Project no. 691735

REPLICATE PROJECT

Renaissance of Places with Innovative Citizenship And Technology

This Project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement N° 691735

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REnaissance of PLaces with Innovative Citizenship And Technology

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H2020-SCC-2015 Smart Cities and Communities

Innovation Action (IA)

D3.10: Report on High speed mobile network based on postWIMAX technology

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Organisation name of lead contractor for this deliverable: Sistelec

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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Editor/Lead beneficiary:	Sistelec
Internal reviewed by:	FSS

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1. REPLICATE

The REPLICATE project will generate smart city business models, and tailor-made solutions in the areas of energy, transport and ICT starting from the districts: Urumea Riverside (San Sebastián), Novoli (Florence) and Ashley, Easton and Lawrence Hill Neighbourhood (Bristol). In summary there will be pilot actions in energy efficiency, efficient and sustainable transport and integrated infrastructures, being the latter the key elements for the integration and development of cross-sectorial solutions. Three follower cities participate in the project: Essen (Germany), Nilufer (Tutkey) and Lausanne (Switzerland).

Being a demonstration project, the main concept that is on the top of the project is REPLICABILITY: it will be necessary that the project results could be applicable throughout the lighthouse cities and in other cities which want to evolve towards the 'smart city' concept, and could grow of scale too. To assure the large-scale deployment of innovative technologies successfully demonstrated in the lighthouse districts specific studies will be necessary for each of the demonstrated solutions to ensure that they are scalable and can be replicated.

Prior to REPLICATE project San Sebastian, Florence and Bristol have already collaborated in a STEEP project (Systems Thinking for Comprehensive City Efficient Energy Planning) which have allowed to the cities generate Smart City Plans. STEEP project has defined a collaborative and participatory methodology to reach the objective of defining an Action Plan for particular districts of each city.

The main objective of REPLICATE project is the development and validation in three lighthouse cities (San Sebastián – Spain, Florence – Italy and Bristol – UK) of a sustainable City Business Model to enhance the transition process to a smart city in the areas of the energy efficiency, sustainable mobility and ICT/Infrastructure, in order to accelerate the deployment of innovative technologies, organisational and economic solutions to significantly increase resource and energy efficiency, improve the sustainability of urban transport and drastically reduce greenhouse gas emissions in urban areas.

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2. INTRODUCTION

2.1 Relation to Other Project Documents

The aim of this deliverable is to explain what are the subtasks developed after the first two-year project, as the process developed while the subtask 3.3.3. During this task Sistelec with the collaboration of Fomento San Sebastian (FSS) had carried out the selection of best manufacturer, engineering process, put into service and installation, and produce the municipal measures.

The main objective of this task, described in this deliverable, is to provide a wide access to both municipality services but also, to other project partners in order to get a transparent network through high speed broadband wireless network. So other municipality services and also third party could be deployed, quickly, without incurring new costs and in an easy way. No adaptors are needed except an RJ45 Ethernet standard connectivity. Thus generate a great infrastructure to deploy current and future proof services and projects that will be supported by the Post WiMAX, broadband wireless network.

This document is a reference for the potential use of the deployed network, although the Smart Lighting pilot (D3.11) uses the PostWimax telecommunications network for remote management of the system as well as for obtaining the data monitored.

On the other hand, within the deployment of PostWimax, the start-up of services is covered and, consequently, both the data of the network itself and those produced by the installed sensors are inputs for D3.10 Monitoring program.

2.2 Reference documents

This document is based in the following projects level documents:

Ref.	Title	Description
REPLICATE Grant Agreement signed 240713.pdf	Grant Agreement	Grant Agreement no. 691735
DoA REPLICATE (691735)	REPLICATE Annex 1 – DoA to the GA	Description of the Action
REPLICATE Consortium agreement signed December 2015 (7th December version)	Consortium Agreement	REPLICATE project – Consortium Agreement

REPLICATE Project Management Plan	D1.1 Project Management Plan (v.1) (29/04/2016)	REPLICATE Project Management Plan
REPLICATE	D3.10 Report on High speed mobile network based on postWIMAX technology	REPLICATE High speed network based in postWIMAX technology

These will also be stored on the shared online platform.

Where there are contradictions, the documents listed above supersede this plan. The Grant Agreement is the contract with the European Commission so takes precedence over all other documents.

2.3 Abbreviation's list

GA	Grant Agreement
CA	Consortium Agreement
DoA	Annex I-Description of the Action
EC	European Commission
H2020	Horizon 2020
PC	Project Coordinator
PL	Pilot Leader
PMP	Project Management Plan
TC	Technical Coordinator
WP	Work Package
WPL	Work Package Leader
FSS	Fomento San Sebastian

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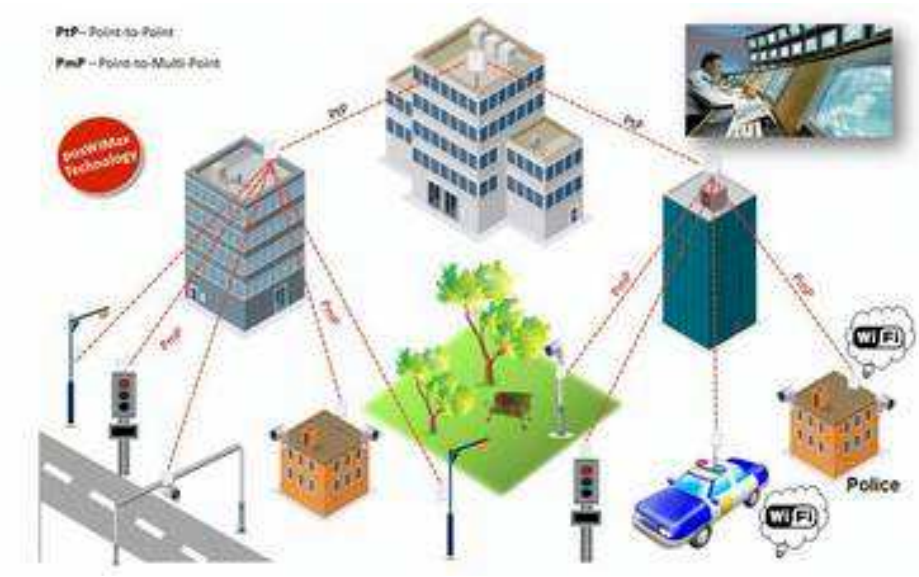
3. DELIVERABLE DESCRIPTION

This deliverable is part of the tasks developed by Sistelec with the collaboration of FSS as part of the task 3.3, focused in the Sub task 3.3.3.

As a part of the task, there were developed some works that will be widely described below each one as a part of a subtask.

The main purpose of the project is to provide a future proof backhaul platform that will be able to provide several and very different services from the lighthouses cities to the final users such as citizens, small business and other services providers.



Typical PtP and PmP wireless network

As the above image shows, there are two main topologies: PtP (Point to Point and Point to Multipoint).

- PtP: are links in which there are only two devices. The communication is bidirectional, throughput is available
- PmP: are links in with from one base station there are many subscribers. Throughput should be shared between subscribers

This deliverable D3.10 is described under the present document which covers:

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- Analyse and study particular needs for San Sebastián district in relation to wireless networks.
- Select the best manufacturer of wireless technology and test their equipment of pre-commercial form.
- Engineer deployment with corresponding technical teams.
- Perform the technical installation, put into service.
- Produce municipal measures.
- Real test and technical trials.
- Recopillate the full process in a technical report.

It is important to note that in addition of the previous description, there are some important sections like lessons learnt, impact and annexes:

- Lessons learnt: describes what the main problems are and how are being solved. How to deploy similar projects in other lighthouse and follower's cities with a maximum probability of success.
- Impact: describes how this task has helped to the whole project, including partners, and current and future services.
- Annexes: describe the support documents that are included in this deliverable that help to understand better the tasks done.

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4. REPORT ON HIGH SPEED MOBILE NETWORK BASED ON POSTWIMAX TECHNOLOGY

4.1 Analyse and Study particular needs for San Sebastian district in relation with wireless networks

Fomento San Sebastian (from now FSS), has been developing a municipality Wifi service since 2004 to provide electronic communications services. The previous project provides the possibility to San Sebastian citizens and also for tourist to get Wifi services, and to provide a great base to develop new wireless services between different activity sectors, such as tourism, govern, ecommerce, training… It is important to note that projects inside the municipality are specially increased providing new possibilities to get San Sebastian city to become a great smart city.

With that premise, Fomento San Sebastian after getting plenty of requirements to develop new services around the whole city, finally decided to deploy a new project in which a Post Wimax network was installed. The project expanded the network making a cross attending to north-south and east-west axis of the city (Boulevard-Easo-Pio XII-Anoeta-Hospitales), where new services with special connectivity needs were launched successfully.

Fomento San Sebastian is also the responsible for the deployment of the public fibre optic network of the city. After the process of development of a Smart plan for the municipality, and in order to provide better services to the public departments and in consequence to the citizens, exploit the value of the combination of the two communication technologies is a must.

The use of a Post Wimax technology was determined by the specific orography of San Sebastian, in which there are hills at a maximum 250 meters high, (Gudamendi), or 164 meters high, Ulia mountain, that lets a great coverage if there is a use of strategic sites to deploy the service. Thus, makes high speed broadband wireless network the ideal solution to generate a total coverage model that could be useful to deploy IoT and M2M services, like immovable devices and mobile sensors.

REPLICATE project lets to Fomento San Sebastian to continue with the deployment of the broadband wireless network to other areas without coverage and to enhance the actual post WiMAX deployment. Access to Urumea area through fibre optic or another wire communication service makes it almost impossible, derivated by the extremely high cost.

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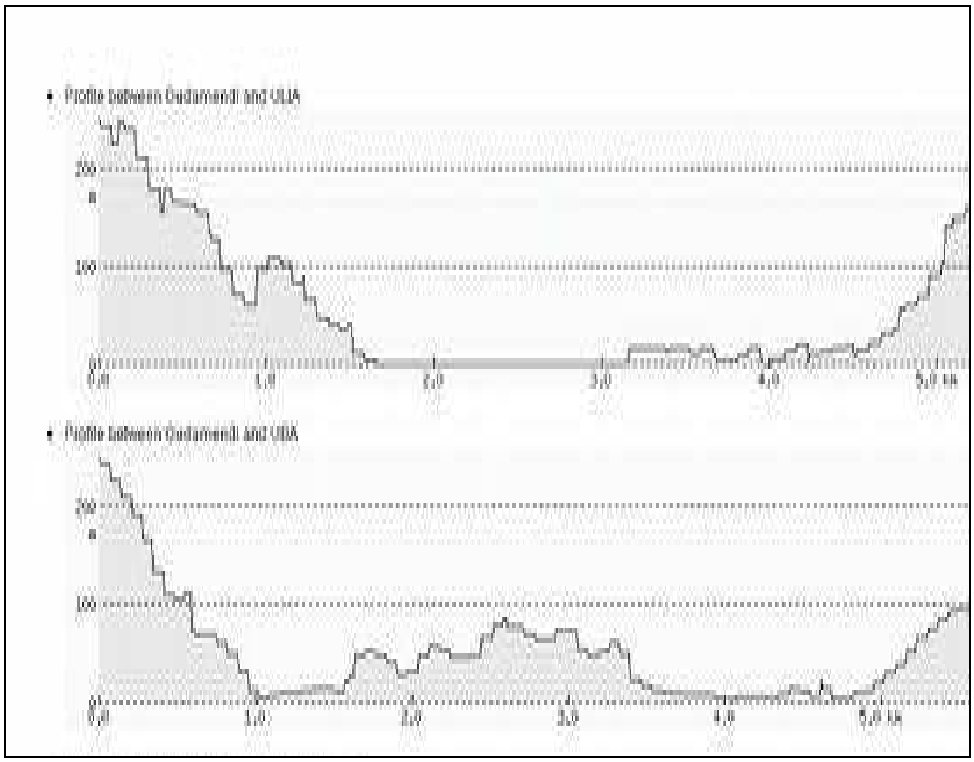

Example of the link between sites of the backbone network

An analysis and study of particular needs for San Sebastián district in relation to wireless networks was done: The city of San Sebastian has been working in the development of a public mobile communication network since 2010. Although there is existing equipment already installed that provide certain coverage in some areas, the network has not the necessary design and structure to make possible a secure and strong network in a future proof concept. Because of that, a deep analyse was needed.

The work of this task was finished after multiple meetings with FSS in order to understand what are the requirements and needs from FSS related with a Broadband wireless network.

The main requisites are:

- Transparent network (should allow to deploy several services transparently)
- The network should provide access to multiple services in a standard way. It is mandatory for this network to provide an easy access to the service level without any interface layer if it is possible
- High bandwidth

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- To provide multiple services within the same transport network, providing easy access and quality of service.
- Minimum Delay
- Delay is critical for some services like voice communications, and some UDP services, so any improvement in the network delay will provide a better solution quality and in consequence better services for the citizens.
- High spectral efficiency
- The solution provided will not require a licensed spectro, so will compete with other service providers and also with other wireless. Related with that, not only the municipality services compete for a wireless spectro, so a much efficient solution will provide a better performance with a considerable interference reduction between networks and will contribute to deploy more networks in a near future.
- Future proof technology
- The provided technology won't be obsolete in a near future. It should provide a development roadmap that generates several improvements without needing a new device deployment.
- Remote management
- All devices deployed should be managed in a remote system, and also be interoperable with other network management systems in order to get a real-time status of the network as well as an alarm indicator. A centralized control centre will deal with the network issues and control the performance of the network in order to maximize the operation and the interoperability with other services.
- Background compatibility to the previous broadband wireless network
- The new devices should be compatible with the previous deployment in order to keep an standardized network, and also to avoid as much as possible the obsolescence of the current deployment.

4.2 Select the best manufacturer of wireless technology and test their equipment of pre-commercial form

Sistelec is known for its wide knowledge and expertise in wireless technologies for more than 20 years. Because of that Sistelec, has had a continuous evolution trough different technologies and different providers always looking for the best manufacturer with the latest technology, and of course focusing in Research and development of new and high added value solutions.

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In order to provide a backbone wireless multiservice network Sistelec has made an analysis of the current and future needs of the services provided by a Smart City like the lighthouses. Focused in the needs of San Sebastian and the particularity of the URUMEA district, there is an important issue of the reliability to provide connectivity to this district through a wired connection. The cost and works needed are out of the scope of any current budget, so a wireless technology should be used.

Sistelec has made a wide market study of different manufacturers and technologies on order to offer the best solution for the needs of the wireless network for San Sebastian lighthouse city. Finally, there are several characteristics that are necessary to be taken into account to select the best provider in this situation.

Based in the initial studies some features provided like throughput and latency are extremely important because they might limit the services deployed under those technologies.

Some of the typical services required in a base communications infrastructure for a Smart City are: VoIP services, Video Surveillance, Internet access, remote data parameters (p. e. traffic, streetlight, water pipe fitting).

So, in order to be able to fit in whatever service lighthouse cities could deploy Sistelec has selected a solution that combines very low latency and a great throughput.

- Low latency allows human-unnoticeable delays between an input being processed and the corresponding output providing real time characteristics. This can be especially important for internet connections utilizing services such as Trading and VOIP.

- The system throughput or aggregate throughput is the sum of the data rates that are delivered to all terminals in a network. The throughput of a communication system may be affected by various factors, including the limitations of underlying analogy physical medium, available processing power of the system components, and end-user behaviour. When various protocol overheads are taken into account, useful rate of the transferred data can be significantly lower than the maximum achievable throughput;

4.2.1 No license Wireless technologies status

In this chapter it is described the most important wireless technologies used in Wireless deployments, also there are focus in pros and cons of each solution to finally make our own conclusions.

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- **Wi-Fi**

Wi-Fi or WiFi is a technology that allows electronic devices to connect to a wireless LAN (WLAN) network, mainly using the 2.4 gigahertz (12 cm) UHF and 5 gigahertz (6 cm) SHF ISM radio bands. A WLAN is usually password protected, but may be open, which allows any device within its range to access the resources of the WLAN network.

WiFi used different standards based in IEEE 802.11. The IEEE 802.11 standard is a set of media access control (MAC) and physical layer (PHY) specifications for implementing wireless local area network (WLAN) computer communication in the 2.4, 3.6, 5, and 60 GHz frequency bands. The main standards today are: b,g,a,n,ac.

Pros	Cons
Very High bandwidth	Latency 100ms
Standard → Multivendor	Very noisy environments too many APs
Easy to deploy	Limited coverage due to power limitations
Network access	Robustness
Evolution new standards (b,g,a,n,ac)…	Focus on final user

- **WiMAX**

WiMAX (Worldwide Interoperability for Microwave Access) is a family of wireless communications standards initially designed to provide 30 to 40 megabit-per-second data rates, with the 2011 update providing up to 1 Gbit/s for fixed stations. The name "WiMAX" was created by the WiMAX Forum, which was formed in June 2001 to promote conformity and interoperability of the standard. The forum describes WiMAX as "a standards-based technology enabling the delivery of last mile wireless broadband access as an alternative to cable and DSL".

Pros	Cons
High bandwidth	Latency 40ms
Standard → Multivendor	Evolution stopped
	No principal vendors

	In process of replacement

- **LTE**

LTE (Long-Term Evolution, commonly marketed as 4G LTE) is a standard for wireless communication of high-speed data for mobile phones and data terminals. It is based on the GSM/EDGE and UMTS/HSPA network technologies, increasing the capacity and speed using a different radio interface together with core network improvements. The standard is developed by the 3GPP (3rd Generation Partnership Project)

Pros	Cons
High bandwidth	Latency 100ms
3GPP standard → Multivendor	Used for telephony
Easy to deploy	Not used in private environments
Use the Network operator's resources	Cost per month
Great operators coverage	Very difficult to deploy new coverage
	No compatible with only private use

- **Post WiMAX**

Post WiMAX is the named commonly used to describe the new technologies that some providers use to evolve from a WiMAX standard to a commonly proprietary platform solution.

There are several brands which technologies are named as Post WiMAX.

Pros	Cons
High bandwidth	Proprietary solutions
Latency < 7ms	Non standard
Easy to deploy	Initial cost
Complementary with other solutions (WiFi)	
Great performance	

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Coverage (Los, nLos and NLos)
Multi-purpose network

- **Conclusion**

Below, it is a comparison between a Post WiMAX technology and a WiMAX standard; so therefore, it is possible to understand the strength and weakness of both solutions.

Feature	Post WiMAX	802.16 (WiMAX standard)
Throughput	>= 250Mbps	Up to 140Mbps (4 radios)
Latency	5~ 7 ms	10~40 ms
Channel Bandwidth	40 /20/ 10/ 5 MHz	10 / 7 / 5 / 3.5 / 1.75 MHz
Multi Band	4900 – 5925 MHz	4900-5875MHz
Max users/Sector	238	50
MIMO	MIMO 2x2	SISO
Spectral Efficiency	6bps/Hz	3.5bps/Hz
Remote Management	Web access by HTTP and HTTPS/TLS NMS by SNMP	Web, SSH, XML-RPL, SNMP v1, 2 y 3

4.2.2 State of the Art

All of the manufactures included in this study are very well-known companies with a wide experience in wireless technologies and offering all of them great products. The selection of one product or another is based on his actual and future performance and evolution as well as wireless base technology used. All of the different products could much very well depend on the service that will be provided and the number of subscribers needed.

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- Proxim

Proxim was previously the leader in post-WiMAX technology, but during the last years their products have been improved by other vendors. However, they also have an impressive product that could be implemented in some situations successfully.

The main product in a Multipoint structure is the Tsunami® MP-8200.

Leveraging the advantages of OFDM, MIMO radio innovations along with Proxim's proprietary Wireless Outdoor Routing Protocol (WORP®), Tsunami® MP-8200 series and the new Tsunami® MP-8200-BSU-G are feature rich equipment's.

Problems:

The main problems of these products are:

- Product based on WiFi with a proprietary protocol on Top.
- The prize of the subscribers is higher than other solutions.
- It is not as robust as other solutions in a hard-interfering environment.

Tsunami® MP-8200

Tsunami® MP-8200-BSU-G when loaded with Proxim's WORP® Sync software has the capability to synchronize its internal clock to the one pulse per second signal of an external GPS receiver or an Ethernet based synchronization module. With the help of this feature multiple MP-8200-BSU-G start following the same transmit/receive pattern and avoid interfering with each other even when using adjacent channels. Additionally, Tsunami® MP-8200-BSU-G has advanced channel management capability and cutting edge QoS class of service which ensures optimal delivery of voice, video and data applications. Tsunami® MP-8200-BSU-G is specifically designed for service providers and government organizations with requirements of all kinds, from last mile broadband wireless access (BWA) to wireless video surveillance and more.

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Highlights:

- Great Performance
    - Point to Multipoint solution that can deliver 300 Mbps data rates
    - High power radio capable of up to 25.8 dBm Tx power to extend the range and coverage
    - Provides reliable high performance under all traffic loads using Proxim's Wireless Outdoor Routing Protocol (WORP®)
    - Dual IPv4 and IPv6 stack for transparent evolution to tomorrow networks
    - Seamless roaming up to 295 km/h (185 mph)
- Non-Line-of-Sight and Advanced Features
    - Non-line-of-sight capable, utilizing OFDM and 3x3 MIMO techniques to improve link performance and penetrate through or around obstructions better
    - Features dual Gigabit Ethernet ports with PoE in/out to power other devices like surveillance cameras and wireless access points
    - Enables packet identification to create unique and sophisticated service rules and tiered service classes with ease
    - BSU redundancy (500 milliseconds switch over time) and Dynamic Channel Selection to ensure continuity of services whatever the condition

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  - Spectrum analysis feature helps to study frequency bands for interference, and select a relatively low interference channel.

- Optimal RF Management
  - Multiple Base Station synchronization based on PPS signal from GPS of Ethernet based Synchronization Module
  - Non-line-of-sight capable, utilizing OFDM and 3x3 MIMO techniques to improve link performance and penetrate through or around obstructions better
  - Spectrum analysis feature helps to study frequency bands for interference, and select a relatively low interference channel.
- Frequency Agnostic
  - Operates in licensed and unlicensed frequency bands from 4.900 to 5.925 GHz with support for 5, 10, 20 and 40 MHz flexible channel size
- Enhanced Feature set
  - Choice of WORP® or WORP® Sync protocol based on application requirements
  - Service flow based QoS with comprehensive packet identification to create unique and sophisticated service rules and tiered service classes with ease
  - Bridging mode with full VLAN capabilities or Routing mode with gateway features
- Carrier-Grade Security
  - Implements tiered security layers for the most secure outdoor wireless communications in the unlicensed frequency spectrum
  - Utilizes Proxim's Wireless Outdoor Routing Protocol (WORP®), which prevents snooping, and features highly-secure remote management via SSL, SSH and SNMPv3
  - Provides military-grade security with AES encryption technology, prevents unsecure client-to-client communications and leverages MAC, Ethertype and IP address packet filtering for granular network security

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Product Specifications:

INTERFACES	
WIRED ETHERNET	Two auto MDI-X RJ45 10/100/1000Mbps Ethernet - Port #1 with PoE In & Data - Port #2 with PoE out (802.3af pin out) & Data
WIRELESS PROTOCOL	WORP® (Wireless Outdoor Router Protocol)
RADIO & TX SPECS	
MIMO	3x3 MIMO with 2 data streams
MODULATION	OFDM with BPSK, QPSK, QAM16, QAM64
FREQUENCY	4.900 – 5.925 GHz (Subject to Country Regulations)
CHANNEL SIZE	40 MHz, 20 MHz, 10 MHz*, 5 MHz* channel bandwidths * DFS availability is country dependent, check the User Guide
DATA RATE	MCS 0 to 15 for High Throughput mode (6.5 – 300 Mbps) with Dynamic Data Rate Selection BPSK, QPSK, 16-QAM and 64-QAM for legacy mode (6Mbps - 54Mbps)
TX POWER	Up to 25.8 dBm (Triple chain)
TX POWER CONTROL	0 – 25 dB, in 0.5 dB steps. Automatic TPC with configurable EIRP limit
RX SENSITIVITY (PER=10%)	

Channel Size	40 MHz	20 MHz	10 MHz	5 MHz
MCS 0	-87 dBm	-93 dBm	-95 dBm	-98 dBm
MCS 7	-71 dBm	-74 dBm	-76 dBm	-79 dBm
MCS 8	-87 dBm	-91 dBm	-93 dBm	-96 dBm
MCS 15	-68 dBm	-72 dBm	-74 dBm	-77 dBm

OTHER	Dynamic Channel Selection (DCS) based on interference detection Dynamic Frequency Selection (DFS) based on radar signature Automatic Transmit Power Control (ATPC) with EIRP limit support

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ANTENNA

MP-8200-BSU or SUA	Three N-type Connectors with built-in Surge Protection
MP-8250-BS1 or SUR	Integrated 2x2 MIMO 23dBi Dual Polarized Panel Antenna
MP-8250-BS9	Integrated 2x2 MIMO 16dBi Dual Polarized 90 degree Sector Antenna

MANAGEMENT

LOCAL	RS-232 serial (RJ11 to DB-9 dongle provided)
REMOTE	Telnet and SSH, Web GUI and SSL, TFTP, SNMPv3
SNMP	SNMP v1-v2c-v3, RFC-1213, RFC-1215, RFC-2790, RFC-2571, RFC-3412, RFC-3414, Private MIB
OTHER	Syslog, sFlow™ agent, SNTP and local time, Spectrum analyzer

SECURITY

ENCRYPTION	AES-CCM 128 bits
AUTHENTICATION	Internal MAC Address Control List, Radius based Authentication (with VLAN and QoS provisioning)

NETWORK

MODES	Bridging, Routing (RIP v2 and IP tunneling)
IP STACK	IPv4 and IPv6 simultaneously
THROUGHPUT	Up to 240 Mbps
GATEWAY FEATURES	DHCP Server & relay, NAT with Std ALGs, PPPoE end point with Proxy DNS
QoS	

Asymmetric Bandwidth Control	UL and DL CIR Control "committed information rate" per service flow UL and DL MIR Control "maximum information rate" per service flow
Packet Classification Capabilities	802.1D/802.1Q/802.1p priority, IPTOS, VLAN ID, IP source/destination address, source/destination port, Ethernet source/destination address, IP protocol, and Ethertype
Scheduling	Best Effort, Real Time Polling Services

VLAN	802.1Q: Management VLAN. Transparent, Access, Trunk and Mixed mode. QinQ double tagging

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ENVIRONMENTAL SPECS

OPERATING TEMPERATURE	-40° to 60°C (-40° to 140° Fahrenheit) Will continue operating if temperature temporarily varies between -50° and 70°C (-58° and 158° Fahrenheit).
STORAGE TEMPERATURE	-55° to 80°C (-67° to 176° Fahrenheit)
HUMIDITY - IP RATING	100% relative humidity - IP67
WIND LOADING	200 km/h (125 mph)

POWER CONSUMPTION

12 Watt typical (22 Watt max)

PHYSICAL SPECS

		DIMENSIONS	WEIGHT
PACKAGED	MP-8200-BSU or MP-8200-SUA	14.56 x 13.69 x 8.18 in. (370 x 348 x 208 mm)	15 lbs (6.8 kg)
	MP-8250-SUR	15.94 x 15.94 x 9.21 in. (405 x 405 x 234 mm)	16.31 lbs (7.4 kg)
UNPACKAGED	MP-8200-BSU or MP-8200-SUA	10.79 x 11.14 x 3.38 in (274 x 283 x 86 mm)	7.7 lbs (3.5 kg)
	MP-8250-SUR	14.17 x 14.17 x 3.70 in (370 x 370 x 94 mm)	9.0 lbs (4.1 kg)

SAFETY STANDARDS

UL 60950, CAN/CSA-C22.2 No. 60950, IEC 60950, EN 60950 (part -1 and -22)

- Radwin

Radwin offers two different versions of his products to compete with this kind of solutions. Both of them are very good products also, but they are based on WiFi communications protocol that perhaps, in some circumstances, is more suitable to interference than others products.

The main characteristics of the products are developed below.

Problems:

The main problems of these products are:

- Radwin 5000 JET comes with integrated antennas. These antennas have a great performance but you can't change it to other than 90 degrees of radiation pattern.
- The prize of the subscribers is higher than other solutions.
- Backwards compatibility

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- Subscribers can't get the whole bandwidth of the AP only the maximum permitted by subscriber.

RADWIN 5000 JET

RADWIN 5000 JET is a point-to-multipoint solution incorporating a smart beam forming antenna and advanced air interface. JET's antenna beam cancels radio interference and enables operation in heavily congested unlicensed bands and in non-line-of-sight (NLOS) conditions, delivering great capacity for longer range.

5000 JET Highlights

- Base Station with smart beam forming antenna
- Up to 750 Mbps per sector, 3 Gbps per cell using 2 x 80MHz
- Variety of subscriber units:
- High capacity – 10, 25, 50 Mbps, upgradeable to 100 Mbps
- Ultra capacity – 100 and 250 Mbps
- Long range – 40 Km / 25 miles
- Interference cancellation due to directional narrow beam antenna
- Dynamic channel bandwidth selection optimized per channel conditions
- Guaranteed SLA per subscriber unit

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- Multiband radio – 3.3 – 3.8 / 3.65 GHz or 4.9–5.8 GHz in the same unit
- Small form factor, IP67 units
- Seamless operation in nLOS/NLOS and severe multipath conditions
- Fixed and nomadic capabilities
- TDD radio synchronization for greater network capacity

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Product Specifications:

Product Specifications

Maximum Net Aggregate Capacity

	Base Station		High-Capacity Subscriber Units			Ultra-Capacity Subscriber Units	
4.9[2]-5.8 GHz	750Mbps (QAM256)	250Mbps	10Mbps	25Mbps	50Mbps	100Mbps (QAM 256)	250Mbps (QAM 256)
3.3-3.8GHz, 3.65 GHz		250Mbps	10Mbps	25Mbps	50Mbps		

Antenna Configurations

4.9-5.8 GHz	Beamforming antenna: 20 dBi (5.1 - 5.8GHz), 17 dBi (4.9GHz)	Int. 17dBi, 23dBi, Con.	Int. 17dBi, 23dBi, Con.	23dBi, Con.	23dBi, Con.	23dBi, Con.
3.3-3.8GHz, 3.65 GHz	Beamforming antenna: 17dBi	Int. 13dBi, 20dBi, Con.	Int. 13dBi, 20dBi, Con.	Int. 20dBi, Con.		

Radio	
Number of HSUs per HBS	Up to 32[3] HSUs simultaneously
Range	Up to 40 km / 25 miles
Frequency Bands	Multiband radio supporting 4.9-5.8 GHz or 3.3-3.8 / 3.65 GHz
Channel Bandwidth	Configurable: 10, 20, 40, 80[4] MHz, in 3.x GHz: also 5, 7,14MHz
Dynamic Channel BW Selection (D-CBS)	20/40/80[5] MHz
Radio Access scheme	2x2 MIMO OFDM
Modulation	BPSK/QPSK/QAM16/QAM64/QAM256[6]
Adaptive Modulation & Coding	Supported
SLA management	CIR, MIR, Best-Effort[6]
End to End Latency	Typical: 3.5msec for 2 HSUs; 20msec for 32 HSUs
Duplex Technology	TDD
Uplink / Downlink BW Allocation	Configurable: Symmetric or Asymmetric
Max Tx Power	HBS : 25dBm @ 5.x GHz, 23dBm@ 3.x GHz (in all modulation schemes) HSU: 25dbm
DFS (FCC & ETSI)	Supported
Diversity	Supported at HBS & HSU, Auto MIMO /Diversity per HSU
Spectrum Viewer	Supported at HBS & HSU
TDD Synchronization	Inter & Intra site synchronization (co-existence with RADWIN 2000 PtP), Embedded GPS receiver and antenna
Encryption	AES 128
Interfaces	
Ethernet Interface	HBS: Two ports for Data & management, 10/100/1000BaseT HSU: 10/100BaseT
Networking	
Sub convergence layer	Layer 2
QoS	Packet classification to 4 queues according to 802.1p and Diffserv, Strict Priority, TTL
VLAN	802.1Q, QinQ, 4094 VLANs
Management	
Management Application	HBS & HSU: RADWIN Manager & Web based management
Protocol	SNMPv1, SNMPv3, Telnet, HTTP, IPv4 & IPv6, RADIUS for AAA Server
NMS Application	RADWIN NMS (RNMS) or integration with 3rd party NMS system via standard MIBs

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Power	
Power Feeding	Provided over PoE interface
Power Consumption	HBS < 25W, HSU < 12 W
Environmental	
Operating Temperatures	-35°C to 60°C / 31°F to 140°F
Humidity	100% condensing, IP67 (fully protected against dust and immersion up to 1m)
Radio Regulations	
FCC	47CFR Part 15 Subpart C and Subpart E, 47CFR Part 90 Subpart Z – Restricted & Unrestricted modes
IC	RSS210- Issue 8, RSS192- Issue 3, RSS197- Issue -1 Restricted Mode
ETSI	EN 301 893, EN 302 326-2, EN 302 502
Safety	
FCC/IC (cTUVus)	UL 60950-1, UL 60950-22, CAN/CSA C 22.2 60950-1; CAN/CSA C22.2 60950-22
ETSI	EN/IEC 60950-1, EN/IEC 60950-22
EMC	
FCC	CFR47 Class B, Part15, Subpart B
ETSI	EN 301 489-1, EN 301 489-4
CAN/CSA	CISPR 22 - 10 Class B
AS/NZS	CISPR 22 - 2009 Class B

RADWIN 5000

The RADWIN 5000 high-capacity point-to-multipoint (PtMP) solution delivers up to 250 Mbps per sector. It is the ideal choice for last mile enterprise connectivity and applications requiring guaranteed bandwidth per subscriber.

RADWIN 5000 point-to-multipoint radios provide high base station capacity, greater spectrum efficiency and robust performance in harsh conditions. RADWIN 5000 assure dedicated bandwidth per end-user, enabling service providers to offer and meet agreed-upon service level agreements (SLAs). RADWIN 5000 radios support an extensive range of frequency bands in the same unit facilitating flexible radio planning.

High gain integrated antenna HSU

Integrated antenna HSU

Highlights

- Up to 250 Mbps per base station sector

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- Capacity upgrades via a software key – from 5 to 25 Mbps
- Fixed and nomadic capabilities
- Variety of subscriber units – 5, 10, 25, 50 Mbps
- Small form factor MIMO subscriber units
- OFDM, MIMO 2x2 and Diversity enabling operation in non-line-of-sight
- Long range – 40 Km / 25 miles
- Widest band offering: 2.4, 2.5-2.7, 3.3-3.8, 4.9-6.4GHz
- Supporting Multiband 4.9 to 6 GHz in the same unit

Product Specification:

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Product Specifications

Capacity

	Base Station				Subscriber units					
	HBS 5010	HBS 5050	HBS 5100	HBS 5200	HSU 500	HSU 510	HSU 610	HSU 520	HSU 525	HSU 550
Maximum Net Aggregate Capacity	25 Mbps	50 Mbps	100Mbps	250 Mbps	5 Mbps	10 Mbps	10 Mbps	25 Mbps	25 Mbps	50 Mbps

Frequency Bands & Antenna Configurations

2.3 – 2.4 GHz		Con.		Con.	Int. 13dbi, Con.			Int. 19dbi, Con.		Int. 19dbi, Con.
2.5 - 2.7 GHz			Con.					Int. 19dbi, Con.		
3.3 – 3.8GHz, 3.65GHz				Con.		Int. 13, 20 dbi, Con.			Int. 13, 20 dbi, Con.	Int. 20dbi, Con.
4.9 – 6.0 GHz	Int. 90°	Int. 90°, Con.		Int. 90°, Con.		Int. 17, 23 dbi, Con.	Int. 25dbi	Int. 23dbi	Int. 17, 23 dbi, Con.	Int. 23dbi, Con.
5.7 – 6.4 GHz		Con.		Con.		Int. 24, 15dbi, Con.				Int. 24 dbi, Con.
PoE Out IEEE 802.3af							√			

Con. – Connectorized unit, Int. – Integrated Antenna

Radio

Number of HSUs per HBS	Up to 32 HSUs or HMUs simultaneously
Range	Up to 40 Km / 25 miles
Frequency Bands	Multiband radio supporting 5.7-6.4 GHz or 4.9-6 GHz or 3.3-3.8 GHz or 2.5-2.7 GHz or 2.3-2.4 GHz
Channel Bandwidth	Configurable: 5, 10, 20 , 40 MHz
Modulation	2x2 MIMO-OFDM (BPSK/QPSK/16QAM/64QAM)
Adaptive Modulation & Coding	Supported
Sector Bandwidth Allocation	Configurable: Symmetric or Asymmetric
DFS (FCC & ETSI)	Supported
End to End Latency	Typical: 4msec to 12msec
Diversity	Supported at HBS & HSU
Spectrum Viewer	Supported at HBS & HSU
Max Tx Power	25 dBm at HBS & HSU
Duplex Technology	TDD
TDD Synchronization	Inter & Intra site synchronization (co-existence with RADWIN PtP)
Encryption, US Security	AES 128/256, FIPS-197

Interfaces

Ethernet Interface	HBS: 10/100/1000BaseT HSU / HMU: 10/100BaseT

Networking

Sub convergence layer	Layer 2
QoS	Packet classification to 4 queues according to 802.1p and Diffserv, Strict Priority, TTL
VLAN	802.1Q, QinQ , 4094 VLANs

Management

HBS & HSU/HMU Management Application	RADWIN Manager or Web based management
Protocol	SNMPv1, SNMPv3, Telnet, HTTP , IPv4 & IPv6
NMS Application	RADWIN NMS (RNMS)

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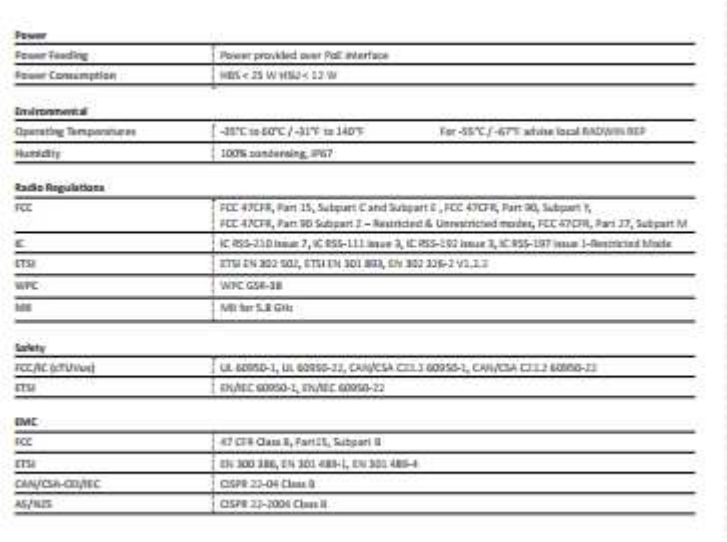

Power		
Power Feeding	Power provided over PoE interface	
Power Consumption	MBS < 25 W MSU < 12 W	
Environmental		
Operating Temperatures	-35°C to 60°C / -31°F to 140°F	For -55°C / -67°F advise local RADWIN REP
Humidity	100% condensing, IP67	
Radio Regulations		
FCC	FCC 47CFR, Part 15, Subpart C and Subpart E , FCC 47CFR, Part 90, Subpart Y, FCC 47CFR, Part 90 Subpart Z – Restricted & Unrestricted modes, FCC 47CFR, Part 27, Subpart M	
IC	IC RSS-210 Issue 7, IC RSS-111 Issue 3, IC RSS-192 Issue 3, IC RSS-197 Issue 1-Restricted Mode	
ETSI	ETSI EN 302 502, ETSI EN 301 893, EN 302 326-2 V1.2.2	
WPC	WPC GSR-38	
MII	MII for 5.8 GHz	
Safety		
FCC/IC (cTUVus)	UL 60950-1, UL 60950-22, CAN/CSA C22.2 60950-1, CAN/CSA C22.2 60950-22	
ETSI	EN/IEC 60950-1, EN/IEC 60950-22	
EMC		
FCC	47 CFR Class B, Part15, Subpart B	
ETSI	EN 300 386, EN 301 489-1, EN 301 489-4	
CAN/CSA-CEI/IEC	CISPR 22-04 Class B	
AS/NZS	CISPR 22-2004 Class B	

4.2.3 European Security commitment.

All the technologies studied meets all the EU regulation needs and also all of them are EU labelled. This means that all regulations and test are passed so they are devices that are safety to be used in any place within EU.

All technologies are committed to meeting the requirements of the European Union (EU) Waste Electrical and Electronic Equipment (WEEE) Directive. This Directive requires producers of electrical and electronic equipment to finance the take back, for reuse or recycling, of their products placed on the EU market after August 13, 2005.

All products that are within the scope of the Directive are labelled with a crossed-out "wheelie-bin" symbol, as required by the Directive. It indicates that the product was placed on the market after August 13, 2005 and that end users should segregate the product from other waste at end-of- life.

The WEEE Directive is being implemented in each of the 27 EU countries through national legislation. Norway and Switzerland have also implemented similar pieces of legislation. As a result, the detailed requirements vary considerably throughout the EU, and the Cambium Networks WEEE compliance approach varies among countries.

Please visit the Annexes in order to check the EU compliance of the selected technology.

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4.2.4 Selected Technology Cambium i450 platform

After the previous studies, Sistelec finally has selected a Cambium as the technology provider and the 450i platform as the product to deploy in the Project.

The key benefits of this product are:

Simple Network Design

A PMP 450i platform network is exceedingly simple. A simple network design allows the system to complement the existing network, and makes it exceptionally easy to install. The equipment is intuitive and efficient, providing built-in installation and deployment assistance that makes it faster to get up and running often in a matter of hours or days instead of weeks or months.

Performance

Cambium access network solutions deliver superior performance using a modulation scheme that improves the quality of data delivery and mitigates interference from other systems. The system's wireless signals are highly effective in penetrating obstacles and avoiding obstructions, making it as efficient in dense urban environments as it is in suburban areas or rural locations.

Security

The 450i platform is a proprietary over-the-air protocol that offers security with over-the-air DES (Data Encryption Standard) encryption or AES (Advanced Encryption Standard) capabilities, which provide 128-bit encryption, to ensure secure data delivery and exceptional reliability.

Interference Tolerance

Because of its signal synchronization, Cambium wireless access network solutions offer a high level of tolerance to self-interference. The system provides reliable service even when the APs are placed close together, or neighbouring networks are in close proximity.

Scalability

Cambium access networks scale to meet network growth so that throughput remains consistent as new subscribers are added to the network. The system was designed to maximize the ability to scale as the network grows, and not suffer any performance degradation. Using synchronization techniques, high performance antennas (allowing frequency re-use between sectors), and tight filtering (to maximize spectral efficiency), Cambium systems can scale as needed.

Return on Investment

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Low infrastructure costs and wireless last mile connectivity yield a payback in terms of months.

Flexible Configuration Options

Cambium solutions include; configuration options that meet and exceed customer expectations. The platform can be configured as a single-site point-to-multipoint system that supports subscribers for distances up to 40 miles (64 kilometres). In addition, the system includes; interfaces that enable it to easily integrate with standard network management tools, as well as diagnostic capabilities needed to remotely monitor the network.

The below table shows the most important features to deploy lighthouse services:

Characteristic	Benefit	Implications
Channel Access	Scheduled TDD – Deterministic and Scalable regardless of load	Without scheduled TDD, users will complain about availability as subscribers are added.
Latency and QoS	Consistent and Deterministic – critical for voice and video and T1 replacements	Without consistent latency, network users will complain about delays and poor performance.
GPS Synchronization	Supported -> Efficient Channel Re-use / Easy Deployment. in Multi-Sector / Multi-Site systems	Unsynchronized systems perform inconsistently and poorly as subscribers are added. Use more channels to serve the same # of users
Throughput and System Capacity (bits/sec/Hz/sq km)	High ability for frequency reuse. Higher aggregate real user throughput and system capacity for given channel width and available spectrum.	Competitive systems require more AP towers to be added to meet demand – but this adds interference.

- Product **Specifications**

The PMP 450 Access Point (AP) can provide up to 125 Mbps throughput in a 20 MHz channel today, and because the product is a software defined radio system, Cambium Networks will make software updates to support 30 and even 40 MHz channel bandwidths, which is expected to provide up to 250 Mbps per sector. Dynamically adaptive modulation modes can provide maximum throughput with good RF conditions (Dual Payload MIMO operation) or provide a more robust link under less ideal link conditions (Single Payload polar diversity operation),

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allowing both near and non-Line-of-site deployments. This is dynamically controlled by the system to optimize the user experience.

PMP 450i platform can enable lighthouses to deliver high performance, reliable, and profitable services that supply customer and user demands for more and faster communications. The PMP 450 offers several key advantages to help these organizations achieve their connectivity objectives, including:

Feature	Advantage
238 SM's per AP	Platform is very flexible and extremely scalable. Customer references include networks of over 75,000 SMs.
Scheduled MAC Layer	Allows scalability, keeps latency low and consistent, fully utilizes available capacity, and removes degradation due to contention-based protocol (i.e. Optimized performance regardless of network load or number of subscribers)
Software Defined Radio	Freedom to develop features to optimize and maximize performance for specific purpose (Fixed Broadband), not constrained by standards, better ability to respond to customer requested features. Architecture can be replicated, allowing rapid frequency proliferation
Spectral Efficiency	Advanced radio design does not require any frequency guard band between adjacent channels, optimized antenna designs allow system to re-use frequencies, leading to high spectral efficiency (over 12.5 bps/Hz)
Well suited for both Enterprise and Residential	Managed Information Rate (MIR) and Committed Information Rate (CIR) available in radio software to provide Best Effort (typical for residential) or SLA (Service Level Agreement, typical for Enterprise) profiles, depending on services needs
L2 and L3 QoS	Can effectively manage network traffic to provide the best customer experience
512 Sub carriers per polarization	Utilizing OFDM operation, 512 FFT is employed for most channel sizes to create robust signal path for transmission
3-5 ms Latency	Latency remains low and consistent regardless of network load or the number of subscribers, providing high level of QoE (quality of experience) especially when used in latency-sensitive operation

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	(e.g. VoIP)
Highest order modulation	Allows 256QAM modulation to provide higher throughput in a given channel bandwidth.
Rapid Dynamic Adaptive Modulation	Frame by frame analysis of the RF transport allows the system to maximize throughput for current (and/or changing) RF conditions without adversely impacting overall throughput
Flexible Duty Cycle	Operator can configure the frame timing to provide customer with symmetric or asymmetric link with fine granularity (1% increments)
Synchronization	GPS synchronization minimizes self-interference, while maximizing the use of available spectrum. Works both intra-site and between sites, even among neighbouring networks using Cambium equipment.
Burst Traffic settings	Cambium 450 has the ability to allow traffic to burst beyond the sustained data rate, in order to provide customers with better experience if the resources are not required by other elements at the time of request.

The PMP 450i is a platform with hardware released in 900 MHz, 2.4, 3, and 5 GHz frequency bands, with additional frequencies planned for the future. The systems can provide LOS, nLOS and NLOS connectivity. They are highly scalable, allowing you to add sector capacity without replacing your existing equipment. Plus, the software-defined radios let you upgrade your existing hardware as system enhancements become available

The main specifications can be show in the table below:

Category	Specification
Frequency Bands	900 MHz, 2.4, 3.5, 3.65, 5 GHz
Max Throughput	Up to 250 Mbps in 40 MHz channel
Max SM per sector	238
Modulation Modes	2x2 MIMO: QPSK, 16QAM, 64QAM, 256QAM
MIMO Modes	Diversity (MIMO-A), Dual Payload (MIMO-B)
Latency	3-5 ms
Max TX Power	+25 dBm

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Channel Bandwidth	5, 7, 10, 20, 30 and 40 Mhz
Environmental	IP67/66, -40° to +60° C Operating Temp
Power Consumption	10-15 W typical, 15-19 W peak

There are also some great features like:

- **Scalable performance**
  - Frequency reuse with GPS sync
  - Supports NLOS, nLOS and LOS
  - Up to 250Mbps throughput per channel (or sector)
  - Up to 40 miles / 64 km LOS range
  - Up to 238 SM's per sector (or per AP)
  - 12.5 bps/Hz spectral efficiency
  - 3 level QoS

- **Versatile configurations**
  - Point-to-Multipoint or Point-to-Point links
  - Synchronized or Unsynchronized
  - Supports different antennas, typically 60º & 90º AP's
  - PoE (Power over Ethernet) and other AC/DC options

- **Reliable network**
  - Advanced Modulation Rate Adaptation based on link quality
  - Flexible Frame Ratio Operation for DL/UL
  - Intuitive GUI and EMS to control/optimize network

- **Product Description**

AP450i ACCESS POINT DESCRIPTION

APs are self-contained, connected outdoor transceivers that contain all the radio, networking, antenna, and surge suppression electronics. APs are designed for use with external antennas, enabling the radios to cope with more difficult radio conditions. Units can be rooftop or tower mounted, and each AP uses an indoor power supply module to provide power-over-Ethernet (PoE). Cat 5e cabling connects the power supply to the outdoor AP.

Each AP provides a specified sector of coverage and has up to 125 Mbps maximum throughput capacity in a 20 MHz bandwidth (planned to get 190 Mbps with a 30 MHz and 250 Mbps with

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40 MHz bandwidth). You can choose to deploy an AP with any sector antenna that meets your network requirements. When using high-performance sector antennas, careful frequency planning, and a clean RF environment, you can re-use frequencies from sector to sector, and site to site, allowing you to most effectively use the spectrum that is available to you, and creating unmatched scalability.

As mentioned above, the PMP 450i Access Point is connected to allow the ability to select the antenna that best meets the needs of their specific application. The key performance factor of the antenna is the front-to-back isolation, which, in combination with GPS synchronization of the system, enables frequency re-use in the network, maximizing the use of available spectrum.

PMP 450 SUBSCRIBER MODULE DESCRIPTION

Subscriber Modules (SM) are integrated outdoor transceivers containing radio, antenna, and networking electronics. SMs can be rooftop or tower mounted, and each SM requires a power supply unit. Cat 5e cable connects the indoor power supply to the outdoor-mounted SM. SMs do not include embedded surge suppression. Therefore, it is recommend adding an external surge suppression device for protection from the harmful effects of power surges induced into the electronics as a result of nearby lightning strikes. Some SM options include an integrated antenna. However, you may add a passive enhancement device to extend the range of the units, if desired.

Each AP can support up to 238 SMs. SMs offer scalable capacities of 4, 10, and 20 Mbps plus an uncapped capacity. The capacity you select is a capacity cap that determines the maximum achievable sustained throughput for each SM. You can begin with a 4 or 10 Mbps and upgrade to 20 Mbps or uncapped capacity at any time without changing your equipment. Uncapped capacity gives you the entire AP capacity throughput. There are many options available when selecting the appropriate Subscriber Module for the particular deployment. Below is a snapshot of the various form factors available:

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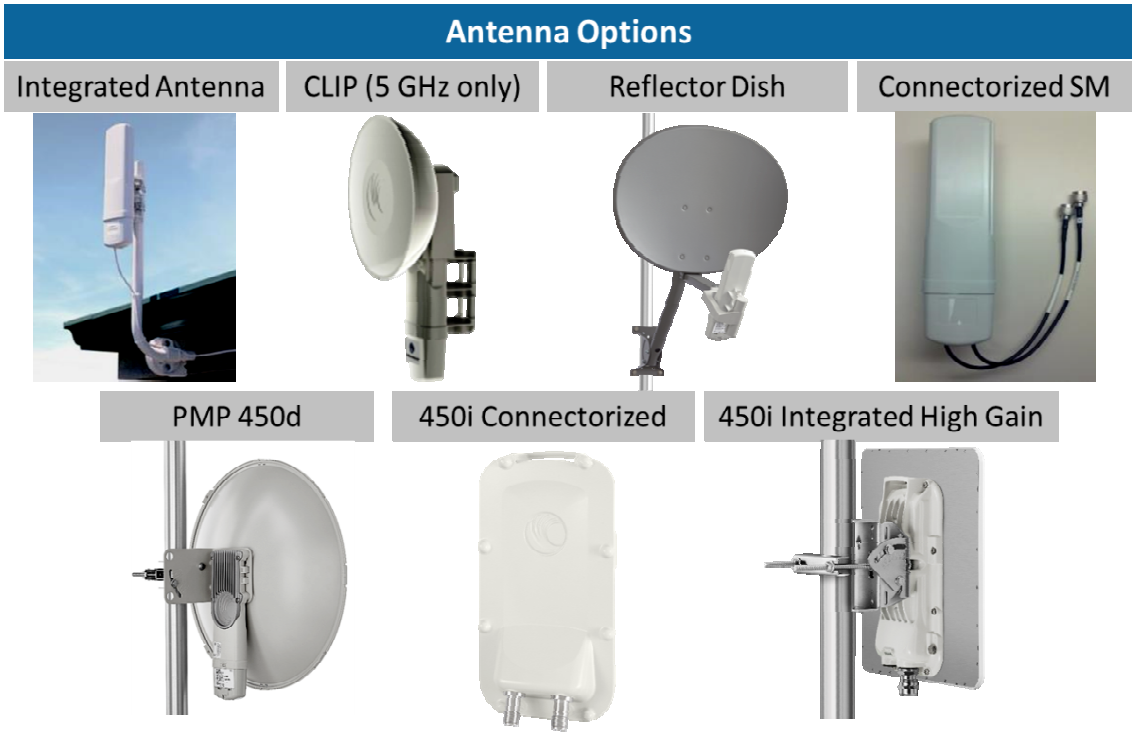

- **Development Status of the selected technology**

Sistelec has selected Cambium technology instead of a WiMAX standard (802.16) because of the continuous development of new solutions. In the following figure is possible to see how the evolution was until nowadays.

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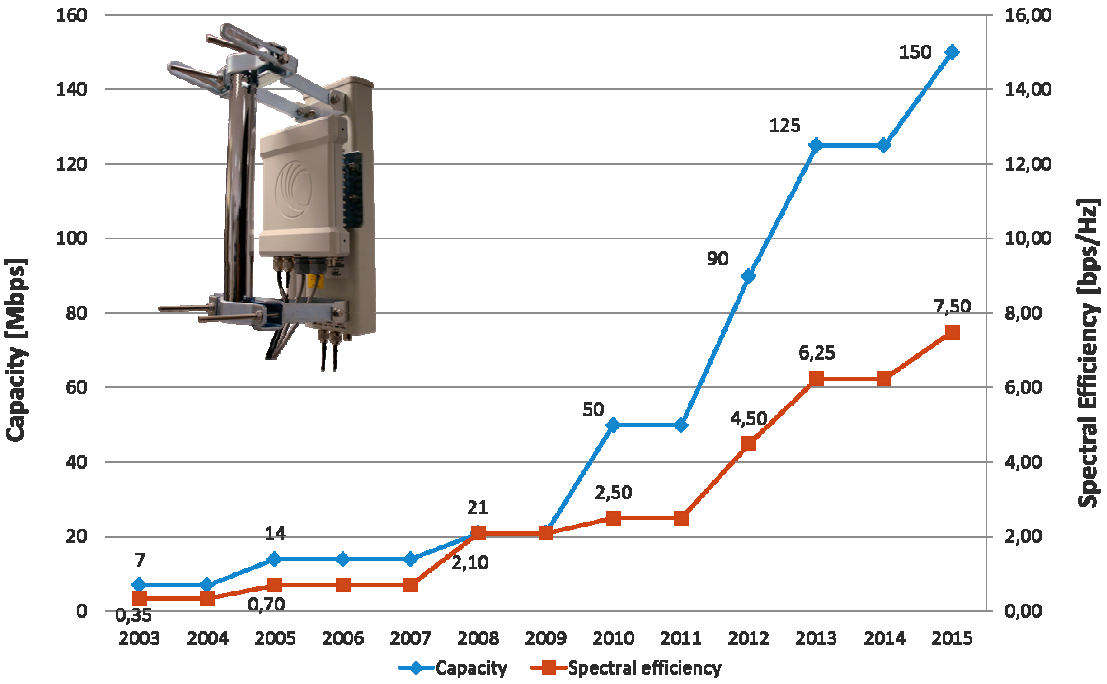

As the above image shows, there is a continuous improvement of the total bandwidth provided as well as a great spectral Efficiency. But the best thing is that with the 450i series selected this improvement is not finished today, because there is a complete Roadmap that will add also more improvements in the total capacity of a PmP solution.

Because the PMP 450i is software defined platform, there is a continuous evolve and enhance the product software. In parallel, there is a development of the architecture and radio design to advance update the underlying technology of the platform. Since the initial product launch in 2012, many significant and noteworthy product evolvement has occurred.

First, there was implemented a Spectrum Agile Architecture. This means it is able to easily adapt the architecture (including PHY and MAC structure) to different frequency bands to add to the tools that service providers need to address their customers.

There was an enhanced both the number of modulation modes as well as increased the highest order modulation that is supported by the system. Now support 256QAM modulation to provide the highest available spectral efficiency, and support both dual and single payload MIMO modulations to take advantage of the best RF conditions that exist for a given link.

The MTU (Maximum Transmission Unit) size has increased from 1522 to 1700 in order to support customer with complex networks (e.g. those using MPLS (Multiprotocol Label Switching) tags).

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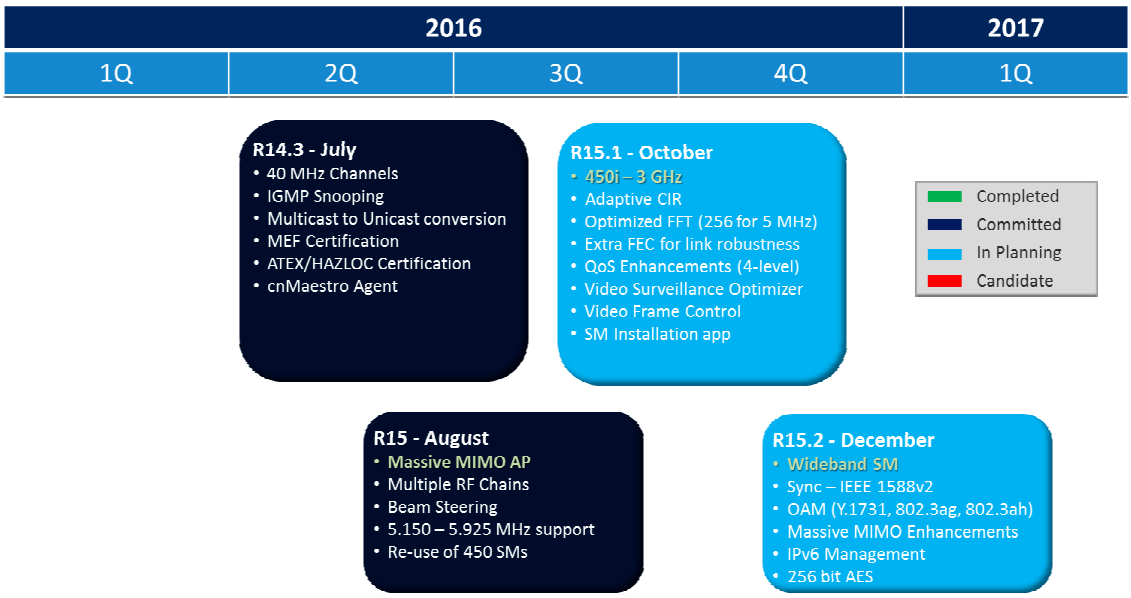
Cambium has added the 450d Subscriber Module to the 5 GHz PMP 450 portfolio of products, which include an integrated parabolic reflector dish, resulting in the highest available gain (25 dBi) and an incredibly pain-free and fast assembly and deployment.

The complementary product, the 450i, was also recently released and does several things for the portfolio. First, it is a step forward in processing power and capability, tripling the packet processing power over that of PMP 450. Second, it interoperates with existing PMP 450 networks, leveraging current investments in the platform. Operating over a wide band of frequencies, 4.9 to 5.9 GHz, the 450i can support the most demanding (or hazardous) deployments, and is as suitable for municipal government operators as rural WISPs (Wireless Internet Service Providers) that want to utilize leading edge technology to provide their customers with the optimal experience.

The most significant evolution is coming in 2016 as the 450 platforms will support wider channel bandwidths, including 30 and 40 MHz, which effectively doubles the amount of capacity per sector (up to 250 Mbps). Shortly after that, implementation of a Massive MIMO architecture will multiply the available bandwidth per sector even further. There is a commitment to building and evolving this platform to keep up with bandwidth needs of even the most demanding service providers for years to come.



All of these improvements will carry out a much better radio performance and a continuous evolution of the product during the project development. Most of the improvements are only software based, so with a simple firmware upgrade the new features could be deploy on an existing deployment. This evolution is shown in the image below.

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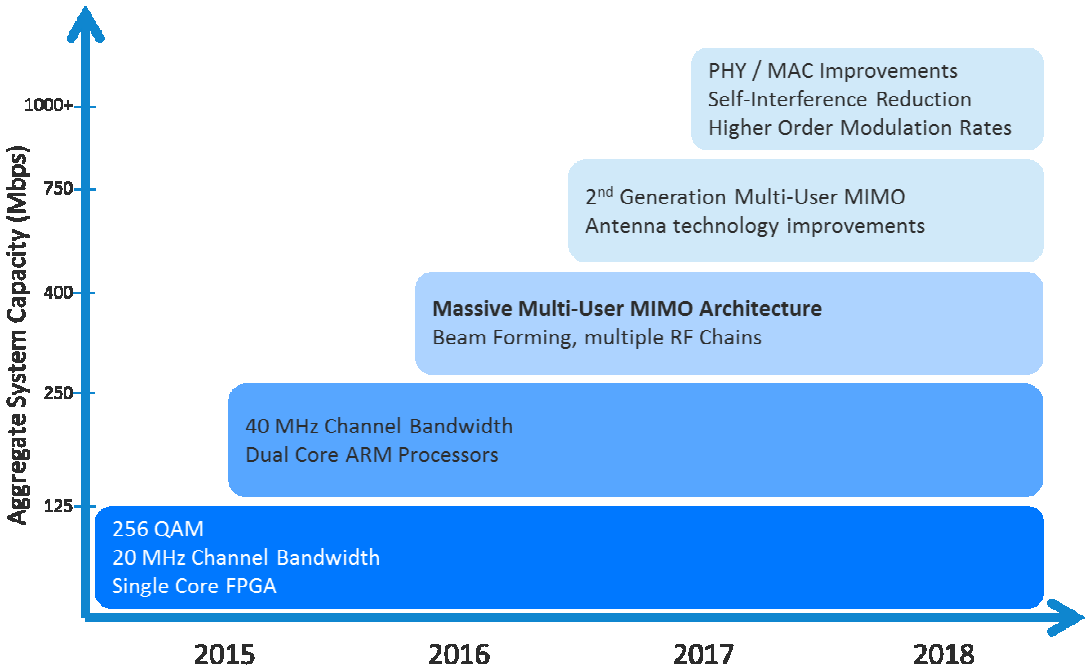

- **Technical fundamentals**

Spectral Efficiency

A key consideration of any wireless technology is the spectral efficiency of the equipment being used. Spectral efficiency is a measure of how efficiently the solution utilizes Radio Frequency (RF) spectrum, and is defined as the throughput achieved per frequency utilized, or bits per second per Hertz (bps/Hz).

Clear spectrum is a scarce resource. Typically, access network technologies employ the use of unlicensed spectrum, which is limited to only those frequencies that regulatory agencies make available for this sort of use. A solution that makes efficient use of this scarce resource provides a superior return on investment to the network operator.

The PMP 450i boasts a great spectral efficiency due to system architecture choices and superior radio design. By combining optimized antenna design, advanced RF radio architecture, and GPS Synchronization, the PMP 450i can re-use the same frequency across the network as shown in the GPS Synchronization example, and does not require any guard band (or unused "fallow" frequency) between adjacent channels to do so. Competing products often require significant levels of guard band in order to work properly when operating in nearby frequencies.

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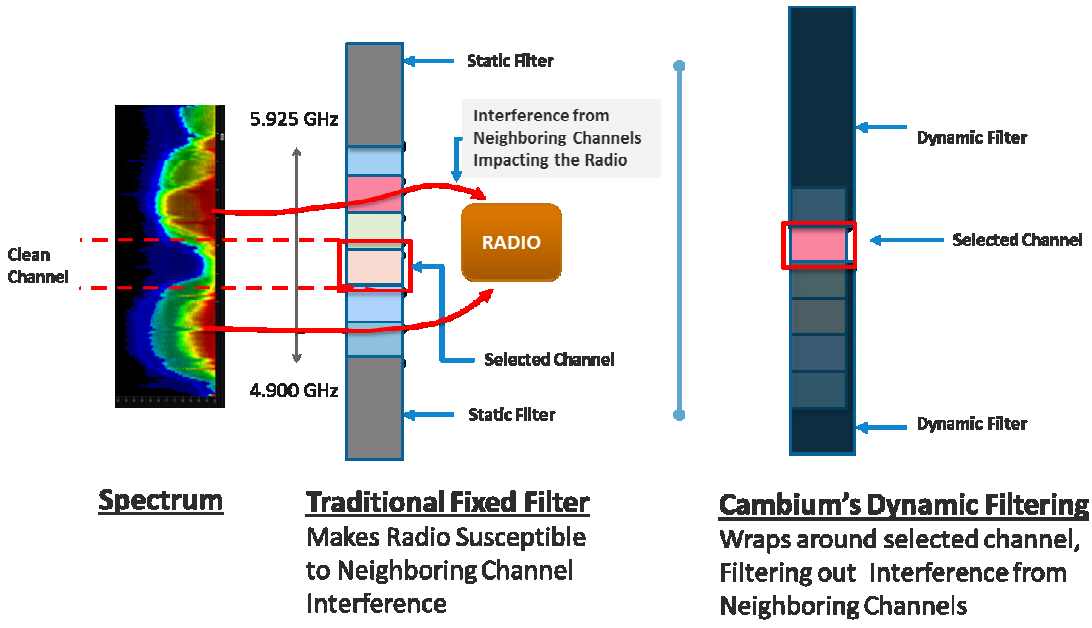
Dynamic interference Filtering

One of the most important features of a radio link is the behaviour under interference environment. A poor interference performance will carry put a very poor real-life performance because of the wide use of the radio spectral.

Traditional Wi-Fi OEM products typically offer filter designs that filter out signals that are outside the permitted range. They however do nothing to mitigate the interference from adjacent channel transmission, which is more common and a major cause of poor performance. Based on Cambium's long experience in noisy outdoor environments, there have been created filters that work across multiple channels. The dynamic filtering technology employed masks out all of the other channels but the channels of interest, markedly improving the clarity of the receiving signals, resulting in fewer retransmissions and higher throughputs across the board for all clients.



Air Interface Protocol

For the most effective interference mitigation, it is crucial to have a network designed to prevent or reduce unwanted signals. This begins with the design approach taken in the Media Access Control (MAC) layer. Unlike many other systems, Cambium designs its MAC frame to carry radio data packets (RDP) of a relatively small size. If and when interference corrupts reception of an RDP, the small size means that retransmission of RDPs is kept to a minimum, assuring a negligible impact on overall network throughput. Cambium's PMP equipment also

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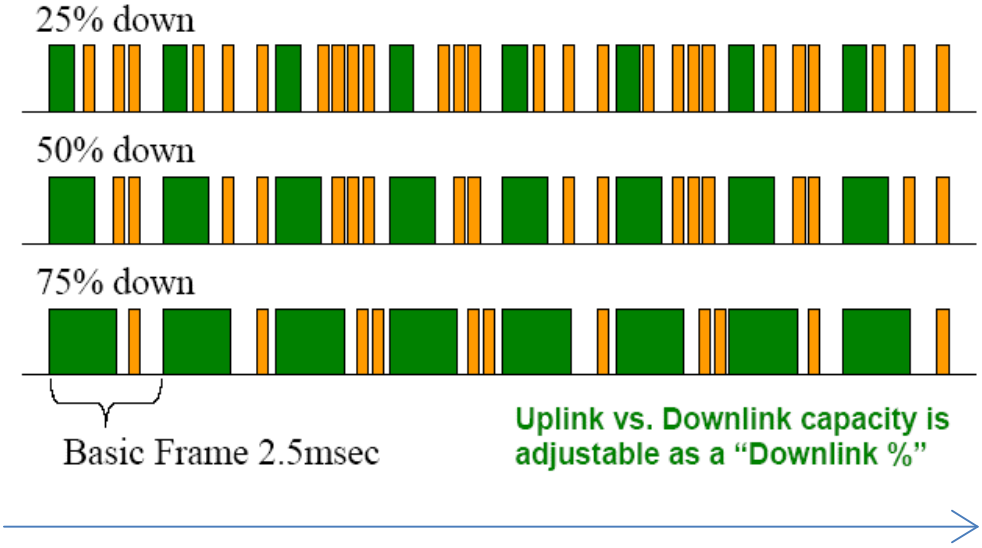
incorporates centralized request-grant transmission control that reduces demand contention and allows SMs to transmit data only when permitted by the access point, reducing data packet corruption and retransmission and maximizing throughput.

Modules use Time Division Duplex (TDD) on a common frequency to divide frames for uplink (orange) and downlink (green) usage, as shown in the figure below:



Efficient and Fast Scheduler

The PMP450i product series uses a TDD (Time Division Duplexing) proprietary frame structure in which the Access Point (AP) and the Subscriber Module (SM) transmit and receive in non-overlapping times using the same frequency. Each transmission frame is 2.5 ms long, and is divided into two portions: a downlink and an uplink. During the downlink time the AP transmits and the SM receives, while during the uplink time the SM transmits and the AP receives. The percentage of frame time dedicated to the downlink is selected by the operator with the Downlink Data parameter, which is a percentage value between 15% and 85%. This allows the operator to dedicate more time to the direction of the most amount of traffic. The downlink and uplink times are divided into symbols; each symbol carries one or multiple data fragments. The PMP450i system can support high throughput and efficiency regardless of the number of subscriber modules connected to the access point, because the downlink and the uplink transmissions are scheduled. A subscriber module does not need to check if the wireless channel is available before transmitting data, as subscriber modules have to do with a listen-before-talk protocol; its uplink transmissions are scheduled at the beginning of each frame, when all subscriber modules receive an uplink map with the uplink scheduling information. This scheduled access method allows the system to utilize all of the frame time, except for the hardware turnaround time and the round-trip transmission delay. The PMP450i scheduler is

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implemented in hardware, making it extremely fast compared to schedulers implemented in software.

Virtual Circuits

Data transmitted between the AP and each SM is carried over Virtual Circuits (VCs). There are 256 downlink and 256 uplink VCs, out of which 238 downlink and 238 uplink VCs are available for data transmission.

VCs can have high or low priority. High priority VCs are scheduled before low priority VCs; therefore, time sensitive data is allocated to high priority VCs. Up to two VCs can be allocated to each SM, one low priority and one high priority VC. If all SMs connected to an AP only have one low priority VC allocated to them, then 238 SMs can be supported by the AP. If all SMs connected to an AP have one low priority and also one high priority VC allocated to them, then 119 SMs can be supported by the AP. Other protocols like 802.11n cannot support such a large number of SMs without compromising the system throughput and latency.

Fragmenting and Guaranteed Packet Delivery

In the PMP450i transmitter each Ethernet packet that needs to be sent is fragmented into 64-byte fragments. One or more fragments are transmitted in each symbol, depending on the modulation mode selected for the transmission. A cyclic redundancy check (CRC) is performed at the receiver and the result is compared to the CRC bits appended to the fragment, which were calculated by the transmitter with the same algorithm. If the two CRCs do not match, the fragment is considered corrupted and the receiving device sends a negative acknowledgement to the transmitting device. This causes the corrupted fragment to be retransmitted. This mechanism is called Automatic Repeat reQuest (ARQ). Only the corrupted fragments are retransmitted, not the whole Ethernet packet. This mechanism, together with the small fragment size, keeps the overhead due to retransmission to a minimum.

The transmitter keeps retransmitting the corrupted fragment until it is delivered correctly to the receiver. The CRC and the ARQ mechanisms guarantee packet delivery and make the system bit-error-rate (BER) virtually zero. Other standard-based protocols like 802.11n and 802.16e stop the retransmission process after a fixed number of failed attempts, leaving the task of recovering the missing fragment to the higher layers. This results in increased latency for the system, because higher layers take a longer time to detect and recover the corrupted portions of the data. Some systems, like LTE and optionally 802.16e, use a soft combining hybrid ARQ mechanism, in which additional transmissions after the first failed one only carry additional redundancy bits, which are used for improving the chances of the channel decoder to correct

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the received information. The original transmitted fragment is stored at the receiver, together with any additional redundancy bits, and the decoding process is attempted after every additional transmission. Even in these systems there is a maximum number of attempts at sending additional redundancy bits, and the fragments that were not decoded correctly after the maximum number is reached need to be recovered at higher layers, increasing the latency of the system.

Low and Predictable Latency

The latency in the PMP450i system is guaranteed to be 3–5 ms regardless of the number of subscriber modules connected to the access point. In other systems using a listen-before-talk protocol, the larger the number of subscriber modules connected to an access point, the more likely it is that a subscriber module tries to access the wireless channel when another module is transmitting. When this happens, all devices waiting to access the network start a timer which has a random value and the timer of the device that expires first after the medium frees gets access to the medium. Therefore, the system latency can grow quickly with increasing number of subscribers. In the PMP450 system this does not happen because all uplink transmissions are scheduled.

Also, the scheduler running at the beginning of each frame schedules data for the current frame. In systems like 802.16e, the uplink scheduler schedules data for the uplink of the next frame, not the current one, thereby adding an entire additional frame time to the latency of the system.

In standards-based systems, like 802.11n and 802.16e, the scheduling latency by itself is on the order of 10 ms; the system latency is much longer, and in listen-before-talk systems like 802.11n, it is heavily dependent on the number of SMs connected to the AP. After the CRC check is performed at the receiver, a positive or negative acknowledgement is sent to the transmitting device, in order to inform the other side if the transmission was corrupted or not.

Another reason latency is low in the PMP450i system is because the acknowledgements for all fragments transmitted in the downlink of a frame are sent in the uplink of the same frame, and the acknowledgments for all fragments transmitted in the uplink of a frame are sent in the downlink of the next frame. This is possible due to the fast processing of received data both in the AP and in the SM.

Rate Adapt Algorithm

The PMP450i system uses a rate adapt algorithm that maximizes in real time the sector throughput. Decisions on the modulation mode to use are based on the changing channel

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conditions of each AP<->SM wireless link. Frame by frame, the AP monitors the quality of the wireless channel and the fragment error rate (FER) for each link, and it selects in real time the modulation mode that delivers the highest possible throughput for the current downlink or uplink transmission.

This mechanism is called a rate adapt scheme because the modulation selected for transmission to and from each SM adapts to the changing conditions of the radio link between the two units. The two-transmission links (downlink and uplink) can be affected differently by the current fading conditions. For this reason, the rate adapt algorithm runs separately on the AP and the SM, which means that each module can transmit and receive at different modulations.

The main benefits of the rate adapt scheme are:

- Increased spectral efficiency: the system operates at the higher data rates for the longest possible time, therefore increasing the overall sector capacity.

- Increased link availability: selecting lower modulation levels the received signal quality improves, increasing the fading margin for the link.

- Reduced service interruptions: during long fading events, the system can still operate at lower modulation levels without interruption of communication, which would happen if the system tried to operate at higher modulation levels.

Interleaving

The PMP450i system uses interleaving of transmitted data at higher order modulation. If transmission in a symbol happens with 16-QAM, 64-QAM or 256QAM modulation, the symbol carries 2, 3 or 4 data fragments respectively. The bits in the 2 (3 or 4) fragments are interleaved so that bits from all fragments are mapped to bits with all levels of robustness in the QAM constellation.

For example, in the 64-QAM constellation, six input bits are mapped to one modulation symbol (three on the I axis and three on the Q axis). Comparing performance for each of the three symbols in the two axes, the first (most significant) bit is the most robust because adjacent symbols share the same value for this bit. The last (least significant) bit is the least robust because adjacent symbols have opposite values for this bit. Performance of the middle bit is in between the performance of the most and least robust bits. In systems with no interleaving, when sending three fragments with 64-QAM modulation, it can happen that all bits from one fragment are mapped to the least significant bit in the 64-QAM constellation, all bits from the next fragment are mapped to the middle bit in the 64-QAM constellation, and all bits from the last fragment are mapped to the most significant bit in the 64-QAM constellation. The result of

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this mapping is that the fragment error rate (FER) of the three fragments is different, making the first fragment more susceptible to loss and retransmission. As the channel quality degrades, the number of errors in the first fragment increases faster than in the other fragments, to the point that the decoder cannot correct the large number of errors and the fragment needs to be retransmitted.

In a system with interleaving, an equal number of bits from the three fragments is mapped to the most robust, middle and least robust bits in the 64-QAM constellation. The result of this mapping is that the FER of all three fragments is the same. Instead of having errors grouped in the first fragment, the errors are equally spread in the three fragments, increasing the probability of correcting all of them with the channel decoder.

Other systems, like 802.16e, 802.11n and LTE, use interleaving for a different purpose, namely to spread the information across the communication channel. When frequency selective fading affects a portion of the channel, errors occur in adjacent subcarriers. If adjacent subcarriers carry adjacent information bits, the errors in the fragments will occur in adjacent bits, and some decoding schemes, like the Viterbi convolutional decoder, are not able to correctly recover the transmitted data in this case. By interleaving the data, errors are spread and the decoder has a higher chance of correcting the errors. In the PMP450 system interleaving is not used for this purpose, because the block decoder used in the PMP450 system has the same performance regardless of the location of the errors in the communication channel.

Contention Slots and Random Access

The uplink subframe is composed of a scheduled portion and an unscheduled portion. The unscheduled portion includes a fixed number of symbols equal to the number of contention slots, which is a programmable number set by the operator, plus any symbols not allocated during the scheduling process. The selected number of contention slots is a fixed number of symbols that are reserved for random access. This means that even if many SMs have requested bandwidth, the uplink scheduler can only schedule up to the uplink length minus the number of symbols that are reserved for contention.

Each SM accesses the unscheduled portion of the frame in two cases: when it registers and when it needs to ask for bandwidth. Every time an SM needs to access the contention area, it randomly selects one symbol out of the available symbols in the contention area. If two SMs select the same symbol in the same frame there will be a collision at the AP and most likely both messages will be lost because they interfere with each other at the AP receiver. If the SM does not receive a response to its message sent in the contention area, it assumes that the message was lost because of collision and waits a randomly selected number of frames before attempting to send the message again. The fact that the back off time is selected randomly by

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each SM decreases the probability of two SMs that already collided in one frame will collide again during their next attempt at sending messages in the contention area.

When selecting the number of contention symbols, the operator has to balance two conflicting needs. When the number of contention symbols is small, more symbols are available for data transmission and the sector throughput increases; but if many SMs are connected to the AP and are requesting bandwidth at the same time, the probability of collision increases because only a few symbols can be randomly selected for transmission. More collisions lead to longer latency in the system because the SMs which did not receive an allocation after a bandwidth request will have to wait a random back off time (which gets longer and longer with any consecutive collision) and then ask for bandwidth again. On the other hand, if the number of contention symbols is large, the probability of collision decreases and so does the latency; but fewer symbols are available for data transmission which means that the sector throughput is lower.

Power Control

The PMP450i system offers the Automatic Transmitter Power Control (ATPC) feature that avoids overloading of the receiver by automatically adjusting the power used by the transmitter. This feature minimizes the interference level caused by modules operating in the same band.

Each PMP450i AP is connected to a large number of SMs at various distances from the AP. The attenuation of the signal received from each SM is different, but the AP needs to receive signals approximately at the same power level from each SM. One of the AP's functions is to monitor the power of the signal received from each SM, and send a message to each SM with instructions on how to adjust their transmit power.

This power adjustment happens during registration, and then happens again every two minutes in order to track any changes in the wireless link.

Burst Capability

The PMP450i system supports a sophisticated method to control bandwidth by setting a sustained data rate referred to as Maximum Information Rate (MIR). To account for the "bursty" nature of bandwidth demand, Cambium Networks complemented MIR by developing the Burst Bucket. The allocation Burst Bucket is a theoretical "container" of bits. These bits are stored up during idle periods and can be used by a subscriber module to consume a limited amount of bandwidth at a rate greater than the link's MIR. This enables the data rate to be temporarily higher for a short duration to support downloading large files. As a result, emails, web pages, movies, images, or other files are quickly transferred so that the network can be idle and available for other users while the downloaded data is consumed by the end user.

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In addition to the Burst bucket concept, the PMP450i system supports the concept of MaxBurst data rate. This second level of throttling control enables the service provider to cap the burst rate while still allowing bursting to occur. With MaxBurst data rate, providers can not only tier their levels of service using traditional MIR controls, they can further refine those tiers with burst profiles with a combination of Burst Bucket size and a maximum burst rate.

Let us compare the PMP450i allocation solution with systems supporting other options:

- Systems that allocate bandwidth on a first come first served basis across all users. When the number of users is large and many of them stream large files like videos, one user can effectively monopolize the data frame and delay other users from being scheduled until the next frame. Although this may satisfy the one user, other users are forced to wait for bandwidth to be available. This will affect customer satisfaction as it can slow down or create inconsistent speeds, and may increase latency.

- Systems that use a bandwidth capping mechanism. This method sets the maximum download speed for a user by setting a threshold in the system to conform to a maximum data rate. However, capping bandwidth has performance limitations. This basic level of control provides some help but constrains throughput even in times when additional capacity is available.

- Systems that offer a bursting option with a fixed bucket size. Allowing bursts up to the allowed data rate would potentially reduce the incentive for end users to buy higher tiers of service, since with such a high burst rate capability they can use bursting to obtain faster service while still paying for a lower tier of service. Also, for service providers, not being able to fully control the burst rate could mean that the capacity in their links would be very quickly saturated by bursting traffic with no means to limit the activity beyond the controls of MIR and bucket size. With only these two controls, the network operator could be forced to constrain MIR and the Burst Bucket to levels that would severely throttle activity and yield a poor user experience to end customers.

Beam Steering and MU-MIMO

Beam Steering is a technology that provides a much better radio performance steering the propagation bean focused on the subscriber. Because of that there are important signal improvements that permit a higher level of modulation and thus a better radio link performance.

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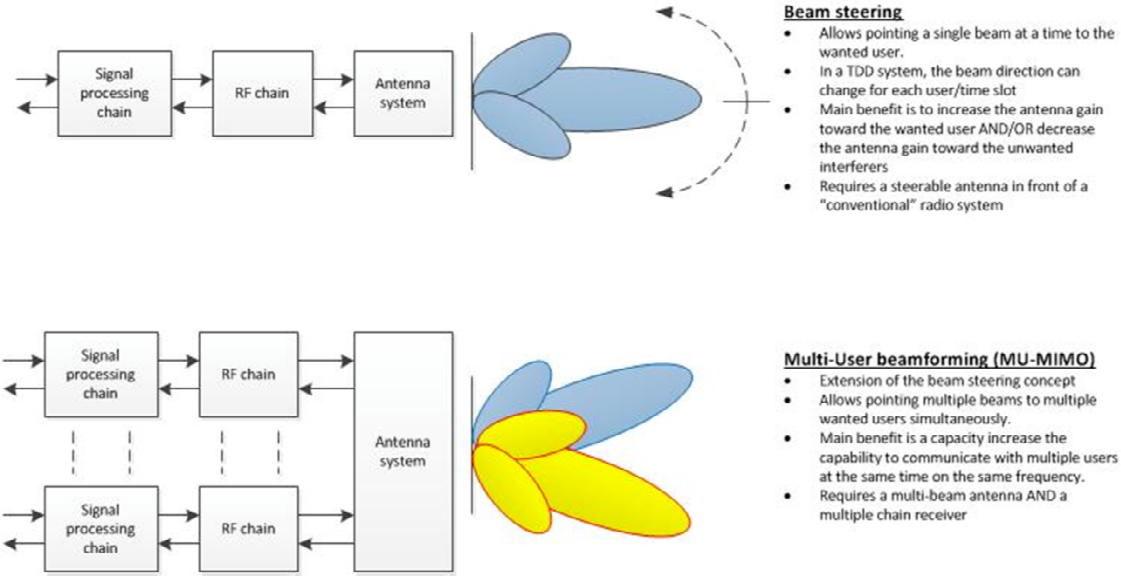

The main benefits of this technology are:

- Cambium MU-MIMO Sector:
    - Single AP Device + Integrated Sector Array Antenna
    - no RF cables to connect
    - Re-use existing frequency plan, no change to RF network
    - Dynamically adjusts to isolate sub-sectors
- Mu-MIMO AP Performance Benefits:
    - >3X Sector capacity increase
    - Higher subscriber density per AP
    - Higher data rate, higher ARPU per SM
    - Higher interference tolerance
    - Enterprise customer focus
- Mu-MIMO AP Operational Benefits

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- Re-use existing PMP 450 subscriber modules
  - SM backward compatible with SW upgrade
- Reduced number of sites
  - Reduced site CAPEX
  - Reduced overall OPEX

- **Conclusion**

The main benefits of the selected technology are:

- Proven field reliability
  - Built upon quality legacy (preceding product fielded for >10 years)
  - >40 Year calculated MTBF (based on field returns and reliability testing)
- Extreme Scalability
  - Access Points can support many subscribers
  - Many Access Points can be deployed at each site for maximal throughput
- OFDM MIMO MU-MIMO
  - 2x2 MIMO provides high bandwidth for LOS access, and a path to MU-MIMO
  - Single payload modulations provide link enhancement for nLOS and NLOS
  - Future-proof your platform investment, utilize PMP 450 SM in the Multi-User MIMO system
- GPS synchronization
  - Maximize spectral efficiency, frequency re-use across network
  - Minimize self-interference, maintain low and consistent latency
- Robust Roadmap for future platform enhancements
  - Serving customer needs for years to come

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4.3 Engineer deployment with corresponding technical teams.

This chapter will describe the engineering process in which the whole Wireless broadband network has been designed through different iterations.

After defining what is the best technology to be used in this project, Sistelec with the collaboration of FSS, has carried out the engineering part of the project.

There is a network deployed in San Sebastian that provides connectivity to some points, like UBA or Gudamenti. This network doesn't cover the needs of performance and bandwidth needed for the new deployment, so an update and reuse of most of them for the new requirements is needed.

The main engineering task was to design the new sites and coverage and evolve the current network to provide the backbone connectivity and coverage to provide Urumea district with a broadband transparent wireless network. So, a complete re-engineering process was required.

During the whole project Sistelec and FSS have been generating different solutions in order to fulfil the FSS requisites like coverage, bandwidth and reliability of the network, among that insuring the security and privacy of the network. Although it will be developed in the following pages, the process of engineering was as follows

- the first need was to design a reliable and resilience backbone network that complementary to the current fibre infrastructure
- Secondly, was to design the hub-sites in order to provide the coverage needed
- Thirdly, was to select the best points for the final clients (note that these clients are devices to provide access to the backbone, they aren't part of a final user, and they are part of the access to provide access to the final services for the citizens.
- Finally, the study of the current deployed network in order to reuse as much as possible devices and sites.
- In the end, there is an iteration feedback process to redesign the network to fulfil are the requirements.

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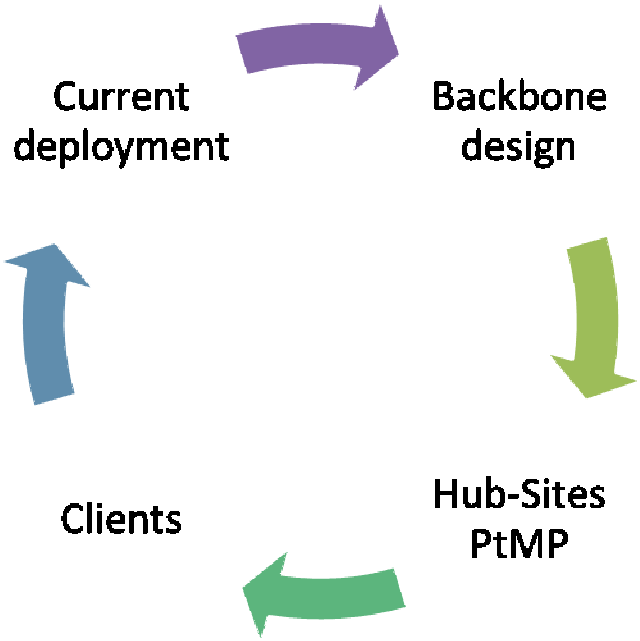

Engineering process deployment

A great challenge was to ensure connectivity with the Urumea district. In that district there is not fibre connectivity, so the backbone network takes much more importance to provide the current and future services for the municipality. Thus, improves the relevance of this network not only to act as a redundant backup network but also to provide the basic connectivity within Urumea district with the rest of the control centres and services provided. This backbone network will be used also to add more resilience to the whole municipality network ensuring the best solution related with the total costs needed.

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Location of the URUMEA district related with San Sebastian City

4.3.1 Backbone Network

All the wireless networks should be connected to the backhauled network in order to provide the requested services and also to have a central management.

San Sebastian municipality has several sites in which this interconnection between networks could be possible. These points should have a fibre connectivity that ensures enough bandwidth and less delay in the communications.

As it was described before one of the most important feature of this backbone might be the reliability. In order to ensure that, Sistelec according with FSS has designed a ring topology that ensures that in case of any device or link failure, there is another path to reach a fibre point interconnection.

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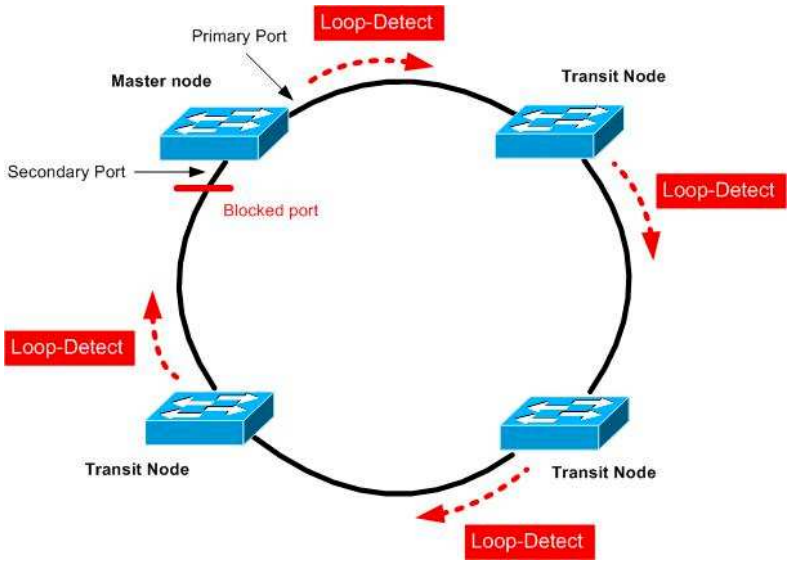

Typical Ring network

As the above image shows, in a ring topology there are two paths for each node, so in order to avoid loops, the network should be configured to detect and block these loops. This will ensure that the traffic is sent through the best path but it is not sent through links that are not good enough or there is a duplicate traffic. However, if one of the links is faulty, the network automatically detects it and is able to reroute the traffic to the other path to finally reach the desired node, as it is shown in the below image.

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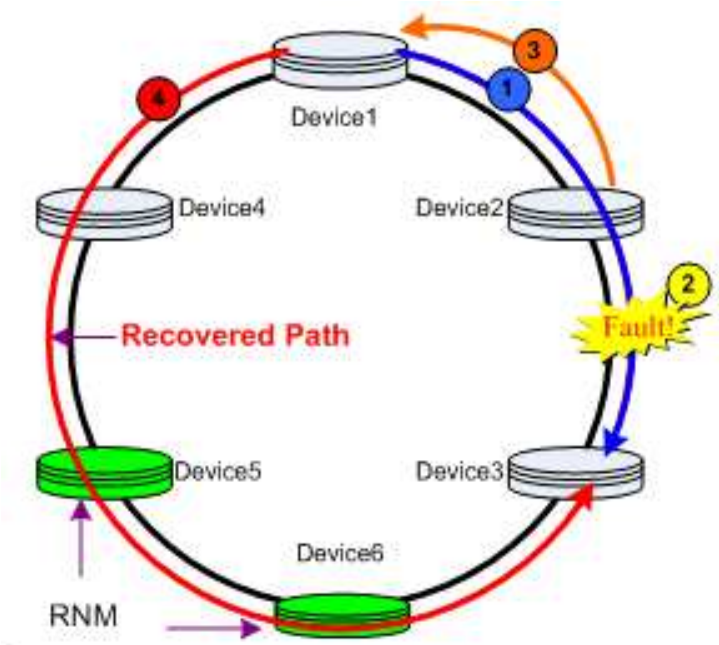

Ring topology link fault

Once the network topology is defined it is important to select the best sites in which install the wireless backbone network.

- Site Select

As It is said before it is very important to select the best points that ensures wireless connectivity as well as fibre interconnection points. After multiple iterations, the selected sites should provide connectivity to the municipality fibre points, and in place where there is no possibility of that, to provide a ring topology that interconnects those points with the fibre points. So, the sites selected with that premises are:

The fibre sites are:

- Uba
- Easo
- Igentea

The intermediate sites are:

- Torre Vodafone

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- Gudamendi
- Urgull
- Ulia

These points are located in San Sebastian city as the following image:

Backbone site selection

In the below image are shown the fibre interconnection points and the points used as support for the connectivity.

Because there are three different points of interconnection, Sistelec and FSS decided to create a double ring that ensures a double point of failure and also a cost-efficient solution. With this topology there are always at least two interconnection points and also, a double path to each point. To enable this redundancy without problems of looping, the Spaning Tree Protocol (STP) is deployed that ensures the redundancy paths to several network points connecting or disconnecting automatically certain paths to enable the communication in real-time and with redundancy.

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This network as it was said before, provide the connectivity for the Point to Multipoint network needed to illuminate with coverage the area of Urumea of this project.

In addition, to provide the best performance, taking into account bandwidth delay and jitter, only one hop is enabled to connect to the fibre point from any other network device. Thus provides as it is said before, the best performance solution.

With the sites selected the Sistelec has designed a double ring network as it is shown in the following image:

Backbone Point to Pont Links

As it is shown, there are two different rings, one that is composed by the sites URGULL, ULIA and EASO

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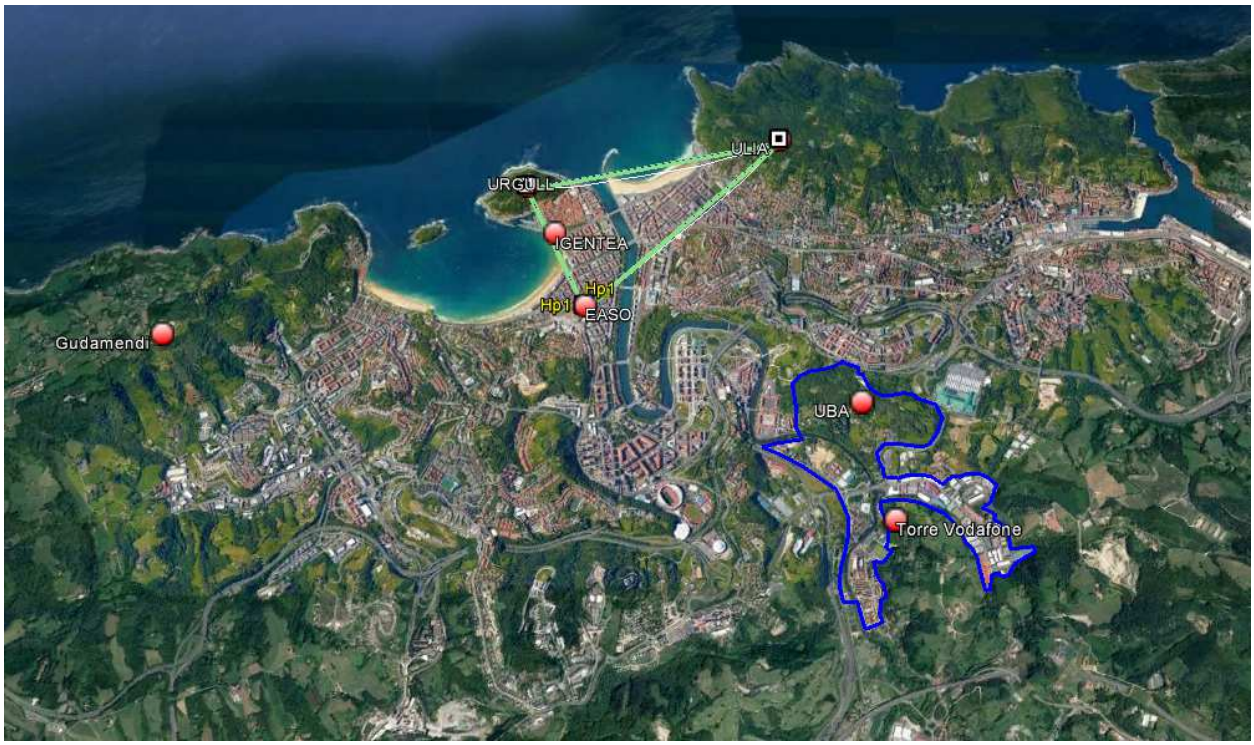

Backbone Ring 1

And the second one that is composed by the sites: INGETEA, GUDAMENDI, TORRE VODAFONE AND UBA.

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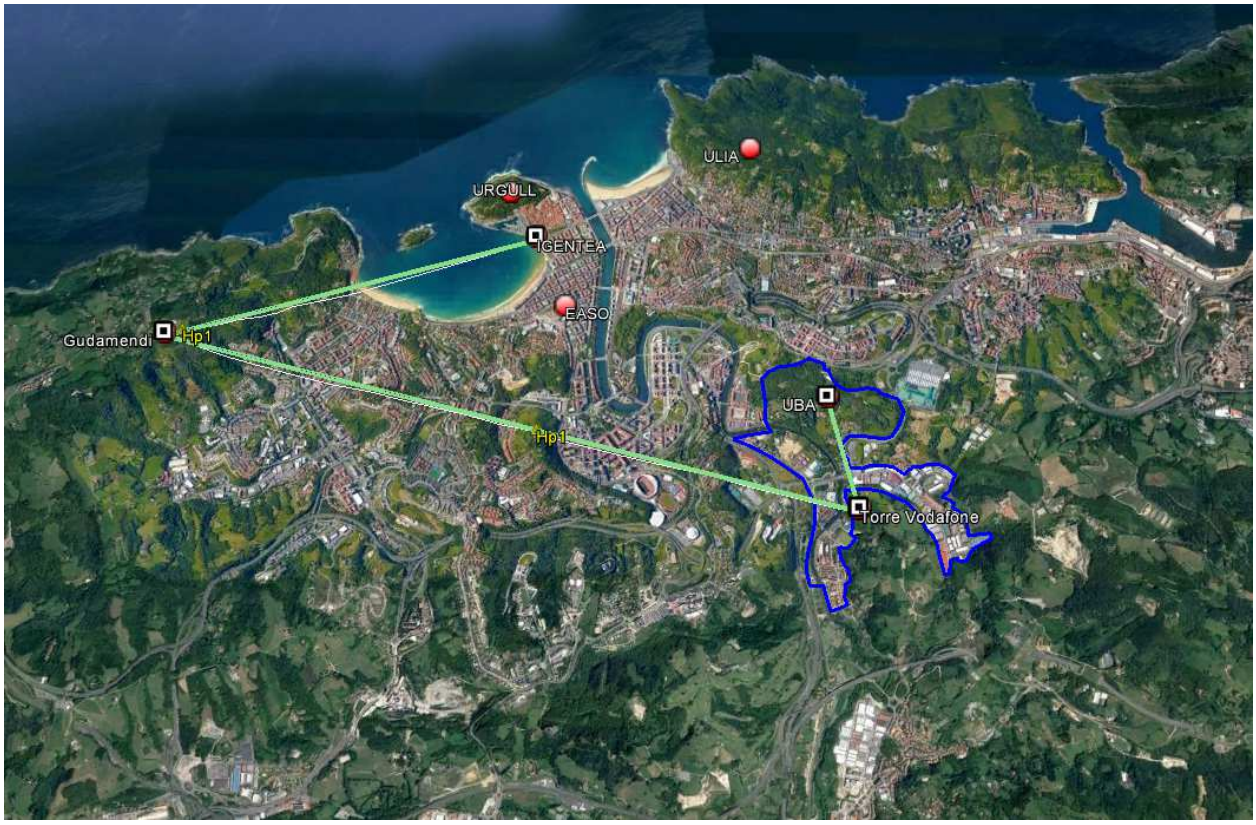

Backbone Ring 2

The interconnection to the municipality network is made in the sites, UBA, INGETEA and EASO. With these two rings, always there is a redundancy to reach one of these sites through two different paths.

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4.3.2 PtMP Network

In this chapter, it is described how Sistelec, in collaboration with FSS, has designed the PtMP (Point to MultiPoint) network that is the main scope of the PostWIMAX distribution network.

The first task was to select the best technology future proof that ensures the fulfilment of the San Sebastian requirements in terms like: reliability, resilience, performance (throughput and latency), security and privacy. Sistelec has selected Cambium PMP 450i devices like a future proof and high-performance technology.

The study and selection of this technology was done in previous chapter, so it is not the target of this chapter to develop more about this.

A Point to multipoint network is based in coverage. So, in order to get the best performance, it is mandatory to select the best points in which install the hubs and sites.

- Hub selection

The scope of the hub selection is to provide as much coverage as possible with the minimum access points. So, in order to provide the desired coverage and after the backbone site selection Sistelec has collaborated with FSS to finally select the Hub points in which devices AP 450i provide broadband wireless coverage.

Hub selection

The selected sites use the municipality fibre backbone network when it is possible and the wireless backhaul network in the hubs where there is not any fibre connection. Thus, makes an

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impressive network that uses the best backbone communication in each hub and also provides the desired coverage.

Another important factor is to provide at least one redundant Access Point for the subscribers. This redundancy provides the necessary resilience for the subscribers that in the worst case that an Access Point was in failure, there is another to which the subscriber can connect to. It is important to note that in an urban environment one subscriber that seems to be under a coverage area, buildings and the physical installation could cause that the nearest Access Point couldn't provide a valid path to be connected to, so another Access Point that provides coverage will be used.

The selected hubs are:

- UBA
- GUDAMENDI
- TORRE VODAFONE
- URGULL
- ULIA
- ESTACIÓN TOMASENE

In all the hub sites, there is at least one AP 450i with an integrated 90º antenna. This solution provides an initial estimated coverage that could be shown in the following image:

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Estimated coverage for the hub selection

The previous figure shows the rough coverage estimated for all the sites selected. Asit could be seen there are sites out of the scope area of URUMEA. These sites, such as Estación Tomasene, are needed to provide the desired redundancy and also for some special dark areas that are identified in a deeper and much more precise coverage analysis.

It is important to note, the collaboration between public and private companies like Torre Vodafone, in which a private tower with private network could be used in the scope of this project thanks to the deep collaboration between organizations.

- Subscriber selection

After having the sites that proved the coverage, the next step is to design where it is necessary to install the subscriber in order to get the municipality network to provide the desired services to citizens.

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The subscriber device has two different networks, one broadband wireless network that connects to an Access point and Ethernet that provides the network connectivity to any desired device. Those devices could provide one or several services like WFI (municipality WIFI access point), traffic lights control, remote sensor measurements, etc. Any device or service that could be provided by an Ethernet port might be suitable to be integrated with a subscriber. This flexibility will provide the basic network that serves as a basic infrastructure to provide wireless services to citizens but also supports other municipal services and can be used by local companies to deploy their own services.

The selected subscribers can be shown in the following image.

Subscriber selection map

The services provided in an initial phase to the URUMEA area thanks to the deployment of the wireless broadband network are:

- Access to the whole municipality WiFi network and platform. Thus, provides the possibility to host any municipality information service.
- Monitoring different points of the network such as, streetlight, traffic lights flow controls, sanitation network, surveillance and traffic cameras…

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- Support for the WIFI network and wireless mobility services to some municipality departments (Local Police vans, civil protection, temporary information screens…
- The wireless broadband network is also disposed to the rest of the REPLICATE partners, to deploy and/or help with some services such as, video and voice transmission, and some data that helps to monitor the partner network (smart streetlights for example).

- Coverage studies

After an initial coverage analysis, Sistelec has performed a wide coverage analysis in order to be sure that the zone selected. A deep knowledge of propagation and also the interrelationship between different hubs, provide a total coverage as it is shown in the figure below:

Deep coverage analysis

These studies have been done for each site and also in an addition environment. So, in order to clarify which sites are needed to install and also, what is the detailed estimated coverage for each hub Sistelec have performed several high detailed coverage analyses.

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For instance, the Urgull Site 1, which seemed to be a little far away the desired coverage area, provides coverage for the north-west zone of the Urumea district as it is shown in the following Figure:

Urgull hub coverage analysis

For the Ulia site, the estimated coverage provides coverage for the north, north-east area.

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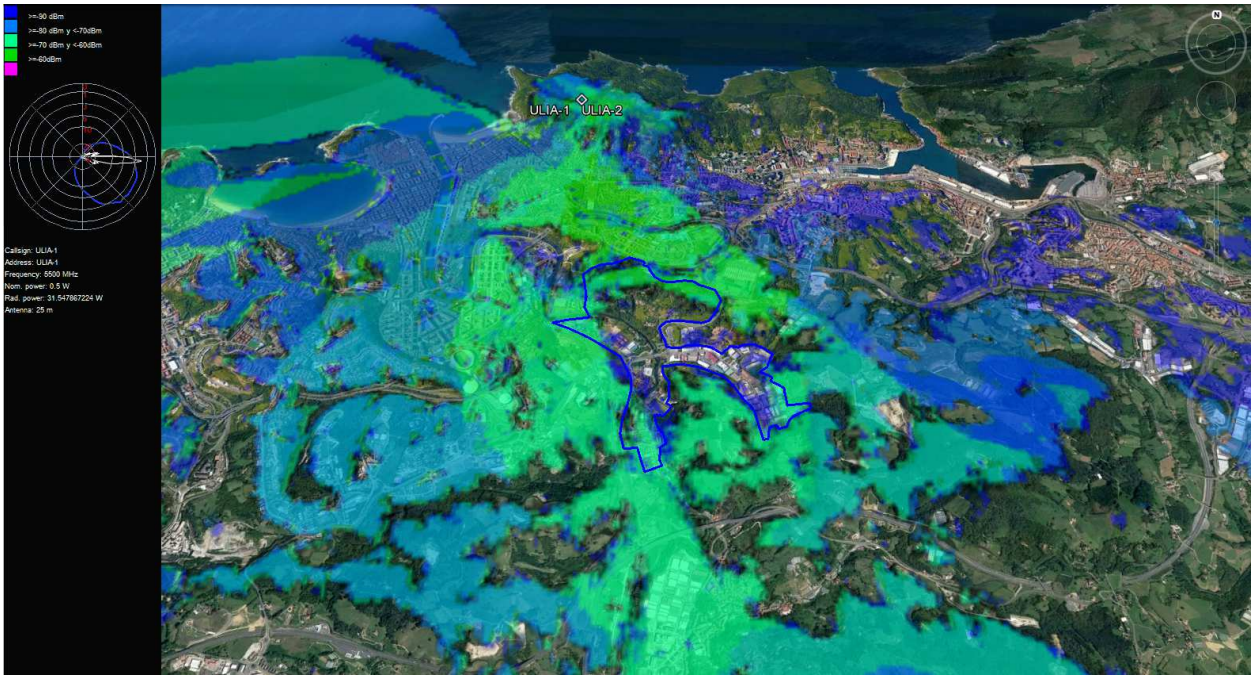

Ulia coverage analysis

Torre Vodafone is closest to the district and it was by itself one a very interesting point. It provides coverage with its two sectors to the zone and east part of Urumea area.

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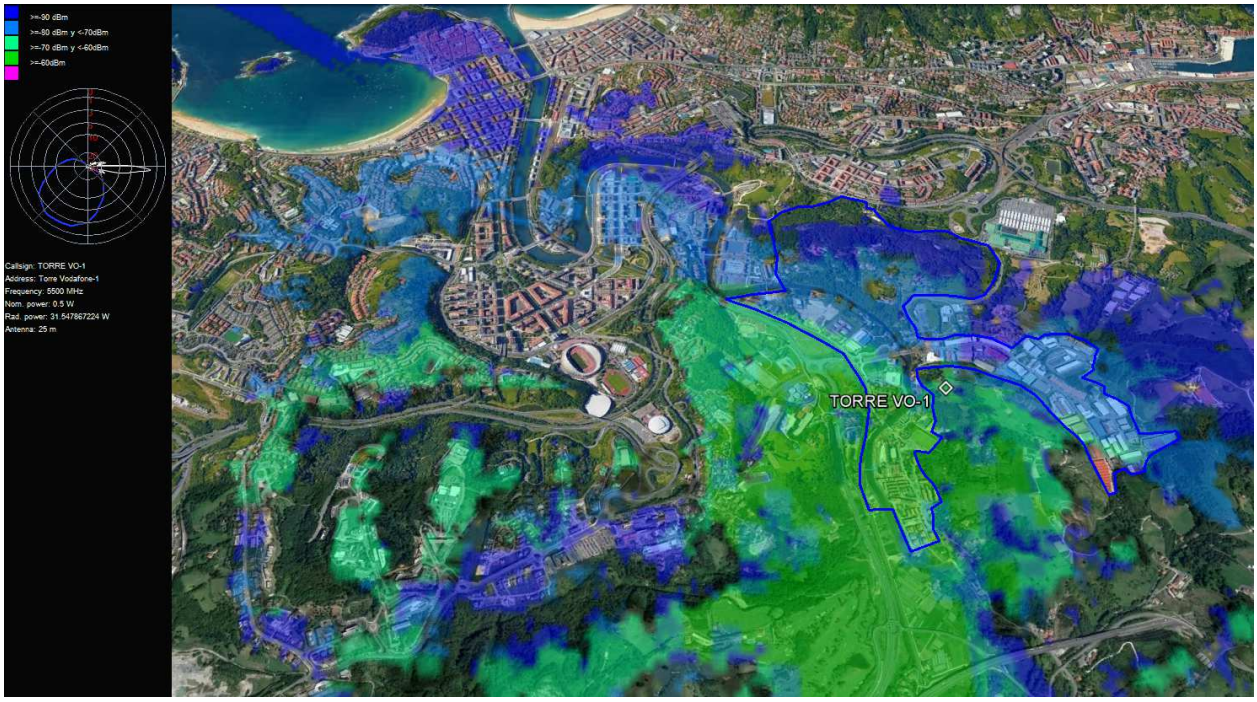
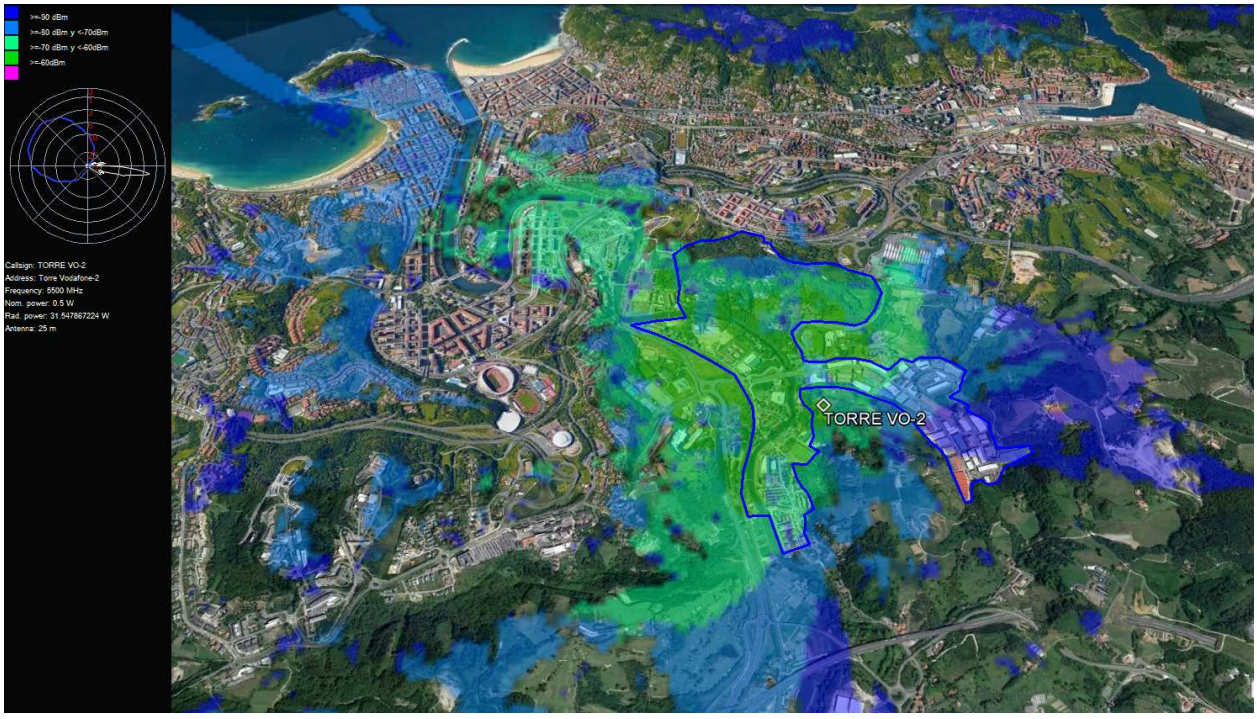


Torre-Vodafone 1 coverage analysis



Torre-Vodafone 2 coverage analysis

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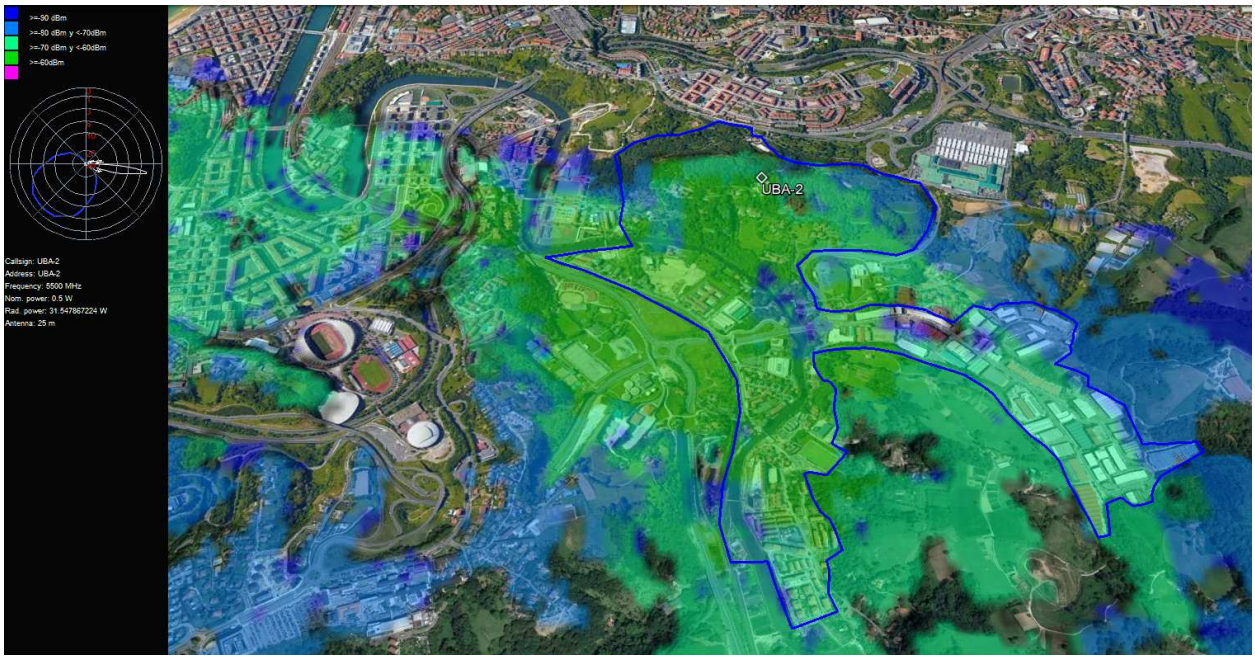
Also, from Uba it is provided a coverage to the centre of Ulia area, as it is shown in the following figure:



Uba coverage analysis

As it is shown there was necessary to provide coverage from several hubs to cover the whole area of Urumea district. Also in order to be completely sure that there is an access point to communicate with the subscribers there are necessary to provide coverage with at least two different Aps for each point.

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4.4 Perform the technical installation, put into service.

Once the engineering phase has ended, the next step is the physical installation of the different devices into their final locations. The most important installations are both the backbone and also the sites, in which the Aps are installed. This is because the backbone needs to provide the connectivity to the municipality network and the sites the coverage needed to deploy the final subscribers.

The description of the installations is divided into three blocks, the backbone, the site hubs and the subscribers.

4.4.1 Backbone and AP network:

The backbone network has to provide the connectivity between the municipality fibre core network with the sites/Aps that also provides coverage to the subscribers.

The backbone network design is as follows:

Backbone network design

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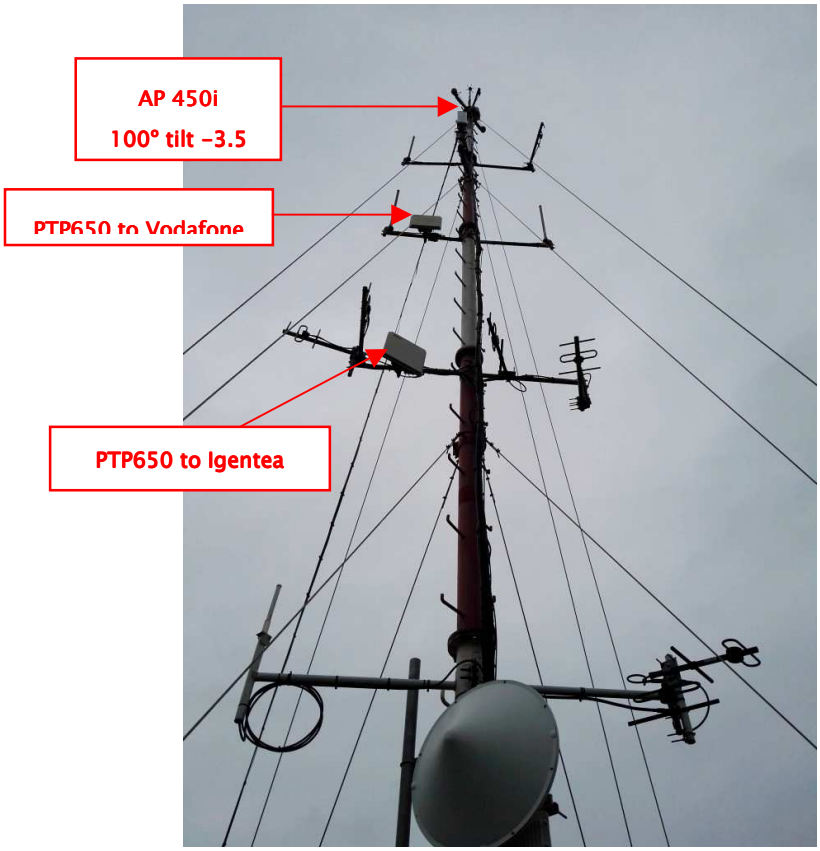
- GUDAMENDI

Gudamendi is located in the coordinates:

Lat	43°18'45.19"N
Long	2° 1'26.07"O
Height	257m
Datum	WGS-84

The antenna installation could be done as follows:



Gudamendi Antenna and installed devices

Is was necessary also to pass all the cables to the internal cabinet in order to have everything controlled, tagged and interconnected.

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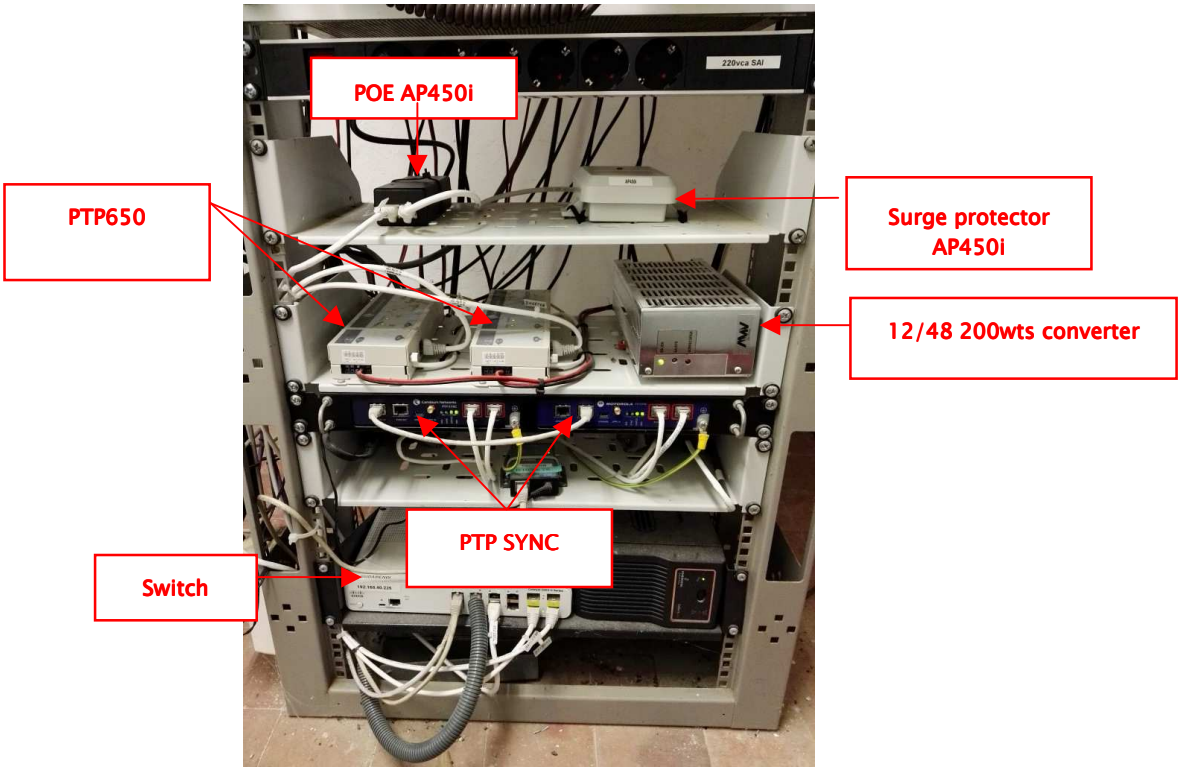

Gudamendi Cabinet installation

- Ulia:

Ulia is located under the following coordinates:

Lat	43°19'42.57"N
Long	1°57'46.88"O
Height	179m
Datum	WGS-84

In this case the devices are installed in the building as it is shown in the following pictures:

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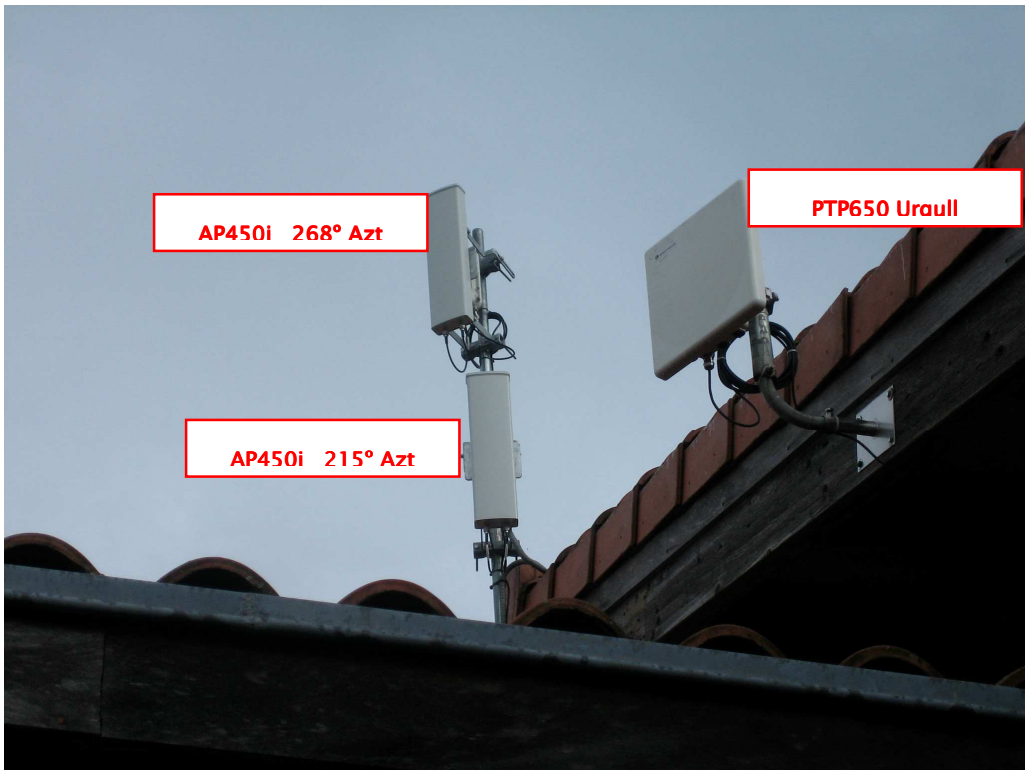

Devices in the roof Ulia

Device in the roof Ulia

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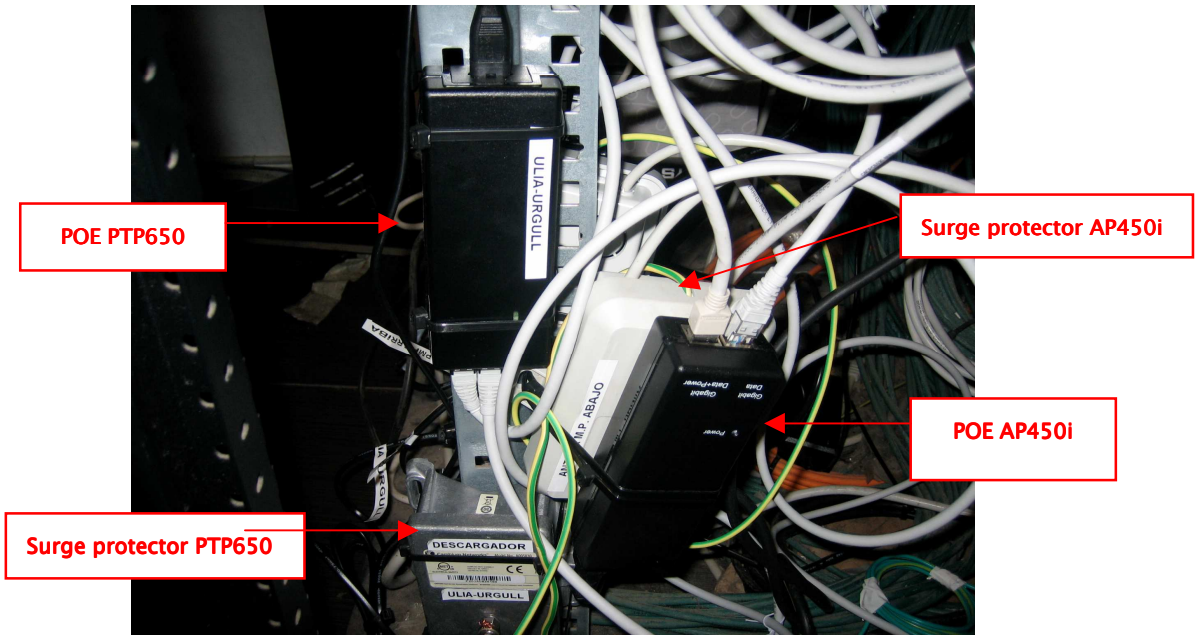
The indoor devices are allocated in the cabinet:

Ulia Cabinet



Ulia Cabinet detail

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- Urgull

Urgull is located under the following coordinates:

Lat	43°19'29.81"N
Long	1°59'20.16"O
Height	124m
Datum	WGS-84

In this case the devices are installed in the building as it is shown in the following pictures:

PTP Device in Urgull

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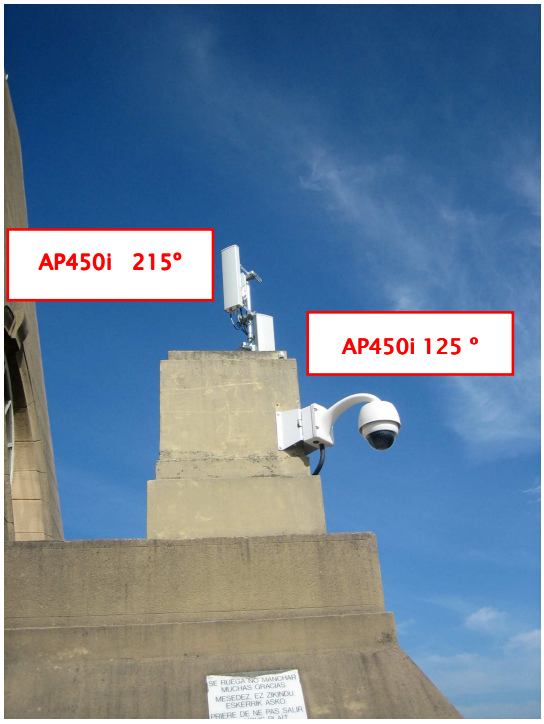
PTP Device in Urgull



Front view of Urgull sector

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Rear view of the Urgull sector

The indoor devices are allocated in the cabinet:

Urgull Cabinet

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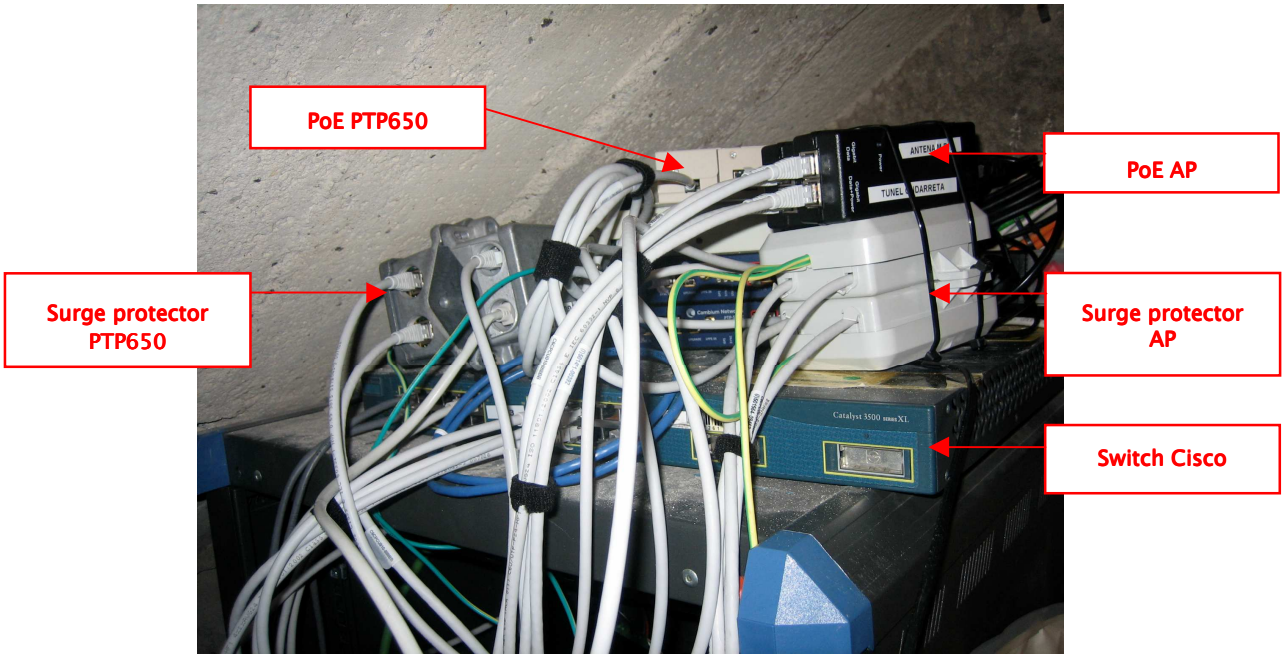

Urgull Cabinet detail

- Igentea

Igentea is allocated in the city town of San Sebastian. It is located under the following coordinates:

Lat	43°19'17.15"N
Long	1°59'9.61"O
Height	6m
Datum	WGS-84

The physical installations of the devices are as follows:

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PTP 650 Igentea installation

There are also two sectors installed in the same building as they are shown in the following figure:

AP 450i sector installation of Igentea

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- Torre Vodafone

Torre Vodafone is allocated in the following coordinates:

Lat	43°17'57.24"N
Long	1°57'6.29"O
Height	59m
Datum	WGS-84

In this case, the installation is in a tower that provides a wide coverage area as it is shown in the following figure:

Torre Vodafone tower

So, the devices are allocated in the tower as well as the indoor devices in the communications cabinet:

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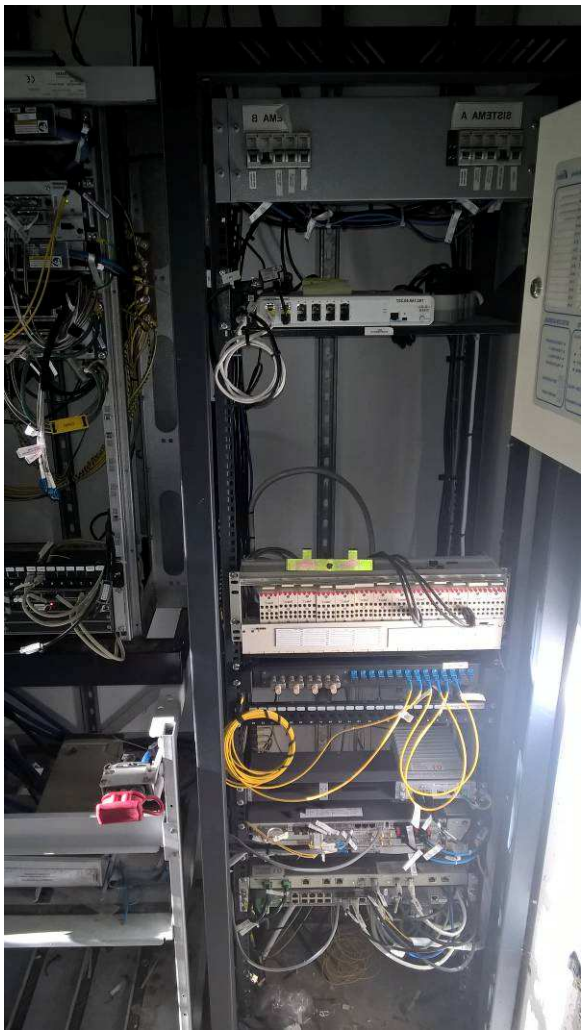

torre Vodafone Cabinet

- Uba

Uba is allocated in the following coordinates:

Lat	43°18'28.43"N
Long	1°57'17.98"O
Height	74m
Datum	WGS-84

The devices are installed as the following figure:

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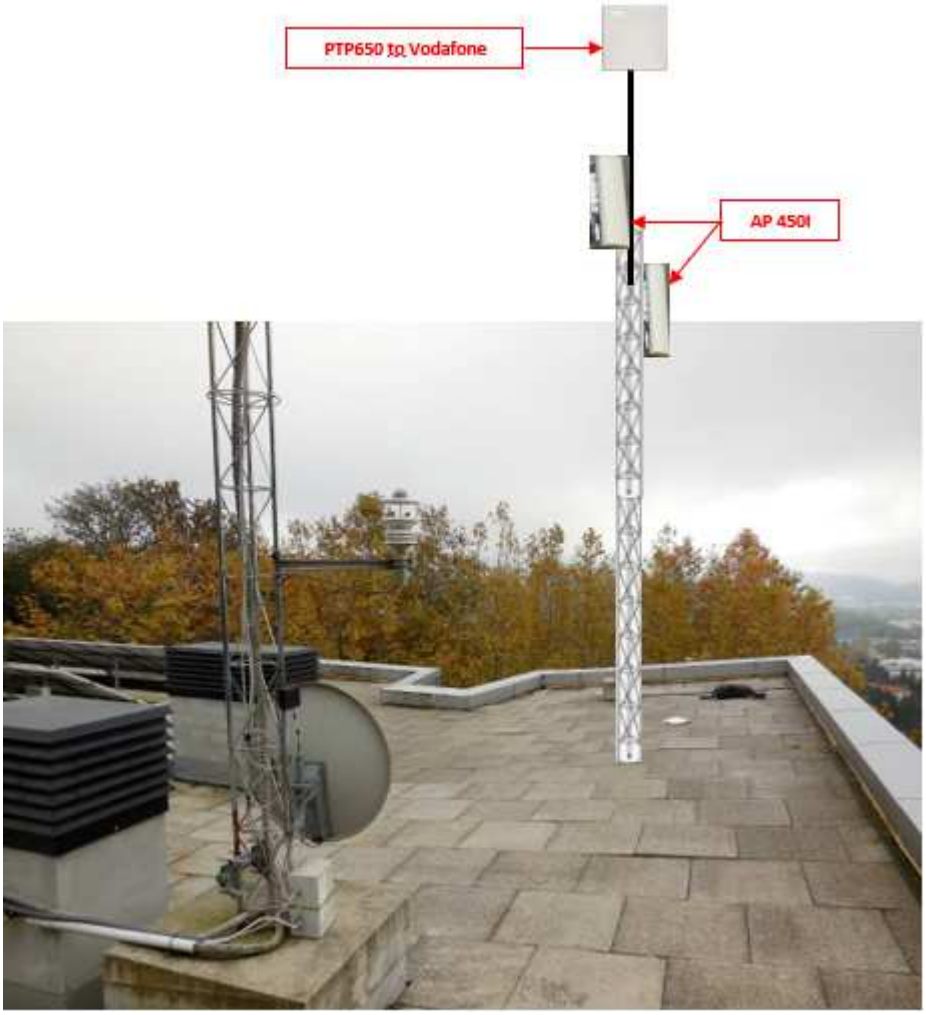

Devices installed in Uba

And also in the indoor communications cabinet:

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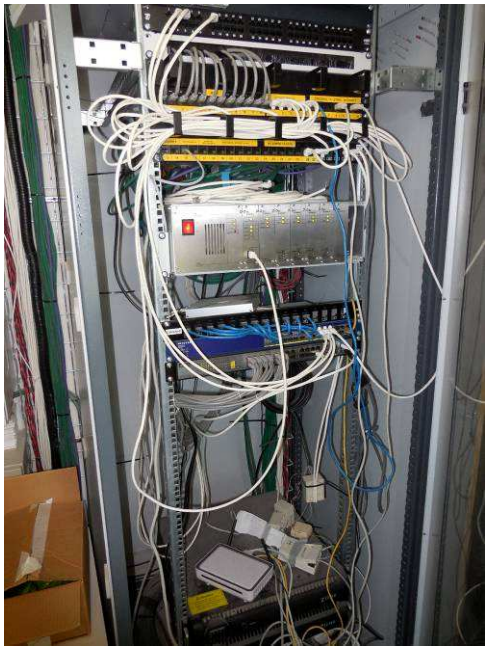

Uba Communications cabinet

- Easo

Easo is allocated in the following coordinates:

Lat	43°18'28.43"N
Long	1°57'17.98"O
Height	74m
Datum	WGS-84

There are installed two PTP 650 that interconnects this site with Urgull and Ulia.

The physical installation in the communications tower could be shown in the following figure:

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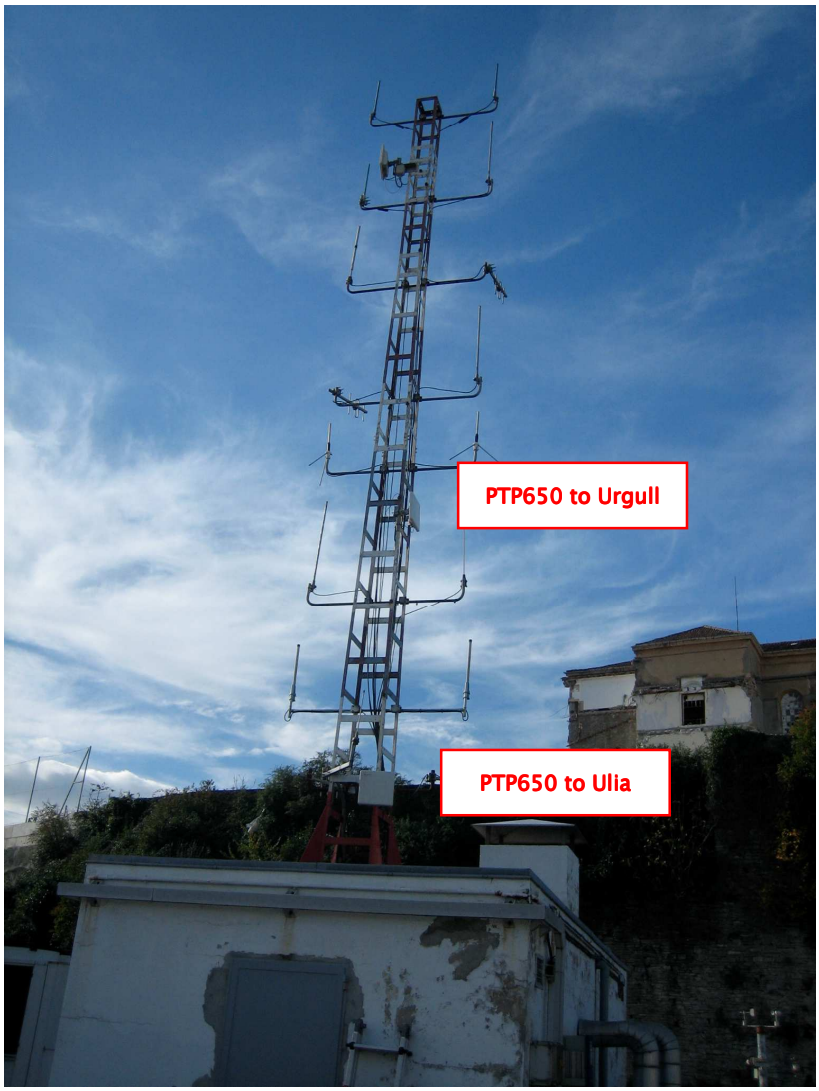

Easo Communications tower

4.4.2 Subscriber installation

There are multiple subscriber's installations in a wide variety. These subscribers are the devices that connect to one Access Point and provide the backbone municipality connectivity to the services remotely deployed. These services could be any device with an Ethernet connection and IP network connectivity.

The subscriber installations could be shown in the following figure:

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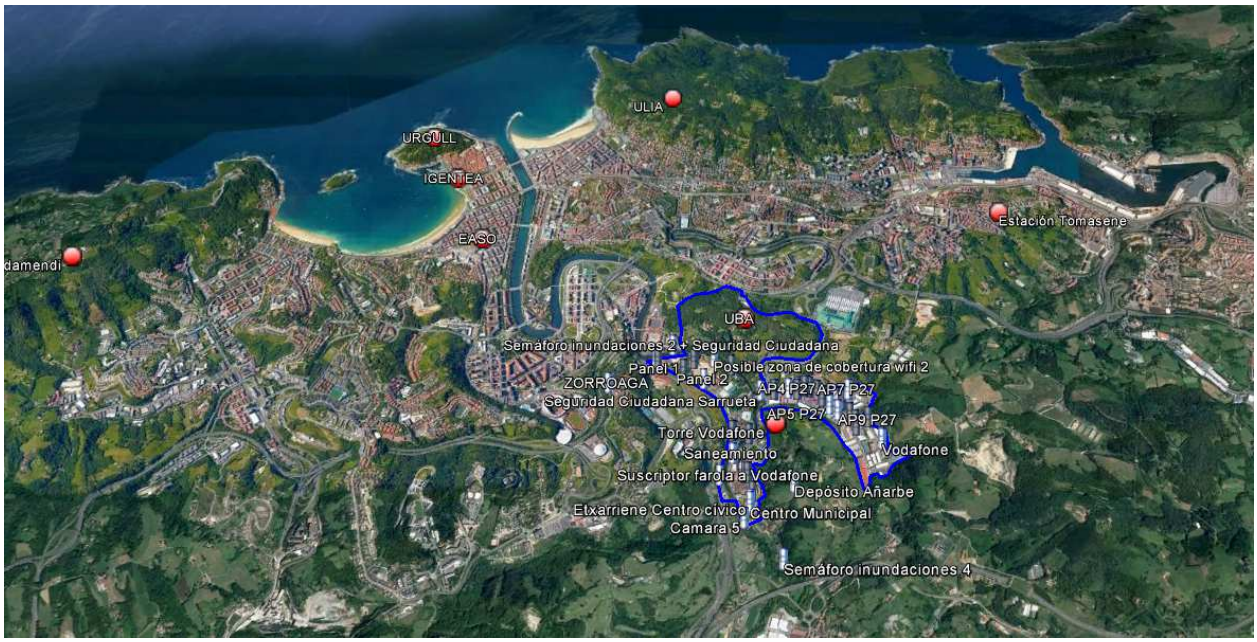

Subscriber allocation

And also, how these subscribers are connected to an AP could be shown in the following picture:

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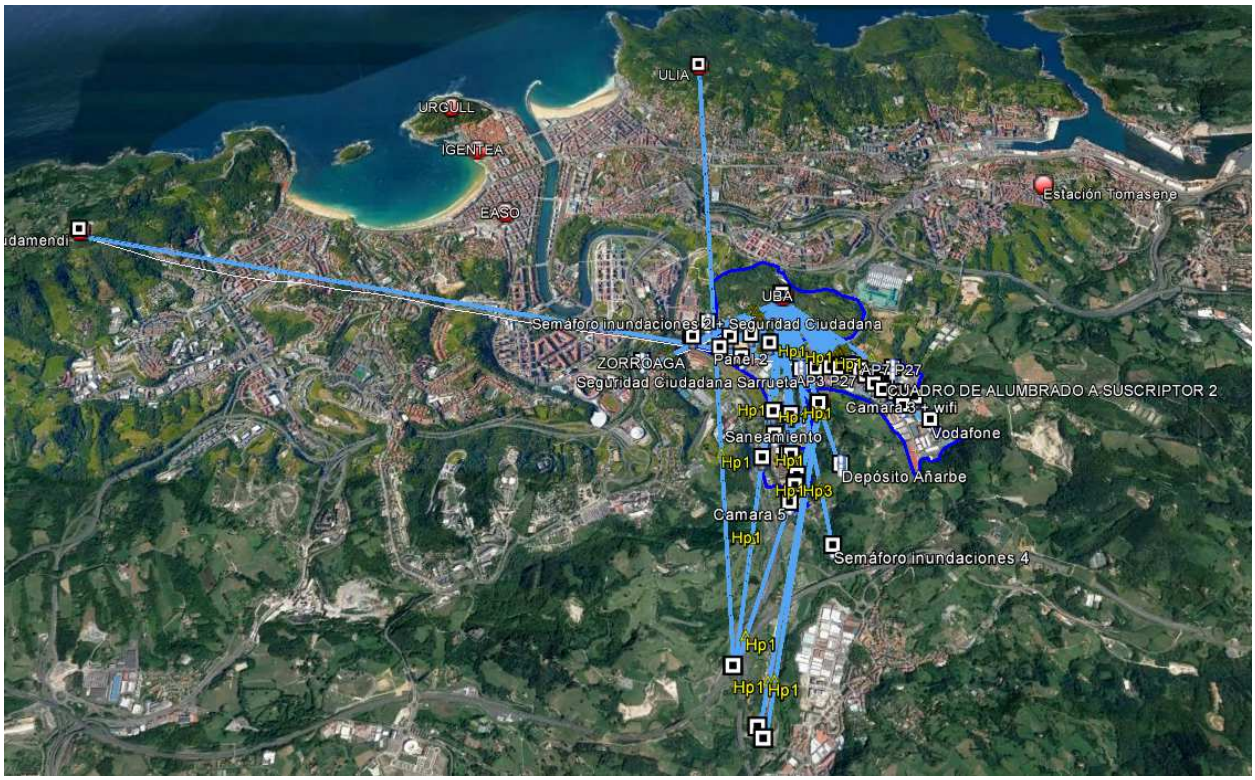

Subscribers Point to Multipoint links

In the previous figure it is possible to note the main AP to the subscriber connects to as a first option, having at least another one spare to be connected in case that the main AP fails. Thus provides, as it is said before, an upstanding reliability and resiliency to the network.

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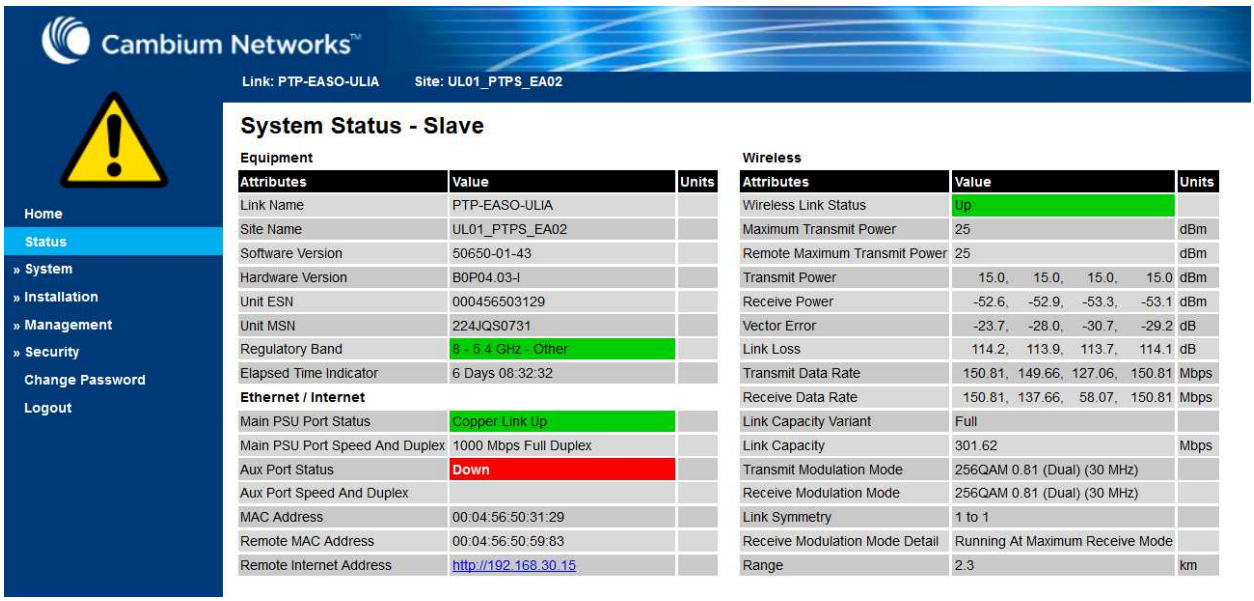
4.5 Produce municipal measures and real test technical trials

Before to start the monitoring phase, Sistelec with FSS have been carried out several measures in order to get an estimation of the packets used in the system.

At the initial phase the most important measures are related with the air interface, related with signal strength and signal to noise ratio. If these parameters are correct then the devices could operate in an elevation modulation mode that provides a greater bandwidth and less delay. As it is described before in this deliverable, the main parameters for a service should be throughput and delay depending of the kind of service. For instance, voice services are critical for delay, however a high volume of date is more important the throughput.

In the Point to Point installation, there is a unique air interface link within two devices. While the initial installation is done, there is an alignment process in which both devices are moved to get the best quality of signal possible. After a while it is necessary a realignment process to ensure that the initial installation is right.

For instance, the Point to multipoint link between Easo and Ulia could be shown in the following figure:



PTP link Easo-Ulia status

As it is shown in the previous figure, there are great values in signal strength and also the in signal to noise ratio, in this case the receive power (RSSI signal) is in order of -52 dBm, and the signal to noise ratio in these devices could be obtained with the vector error that is ratio between received signal with the theoretical signal that should be received. In this case is in

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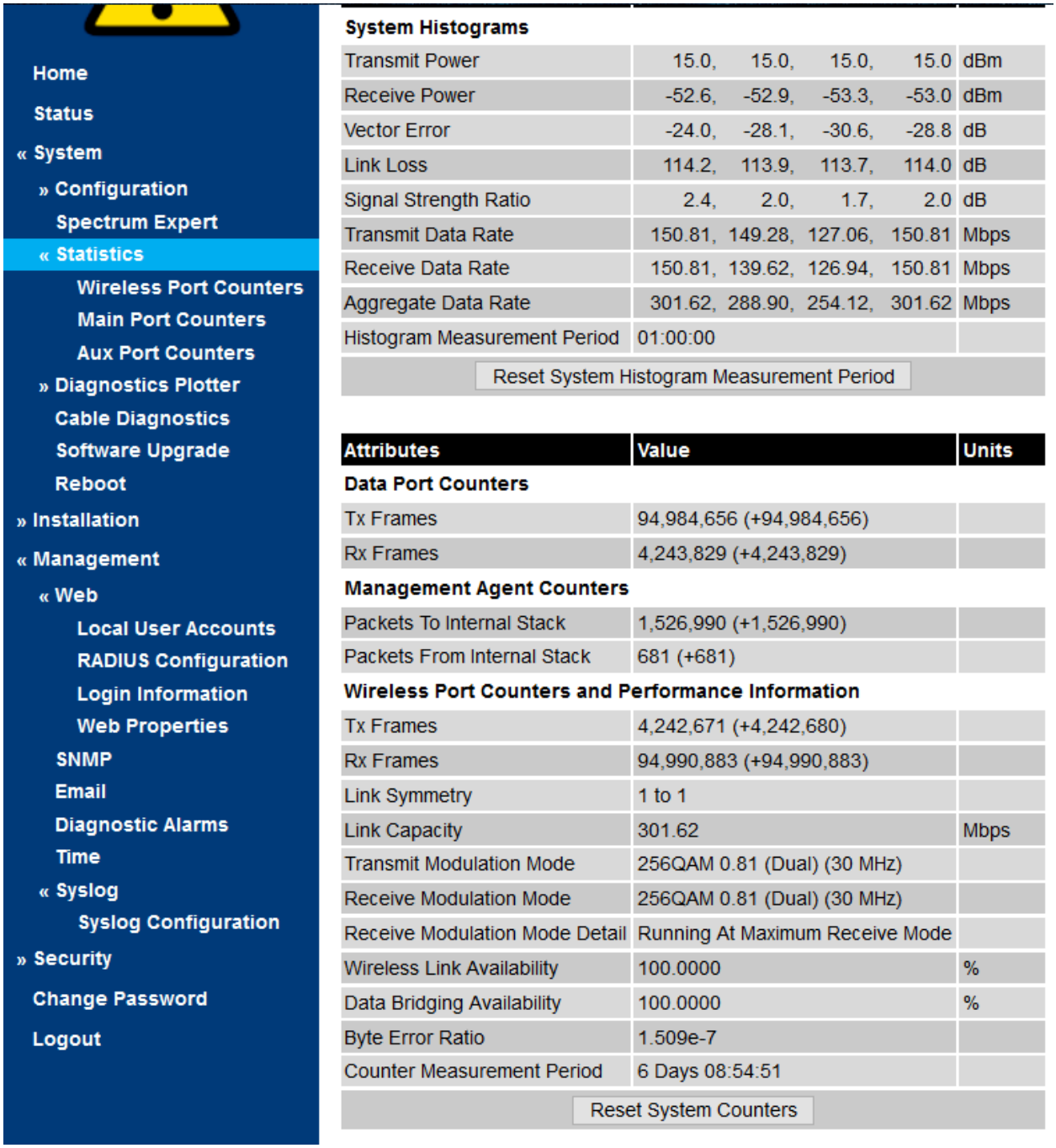
order of 30 dB that is a great value. Thus, creates a total bandwidth of more than 300 Mbps. That is got by the use of the highest modulation (256 QAM).

Taken a look to the statistics it is possible to see that the link availability is a 100% with the maximum receive modulation.



PTP statistics

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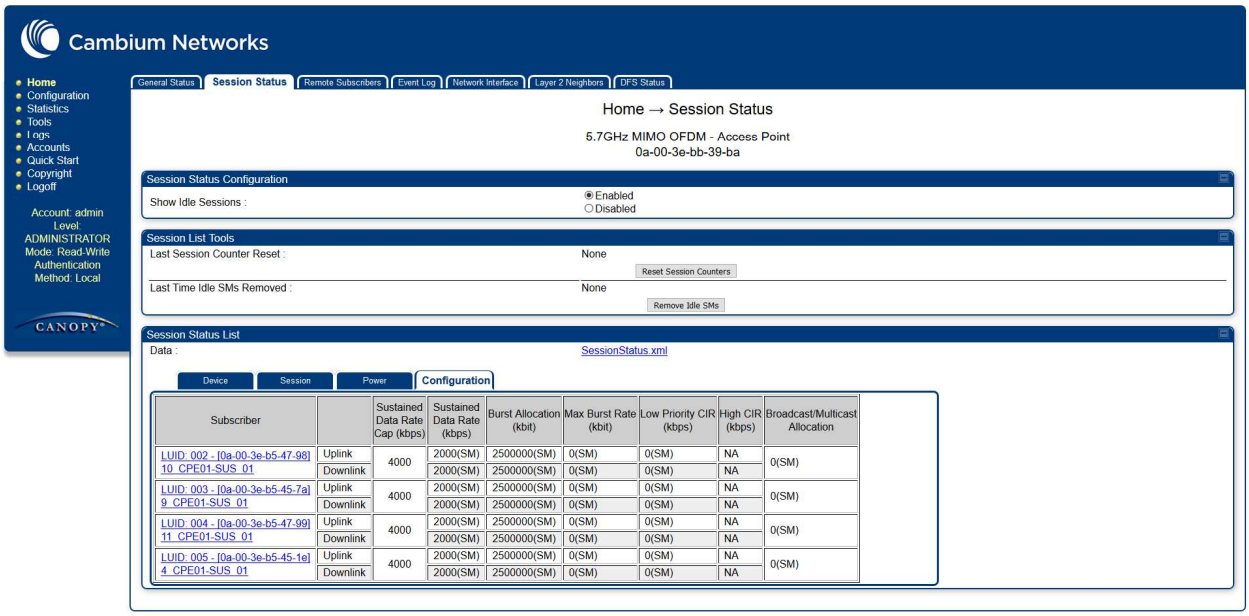
From the Access Point, it is possible to control which subscribers are connected to, and what are the configuration related with throughput for each one.



Urgull AP subscriber throughput configuration

If take a look at the throughput, from the point of view of an AP the most important value are the total packets that the AP is capable to process.

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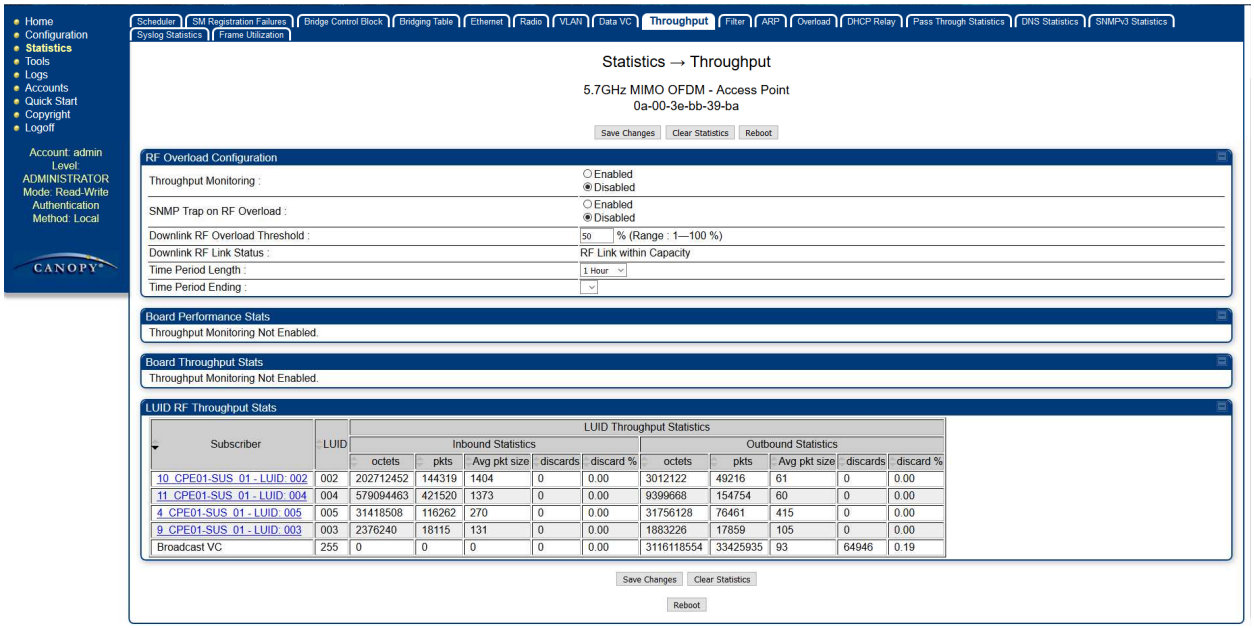
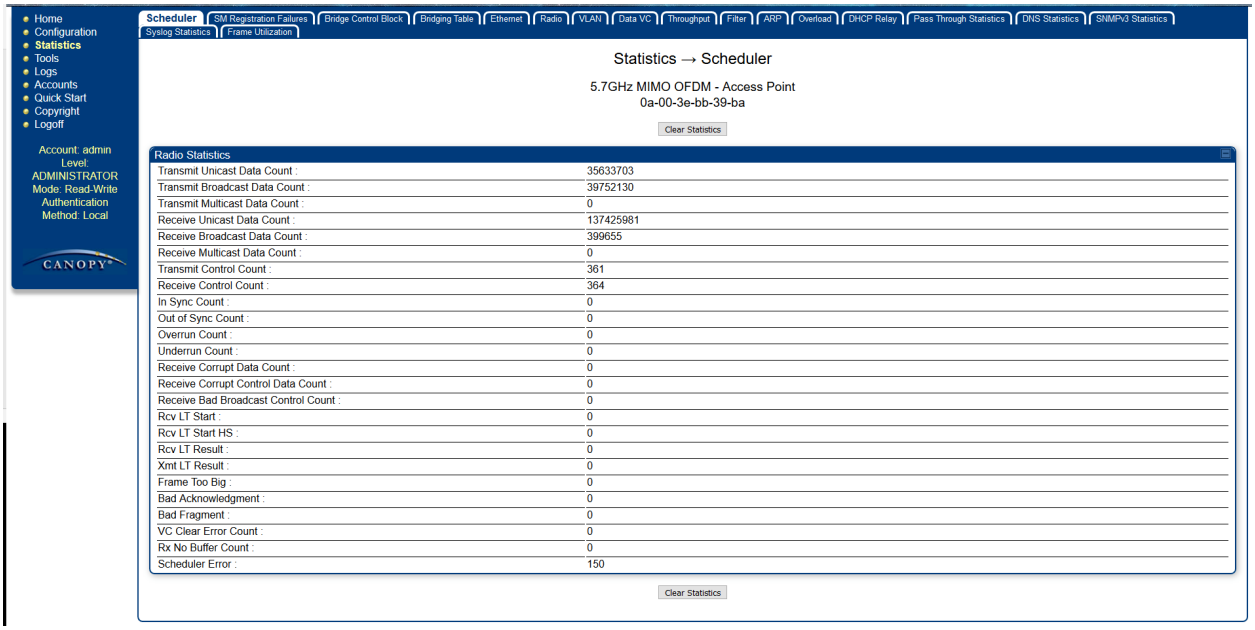


Urgull AP packet throughput

Each device can provide a wide range of statistics information that could be collected by the web interface and/or through a SNMP protocol.



Urgull AP statistics

The total traffic could be shown in the statistics, like the following figure:

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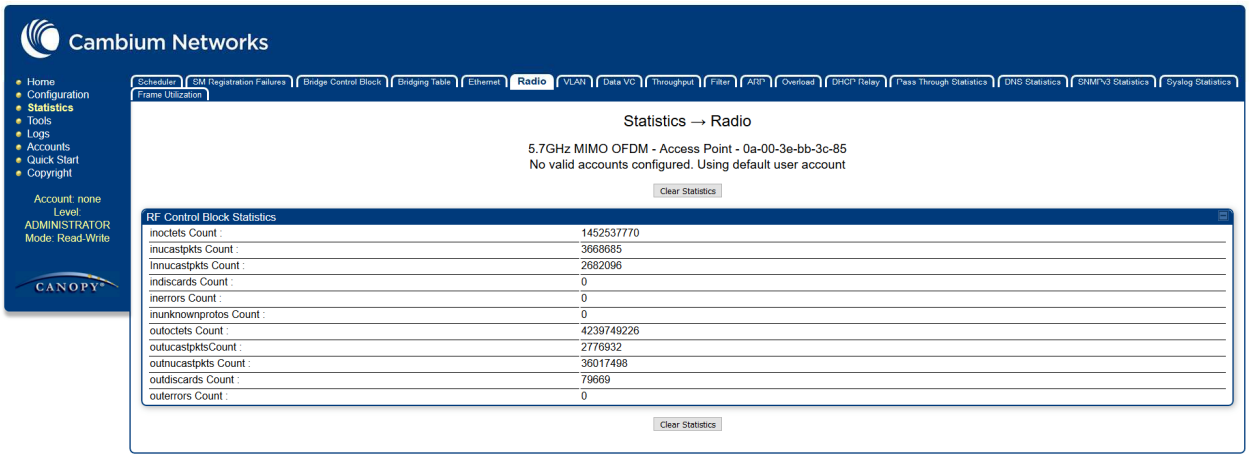

Tomasese AP Radio statistics

This process will be complemented during the monitoring phase that will start after M24 through the installed broadband wireless network.

4.6 Recopillate the full process in a technical report.

The whole process of this subtask is shown in this deliverable. It covers the different task included in this subtask, and also some extra attachments in order to provide the desired information.

This task was developed by Sistelec, however the collaboration of FSS was required. So, with a mutual and great collaboration between the partners it could be possible to finish the task in time.

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5. LESSONS LEARNT

The development of this project has provided several knowledges learnt that could be used in other future projects inside the San Sebastian city but also, to provide a wide deployment in other cities related or not with this project.

The main lessons learnt are described below:

- Designing, measure, feedback methodology is needed and mandatory. Although the theoretical analysis is extremely various, always there are differences from theory to practice that in a feedback process could be solved step by step.
- Urban topology is one of the most complicated coverage projects. The addition of buildings, hills, and multiple spectral interferences makes these kinds of projects the most complicated to design and deploy. Although a great engineering process have been done, always there are deviations from the theory. The mounting points are in the street lights, or traffic lights or buildings. So, the propagation patterns completely change because of the metal and the line of sight obstruction. This makes necessary a widely redundant coverage to ensure the desired connectivity will be reached.
- The installation process varies within the rights needed to the installation and also the weather conditions. Several times, it was needed to postpone the installation because the planned date with the weather conditions makes the installation impossible keeping the installers physical risks under control.
- The background of the different partners was very important in order to reduce the engineering analysis. However, in this project there were more than fifteen iterations between partners to finally get a ready to deploy project.

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6. IMPACTS

This task has provided a wide impact into the San Sebastian municipality. The main impacts are described below:

- Quick deployment of new services.
- Redundant network to provide services to the citizen's. Both wired and wireless network collaborate and complement each other.
- Services in places without any other way of communication. Sometimes because the orography or because it is very complicated to install a wired connection.
- Own municipality network. Thus, allows to complete control of the network facilitating for instance the priority of traffic and some services against others, reduce the dependency from a network operator, and in the unlikely event that something goes wrong within the city, there is always the possibility to control (reconfigure or reuse services) or to add new deploys in a very short time.
- Centralized management, all the network could be managed through a unique control centre.
- Easy to manage, through web interfaces and through standard SNMP that facilities the integration between systems.
- Deployment reduction costs. The sum of the devices needed plus the installation time and resources makes this kind of network extremely profitable compared with wired networks.
- Backbone network for multipurpose and multiservice. This network is transparent to the deployed services inside it, so it makes an extremely multipurpose and easy to deploy services end to end.
- Interconnection with final services. The use a standard RJ45 port with a ethernet connectivity creates an outstanding easy to integrate services within the municipality network.

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7. ANEXES

7.1 Engineering documents

There are two annex documents that describe in detail all the engineering process to deploy the whole network. The document I+D DONOSTI v15 PTP.pdf describe the process and the estimated process for the point to point network that is reserved to the backbone network.

The second document I+D DONOSTI v15 PMP.pdf describe in detail the engineering process of the Point to Multipoint network in which all the Access Points and the subscribers are allocated and how should be the air links between AP and subscriber.

7.2 EU compliance

There are also three documents attached that describe how the products selected fulfil the security requirements and certifications needed in the UE in order to provide the security needed for citizens.

These documents declare the EC DECLARATION OF CONFORMITY for the solution provided.