as rectangular blocks. Each block has a label indicating the name of the block and a list of parameters.
- **Parameters**: Parameters influence the function of a signal block. For example, a parameter can be a sampling rate, a gain, or a flag. Most parameters for a signal block are displayed below its label.
- **Sockets**: Sockets are the inputs and outputs of a signal block. Each signal block has certain sockets associated with it. For example, an adder has two input sockets and one output socket. GRC represents a socket as a small rectangle attached to the signal block. The socket has a label indicating its function. Labels are usually named "in" or "out". Some labels are named "vin" or "vout" to indicate a vector type. Sockets are also colored to indicate their data type. Blue for complex, Red for float, Green for int, Yellow for short, and Purple for byte.
- **Connections**: A connection joins an input and an output socket. GRC represents connections by drawing a line between the two sockets. Connections must be between matching data types, including vectors.
- **Variables**: A variable holds a number that is available to all elements in the flow graph. Variables serve two purposes: First, parameters can use a variable as a way to share values. For example, if all parameters for sampling rate use the samp_rate variable, changing the samp_rate variable once is easier than modifying every parameter. Second, variables can also have range (min and max) associated with them. Variables with ranges can be dynamically changed while the flow graph is running.

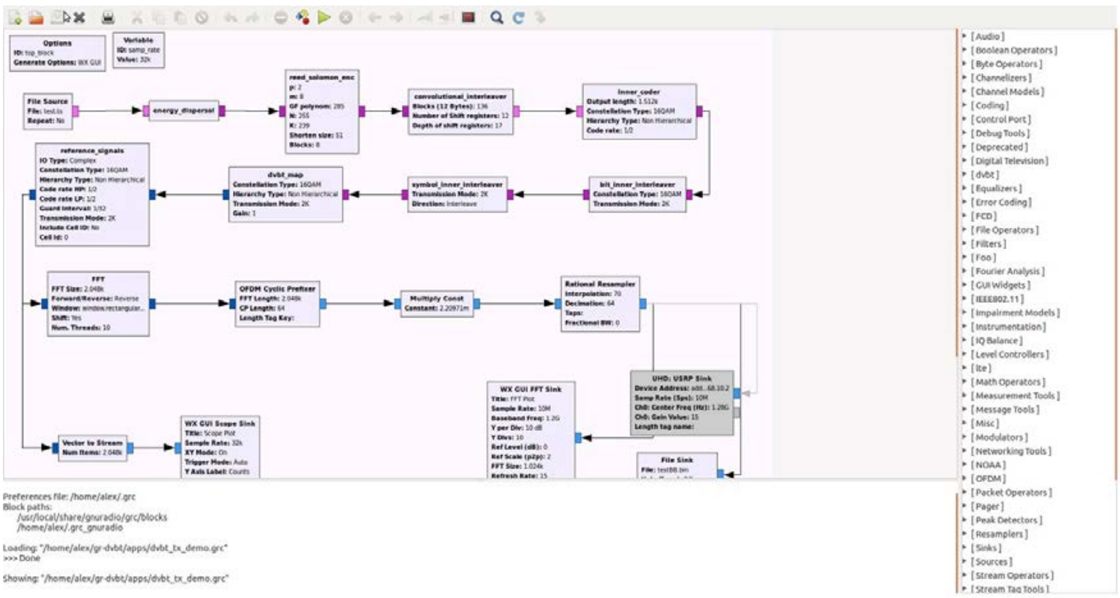


Figure 44 – an example of Gnu Radio Companion

Available features and advantages

The basic features and advantages of GNU Radio are the following:

- Ready-to-use blocks, which can be easily drag and dropped to GRC canvas and connected to each other using wires.
- Most of the signal processing blocks are already available.
- Parallel programming is possible
- GNU Radio can be integrated with Scilab and Xcos for complex commutation, GNU can start Scilab and send commands to it for processing. It can also retrieve values from Scilab variables present in the Scilab memory for that instance.
- Features which are not available can be easily included by adding custom blocks. Every block in GRC corresponds to an XML file that describes the block's parameters, input, output, and other attributes. Adding a custom block onto GRC is simply a matter of creating one of these XML block definition files.
- GNU Radio has the ability to plot the output in real time
- GNU Radio includes features such as knobs and sliders to change the parameters values during run time.
- Other than communication through serial port, integrating GNU Radio with COMEDI, which contains device drivers for DAQ devices.
- GNU Radio can be equipped with image processing by integrating it with OpenCV

FASTTRACKS implementations provided by using Gnu Radio

The following list shows the possible modulations and technology implementation via Gnu Radio:

List of modulations	List of technologies
SSB	
AM	IEEE 802.11 a/b/g/p/n/ac
FM	GSM/GSM-R
OFDM	UMTS
PM	LTE
GSMK	BLUETOOTH
PSK	ZIGBEE
QPSK	DVB-T2
QAM	DVB-S2
CDMA	LORA
	TETRA

Table 14 – List of modulation and technologies available with GNU Radio

During the software development phase in FastTracks, we are committed to develop at least four of the technologies indicated in the table: 802.11 n, LORA, Tetra and LTE.

Disadvantages

- Depending on what you want to do, it may require both software programming abilities and a deep understanding of RF and electronics. This can even be a concern when customizing someone else's code.
- Data decoding features are either expensive (commercial products), or else rough around the edges (open source software still in early development).
- Some SDR hardware can be very expensive.

5.2 Zeroshell

Zeroshell [13] is a Linux based distribution dedicated to the implementation of Router and Firewall Appliances completely administrable via web interface. Zeroshell is available for x86/x86-64 platforms and ARM based devices such as Raspberry Pi. Some advanced features of Zeroshell are:

- Load Balancing and Failover of Multiple Internet Connections
- VPN Site to Site and VPN Host to Site
- Captive Portal Access for Internet Hotspot
- Firewall Rules using Deep Packet Inspection (Layer 7 Filters and nDPI)
- Quality of Services and Traffic Shaping using Deep Packet Inspection
- Transparent Web Proxy with Antivirus and URL Black Lists
- RADIUS Authentication and Accounting
- Bridging and VLAN Management
- Wireless Access Point with Multiple SSID Support
- Mobile Connections
- Tracking and Logging of the Network Connections

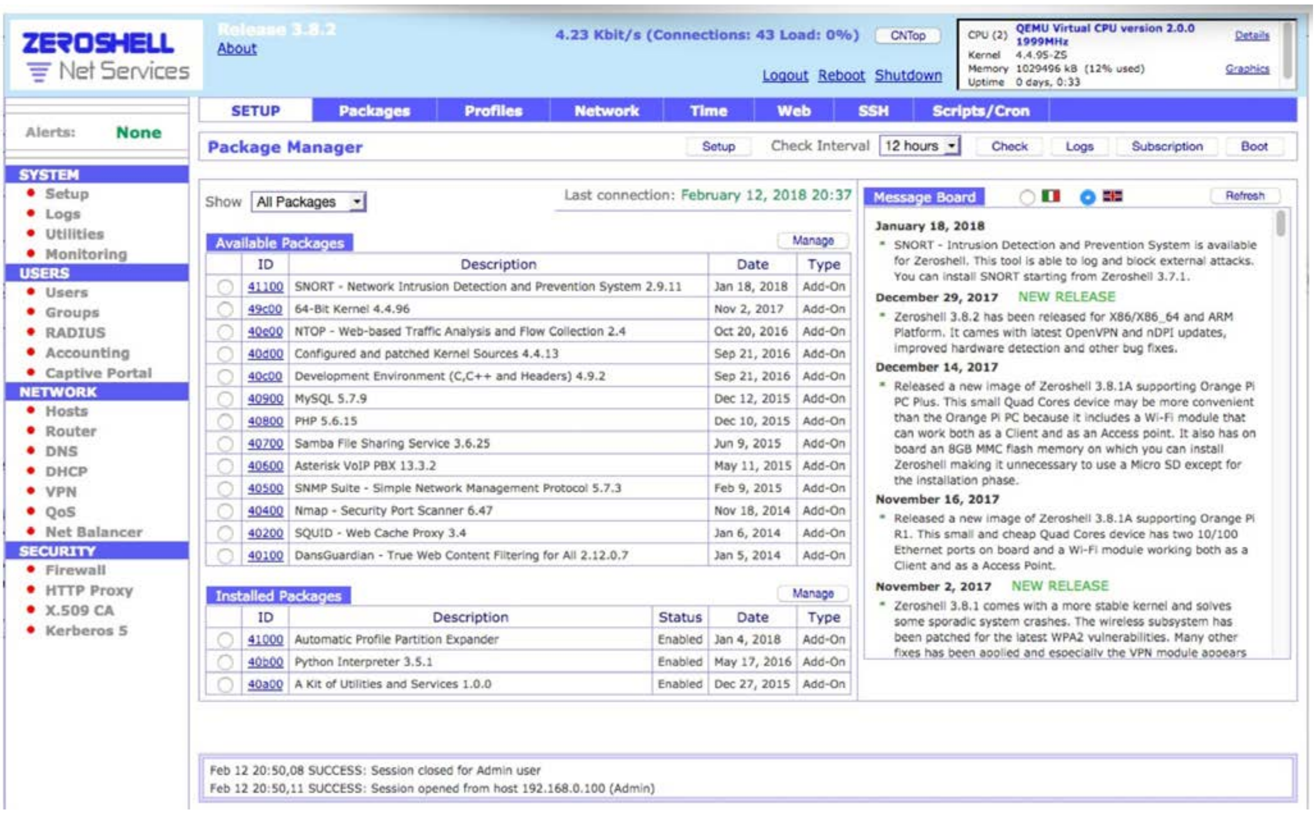


Figure 45 – Zeroshell WEB Interface

5.3 Compex APC

Compex APC (Access Point Controller) [14] is an opensource tool for centralized management of wi-fi Access points. The Compex AP controller is a software that provides centralized management for all Wi-Fi Access Points within the wifi network. The APc utilizes the SNMPv3 protocol to manage and monitor the APs. It can be accessed through any supported device with a web browser. A single APc running on a dedicated server can manage multiple APs. Most of the features available on the configuration web page of the CompexWRT APs are available on the APc. Customers can use our APc to edit an AP individually, or group them together and edit at the same time. The APc monitors all the virtual APs (VAPs) of each CompexWRT AP to provide the user with a full overview of what is happening on the AP. The following image shows a view of the tool:

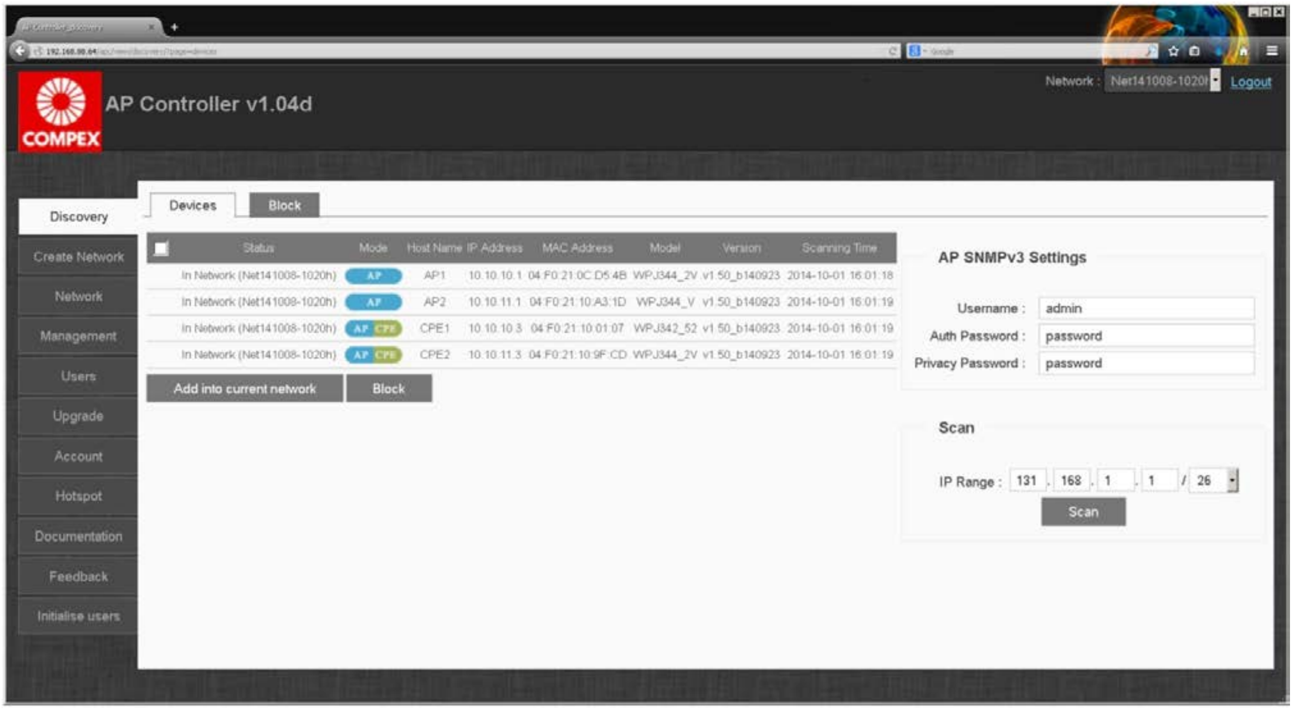


Figure 46 – Compex Access Point Controller WEB Interface

6 Software Tools

This section introduces a brief list of the software development toolkits we aimed to use during the project development. The tools indicated are specially tailored for hardware design, software design and RF – radiocoverage tests.

6.1 COMSOL Multiphisics

Engineers and scientists use the COMSOL Multiphysics® [15] software to simulate designs, devices, and processes in all fields of engineering, manufacturing, and scientific research. COMSOL Multiphysics® is a simulation platform that encompasses all of the steps in the modeling workflow — from defining geometries, material properties, and the physics that describe specific phenomena to solving and postprocessing models for producing accurate and trustworthy results. To create models for use in specialized application areas or engineering fields, you can augment COMSOL Multiphysics® with any combination of add-on modules from the product suite. The interfacing products make it possible to also integrate simulation with other engineering and mathematical software used in product and process design. When you have developed a model, you can even convert it into a simulation app with a dedicated user interface, which can be designed for a very specific use by people beyond the R&D department.

6.2 Autocad

AutoCAD [16] is a commercial computer-aided design (CAD) and drafting software application. Developed and marketed by Autodesk, AutoCAD was first released in December 1982 as a desktop app running on microcomputers with internal graphics controllers. Before AutoCAD was introduced, most commercial CAD programs ran on mainframe computers or minicomputers, with each CAD operator (user) working at a separate graphics terminal. Since 2010, AutoCAD was released as a mobile- and web app as well, marketed as AutoCAD 360. AutoCAD is used across a wide range of industries, by architects, project managers, engineers, graphic designers, and many other professionals. It was supported by 750 training centers worldwide in 1994.

6.1 EAGLE PCB Design Software

EAGLE [17] is a scriptable electronic design automation (EDA) application with schematic capture, printed circuit board (PCB) layout, auto-router and computer-aided manufacturing (CAM) features. EAGLE stands for Easily Applicable Graphical Layout Editor (German: Einfach Anzuwendender Grafischer Layout-Editor) and is developed by CadSoft Computer GmbH

6.2 AWE Communications

AWE Communications GmbH (AWE) [18] focuses on the development of software tools for wave propagation and radio network planning. The headquarters of AWE were located in Gärtringen, Germany and the R&D and sales team were part of the Software Centre in Böblingen, Germany.

6.3 Wireshark

Wireshark [19] is the world's foremost and widely-used network protocol analyzer. It lets you see what's happening on your network at a microscopic level and is the de facto (and often de jure) standard across many commercial and non-profit enterprises, government agencies, and educational institutions. Wireshark development thrives thanks to the volunteer contributions of networking experts around the globe and is the continuation of a project started by Gerald Combs in 1998.

6.4 Iperf

Iperf [20] is a widely used tool for network performance measurement and tuning. It is significant as a cross-platform tool that can produce standardized performance measurements for any network. Iperf has client and server functionality and can create data streams to measure the throughput between the two ends in one or both directions. Typical Iperf output contains a time-stamped report of the amount of data transferred and the throughput measured. The data streams can be either Transmission Control Protocol (TCP) or User Datagram Protocol (UDP). Iperf is open-source software written in C, and it runs on various platforms including Linux, Unix and Windows (either natively or inside Cygwin). The availability of the source code enables the user to scrutinize the measurement methodology. Iperf is a compatible reimplementation of the ttcp program that was developed at the National Center for Supercomputing Applications at the University of Illinois by the Distributed Applications Support Team (DAST) of the National Laboratory for Applied Network Research (NLANR), which was shut down on December 31, 2006, due to termination of funding by the United States' National Science Foundation

6.5 Matlab

MATLAB [21] (matrix laboratory) is a multi-paradigm numerical computing environment. A proprietary programming language developed by MathWorks, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, C#, Java, Fortran and Python. Although MATLAB is intended primarily for numerical computing, an optional toolbox uses the MuPAD symbolic engine, allowing access to symbolic computing abilities. An additional package, Simulink, adds graphical multi-domain simulation and model-based design for dynamic and embedded systems. As of 2017, MATLAB has roughly 1 million users across industry and academia. MATLAB users come from various backgrounds of engineering, science, and economics.

6.6 D-ITG

D-ITG [22] (Distributed Internet Traffic Generator) is a platform capable to produce traffic at packet level accurately replicating appropriate stochastic processes for both IDT (Inter Departure Time) and PS (Packet Size) random variables (exponential, uniform, cauchy, normal, pareto, ...). D-ITG supports both IPv4 and IPv6 traffic generation and it is capable to generate traffic at network, transport, and application layer.

6.7 Eclipse

Eclipse [23] is famous for our Java Integrated Development Environment (IDE), but our C/C++ IDE and PHP IDE are pretty cool too. You can easily combine language support and other features into any of our default packages, and the Eclipse Marketplace allows for virtually unlimited customization and extension.

6.8 Virtual Box

VirtualBox [24] is a powerful x86 and AMD64/Intel64 virtualization product for enterprise as well as home use. Not only is VirtualBox an extremely feature rich, high performance product for enterprise customers, it is also the only professional solution that is freely available as Open Source Software under the terms of the GNU General Public License (GPL) version 2. Presently, VirtualBox runs on Windows, Linux, Macintosh, and Solaris hosts and supports a large number of guest operating systems including but not limited to Windows (NT 4.0, 2000, XP, Server 2003, Vista, Windows 7, Windows 8, Windows 10), DOS/Windows 3.x, Linux (2.4, 2.6, 3.x and 4.x), Solaris and OpenSolaris, OS/2, and OpenBSD. VirtualBox is being actively developed with frequent releases and has an ever growing list of features, supported guest operating systems and platforms it runs on. VirtualBox is a community effort backed by a dedicated company: everyone is encouraged to contribute while Oracle ensures the product always meets professional quality criteria.

6.9 VMWARE ESXi

VMware ESXi (formerly ESX) [25] is an enterprise-class, type-1 hypervisor developed by VMware for deploying and serving virtual computers. As a type-1 hypervisor, ESXi is not a software application that is installed on an operating system (OS); instead, it includes and integrates vital OS components, such as a kernel. After version 4.1 (released in 2010), VMware renamed ESX to ESXi. ESXi replaces Service Console (a rudimentary operating system) with a more closely integrated OS. ESX/ESXi is the primary component in the VMware Infrastructure software suite. The name ESX originated as an abbreviation of Elastic Sky X

6.10 WMWARE Workstation

VMware Workstation [26] is a hosted hypervisor that runs on x64 versions of Windows and Linux operating systems (an x86 version of earlier releases was available); it enables users to set up virtual machines (VMs) on a single physical machine and use them simultaneously along with the actual machine. Each virtual machine can execute its own operating system, including versions of Microsoft Windows, Linux, BSD, and MS-DOS. VMware Workstation is developed and sold by VMware, Inc., a division of Dell Technologies. There is a free-of-charge version, VMware Workstation Player, for non-commercial use. An operating systems license is needed to use proprietary ones such as Windows. Ready-made Linux VMs set up for different purposes are available from several sources. VMware Workstation supports bridging existing host network adapters and sharing physical disk drives and USB devices with a virtual machine. It can simulate disk drives; an ISO image file can be mounted as a virtual optical disc drive, and virtual hard disk drives are implemented as. vmdk files. VMware Workstation Pro can save the state of a virtual machine (a "snapshot") at any instant. These snapshots can later be restored, effectively returning the virtual machine to the saved state as it was and free from any post-snapshot damage to the VM. VMware Workstation includes the ability to group multiple virtual machines in an inventory folder. The machines in such a folder can then be powered on and powered off as a single object, useful for testing complex client-server environments.

7 Conclusions

In this deliverable, we have presented the first report of hardware firmware and software selected to develop the FAST-TRACKS platform. Some of these components are well known, some are new produts and we need additional time to investigate on it to establish if their contribution to the development of FASTTRACKS is advantageous or not. All the components analysed (firmware, software and hardware) will be considered only as starting point for the project development and integration of the technologies, we will describe in the next deliverables.

8 References

[1] FAST TACKS Project - SME Phase 1 - 2015 http://cordis.europa.eu/result/rcn/186390_it.html

[2] European Patent Office – Patent Pending: RADIO COMMUNICATION APPARATUS, SYSTEM AND METHOD FOR A RAILWAY INFRASTRUCTURE - Author: Paquale Donadio - Comesvil

[3] European Patent Office – Espacenet - https://worldwide.espacenet.com/

[4] OpenWRT - https://openwrt.org/

[5] LEDE - https://lede-project.org/

[6] CompexWRT - https://www.compex.com.sg/compexwrt/

[7] DD-WRT - https://www.dd-wrt.com/site/index

[8] Tomato - https://advancedtomato.com/

[9] GNU Radio/USRP - https://www.gnuradio.org/

[10] GNU Radio Companion (GRC) -

[10] Matt Ettus - https://www.ettus.com/

[11] Open Networking Foundation (ONF) – Openflow - https://www.opennetworking.org/sdn-definition/

[12] Optimized Link State Routing for ad Hoc networks – P. Jaquet, P. Muhlethaler, T. Clausen, A. Laouiti. A. Qayyum, L. Viennot – Hipercom Project, INRIA – France

[13] Zeroshell – www.zeroshell.net

[14] Compex APC - https://wiki.compex.com.sg/wiki/The_Management_Page_(APc)

[15] https://www.comsol.it/

[16] https://www.autodesk.it/products/autocad/overview

[17] https://www.autodesk.com/products/eagle/overview

[18] https://altairhyperworks.com/product/FEKO/WinProp-Propagation-Modeling

[19] https://www.wireshark.org/

[20] https://iperf.fr/

[21] https://it.mathworks.com/

[22] http://www.grid.unina.it/software/ITG/

[23] https://www.eclipse.org/ide/

[24] https://www.virtualbox.org/

[25] https://www.vmware.com/products/vsphere-hypervisor.html

[26] https://www.vmware.com/products/workstation-pro.html

9 Acronyms

[CAPEX]	[Capital expenditures]
[CBTC]	[Communication based train control]
[CR]	[Cognitive Radio]
[DCS]	[Data Communication System]
[ERTMS]	[European Rail Traffic Management System]
[ETCS]	[European Train Control System]
[FCP]	[Fixed Communication Plane]
[GMPLS]	[Generalized Multi Protocol Label Switching]
[GSM-R]	[Global System for Mobile Communications Railway]
[LoRa]	[Long Range]
[LTE]	[Long Term Evolution]
[LTE-R]	[Long Term Evolution Railway]
[MCP]	[Mobile Communication Plane]
[MIMO]	[Multiple Input - Multiple Output]
[MFR]	[Mobile Fixed Radio]
[MMR]	[Mobile Modular Radio]
[NCP]	[Network Control Plane]
[OTN]	[Optical Transport Network]
[OFDM]	[Orthogonal frequency division multiplexing]
[OPEX]	[Operational Expenditure]
[PAAS]	[Platform-as-a-Service]
[PHY]	[Physical Layer]
[PI]	[Physical Infrastructure]
[PMR]	[Professional Mobile Radio]
[PSC]	[Project Steering Committee]
[QOS]	[Quality of Service]
[RCP]	[Radio Control Plane]
[RMP]	[Radio Monitoring Plane]
[RSSI]	[Received Signal Strenght Indication]
[SDN]	[Software Defined Networks]
[SDR]	[Software Defined Radio]
[SME]	[Small Medium Enterprises]
[Telco]	[Telecommunications companies]
[TETRA]	[TErrestrial Trunked RAdio]
[VIMS]	[Virtual Infrastructure Management System]
[VM]	[Virtual Machines]