What to do With the Wi-Fi Wild West

Funding scheme: H2020-ICT-2014-1
Grant number: 644262

Horizon 2020
European Union Funding
for Research & Innovation

Deliverable	D2.3
Title	Wi-5 use cases and requirements
Date	31/12/2015
Milestone	MS2
Editor	Ignacio Berberana (TID)
Reviewers	Michael Mackay (LJMU), Faycal Bouhafs (LJMU), Jose Saldaña (Unizar), Jan de Nijs (TNO)
Approved by	General Assembly
Dissemination	Public

Abstract

The *What to do With the Wi-Fi Wild West* H2020 project (Wi-5) combines research and innovation to propose an architecture based on an integrated and coordinated set of smart solutions. The resulting system will be able to efficiently reduce interference between neighbouring Access Points (APs) and provide optimised connectivity for new and emerging services.

In this deliverable we present the use cases that the project has selected as representative of ways of using the Wi-Fi technology that may benefit from the innovations proposed by Wi-5. The use cases have been selected from those originally proposed by IEEE for the definition of the new generation of the standard, 802.11ax, and the selection process has counted with the assistance of the project's Operator Board. Also, the requirements derived from the analysis of these use cases are presented in this deliverable, distinguishing between functional and performance requirements. For guiding the process from requirements to the definition of the architecture, a number of design principles are being adopted by the project that are also collected here. Last but not least, the relationship of the use cases and requirements identified with the new business roles identified in D2.1 is considered.

Wi-5 Consortium

LIVERPOOL JOHN MOORES UNIVERSITY	Liverpool John Moores University	2 Rodney Street Egerton Court Liverpool, L3 5UK United Kingdom
TNO	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek	Schoemakerstraat 97 Delft 2628 VK Netherlands
Universidad Zaragoza 1542	Universidad de Zaragoza	Calle Pedro Cerbuna 12 Zaragoza 50009 Spain
Telefonica	Telefonica Investigación y Desarrollo SAU	Ronda de la Comunicacion S/N Distrito C Edificio Oeste 1 Madrid 28050 Spain
AirTies	AirTies Kablosuz İletişim San ve Dış. Tic. A.Ş	Gulbahar Mah Avnidilligil Sok 5 5A 7A 7B 9A 11A 11B Mecidiyekoy Instanbul 34394 Turkey

Executive Summary

According to the project work plan, in order to validate the solutions proposed by Wi-5, a number of representative use cases need to be selected. These use cases have a double function:

- Help in the identification of the technical requirements that the solutions proposed by the project have to address, both in terms of functionality and performance.

- Be the basis for the evaluation scenarios that will be used for the validation of the technological innovations developed, either by means of simulations or with trials.

This deliverable provides the description of the use cases that Wi-5 has selected in order to use them in the validation process. The use cases also have the objective to help in the definition of the requirements for the technical innovations and architecture to be developed by the project.

For these purposes, the project used as an initial basis the use cases defined by the IEEE HEW study group, complemented with others resulting from the consideration of the usage trends expected in the following years. The Wi-5 uses cases, in this sense, are intended to be representative of the utility that the innovations proposed by the project can bring to the Wi-Fi ecosystem, and are also consistent with the business models that the project has identified. It also took into account the feedback from the Operators Board, which was provided in an ad-hoc meeting held with them.

The selected use cases are the following:

- Airport/train station
- Dense apartment building
- Pico-cell street deployment
- Large home/SOHO
- Community Wi-Fi

For each of these use cases, the following sets of information have been produced:

- Description of each use case, including operational conditions and potential added value.
- Functional requirements associated to each use case
- Performance requirements for having an adequate quality of experience for each use case.

On top of the use cases and requirements, the deliverable also includes a set of design principles to apply in the realization from requirements to architecture. These design principles are based on the state of the art of the technology and the experience of the partners; however, it must acknowledge that other principles may have been selected for fulfilling the same set of requirements.

With this deliverable, we set the foundations for the design and evaluation of the architecture to be developed by the project. It is also expected to help towards standardisation and adoption of our results, as they can be demonstrated to be useful for improving the performance of relevant use cases that are of interest to potential operators.

This deliverable is organized into six main sections. Beyond the introduction, section 2 explains the methodology used for the selection of the use cases under consideration by the project. It also includes a section explaining the relationship of the use cases with the business models identified in deliverable D2.1. Section 3 provides the description of the use cases selected and section 4 collects the requirements

derived from the analysis of the use cases, both related to functionalities to be supported and performance to be provided. Section 5 enumerates the design principles expected to guide the process from requirements to network architecture. Finally, section 6 collects the main conclusions from the work carried out.

Contents

Glossary

3GPP	3rd Generation Partnership Project
AP	Access Point
BSS	Basic Service Set
CAIDA	Center for Applied Internet Data Analysis
CC-BY	Creative Commons Attribution 4.0 International Public License
CC-BY-SA	Creative Commons Attribution-ShareAlike 4.0 International Public License
CC0	Creative Commons license *No Rights Reserved*
DOI	Digital Object Identifier
EC	European Commission
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
LTE	Long Term Evolution
M2M	Machine to Machine
MTC	Machine Type Communication
NS2	Network Simulator version 2
QoE	Quality of Experience
QoS	Quality of Service
SMB	Small Medium Businesses
SOHO	Small Office / Home Office
VoIP	Voice over IP
WFA	Wi-Fi Alliance

1 Introduction

1.1 Objectives of the Wi-5 Project

The last few years we have witnessed a significant increase in the use of portable devices, especially smartphones and tablets. Thanks to their functionality, user-friendly interfaces and affordable prices, they have become ubiquitous worldwide. Most of these devices make use of IEEE 802.11 wireless standards, commonly known as Wi-Fi.

Given this increasing demand, Wi-Fi is facing mounting issues of spectrum efficiency due to its utilisation of non-licensed frequency bands, so improvements continue to be added in order to enhance its performance. For example, as Wi-Fi saturation increases in scenarios such as business centres, malls, campuses or even whole European cities, interference between these competing Access Points (APs) can negatively impact a user's experience.

At the same time, real-time interactive services such as Voice over IP, video conferencing or networked online games, have grown in popularity and are now used across a range of mobile devices. These share the same connection with "traditional" applications, such as e-mail and Web browsing, but are far more bandwidth intensive and require consistent network capacity to meet user Quality of Experience demands.

The *What to do With the Wi-Fi Wild West* H2020 project (Wi-5 from now) combines research and innovation, to propose an architecture based on an integrated and coordinated set of smart solutions able to efficiently reduce interference between neighbouring APs and provide optimised connectivity for new and emerging services. Cooperating mechanisms will be integrated at different layers of the protocol stack with the aim of meeting a demanding set of goals such as seamless hand-over, reduced congestion, increased throughput and energy efficiencies.

The project is expected to develop a variety of different solutions, which will be made available in academic publications, in addition to other dissemination channels.

1.2 Wi-5 use cases and requirements

In order to validate the solutions proposed by Wi-5, a number of representative use cases must be selected. These use cases will have a double function:

- Help in the identification of the technical requirements that the solutions proposed by the project have to address, both in terms of functionality and performance
- Be the basis for the evaluation scenarios that will be used for the validation of the technological innovations developed, either by means of simulations or with trials.

Wi-5 has selected a limited set of use cases, compatible with the resources available in the project, but with the double characteristics of being of interest for the partners and the Operators Board, as well as suitable for the validation of the technological innovations proposed by the project.

1.3 Organization of the Deliverable

This deliverable is organized into six main chapters. Beyond this introductory chapter, chapter 2 explains the methodology used for the selection of the use cases under consideration by the project. It also includes a section explaining the relationship of the use cases with the business models identified in deliverable D2.1. Chapter 3 provides the description of the use cases selected. Chapter 4 collects the requirements derived from the analysis of the use cases, both related to functionalities to be supported and performance to be provided. Chapter 5 enumerates the design principles expected to guide the process from requirements to network architecture. Finally, chapter 6 collects the main conclusions from the work carried out.

1.4 Relationship with other deliverables

The material in this document relates to the following deliverables:

D2.1: This deliverable identified the main stakeholders in Wi-5 and proposed the initial business models used to select and refine the use cases to be defined later in this deliverable D2.3. The specific requirements derived from these use cases have taken into account the concerns of all stakeholders playing a role in the business models.

D2.4: The initial Wi-5 architecture has been designed to account for the use cases selected and ensure that it meets the functional and performance requirements elaborated from them. A set of design principles are also identified here that have been used to guide the design.

D5.1: The use cases identified will be used to guide the definition of the tests that will be documented in deliverable D5.1 in M24 of the project.

2 Methodology

In the Wi-5 project, the selected use cases are used to derive technical requirements and validate the technical innovations and the architecture proposed. This validation will be carried out either by means of simulations, in trials or both.

In this chapter we first provide the terminology that has been adopted by the project, which is consistent with those used by a number of standardisation bodies, like the IEEE or 3GPP. Next, the methodology adopted by the project is explained which describes the steps taken to elicit the use cases and requirement. In the third section of this chapter, the work carried out by the IEEE and Wi-Fi Alliance (WFA) is presented to show how the selected use cases outline their vision for the next generation of the Wi-Fi technology. It is also explained why Wi-5 has decided not to adopt the same use cases selected by IEEE and the WFA. Finally, the interaction with, and feedback from, the Wi-5 Operators Board is discussed which helped to refine the selected use cases.

2.1 Terminology

In Wi-5 we are managing the following terms which are used to define the use cases:

- A **use case** describes all the ways of utilising a system, in this case a Wi-Fi network, to achieve a particular goal for a particular user. A use case includes an application in a deployment environment with details regarding the activities carried out and both sides of the link. Taken together, the set of all the use cases gives all of the conceivable ways to interact with the system, and illustrates the value that it will provide.

- A **scenario** is an instantiation of a use case, the set of conditions that describe how the use case takes place. It includes:
  - Pre-Conditions – Initial conditions before the use case begins.
  - Application – A source and/or sink of wireless data that relates to a particular type of user activity. Examples are streaming video and VoIP.
  - Environment – The type of place in which the network of the use case is deployed, such as home, outdoor, hot spot, enterprise, metropolitan area, etc.
  - Traffic Conditions – General background traffic or interference that is expected while the use case steps are occurring. Overlapping BSSs, existing video streams, and interference from cordless phones are all examples of traffic conditions.

- **Requirements** are a description of what the network must do in order to support a given use case, which provides the foundation for the design. In the context of Wi-5, we distinguish different kinds of requirements:
  - Functional requirements: identify the kind of functionalities that are required to be supported by the network in order to support each use case.
  - Performance requirements: indicate values or a range of values for network performance parameters that are consistent with a good experience of the use case and normal operational conditions.
  - Other requirements: are requirements associated to the operation of the network that are not associated to the user experience or to the measurable network performance. For example, the requirement that a use case must be supported even if the network infrastructure required is

owned by different actors would fall into this category, as would happen with requirements on energy efficiency.

- The **User** is a party outside the system that interacts with the system in order to get communication services. It may be a person or a process in a machine.

In the IEEE 802.11 terminology, a **usage model** = use case + scenario. We do not explicitly use this term in Wi-5 but it is referred to where necessary to draw comparisons with our use cases.

2.2 Methodology

The methodology proposed is based on a top down approach, with a number of steps that are indicated in the following points:

1. Consider use cases from relevant sources, mainly from IEEE 802.11, Wi-Fi Alliance, Wireless Broadband Alliance, etc., as well as expected Wi-Fi usage trends, in order to select those use cases that are more relevant for the project.
2. Ensure that the use cases selected map into all the technical innovations proposed by Wi-5. If not, look for additional use cases that may be used to validate the proposed innovations.
3. From the analysis of the selected use cases, derive both functional and performance requirements, and identify any other requirements as described above.
4. In order to validate that the innovations proposed fulfil the requirements identified here, define evaluation scenarios that can be used for this purpose, either by means of simulations or field trials.
5. The requirements, along with some design principles, are used to derive and refine the architecture proposed by Wi-5. The design principles are identified from the requirements but take into account our understanding of the current state of the art and operator constraints.

The methodology proposed is represented in figure 1 below:

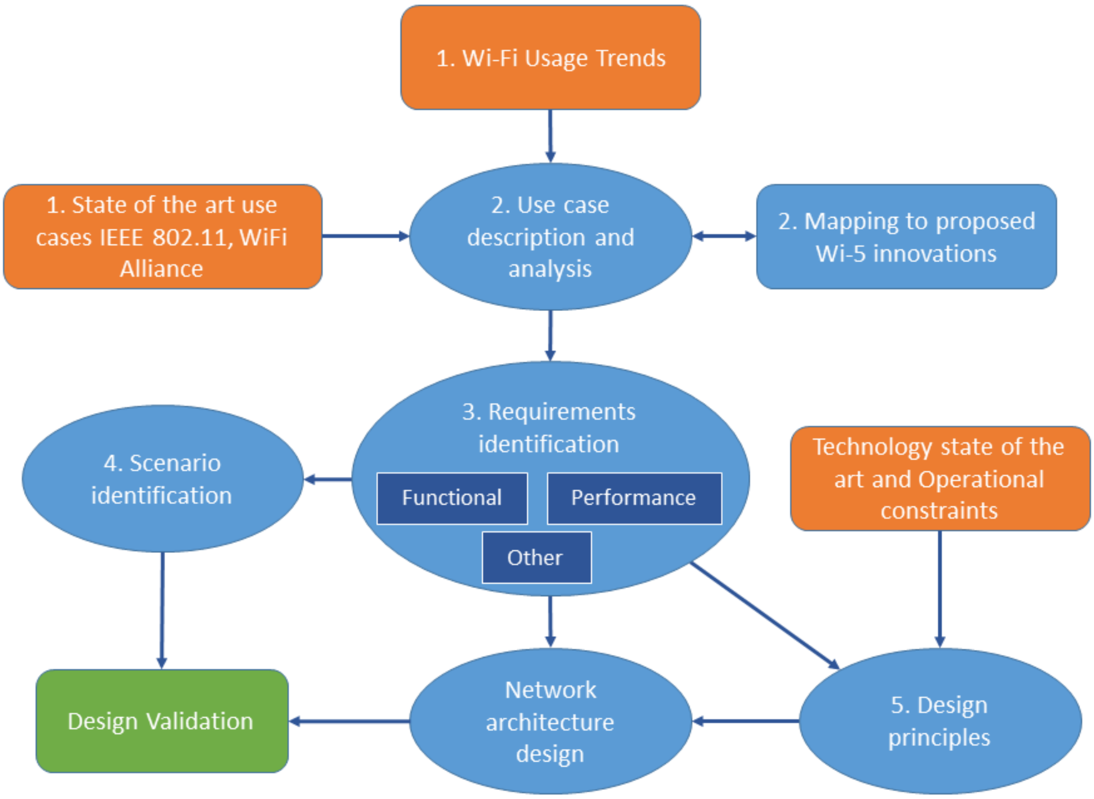


Figure 1: Methodology for the selection of use cases and identification of requirements

In the context of Wi-5, we believe that Wi-Fi usage evolution up to and beyond 2020 will be driven by a number of trends, among them:

1. Very dense deployments.
2. Use of Wi-Fi in outdoors environments: parks, streets, stadiums, train stations, and others.
3. Increased use of non-STA Wi-Fi devices (e.g., wearables).
4. Improved support of real-time, low latency applications: games, real time video.
5. Potential competition with other technologies for the use of non-licensed spectrum, especially the 5GHz band (e.g., LTE LAA).
6. Generalization of Voice over Wi-Fi services.
7. Potential use of new frequency bands (e.g., UHF White Spaces, using IEEE 802.11af).
8. Potential use of Wi-Fi for MTC/M2M/IoT applications (based on the use of sub 1 GHz ISM frequency bands with 802.11ah).

All of these trends result in some additional requirements that should be taken into account in the selection of the use cases.

2.3 IEEE 802.11 work on Wi-Fi use cases and requirements

The main source for the use cases considered by Wi-5 is the work carried by the IEEE. On March 22, 2013 the IEEE 802 EC approved an 802.11 request to create a new Study Group called High Efficiency WLAN (HEW), of which the main purpose was *"to enhance 802.11 PHY and MAC in 2.4 and 5GHz with a focus on:*

- *Improving spectrum efficiency and area throughput*
- *Improving real world performance in indoor and outdoor deployments*
    - *in the presence of interfering sources, dense heterogeneous networks*
    - *in moderate to heavy user loaded APs"*

The HEW marketing group defined a number of usage models that were classified into five groups of use cases characterized for similar requirements [2]:

1	**high density of APs and high density of STAs per AP**	**a**	**Stadium**
		b	**Airport/train stations**
		c	**Exhibition hall**
		d	**Shopping malls**
		e	**E-Education**
		f	**Multi-media Mesh backhaul**
2	**high density of STAs – Indoor**	**a**	**Dense wireless office**
		b	**Public transportation**
		c	**Lecture hall**
		d	**Manufacturing Floor Automation**
3	**high density of APs (low/medium density of STAs per AP) – Indoor**	**a**	**Dense apartment building**
		b	**Community Wi-Fi**
4	**high density of APs and high density of STAs per AP – Outdoor**	**a**	**Super dense urban street**
		b	**Pico-cell street deployment**
		c	**Macro-cell street deployment**
5	**Throughput-demanding applications**	**a**	**Surgery/health care**
		b	**Production in stadium**
		c	**Smart car**

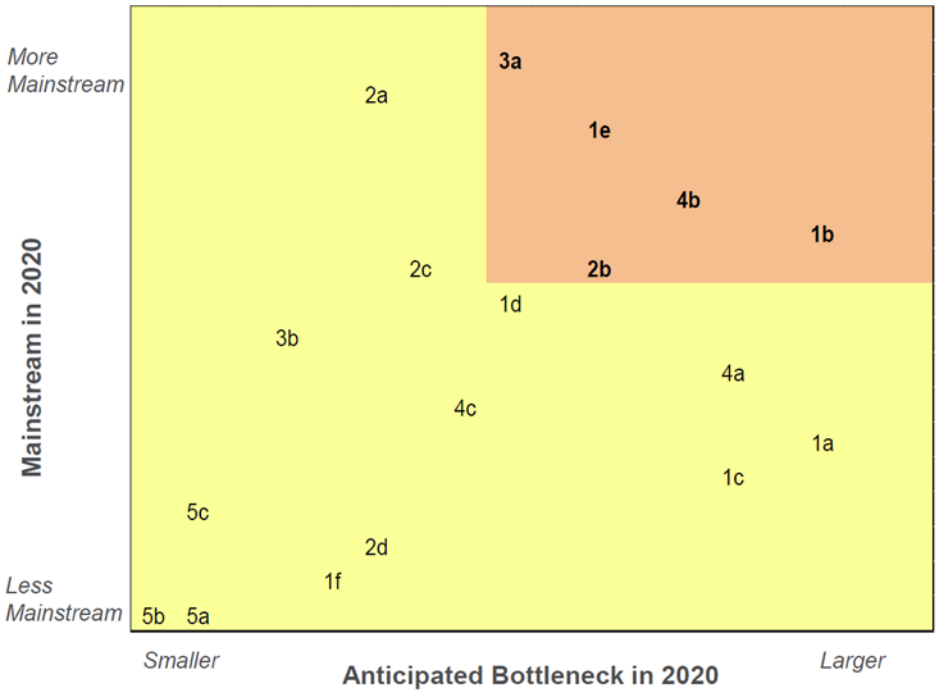
Because of the relatively high number of usage models identified here, it was considered necessary to first prioritise them and select a lower number to be used in the evaluation of the technological solutions proposed for achieving the HEW SG objectives. However, it was decided that the selection should not be made by HEW SG but by the Wi-Fi Alliance, which is a separate body.

In July 2013, the IEEE 802.11 Working Group sent a liaison to the Wi-Fi Alliance, requesting the Wi-Fi Alliance to provide input on prioritization of the set of usage models developed by the HEW SG, and any additional feedback. In September 2013, Wi-Fi Alliance formed a dedicated HEW Use Case Marketing Task Group to respond to this request, targeting a response by November 2013.

The prioritisation of the HEW usage models took the form of an evaluation focused around two key points:

- "**Mainstream**": whether the usage model will be more or less mainstream in the target timeframe window (around 2020).
- "**Bottleneck**": whether the usage model is more or less likely to experience Wi-Fi network bottlenecks in the target timeframe window (2020), i.e. the degree to which the traffic requirements for the links in the usage model can be met.

The outcome of this evaluation is represented in figure 2, with the most important usage models focused in the top right corner (coloured orange).



#	Usage Model
1a	Stadium
1b	**Airport / Train station**
1c	Exhibition hall
1d	Shopping mall
1e	**E-Education**
1f	Multi-Media Mesh backhaul
2a	Dense wireless office
2b	**Public transportation**
2c	Lecture hall
2d	Manufacturing floor automation
3a	**Dense apartment building**
3b	Community Wi-Fi
4a	Super dense urban street
4b	**Pico cell street deployment**
4c	Macro cell street deployment
5a	Surgery/healthcare
5b	Production in stadium
5c	Smart car

Figure 2: prioritisation of use cases by the Wi-Fi Alliance

So, the top-five prioritisation of usage scenarios selected by the Wi-Fi Alliance were as follows:

- 1b Airport / train station
- 1e E-Education
- 2b Public transportation
- 3a Dense apartment building
- 4b Pico-cell street deployment

Although it would have been perfectly reasonable for Wi-5 to simply adopt the same use cases and take them as fact, it should be noticed that the objectives for the selection are not the same for IEEE/WFA and Wi-5. IEEE/WFA is focused on introducing modifications in the PHY and MAC layers of the Wi-Fi radio interface, in order to improve the spectral efficiency of Wi-Fi networks, mainly for use cases with high interference levels. The objective of Wi-5, on the other hand, is to complement these improvements by incorporating additional functionalities on top of existing systems that may further improve the performance and reliability of Wi-Fi networks as well as the Quality of Experience (QoE) of their users. In this sense, emphasis is put on the coordination of the wireless services providers and the creation of new roles in the ecosystem.

For these reasons, Wi-5 decided to review the selection of the use cases to be considered by the project, starting with those defined by HEW, but complementing them with other use cases associated with new usage trends for Wi-Fi that have been identified by us. Also, Wi-5 looked for the feedback of a selected set of operators that provide additional context for the deployment of Wi-Fi based services and this too was taken into account.

2.4 Business models

Business models are an important and necessary aspect of the Wi-5 system solution. Without an appropriate business model, it may be more difficult and less economically viable to deliver the Wi-Fi network services demanded by the (future) market, if not totally impossible. Therefore, technological improvement and business model innovation are fully integrated in the Wi-5 project approach for defining use cases.

A main Wi-Fi concern we identified is the consequences of its rapidly growing popularity. Wi-Fi uses unlicensed and unmanaged spectrum, so there is no guarantee that interference is manageable at all times. The first cases of spectral congestions are already widely reported and, without an appropriate remedy, this spectral congestion will increase and become a serious threat to Wi-Fi.

In Deliverable 2.1 "*Viability of business models for multi-operator Wi-Fi coordination platforms"*, we have discussed the issue of spectral congestion and the conceivable remedies. Wi-Fi, specifically the Wi-Fi frequency spectrum, shows striking similarities with the common pastures issue of the United Kingdom in the past. These pastures were free to all which often resulted in devastation by overgrazing, whereas private pastures remained green and had plenty of grass at all times. The self-interest of the herdsmen of a common easily led to overgrazing of the pasture and to starvation of the cattle, which eventually turned out to be disastrous for all. In its treatise "*The Tragedy of the Commons*" of 1968, Garrett Hardin gives an extended analysis of the phenomenon that limited but free resources collapse under conditions of (perceived) shortage. He concludes that such problems have no technical solution, but "require a fundamental extension of morality".

In analogy with the pastures, the unlicensed 2.4 and 5 GHz frequency bands are a limited resource free to all. In the broadband market, all stakeholders are looking for technical solutions to maximize the use of these bands: IEEE 802.11 has developed a series of technologies with increasing system bandwidth, and more recently even a second technology is proposed: LTE-Unlicensed. All of these technologies pursue higher bit rates using more spectrum and more advanced technologies, however, none of them provides a solution to avoid the "tragedy". And, in the wording of Hardin, there is no technical solution. In Deliverable 2.1 we have analysed this dilemma, and concluded that the Wi-Fi business models have to be adapted to take this into account. A new business role is needed to grant the available frequency spectrum to the different users in a fair and optimized manner: a spectrum usage broker is needed to bring this morality.

In this deliverable, we present and analyse the use cases and their functional and performance requirements. However, from the viewpoint of the Wi-Fi end user services, the business model is not relevant; only availability, bit rate and QoS count. The business model like the technology is merely a component of the solution to deliver the services. As such, the business model has to be taken into consideration in the system architecture and system design, but not in the use cases. The use cases only describe the services as desired by the end users. However, in the selection of the use cases, we have to assure that the use case(s) most susceptible to spectrum congestion is (are) included.

2.5 Feedback from Operator Board

The feedback provided by the Operator Board (see [1] for an explanation of the objectives and composition of this board) has helped to refine the selection of the use cases in the context of operational and business concerns, confirming their interest in four of those originally identified by the Wi-5 consortium and suggesting the substitution of the fifth one. This suggestion has been accepted by the project, so the use cases that will be described in the next section are also the result of our interaction with the Operator Board.

The Operator Board has also helped to refine the description of the use cases and to identify the most relevant aspects of each of them that may require new technological solutions in order to fulfil the customers' expectations. In this way we can ensure that the innovations proposed by Wi-5 respond to existing needs of a wide selection of operators with different business models that base their commercial offers on the use of Wi-Fi.

3 Wi-5 selected use cases

In this chapter, we collect the five use cases selected by the project in order to derive requirements and to define evaluation scenarios. For selecting the Wi-5 use cases we started with the complete list of IEEE HEW usage models, as well with new use cases justified for late developments of Wi-Fi technology, and then selected those that were considered more important according to three criteria:

- Whether the use case is relevant (in general).
- Whether the use case is of interest for most or all the Wi-5 partners.
- Whether the Wi-5 innovations are relevant for the use case.

For the selection of the use cases it is also important that they are representative of some of the different operational conditions that may be present in the operation of Wi-Fi networks, so that they are useful in order to derive a variety of functional and performance requirements. The main ones considered are:

- AP Density: low, medium or high
- Client Density: low, medium or high
- Management domains: single, multiple
- Indoor/Outdoor

The outcome of this process has been the selection of 5 use cases, where 4 coincide with those proposed by the WFA and one has been proposed by the Operator Board.

3.1 Airport/train station

The Airport / Train Station use case addresses the typical network deployments found in public places, where a number of Wi-Fi APs are used to provide coverage to users in the area. The wireless network is mostly used in waiting rooms or lounges, for example where users wait for their flights. Whereas the user mobility with a laptop can be considered as *nomadic* (i.e. a user may move, but he/she will stay for a long time in the same place), smartphone and tablet users may walk whilst using real-time services. As a consequence, handoffs between APs have to be considered. Figure 3 shows some of the typical scenarios corresponding to this use case.

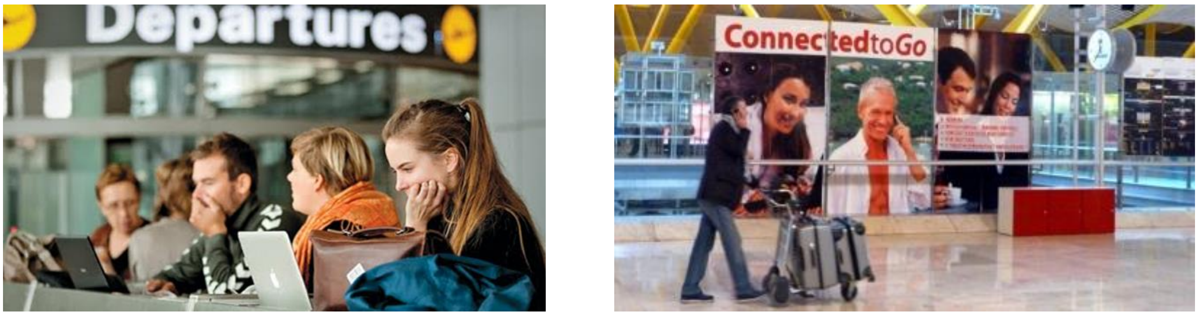


Figure 3: Airport/train station use case

Although the use case primarily considers airports and train stations, many of the solutions would also be useful in business centres and shopping malls. This use case corresponds to the usage model **1b**, defined by the 802.11ax (HEW) group as *airport/train stations*, included in the category *high density of APs and high density of STAs per AP* [2].

As stated in that reference, *“Airports and train stations are typical places where many service providers install their APs and many passengers use WLAN services. (…)The Next Generation Wi-Fi is expected to provide very high capacity for the people using bandwidth consuming applications in a dense deployed environments.”* The use case considers that *“Travelers are using the network to surf websites, watch movies, play online games and access cloud services.”*

Therefore, the applications we are considering without loss of generality can be classified according to their tolerance of latency into:

- Tight real-time constraints: online games
- Medium constraints: cloud services.
- No real-time constraints: web browsing, video downloading

When a user is running a service with tight real-time constraints, the handoff between APs must be run seamlessly, otherwise the user may experience a disruption (e.g. in a game or in a VoIP call) which will jeopardize his/her QoE.

The traffic conditions consider four sources of interference: *i)* APs belonging to the same network may interfere if the density is high. This can be alleviated with adequate frequency planning, as is being considered in the Wi-5 project, especially in the solutions included in WP3. *ii)* Interference between APs belonging to networks controlled by different operators. This will be addressed in WP4. *iii)* Interference with unmanaged networks, which can be alleviated if all the APs implement smart scanning functionalities, making them able to select the best channel (addressed in WP3). *iv)* Interference with cellular (e.g. TD-LTE) in an in-device coexistence scenario, if the user device runs Wi-Fi and TD-LTE at the same time. This is being explored in WP4.

3.2 Dense apartment building

The dense apartment building use case corresponds to a Wi-Fi scenario where the tenants in each apartment arrange their broadband connection independently. The broadband connection in each apartment can be provided by different service providers, such as cable providers, telecom operators and mobile operators. The Wi-Fi APs in each apartment, either provided by operators or bought from a shop, are installed and configured in an unmanaged manner. As a result, Wi-Fi APs may severely interfere with each other. This severe interference results in inefficient usage of the unlicensed and unmanaged wireless spectrum.

One possible solution applied by some tenants can be to install stronger APs and a lot of repeaters. In the short term the tenants applying this solution may be satisfied but, on the other hand, other tenants suffer from more severe interference and more degraded throughput than before. Therefore, they may also buy extra strong Wi-Fi APs and repeaters. The final result is reduced performance for everyone. This phenomenon is known as “tragedy of the commons” [3] and much effort has been made to solve this basically economic problem. This use case corresponds to the usage model **3a**, defined by the 802.11ax (HEW) group as *dense apartment building*.

In a dense apartment building use case, tenants are free to make mutual agreements about the usage of wireless spectrum and a spectrum broker could be deployed to execute or enforce the agreements. In the Wi-5 architecture, spectrum will be managed and controlled by the spectrum broker's SDN based Wi-5 controller. The Wi-5 controller framework will also give a traffic offloading opportunity to the tenants, who may have better cellular coverage and suffer from relatively strong intra-apartment Wi-Fi interference. More information on the business role of the spectrum broker can be found in D2.1 “Viability of business models for multi-operator Wi-Fi coordination platforms”.

Users in a dense apartment building will demand a wide range of applications, including high quality video content coming from the Internet or cloud, video chat, VoIP and online gaming. They want seamless wireless connectivity, while they are moving around. Wireless usage is expected to reach the peak point in the early evening, and more steady usage is expected throughout the day.

3.3 Pico-cell street deployment

For economic reasons, operators are building 3G/4G networks with large overlay cells for coverage and micro cells for local capacity that are seamlessly integrated into a single network. A next step here is the addition and integration of Wi-Fi small or pico-cells to locally provide an even higher capacity in public areas like shopping streets and squares with terraces. This evolution can also be seen as the integration of the former Wi-Fi hot spots and 3G/4G networks. Moreover, many national operators now offer fixed consumer broadband services complementary to their mobile proposition. The customer home gateway used to deliver the fixed service often has an integrated Wi-Fi access point. For the same reason of increasing local network capacity, the providers of fixed and mobile services are exploring the deployment of Wi-Fi community networks as a further extension of their mobile proposition (see section 3.5).

Apart from improving the mobile proposition and customer experience, the integration of Wi-Fi pico-cells is driven by pure economics: the offload of (expensive) 3G/4G networks. It can therefore be foreseen that various mobile providers will deploy Wi-Fi pico-cell networks in the same streets and public places. At the edges, these networks will overlap with other Wi-Fi networks like residential and office networks. Since all providers will use the same frequency bands, radio resource management has to be optimized across these networks. This use case corresponds to the usage model **4b**, defined by the 802.11ax (HEW) group as *Pico-cell street deployment*.

In this pico-cell use case, an operator could deploy a 3G/4G underlay network; however, this would bring spectral management complications and restriction. Deployment of a Wi-Fi network offers the advantage that spectral management of the 3G/4G overlay and Wi-Fi underlay networks are completely separated. Equipment manufacturers too have spotted the advantage of using unlicensed spectrum, and have proposed a modified LTE technology, LTE in unlicensed spectrum (LTE-U) designed to operate in the 5 GHz unlicensed frequency bands. Evidently, when Wi-Fi and LTE-U networks are deployed in the same area, both technologies will compete for the available capacity.

As an off-load network, the pico-cell street network will specifically serve nomadic users, pedestrians and other users with a low speed; all high speed users will remain on the overlay 3G/4G network. As such, the service demand of this use case will encompass a wide range of services, including common Internet access for browsing, telephony (VoIP), streaming audio and video and online gaming. In shopping streets and squares, medium to large numbers of users can be foreseen. In addition, customers will expect support for network roaming.

3.4 Large home/SOHO

The Large home or Small Office / Home Office (SOHO) use case is a common Wi-Fi scenario which has evolved beyond a simple deployment around a single, central AP. In the case where the area is particularly large, it may have specific wireless resource restrictions, or the coverage needs to extend over a wide area, so the user may need multiple APs in the same property. This scenario applies equally well to residential users where the property is very large. While modern houses tend to be more compact and built from materials more conducive to wireless communications, there exists a large base of older properties, across Europe and beyond, which may be comparatively large and which use materials which can block or severely impede Wi-Fi signals. This is the only use case considered by Wi-5 that does not have a corresponding usage model defined by the 802.11ax (HEW) group but was instead nominated by the Operators Board as an interesting scenario for study.

Here, we will consider how the Wi-5 solutions can be used to coordinate the deployed infrastructure and improve coverage and QoE. In this use case, we consider that the user is responsible for managing their own local Wi-Fi access network, which is connected to a high capacity broadband connection supplied by their provider. The placement and configuration of the APs is determined by the user in order to provide optimal coverage of the property, but the user may have a limited level of technical competence. The network will be used daily either by a small number of business users in the SOHO scenario, or a small number of family members, or both. There may also be a limited number of visiting users.

Users will expect the wireless network to support a wide range of applications and services simultaneously which might include a mix of traditional Internet applications such as web/email, high bandwidth services like video streaming or large data transfers, or demanding applications such as VoIP/Video Conferencing or online gaming. Moreover, usage might be focussed around specific times of day, such as in the early evening when the family comes home, or more steady throughout the day. Users may also have a degree of local mobility, that is they may move between rooms in the property, and expect to remain constantly connected.

3.5 Community Wi-Fi

Community Wi-Fi networks allow operators to offer Wi-Fi network access to their on-the-go subscribers by using existing residential and Small Medium Businesses (SMB) Wi-Fi infrastructure – if the owners of the infrastructure agree with the provision of the service. Operators can also use this coverage to offer services to retail and roaming partner operators' subscribers. Community Wi-Fi networks are actively being deployed across Europe (as well as in North and South America and East Asia) by a variety of operators including cellular, over the top, and broadband service providers. However, we consider that the Wi-5 proposed solutions may help to provide a better quality of experience for Community Wi-Fi users.

Currently, Community Wi-Fi services are typically implemented at layer 3, using different VLANs for public (hosted) and private traffic, with some peculiarities:

- Public traffic VLAN is typically restricted to a maximum bit rate value (e-g., 1 Mbit/s) per AP.
- Public and private networks are considered as separate BSS (with separate APs) from the 802.11 perspective.

In this use case, we consider a user that has subscribed to a Community Wi-Fi service provided by a network operator or a wireless service provider – the terms for the agreement between the two parties are out of the scope of the use case description. In the most common operational conditions, the Community Wi-Fi provider will be also the provider of the Internet connection for the user’s home, although this is not mandatory. This use case corresponds to the usage model **3b**, defined by the 802.11ax (HEW) group as *Community Wi-Fi*.

The service allows the user access to the network resources of other Community Wi-Fi subscribers when out of his home. The service level that the user can get in the visited networks is established based on the subscription contract to the service, and it should never result in a loss of QoE for the hosting users. In exchange, the user allows other Community Wi-Fi users to connect to their home network in return.

When being a visitor, the user should be able to access the visited Wi-Fi network in the same way they accesses their home network, as seamlessly as possible and using the same credentials for accessing the home network – no need for extra software or visitor portal access should be needed. The user should also expect that the home network they are connecting to would not have access to these credentials or be able to save them in any way. When allowing the access of visitors to their home network, the user expects not to be legally bound to the information the visitors may send or retrieve or the places they may access.

3.6 Relevance of the selected use cases

In order to exploit the relationship between the tasks in WP2, the relevance of the selected Wi-5 use cases should be analysed from a business viewpoint, as well as from a technical viewpoint. From a business viewpoint, the relevance of the use cases selected is ensured by different factors:

- Three of the use cases selected are also considered to be among the most relevant by the Wi-Fi Alliance.
- The interest of all use cases has been assessed by the Operator Board, whose feedback has been taken into account. All the use cases finally selected were considered relevant by the operators involved.
- The use cases are consistent with the business models that have been identified by the project in Task 2.1.

From a technical viewpoint, the use cases selected represent a variety of requirements in terms of the operational conditions for the different factors that may influence the quality of experience for the services. These will be considered when defining the architecture in Task 2.3.

Use Case	AP density	Client density	Management domain	Outdoor/indoor
Airport/train station	High	High	Single	Outdoor
Dense apartment building	Medium-high	High	Multiple	Indoor
Pico-cell street deployment	Medium	High	Multiple	Outdoor
Large home/SOHO	Low	Low	Single	Indoor
Community Wi-Fi	Medium	Medium	Multiple	Both

4 Requirements

This chapter collects the requirements derived from the analysis of the different use cases. According to the methodology adopted, we distinguish between functional requirements (the functionalities the network has to provide in order to support the use cases) and performance requirements (the expected performance of the network that is compatible with an adequate user experience).

4.1 Functional requirements

4.1.1 Airport/train station

Nº	Requirement
1	The network should automatically self-configure, periodically running a channel allocation algorithm, which establishes an optimal channel distribution between APs. In addition, load balancing must be automated, moving users between APs when required.
2	The network must detect the interference level caused by other Wi-Fi networks in the same location, and take this information into account in order to establish the optimal channel allocation and load balancing. The network should not affect other local Wi-Fi networks when running these algorithms.
3	The network must be able to automatically detect the devices running applications with tight real-time requirements, in order to associate them with their corresponding latency limits. This detection must rely on techniques preserving network neutrality and user privacy.
4	Users in these scenarios may move (at walking speed) while using network services, so handoffs between APs must be supported. These handoffs must be seamless, at least when real-time services are being run by the user.
5	Only authorised users should be able to join the network and use the service.

4.1.2 Dense apartment building

Nº	Requirement
1	The network should support multi-operator facility, such that the broadband connection in each apartment is provided by different ISPs.
2	The network should sense the surrounding interference level and use this information to provide the optimal channel, AP and transmit power configuration to the users without affecting the neighbouring networks.
3	The network should support traffic offloading to cellular networks for users who have better cellular coverage.
4	The network should detect the service type of users to meet certain level of QoS, in terms of bit rate and latency requirements.
5	The network should seamlessly handover users to the AP that would offer better QoE.
6	The network should provide a secure connection, such that only authorized users can join the network.

4.1.3 Pico-cell street deployment

Nº	Requirement
1	The network should support numerous users, and it should be capable of delivering a wide range of end user services, each with the appropriate service quality.
2	The network should be able to self-configure and maintain itself with minimal operator interaction, but in a manner that the operator can monitor and manage the network. For example, the operator has to be able to configure user profiles, provision services, control network access, etc.
3	The radio resource management of overlapping Wi-Fi pico-cell networks of different providers should be integrated, as if the networks form a single entity. The radio resources should be allocated in a transparent and fair manner to all users, irrespective of the specific operator, but taking into account the network capacity of each operator in an area.
4	The network should support seamless mobility between overlapping APs and between Wi-Fi and 3G/4G networks. The network should support roaming between mobile networks (3G/4G and Wi-Fi) of different providers.
5	The network should support radio resources management mechanisms in order to minimize interference issues with users indoors but close to the pico-cell deployments.

4.1.4 Large home/SOHO

Nº	Requirement
1	The network should be able to self-configure and maintain itself with minimal user interaction.
2	The network should be optimised to support a limited number of users but be capable of supporting a wide range of applications.
3	The network should be able to adapt the infrastructure to maximise Wi-Fi coverage whilst optimising wireless resource utilisation.
4	Support for seamless mobility within the network should be available as user move around within the property.
5	The network should maintain acceptable levels of security such that only authorised users may join the network.

4.1.5 Community Wi-Fi

Nº	Requirement
1	The network should be able to support multi-tenancy, i.e., the possibility that the Wi-Fi home network provider and the Community Wi-Fi provider are not the same.
2	The network should be able to provide differentiated services and policing to visitors based on the location of the access network to which they are connected.
3	The network should be able to control the service level that is provided to hosts and visitors taking into account the applications being used, the traffic conditions and the service subscription conditions contracted.
4	Security procedures should not be based on the transfer of security credentials of the visitor to the hosting network.
5	Hosted communications from visitors should be isolated from those of the hosting users.

Nº	Requirement
6	It should not be possible for visiting users to communicate directly with hosting users. The network should be able to preclude direct communication between visiting users.
7	Visiting users' usage of resources should be accounted for on a per user basis.
8	The network should be able to support the Lawful Intercept requirements of the country where the service is provided. These may include the ability to identify the Geo-location of a mobile device that is connected to a visited WLAN access point and the ability to track the device's roaming within the network, even when there are no active IP flows.

4.2 Performance requirements

4.2.1 Airport/train station

Nº	Requirement
1	When the user is moving, the detection of his/her movement has to be fast enough in order to enable a handover while maintaining the connection without disruptions. This is a hard requirement for real-time services, but may be relaxed for non-real-time services (e.g. web browsing, file downloading).
2	The latency (and jitter) experienced by the users of real-time services has to be kept under a predefined limit where possible (see a survey of these limits in [4]). Once this requirement is accomplished, users of non-real-time services should obtain a fair share of the rest of the available bandwidth.

4.2.2 Dense apartment building

Nº	Requirement
1	Tight real time constraints for users, playing online games or making VoIP calls should be met in order to provide seamless connectivity.
2	The service maintained to the users streaming high quality video should be sustainable such that bit rate and latency requirements should be met wherever possible, even when there is high congestion in the network.

4.2.3 Pico-cell street deployment

Nº	Requirement
1	Provided that the network is appropriately designed and built and that the use of the network resources is optimized, the network should be capable to deliver all types of end user services (web browsing, VoIP, streaming media, online gaming, and others) with their appropriate QoS.
2	The handover of a connection from one AP to another one should not result in a noticeable service interruption or QoS degradation. Roaming may not result in a service loss, but a noticeable and automatically restored interruption is acceptable.

4.2.4 Large home/SOHO

Nº	Requirement
1	The service provided to individual users and sessions should be adaptable such that they experience an acceptable Quality of Experience at all times.
2	During times of peak congestion, the network should optimise local resources wherever possible to minimise service disruption.

4.2.5 Community Wi-Fi

Nº	Requirements
1	Hosting network users should not perceive any degradation in their Quality of Experience when visitors are served.
2	Authentication and association times for visiting users should be comparable to those observed in their home networks.

4.2.6 Summary

The analysis of these uses cases has identified the functional and performance requirements that need to be met by the Wi-5 architecture in each case. Although each use case has been analysed separately, the requirements described below are shared between the use cases and will be used as a guide when designing the architecture:

- **Seamless Mobility**: There is an emphasis on the need for seamless mobility in all the use cases studied. This requirement means that the user can roam within a single network or across many networks without service interruption.

- **QoS Awareness**: Similarly to Seamless Mobility, there is an emphasis on QoS awareness in all uses cases studied in this project. Users in the scenarios considered need the network to deliver the necessary performance to maintain the quality of service required by their applications such as: VoIP, Online Gaming, etc.

- **Self-Configuration**: In all use cases, there is a requirement that the network should be able to self-configure and maintain itself with minimal user input. For instance, in the case of high interference levels caused by a neighbouring Wi-Fi network, the network should be able to detect the interference and apply a radio configuration that appeases the level of interference and its effect on the network users.

- **Spectrum Usage Optimisation**: This requirement is emphasised in several of the use cases studied in the project. In the case of dense apartment buildings, the network will need to find a radio configuration that achieves optimal performance while minimising interference levels. In the Wi-Fi pico-cell deployment, the spectrum should be allocated fairly among users but taking into account the network capacity of each operator in an area. In the large home/SOHO scenario, the network should be able to adapt the infrastructure to maximise Wi-Fi coverage whilst optimising wireless resource utilisation.

- **Authentication, Authorisation and Accounting**: In the community Wi-Fi use case, the network is required to control the service level that is provided to hosts and visitors while taking into account the applications being used, the traffic conditions and the service subscription conditions contracted. In the dense apartment building use case and large home/SOHO use case, there is also an emphasis on the necessity to authenticate users such as only authorised users may join the network.

5 Design principles

The Wi-5 project methodology also postulates additional *design principles* be defined here in order to guide the transition from requirements to network architecture realization. Unlike a requirement, which is derived from a specific use case, a design principle is a philosophical stance that is informed by the collective experience and expertise within the project, so it is both subjective and subject to debate. In other words, different design principles may be applied in order to support a given set of requirements.

In Wi-5, we have adopted a design approach based on novel control functionalities focused on enhancing the Wi-Fi access points' functionalities and integrated into the wireless network. The main design principles we have adopted are:

- Use of the **Software Defined Networking (SDN)** paradigm for the design of the Wi-5 network architecture solutions. The SDN has achieved great success for controlling wired networks but it may not yet be optimized for wireless networks. A wireless optimized SDN will be studied considering the best use of existing features to overcome the performance issues, which may arise in pure SDN solutions.
- Using **Network Functions Virtualization (NFV)** paradigms for the design of the Wi-5 network architecture solutions. The idea is to use IT virtualization technologies to compose entire classes of traditional network node functions into building blocks that may connect, or chain together, to create communication services. This will also align Wi-5 with ongoing efforts to define the upcoming 5G standards.
- Use of the **IEC/ISO/IEEE 42010** standard for the description of the Wi-5 architecture to formalize the definition of software functionality and simplify the wider exploitation and standardization of the architecture.
- Release of selected project innovations as **open source software**. Open source software initiatives should be considered as complementary to formal standardization processes.
- Use of the roles identified in the **business models analysis** carried out in deliverable 2.1, in order to ensure the economic viability of the services to be supported.

Following these design principles we aim to simplify the integration of novel Wi-5 functionalities across the whole Wi-Fi network, by separating the control plane of the Wi-Fi access points from the data plane. The network controller will be the main focal point of the system with the Wi-5 functionalities running on top of the controller, as depicted in Figure 4. This modular approach will make the integration of Wi-5 functionalities and subsequently the Wi-5 system, scalable, extendible, and easy to implement.

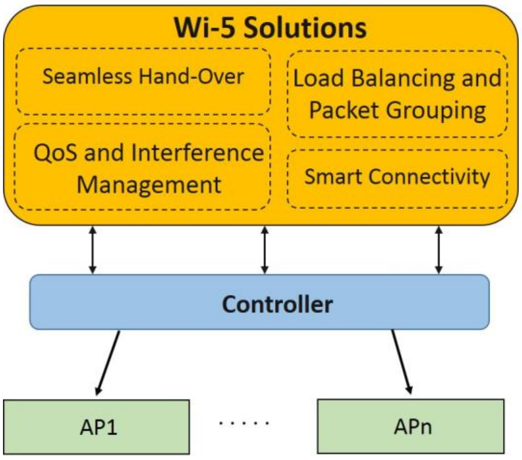


Figure 4: Wi-5 Design Approach

6 Conclusions

This deliverable provides the description of the use cases that Wi-5 has selected in order to help in the definition of the requirements for the technical innovations and architecture to be developed by the project. The use cases will also be used in the validation process of the implemented functionalities.

For these purposes, the project used as an initial basis the use cases defined by the IEEE HEW study group, complemented with others resulting from the consideration of the usage trends expected in the following years. The Wi-5 uses cases, in this sense, are intended to be representative of the utility that the innovations proposed by the projects can bring to the Wi-Fi ecosystem, and are also consistent with the business models that the project has identified. They also take into account the feedback from the Operator Board, which was provided in an ad-hoc meeting held with them.

The selected use cases are the following:

- Airport/train station
- Dense apartment building
- Pico-cell street deployment
- Large home/SOHO
- Community Wi-Fi

For these use cases, the following sets of information have been produced:

- Description of each use case, including operational conditions and potential added value.
- Functional requirements associated to each use case, identifying the functionalities that should be supported for the implementation of the use case.
- Performance requirements for having an adequate quality of experience for each use case.

On top of the use cases and requirements, the deliverable also includes a set of design principles to apply in the realization from requirements to architecture. These design principles are based on the state of the art of the technology and the experience of the partners; however, it must reckon that other principles might have been selected for fulfilling the same set of requirements.

With this deliverable, we set the foundations for the design and evaluation of the architecture to be developed by the Wi-5 project. It is also expected to contribute towards standardisation and adoption of our results, as they can be demonstrated to be useful for improving the performance of relevant use cases that are specifically of interest to operators.

7 References

[1] Wi-5 D6.2 "Dissemination, exploitation and standardisation plan," August 2015.
[2] L. Cariou, "HEW SG usage models and requirements - Liaison with WFA," https://mentor.ieee.org/802.11/dcn/13/11-13-0657-03-0hew-hew-sg-usage-models-and-requirements-liaison-with-wfa.ppt, [Accessed Nov 2015].
[3] G. Harding, "The Tragedy of the Commons", Science, vol. 162, pp. 1243-1248, 1968.
[4] M. Suznjevic, J. Saldana, "Maximum Tolerable Delays when using Tunneling Compressed Multiplexed Traffic Flows," draft-suznjevic-tsvwg-mtd-tcmtf-05. (Jun. 2015). Available at http://datatracker.ietf.org/doc/draft-suznjevic-tsvwg-mtd-tcmtf/