Wireless alternatives for Fixed Broadband replacement

Jose TORRIJOS1[1] , Ignacio BERBERANA[2] , Pedro Olmos[3], Luis CUCALA[4]

[1]*Telefónica Investigación y Desarrollo, Don Ramón de la Cruz 84, 28006 Madrid, Spain*
Tel: +34 913128838, Email: jgijon@tid.es
[2]*Telefónica Investigación y Desarrollo, Don Ramón de la Cruz 84, 28006 Madrid, Spain*
Tel: +34 913128792, Email: ibfm@tid.es
[3]*Telefónica Investigación y Desarrollo, Don Ramón de la Cruz 84, 28006 Madrid, Spain*
Tel: +34 913128802, Email: pedro@tid.es
[4]*Telefónica Investigación y Desarrollo, Don Ramón de la Cruz 84, 28006 Madrid, Spain*
Tel: +34 913128804, Email: lcucala@tid.es

Abstract: This chapter provides a first analysis of wireless alternatives that could be used in the access network to provide fixed broadband services to residential users avoiding the deployment of expensive FTTH solutions up to the customer premises. Wireless local drop (WLD) concept proposes the convergence of fiber and wireless networks (Wi-Fi or mobile) as the preferred solution for business areas with a low customer penetration as an intermediate step before a complete FTTH deployment. This work presents the main ideas related to the general WLD architecture, the operating scenarios, the main requirements, the candidate technologies to implement this solution and the first laboratory tests to assess the suitability of the proposed solution.

Keywords: xPON, FTTH, access, fixed broadband, Wi-Fi, wireless.

1 Introduction

Telecom operators started to provide broadband services using the deployed copper cables traditionally used to provide voice service and low speed data services. However, broadband services require the deployment of fibre technologies closer to the customer. Currently, there are many Fiber to the x (FTTx) solutions, and depending on the type of the fibre deployment (far or close to the customers' premises) it is possible to have different network topologies, such as, fiber to the Exchange (FTTEx), Fiber to the Curb/Cabinet (FTTC), Fiber to the Building (FTTB), Fiber to the Home (FTTH), or the new Fiber to the Distribution Point (FTTdp), which combines fibre and copper technologies to deliver aggregated data rates up to 250 Mbps over 200 m twisted-pair copper line length and is under development[1].

The main difference among the previous deployment types is where the fibre ends, so the closer the fibre is to the customers, the higher capacity can be provided to them. In the other hand, deploying fibre near to the customers is expensive, so telecom operators have always tried to offer the maximum capacity with the minimum cost, designing new deployment alternatives to upgrade their access networks with the lowest capital expenses. One solution to do that is not to deploy fibre up to the customer's home and reuse the existing copper lines, but it is not always possible (for example, for new entrant operators) nor practical (in case of a low customer penetration).

Wireless alternatives can be used in the previous scenarios by network access operators to replace fixed technologies used to provide broadband services to final users, avoiding to reuse or to install cables in the last drop up to the customer's premises. The main motivation for replacing fixed technologies by wireless solutions is to reduce the costs of providing FTTH connections (using Gigabit-capable Passive Optical Network-GPON for example), avoiding the visits of installation personnel to the customer home to perform the connection and configuration of the ONT (Optical Network Terminal) to the incoming fiber, a process that takes time and is expensive.

FTTH deployments are more efficient in cost when the number of customer per building is maximized, so all the deployed elements and the infrastructure built are used by many users and their cost can be shared among all of them. In broadband deployments with an estimated low number of customers per building, the connection cost per customer is higher and FTTH solutions could not be profitable, so FTTB or FTTC are typically used instead FTTH to increase the number of households and decrease the total cost per customer.

The alternatives proposed in this section are considered to be used in low penetration areas with a low number of customers per building and may constitute a temporal reprieve until the conditions for complete FTTH deployment are achieved.

2 General architecture

This new Wireless Local Drop architecture or WLD is similar to a traditional FTTB or FTTN architecture and it is composed of the following three elements:

- A Multi-Dwelling Unit (MDU). Located in the last network termination point of the access network, the MDU is responsible of the physical layer and layer 2 processing. It is composed of an ONU (Optical Network Unit) that is connected to the central office using a shared fibre following a point-to-multipoint PON approach.
- A point-to-multipoint wireless transceiver (PtM WLD). This element establishes a (most likely directional) radio link with the wireless receivers located inside the customer premises. It also implements some radio resources management and security functions and the interface with the MDU.
- A domestic point-to-point wireless transceiver (PtP WLD). It corresponds to the wireless device located in the customer side that connects the home network to the point-to-multipoint wireless transceiver.

The architecture is represented in the following figure:

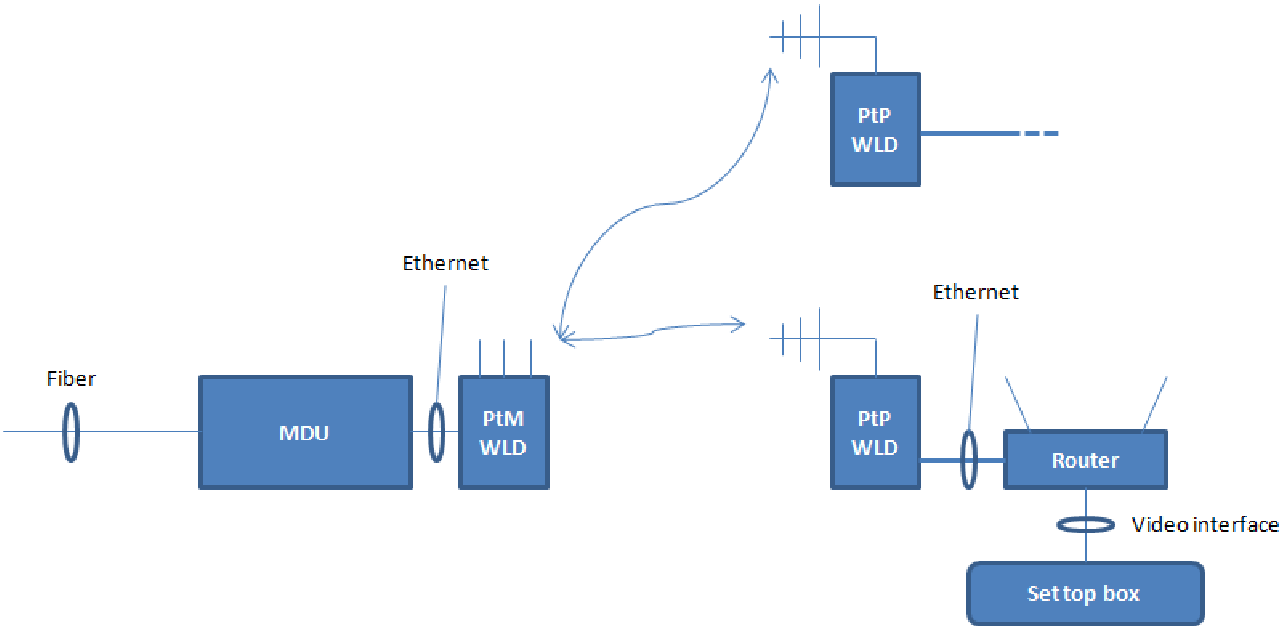

FIG1.pptx

Figure 1: Wireless Local Drop main elements

The MDU for this application has the same kind of functionality used in MDUs in cabinets for FTTB/FTTN solutions. The assumption for the MDU interface to the PtM WLD element is that it will be Ethernet, so a single MDU may attend several point-to-multipoint WLD elements, as it can support several Ethernet interfaces. Additionally, the MDU will have a fiber interface based on xPON. An implementation option would be to integrate both elements (MDU and PtM WLD) into a single device.

3 Requirements

The requirements identified in this section constitute the main criteria for the selection of the best WLD alternative from both technical and economic viewpoints.

- Minimum range for the wireless link: 10-15 m
- Targeted to provide broadband service in low penetration scenarios:
  - Minimum PtM WLD aggregated peak data rate: 40-50 Mbps
  - Moderate data rates: 5-20 Mbps per customer and 3-4 customers/access point to be served by each PtM WLD. It must integrate mechanisms to assure fairness between users
- Spectrum availability
  - As interference free as possible
- Easy deployment & operation
  - No radio planning required, NLoS preferable
  - Low power consumption
  - Easy installation of wireless access points and home equipment
  - Management & monitoring capabilities
- Standard and cost-effective
- Low transmission power operation: both for avoiding excessive energy consumption and electromagnetic radiation issues. No refrigeration should be required, even in extreme weather conditions.
- Services supported: triple play support is assumed by default. Voice support is assumed to be provided, most likely as VoIP (Voice over IP).
- QoS (Quality of Service): the WLD alternative should guarantee a certain quality of service defined by parameters as BER (Bit Error Rate), availability, mean time between failures, etc.
- Security requirements: the WLD radio link should be ciphered in order to avoid any eavesdropping, as fibre security mechanisms are terminated at the MDU.
- Remote configuration and management capabilities: all the elements of the WLD should have the capability of being remotely provisioned, configured and monitored, using TR-069 [2] or a similar standard.
- Cost: regarding the total cost of ownership (capital and operational expenditures), WLD solution is required to have significantly lower cost than fiber to the home solutions.
- Other constructive requirements: part of the solution may be installed outdoors and must be prepared for this kind of operation.
- MDU WLD installation requirements: minimization of installation costs with additional visual impact associated restrictions.
- Customer installation requirements: mainly related to limitations in the installation of the antenna (e.g., whether if it is possible to install outside the windows in the buildings façades).

4 Radio technology

Implicit in the previous description is the assumption that WLD will be based in the establishment of directional links between the network side and the customer side of the system (this should be understood as that at least one of the antennas is highly directional). The use of directional links is considered mandatory in order to provide the capacity and the QoS expected (which should be equivalent to those provided with fibre) and to avoid interference related issues (especially if license free frequency bands are used).

The problem is that the support of (at least) 60 Mbps of *effective* throughput over the PtM/PtP WLD interface would require, for most of the radio technologies considered, the use of advanced radio features like MIMO (Multiple-Input and Multiple-Output) or carrier aggregation unless very good SINR (Signal to Interference plus Noise Ratio) conditions are guaranteed (or a very large bandwidth is available). For example, in the case of one of the technologies considered, Wi-Fi IEEE 802.11n, the maximum effective throughput that can be supported without MIMO and carrier aggregation (but using transmission diversity and packet aggregation) is of the order of 62 Mbps. Using 40 MHz channels, a maximum effective throughput of the order of 116 Mbps can be supported[1]. Using both MIMO 2x2 and carrier aggregation would allow the support of a maximum effective throughput of 198 Mbps. However, using MIMO would result in a higher interference generation, which could impact both on other WLD systems and on Wi-Fi systems operating in the same frequency band. On the other hand, it is not clear that in the operating environments foreseen the performance of MIMO could be considered optimal. This may be due to the fact that the required de-correlation between antenna elements cannot be achieved or that the SINR is not high enough.

In this sense, it is considered that the improvement in the SINR that can be achieved with directional antennas can compensate for the increased spatial resources available with MIMO and allow for the support of higher effective throughput. On top of that, beamforming is more resilient to interferences in case the solution is generalized or there are other users that may use the same radio technology (e.g., Wi-Fi at 5 GHz).

On the other hand, it seems unlikely that the objective of a low installation cost can be compatible with the use of high directivity antennas that should be accurately pointed. In this sense, the use of some kind of beam forming technology, based on the use of phased array antennas[2] or any other solution (e.g., fixed multi beam), at least in the network side of the WLD, is considered a technical requirement for the final solution.

On the customer side of the WLD it is assumed that the antenna used has at least certain directivity, with a minimum gain of 5-7 dBi[3]. Simple patch antennas are in principle the preferred option. In [4] it is shown the radiation patterns of a single patch antenna with 8.8 dBi gain and an azimuth plane beamwidth of 70 degrees and an elevation plane beamwidth of 57 degrees.

5 Operating scenarios

This section provides a taxonomy of the operating scenarios foreseen for the WLD operation.

5.1 Urban deployment

Urban deployment (for the purposes of this analysis) is characterized by multi-floor buildings with a relatively high number of potential homes to be connected per building. Homes can be characterized as exterior, if the signal can arrive to the customer side WLD from outside the building, or interior, if the network side of the WLD is installed inside the building served.

Several alternatives are possible to support the WLD in this environment. They are presented in the following sections.

[1] The maximum bit rate supported at PHY level would be 72 Mbit/s and 150 Mbit/s, respectively. The values indicated are taken from [3].

[2] A phased array comprises multiple antenna elements each transmitting (or receiving) an attenuated, phase shifted copy of the same RF signal. By varying the amount of attenuation or phase shift, a device can control the radiation pattern of the antenna, including the direction of maximum gain or the size and location of lobes. The flexibility of a phased array increases rapidly with the number of antenna elements.

[3] An antenna built with a single patch will have a maximum gain of about 9 dBi, whilst a collinear omnidirectional antenna has a typical gain of 5.8 dBi.

- Coverage from a different building:
  This option is based on the idea of decoupling the building where the network side of the WLD is installed from the building where the customer side WLD resides. This alternative contemplates the possibility of illuminating several buildings from a single location, for example providing coverage from rooftop (see Figure 2A) or from the façade (see Figure 2B).
  A second variant (although it is not strictly speaking coverage from a building) would consider the use of urban furniture to place the PtM element. This may be synergic with the deployment of mobile broadband microcells (see Figure 2C):

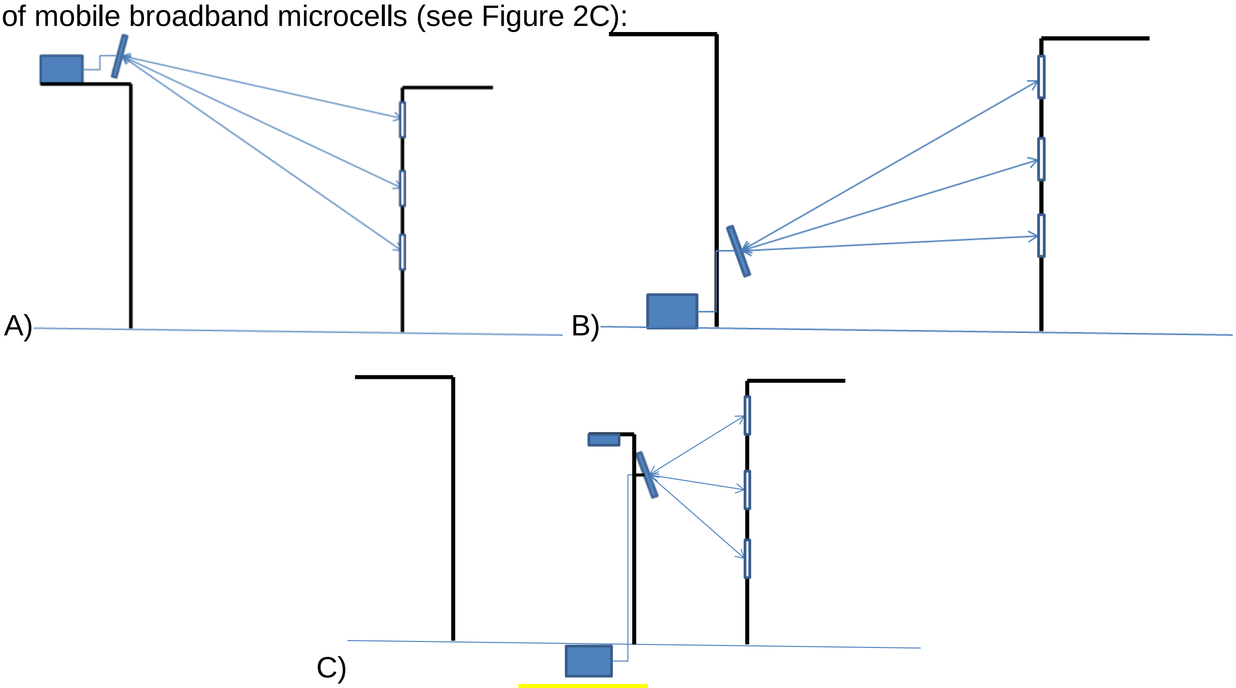

FIG2.pptx

Figure 2: WLD urban deployment scenarios (I)

  The advantages associated with these options compared to the following alternatives are: better horizontal penetration of the signal and less sensitivity to the presence of ornamental elements in the building façade, feasibility of using patch antennas installed in the customer windows or even using antennas inside the building, possibility (in the case of rooftop installation) of covering several buildings from a single location, possibility of reusing the infrastructure already deployed for mobile networks (cell sites, both macro and micro, masts, etc.) or central offices.
  The main problems associated with this option are the risk of having to pay the deployment of the infrastructure, the possible propagation problems associated with vegetation and rain attenuation, and the need to support 3D beamforming.
  The clearest niche of opportunity for this option is the one based in the use of existing infrastructures to host the network elements of the WLD solution.

- Coverage from outside the same building:
  There are several options for providing the WLD from the same building where the clients are located. These alternatives can be applied for both interior and exterior homes, for example providing coverage from the building roof, as shown in Figure 3A, or from the lower part of the building, as can be seen in Figure 3B (in both cases, no 3D beam forming capabilities would be required)

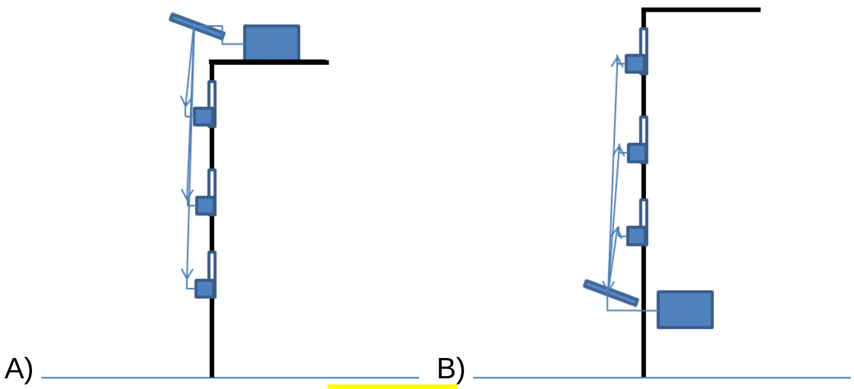

FIG3.pptx

Figure 3: WLD urban deployment scenarios (II)

Disadvantages that may be associated with this option are: limitations in the installation of the system elements, possible blocking by façade constructive elements and the need to install an antenna for the PtP WLD in the building façade.

- Coverage from inside the same building:
  A first case for coverage from inside the building is the coverage from indoor patios for interior homes. From a conceptual viewpoint, the solutions that can be adopted are equivalent to those considered for coverage from a different building and from outside of the same building. However, some special conditions should be taken into account, like the shorter distances between PtP and PtM elements. These would require to support larger angular variations of the beams, which would be more difficult to achieve.
  A second possibility for the WLD is to locate the PtM WLD element in a common area inside the building, like the landing area in the stairs. In this case, the WLD signal should be able to go through one or more walls in order to establish the link. In this case it is assumed that the MDU/ONU would be located in the basement, the roof or another common area of the building and the signal is distributed through Ethernet or a similar technology. Otherwise an MDU/ONU should be installed per floor where the service is supported.
  Some problems associated with this last option are: as it is a NLOS scenario it would be complicated to predict wireless capacity, the necessity of deploying additional wires to link the MDU with the PtM WLD element, and the visual impact limitations imposed by proprietors and tenants.

5.2 *Suburban deployment*

Suburban deployment is characterized by a lower density of dwellings (one or two per buildings). Distance between buildings is also considered to be longer on average. In this case, only coverage from outside the building is considered. For these purposes, lampposts or telephone poles are the most likely candidates for the installation of the network side elements of the WLD solution (see Figure 4).

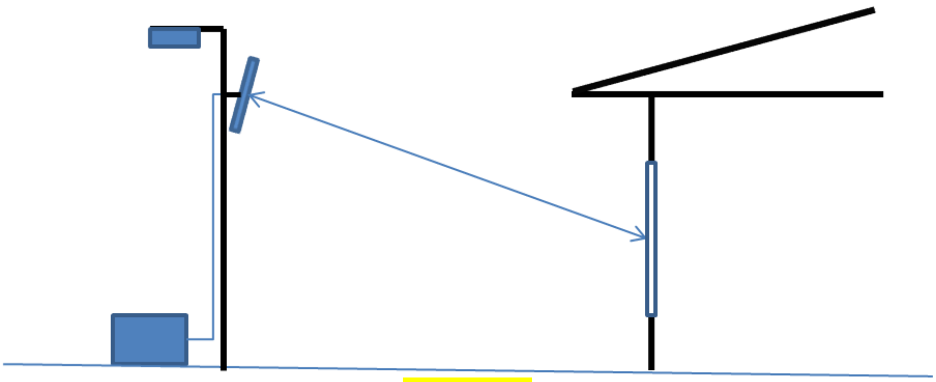

FIG4.pptx

Figure 4: WLD suburban deployment scenarios

One advantage of the suburban coverage is that 3D beamforming is less probable to be required if all the houses to be connected are of a similar height and the terrain is relatively plain. Even, there is the possibility of using fixed multi-beam array antennas, if there is a regular distribution of the dwellings.
The drawbacks of this option are similar to those encountered in the urban environment. Especially relevant is the impact of the vegetation on the reliability of the radio link.

6 Key aspect to analyze

For the selection of the most adequate solution for each operating scenario several aspects should be analyzed. Ideally, a single technical solution that meets all the technical requirements would be the best option.

6.1 Capacity

The WLD solution should support at least three traffic profiles: voice (low bitrate and strict delay and jitter requirements), video services (high bitrate with less strict delay and jitter requirements) and internet services (typically best effort).
It can be assumed that the downlink capacity required (from the network to the customer equipment) will be significantly larger than the capacity needed for the uplink.
As the number of user per PtM WLD is expected to be low, no significant statistical multiplexing gain can be expected. So, it can be assumed that the total capacity for the WLD is the sum of the capacity to be guaranteed to each individual user. The latter is determined by the commercial offer for the service. It is considered that at least 20 Mbps per drop of effective throughput is required for providing simultaneous support of video transmission and internet access. This means that the WLD capacity should be of the order of 60-100 Mbps to accommodate several users at one time.

6.2 Characteristics of the spectrum

There are different criteria for characterizing the frequency bands that can be used for the WLD implementation. As a function of the capacity and quality requirements of the solution, two main options are considered:

- Use of license free frequency bands: 2.4 GHz, 5 GHz and 60 GHz.
- Use of licensed frequency bands that are not being used for other services or could be re-allocated to the support of WLD support: 3.5 GHz, 2.6 GHz TDD (Time Division Duplex) band, 2 GHz TDD band, LMDS (Local Multipoint Distribution Service) band and 80 GHz.

License free implies a lower cost and, generally speaking, the availability of larger bandwidths; on the other hand it is certainly more prone to interference issues. Licensed spectrum is certainly more protected from interferences, but there is (generally) less bandwidth available and less commonality in the spectrum that is available in different countries. Also, licensed spectrum may be relatively expensive to acquire.
Concerning the use of paired or unpaired spectrum, in general terms, given the asymmetry of the capacity required for each link direction, it is considered that the use of TDD spectrum is the best option. The use of TDD spectrum also has the advantage of being better suited for the support of beam forming schemes.
With respect to the spectrum to be used and its propagation characteristics, it is possible to distinguish three sets of frequency bands: low (bellow 10 GHz), intermediate (20-30 GHz) and high frequencies (60-80 GHz). Lower frequencies have better propagation characteristics (lower attenuation with distance, lower penetration losses through materials, etc). But for this application, one main factor for the selection of the frequency is the suitability for the implementation of beamforming technique.
As antenna directivity (beamwidth) is limited by the physical principle of diffraction wherein the beamwidth is inversely proportional to the operating frequency, higher frequencies are in principle

more advantageous for directive radio links. So, at 60 GHz, for example, the beamwidth is far narrower than at lower frequencies (2.4 GHz, for example). Table 1 shows the beamwidth for several unlicensed frequency bands at 1 km with 33 cm diameter antennas [5]:

Frequency	*Beamwidth*
2.4 GHz	117 degrees
24 GHz	12 degrees
60 GHz	4.7 degrees

Table 1: Comparisons of beamwidths of wireless backhaul solutions

A very narrow beam solution gives at least the following advantages: avoids interference from other emitters in the same band (as the beam is so narrow the potential for interfering with another such beam on the same frequency is very unlikely), offers superior security (if the beam is very narrow, it is difficult to intercept or otherwise exploit) and offers an increased power to overcome rain fades.
However, having a very narrow beam also requires a more careful installation, which is not compatible with the economic requirements of the solution. On top of that, higher frequencies are more sensible to fadings due to vegetation and obstructions. Also, the cost of the equipment is expected to be higher for higher frequencies.

6.3 Antenna technology

Several aspects related to the antenna technology used in the solution should be analyzed:

- Beamforming versus fixed multibeam. The second option may be cheaper and less complex and adequate for scenarios where 3D beam forming is not necessary. So it is important to know or estimate the number of beams needed.
- Gains associated with beamforming capabilities, both in terms of increased antenna gain and interference rejection.
- Viability (both technical and economic) of supporting 3D beamforming of cheaper technologies that could combine horizontal beamforming with fixed multibeam in the vertical plane.

6.4 Security

In order to ensure the wireless link, some security mechanisms should be implemented. An analysis of the security capabilities available for each candidate technology should be carried in order to assess that they meet the requirements of the contents being distributed and the communications supported.

6.5 PON integration

In terms of the impact of the solution proposed on the access network architecture it should be taken into account that the WLD solution must be integrated with the service architecture of GPON (or a similar PON technology), requiring as few changes as possible. In order to do that, users could be differentiated by means of VLANs (Virtual Local Area Network) using 802.1Q tunneling and services by means of 802.1p priorities. Fortunately, these capacities are already supported in different Wi-Fi products.
In terms of security aspects, the main issue is that, as security in GPON is terminated in the MDU/ONT, if no additional security is provided the WLD radio link would be transmitted on clear. The use of standard Wi-Fi security WPA (Wi-Fi Protected Access)/WPA2 or WPS (Wi-Fi Protected Setup) for securing the radio link could be considered an adequate solution.

7 Candidate technologies for the radio link

Taking into account the aspects indicated in the previous section, the following two radio technologies are considered prime candidates for the implementation of a WLD solution:

7.1 IEEE 802.11n

The option of using Wi-Fi technology at 5 GHz band seems the most natural candidate for WLD support, as the availability of the spectrum is practically universal. Other advantages are:

- Being located in the low frequency band, has better penetration characteristics which may be an important advantage in some of the scenarios.
- Better directivity characteristics than lower frequencies to be used with other alternatives, like LTE (Long Term Evolution) or WiMAX (Worldwide Interoperability for Microwave Access).
- Relatively high transmission power, depending on the specific part of the band that is used and also if it is employed indoors or outdoors (transmission power at 5 GHz can be as high as 1 W EIRP -Equivalent Isotropically Radiated Power, compared to 100 mW at 2.4 GHz).
- Use of 40 MHz channels, which allow for higher bit rates.
- More spectrum available. In the EU, 20 channels of 20 MHz bandwidth each are available for Wi-Fi, from 5150 to 5350 MHz and from 5470 to 5725 MHz .

Wi-Fi is also a technology where customization in order to meet some specific requirements can be more easily achieved than with other technologies (e.g., LTE). In principle, it is the preferred solution for the implementation of the WLD. Also, the evolution towards 802.11ac, which would support higher bit rates through higher order MIMO, 80 MHz channels and 256QAM modulation (among other improvements), may help to guarantee that the solution can evolve to meet future, more stringent requirements.

7.2 TD-LTE

The use of the TDD mode of LTE is another alternative for the WLD radio interface. It is assumed that the use of the technology in China and other countries and its support by most chipset vendors would result in economies of scale compatible with the economic objectives of the WLD solution.

Two main operating frequencies for a TD-LTE solution could be used: the TDD spectrum at 2.6 GHz band and the 3.5 GHz (currently being used for WiMAX in most countries) with a minimum bandwidth of 20 MHz is required to support the capacity expected for WLD.

From an architectural viewpoint, this solution is more complex than the one based in Wi-Fi. In principle, it is assumed that the PtM WLD part can be implemented reusing a HeNodeB (i.e.: a femtocell) and the PtP WLD would be an LTE UE (user equipment). However, the users' traffic should not go through the EPC (Evolved Packet Core).

The use of SIPTO (Selected IP Traffic Offload) is one of the possibilities for carrying out an early offloading of the traffic. The support of this feature, specified in 3GPP Release 10, should be incorporated in the solution.

TDD-LTE is considered a fallback in case for any reason Wi-Fi based solution is not feasible.

7.3 Technologies discarded

Several technological solutions have been discarded in an initial analysis, even if they are feasible from the technical viewpoint.

- WiMAX: Although in terms of its technical characteristics, WiMAX may be an adequate solution for the WLD radio interface, its unclear future, the lack of vendors and the low economies of scale advise not to consider it. On top of that, it is not clear that there is availability of low power solutions that can be adapted for a WLD scenario.
- FDD (Frequency Division Duplex) LTE: Again, although FDD LTE may be an adequate solution from the technical viewpoint, it is considered that the use of the spectrum for providing other services (i.e., mobile broadband services) makes more sense from the economic viewpoint.
- 60 GHz solutions: Main problem for the solutions based on the use of the 60 GHz band is that, in short/medium term, are not expected to be cost effective enough to meet the requirements for the WLD solution.

8 Proof of concept

A proof of concept test has been carried out using off-the-shelf Wi-Fi equipment and different antennas to assess the suitability of the proposed solution. For this purpose, a bidirectional Wi-Fi link between two buildings (the first one at ground level and the second one at a second floor) was established with a total link distance of 16 meters.

A photograph of the outdoor environment can be seen in the following photograph:

FIG5.jpg

Figure 5: Outdoor environment of the proof of concept

The main aspects of the tested were:

- A Wi-Fi link using the 10 GHz frequency band with a bandwidth of 20 MHz. For this link it was used an IEEE 802.11b/g protocol with a maximum data rate of 54 Mbps with a single channel of 20 MHz. Free space losses were approximately 76.5 dB for 10 GHz.
- A Wi-Fi link using the 5 GHz frequency band with a bandwidth of 20 and 40 MHz. For this link it was used an IEEE 802.11a/n protocol with a maximum data rate of 65 Mbps using a 40 MHz channel. Free space losses were approximately 70 dB for 5 GHz.
- 2.4 GHz frequency band was not been tested due to its high interference level from other Wi-Fi links and the lack of support of support of 40 MHz channels.
- Several antenna types were tested at both sides of the link.
  - In the 10 GHz testbed: for the access point, a horn antenna with an isotropic gain of 17 dB was used. In the client side two different antennas were used: a quarter-wave vertical antenna and a log-periodic antenna with 5 dB isotropic gain to emulate a more real antenna.
  - In the 5 GHz testbed: for access point, the same horn antenna was used and an additional flat panel with a gain of 19 dB was also tested. The antennas used in the client side were the same log-periodic antenna than 10 GHz and a horn antenna with 13 dB of gain.
- The measurements were taken using an access point and a Wi-Fi client (based on personal computers running Microsoft Windows XP and Ubuntu 10.04 respectively). The data rate was measured while a 1 GByte video file was transmitted in both downlink and uplink (although not simultaneously). The antenna corresponding to the access point was located on open air whereas the client antenna was located behind a double glass coloured window so the signal level is smaller compared to only free-space losses.

The following figure contains the setup for the 10 GHz testbed composed of the previous elements described. In transmission, the signal from the 2.4 GHz Wi-Fi adapter is mixed with an 8 GHz local oscillator to produce a 10.4 GHz which is sent to the RF power amplifier. In reception, the signal received by the antenna is amplified and mixed another 8 GHz to generate the original Wi-Fi signal.

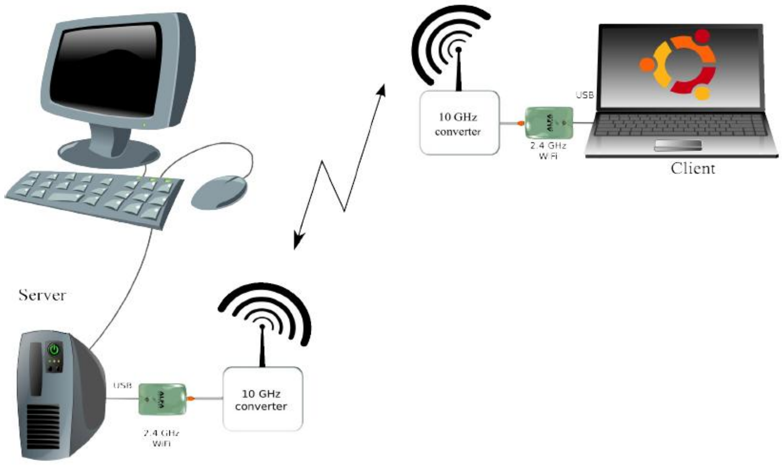

Figure 6: 10 GHz setup

FIG6.jpg

The 5 GHz setup was simpler than the previous one as 5 GHz devices can be found easily in the market, so 5 GHz Wi-Fi adapters were connected directly to the antennas.

The main conclusion obtained with the previous tests is that it would be possible to provide broadband services to users (considering the previous technical requirements) through radio links using the 5 and 10 GHz frequency band with client side antennas with low gain (5 dB gain could be assumed the average gain of a patch antenna located on a window). Other results were:

- Downlink bitrates between 20 and 25 Mbps and uplink bitrates between 10 and 15 Mbps using 10 GHz frequency band (the best combination was the horn antenna in the access point and the log-periodic antenna in the client side).
- Downlink bitrates between 30 and 45 Mbps and uplink bitrates between 30 and 40 Mbps using 5 GHz frequency band (the best combination was the panel antenna in the access point and the log-periodic antenna in the client side).
- High impact of the antenna directivity, obtaining 100% increase in the throughput with 5 dB increase in antenna gain.
- Good performance was observed in 5 and 10 GHz bands, so both frequencies could be considered to be used in commercial services from the technical point of view.
- The measured data rate depends almost exclusively of signal level (and evidently on the bandwidth and the modulation type used).
- Minimum impact observed (less than 2 dB) due to the vegetation (in a low vegetation scenario).

9 Conclusions

In this chapter the Wireless Last Drop concept has been defined, the main requirements associated to it identified and the possible application scenarios analyzed. The main conclusions were that both wide frequency channels (at least 20 MHz) and directive antennas are required in order to ensure the capacity and reliability expected to be a realistic replacement for fixed broadband solutions. Based on these conclusions, the candidate technical solutions for its implementation have been identified. They are basically two: a Wi-Fi based solution using 40 MHz channels in the 5 GHz band with directional antennas; and a TD-LTE solution, based on the use of 20 MHz channels in 2.6 GHz or 3.5 GHz bands. Due to the availability and cost of the components when implementing a WLD system with each of these possible solutions, it has been considered that the former is the one that should be pursued firstly.

Acknowledgements

Wireless combination with PON concepts presented in this paper is based on the work being developed inside COMBO project (COnvergence of fixed and Mobile BrOadband access/aggregation networks), which started 1st January 2013 and is funded by European Union's Seventh Framework Program (FP7/2007-2013) under grant agreement n° 317762.

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