**E3NETWORK**

**Energy Efficient E-band transceiver for backhaul of the future networks**

# DELIVERABLE **D.6.3.3**

# Report on Business Plan 3

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# INDEX

# EXECUTIVE SUMMARY

Driven by the growing adoption of data-hungry smart-phones and tablets, carriers worldwide are spreading concerns over an increase of data traffic on their networks. To cope with such high levels of mobile traffic, wireless carriers need to invest in the network updates, especially in the backhaul part. One of the key technologies, involved in mobile backhaul network, is the traditional Microwave radio, which has so far played a dominant role, with almost 50% of the Worldwide mobile backhaul pie.

The use of traditional Microwave radio in frequency bands below 42GHz for mobile backhaul application is today limited to smaller channel sizes with a maximum channel size of 112 MHz and consequently a data rate around 650 Mbps. The demand for higher capacity poses challenges in this specific part of the network regarding the suitability of conventional microwave spectrum.

The adoption of millimetre-wave radio operating in E-band with the larger channel sizes here available is recognized as the feasible solution when data rate will go beyond 1Gbps and up to 10Gbps. For this reason, 71-76 and 81-86 GHz frequency spectrum, is recognized as the place where the most attractive future radio solution, providing connection at Ultra High Capacity, for the needs of the 4G and 5G network backhaul, will find space.

In 2015, new frequency bands have been identified, mainly for high data rate application over distances of few kilometres. In particular two frequency bands, today identified as W-band (92-114.5 GHz) and D-band (130-174.8 GHz). Considering the approach taken for these bands, the use of 250MHz channel size and possible aggregation of a given numbers of channels for having larger channel option, a lot of results and HW parts from E3NETWORK could be exploited, as it is, creating added value to our project.

Last but not least, a new approach in link design, based on the concept of Channel aggregation, will improve a lot, the applicability of E-Band solution.

Summarising, the main applications, where a millimetre radio solution can be applicable are:

- Traditional mobile backhaul network
- Emerging new moile backhaul network Front-haul/C-RAN
- Small cell backhaul
- Vertical Market

In the context of E3NETWORK, this document presents the attempt to define the perimeter within which it would be possible to exploit the E3NETWORK solution and more in general the E3NETWORK studies and results.

# 1. INTRODUCTION

This document will try to describe in detail the potential applications and the market segments can benefit of the E3NETWORK millimetre-radio solution as a whole or of the E3NETWORK solutions parts or and results obtained.

We started to describe what E-Band is and would be, compared to traditional microwave frequency bands. After that, an overview of the frequency segmentation and relevant channel arrangements adopted, as defined by the spectrum authorities according to applications and use cases the stockholders needs, is reported. An exhaustive description of the worldwide licensing regulations and fees is as well provided complemented with an overview of the current E-Band radio solutions already present on the market.

The E3NETWORK potential results are then positioned inside actual existing solution already present on the market, in such a way to better show, where and what, all the possible "E3NETWORK parts" can be exploited.

Then, a deeply analysis to provide an estimation of the potential market can be addressable exploiting the E3NETWORK solution, results and parts, is provided.

In chapter 3, the exploitation plane areas have been identified, subdivided also among the E3NETWORK actors. Commercial and not commercial, academy and standardization areas are considered. At the end, individual exploitation plans of each partner are reported.

## 1.1 Introduction to the E-Band point-to-point communications

The 71-76 and 81-86 GHz bands (widely known as "E-band") are worldwide allocated for ultra-high capacity point-to-point communications. E-band wireless systems, today available, offer full-duplex Gigabit Ethernet connectivity at data rates up to 1Gbps and rarely up to 2.5Gbps. These solutions are today higher in cost when carrier class performances are provided/requested.

The 10 GHz of spectrum available represents, by far, the most ever allocated by ECC and ITU at any one time. This band, as depicted in the following picture, represents almost the 50% of the entire spectrum allocated so far for Fixed service, practically equal to all the microwave spectrum. With 5 GHz of bandwidth available per band (or sub band), and then with a possibility to have a 5GHz full duplexer channel, gigabit and greater data rates can easily be accommodated with reasonably simple radio architectures. With propagation characteristics comparable to those at the widely used microwave bands, such as 38 GHz and 42 GHz, link distances of some kilometres and beyond can confidently be realized.

Millimetre-wave radios, operating in this frequency band, are recognised as the most cost effective and less time consuming deployment viable solutions when a connection requiring very high capacity and a solution based on fibre is not available or feasible (mainly due to cost) and when traditional microwave is not fast enough.

Recently, a new work item, "Analysis of spectrum, license schemes and network scenarios in W-band and D-band" has been opened in ETSI ISG mWT [9]. The purpose of this WI is to produce a document on foreseen scenarios, spectrum usage and propose channelization of W-band (92-114.5 GHz) and D-band (130-174.8 GHz) to facilitate the deployment of future high capacity backhaul systems, able to decongest the network over distances shorter than usual ones for transport.

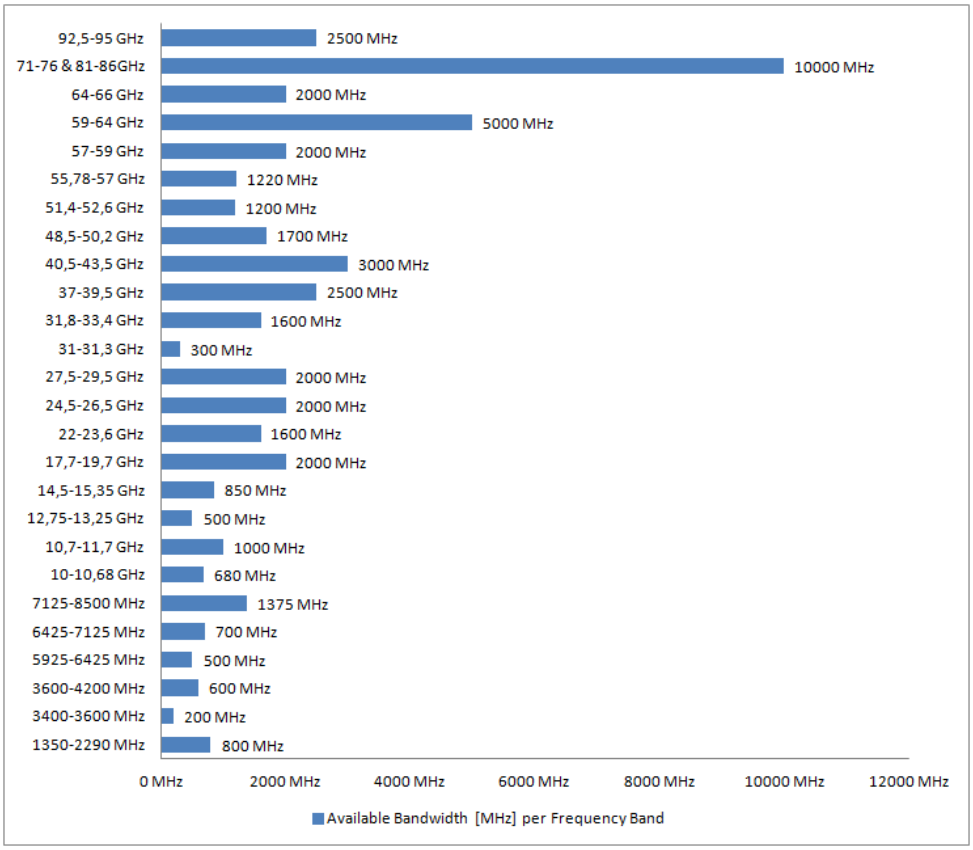


**Figure 1 – Fixed services: Available Bandwidth per frequency band**

Following the new trend introduced with E-Band, a first proposal for Channel spacing in W-band and D-band is based on 250MHz raster.

### 1.1.1. E-Band Frequency segmentation

The European Conference for Postal and Telecommunications Administrations (CEPT) released a European-wide band plan based on 250MHz channel spacing with the possibility to aggregate multiple channels to obtain up to almost 5GHz channel spacing. Current situation, depicted into last revision of ECCREC (05)07 and considering also, the last request of modification, is showing as a very complicated scenario. The reason behind this is mainly due to the lack of a real common view in regulatory approaches the National Administrations may have. Moreover, different views among manufacturer haven't helped in reaching an more homogeneous spectrum segmentation.

On the one hand, there is a view that is considering E-Band as the last chance for a Radio Equipment to transport multi-Gbps data rate at reasonable distance. In fact, in order to be able to transport higth data rate, a wireless system needs to have a wider channel size. In particular for data rate in the magnitude of multi-gigabit per second a channel size larger than conventional 56-112 MHz, currently available in lower frequency bands is needed. The following picture depicts this situation.

On the other hand, there is a view that is considering E-Band, just as a complement band for traditional microwave application, for data rate according to the current level requests, and so up to 600Mbps.

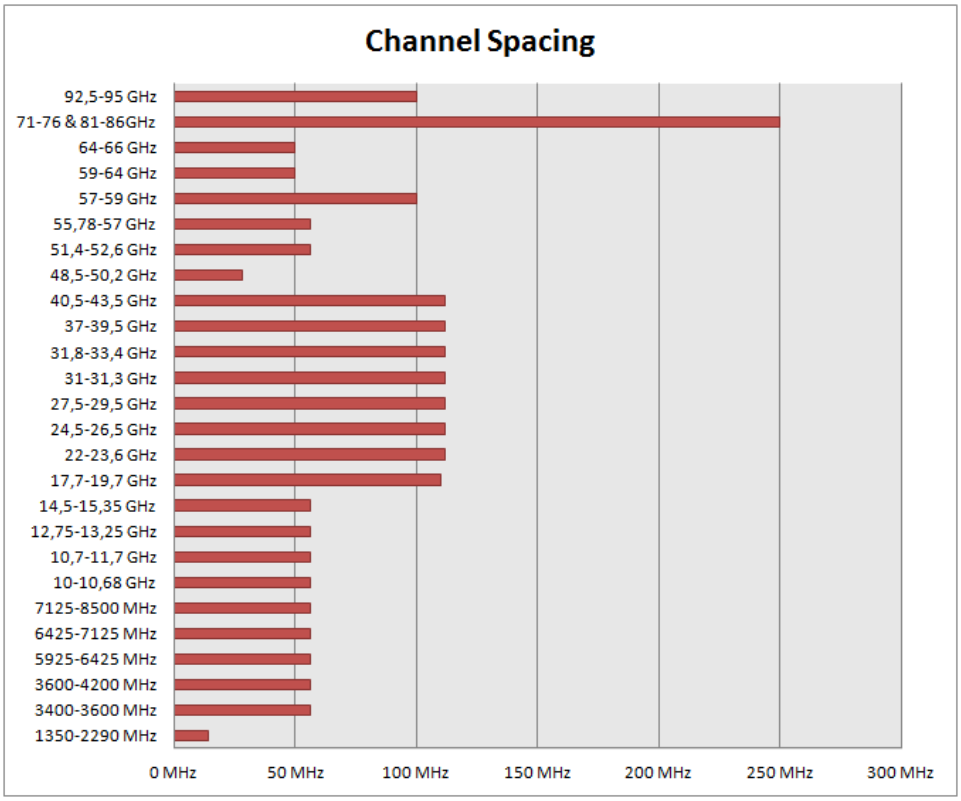


**Figure 2- Fixed services: Available channel size per frequency band**

A point it may be worth noticing here is that, in case of E-Band, it is also allowed to aggregate multiple channels in such a way to obtain a wider one enabling a single carrier emission transporting an high data rate. In particular, considering the relevant ECC recommendation but also the relevant ITU-R recommendation depicted the possible frequency arrangement for E-Band, the widest channel that can be used in E-Band are equal to 19x250MHz, and so close to 5GHz.

For the future, following the approach introduced with E-Band, current proposals, under consideration in ECC, for frequency arrangements and channel spacing in W-band (92-114.5 GHz) and D-band (130-174.8 GHz) are considering a channel raster based on 250MHz with the possibility to aggregate up to N channels. Considering this, we can conclude that some E3NETWOK studies and solutions, and here mainly the Network interface, the MODEM parts and the AD and DA converters, can be exploited for solution in these new frequency bands as well..

### 1.1.2. E-Band licensing regulation

The licensing regulation is reflecting the situation in frequency arrangement. Today, we observed that more than 40 countries have opened the E-Band.

The situation, in terms of licensing, is by far very variegated and not uniform at all. The most common regulation is the conventional link-by-link coordination made under administration responsibility. In this case a high level of fee, usually yearly based and depending on channel size is due. A table that is summarising current situation in EU is reported in D6.4.2

In some other countries, like US, UK, Australia and others, the E-Band is regulated with a "light-licensing" regime: Self-coordinated, first-come-first-served basis regulated with a register maintained by spectrum authority. In this case, a low level fee is requested. In other countries, like Mexico and Russia, the E-Band is licensing exceptions, so there is no coordination and usually fees are not requested.

In UK [2][5], a strange situation is going to take place, where the band is subdivided into two parts, a part regulated as fully coordinated and the upper parts as self coordinated. The next figure shows how the frequency arrangement will be implemented.


**Figure 3- UK Proposed E-Band frequency arrangement**

The following table reports a partial estimation of license cost per year for European countries for an FDD link that requires 2 GHz channel, using 64 QAM modulation scheme and for a hop length of 1 Km.

**Table 1- License type and cost in European countries**

| Country | License type | Allocated Frequencies | Estimative License fee for 2GHz/years |
|---|---|---|---|
| Albania | License | 71-76 GHz, 81-86GHz | More than 10000 € |
| Austria | License | 73-76GHz, 83-86 GHz | € 1.200,00 |
| Belgium | License | 71-76 GHz, 81-86GHz | € 27.500,00 |
| Bosnia and Herzegovina | License | 74-76 GHz, 84-86GHz | na |
| Bulgaria | ? | 71-76 GHz, 81-86GHz | ? |
| Croatia | Light licensing ? | 71-76 GHz, 81-86GHz | € 50,00 |
| Cyprus | License | 71-76 GHz, 81-86GHz | € 3.400,00 |
| Czech Republic | Free | 71-76 GHz, 81-86GHz | Free |
| Denmark | License | 71-76 GHz, 81-86GHz | € 960,00 |
| Estonia | License | 71-76 GHz, 81-86GHz | € 1.840,00 |
| Finland | License | 71-76 GHz, 81-86GHz | ? |
| France | License | 71-76 GHz, 81-86GHz | € 4.000,00 |
| Germany | License | 71-76 GHz, 81-86GHz | € 8.600,00 |
| Greece | License | 71-76 GHz, 81-86GHz | € 500,00 |
| Hungary | Light licensing | 71-76 GHz, 81-86GHz | € 80,00 |
| Iceland | License | 74-76 GHz, 84-86GHz | n.a. |
| Ireland | License | 71-76 GHz, 81-86GHz | € 180,00 |
| Italy | License | 71-76 GHz, 81-86GHz | under discussion |
| Latvia | | 74-76 GHz, 84-86GHz | n.a. |
| Liechtenstein | License | 71-76 GHz, 81-86GHz | € 5.200,00 |
| Lithuania | Light licensing | 74,6–75,9 GHz 84,6–85,9GHz | n.a. |
| Macedonia | License | 71-76 GHz, 81-86GHz | € 20.000,00 |
| Malta | License | 71-76 GHz, 81-86GHz | € 90.000,00 |
| Montenegro | ? | ? | ? |
| Netherlands | License | 71-76 GHz, 81-86GHz | ? |
| Norway | License | 71-76 GHz, 81-86GHz | € 50,00 |
| Poland | License | 74-76 GHz, 84-86GHz | n.a. |
| Portugal | License | 71-76 GHz, 81-86GHz | € 23.000,00 |
| Romania | License | 71-76 GHz, 81-86GHz | € 360,00 |
| Russian Federation | Free | 71-76 GHz, 81-86GHz | ? |
| Serbia | Free | 72-76 GHz, 82-86GHz | ? |
| Slovakia | Free | 71-76 GHz, 81-86GHz | ? |
| Slovenia | License | 74-76 GHz, 84-86GHz | n.a. |
| Spain | License | 71-76 GHz, 81-86GHz | € 2.400,00 |
| Sweden | License | 71-76 GHz, 81-86GHz | under discussion |
| Switzerland | License | 71-76 GHz, 81-86GHz | € 2.700,00 |
| Turkey | License | 71-76 GHz, 81-86GHz | ? |
| Ukraine | ? | ? | ? |
| United Kingdom | Double regime - free and Light licensing | 71-76 GHz, 81-86GHz | € 2.300,00 |

As already said, the situation is very varied, with countries where you can deploy links at no cost at all, and other countries where the cost of these links can rise up to a prohibitive 90K€.

A recent work issued in ETSI [8], has collected the fees World-Wide due for a specific case: a 250 MHz channel per one year and where this point impacts, for 1 Km.

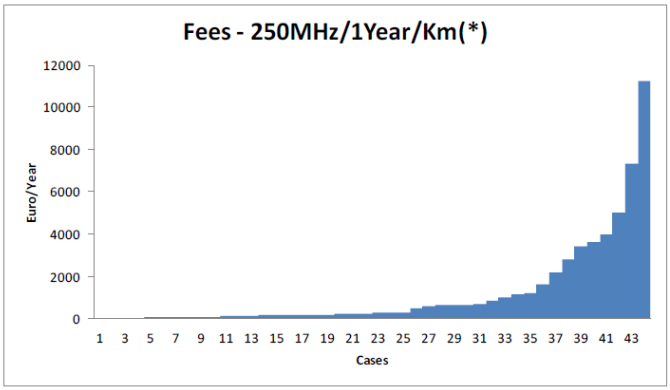


**Figure 4- E-Band Spectrum fees distribution in Europe**

Analyzing these data they observed that:

- 9% of the cases require no fee, likely to be in line with an unlicensed regime
- Up to 57% of the cases require less than €300 per year
- In average the fees due for this case (250MHZ/Year/Km) are €1 186, but it may be worth noticing that almost 85% of the cases require less than this average value.
- Almost 75% of the cases require less than €1 000.

Main conclusion reached, on licensing and fees:

" *…. , we reported an enormous difference of fees for a link license, mainly due to different models adopted for fee calculation, with fees sometimes too expensive and discouraging deployments*."

### 1.1.3. E-Band Equipment segmentation

Millimetre radio solutions, operating in E-Band have been available for over a decade on the market, without getting much attention for some reason. The main reason was due to big challenges in having components able to work with:

- The so high frequency
- The so high data rate, above 1Gbps

These two points have resulted so far in radio solutions too expensive in a very low volume market, at least until two years ago.

Figure 4 shows the current Millimetre-wave Radio Ranking Matrix. This figure, from [3] is reflecting what already mentioned above, a not clear and unique market strategy/view for millimetre-wave radio.

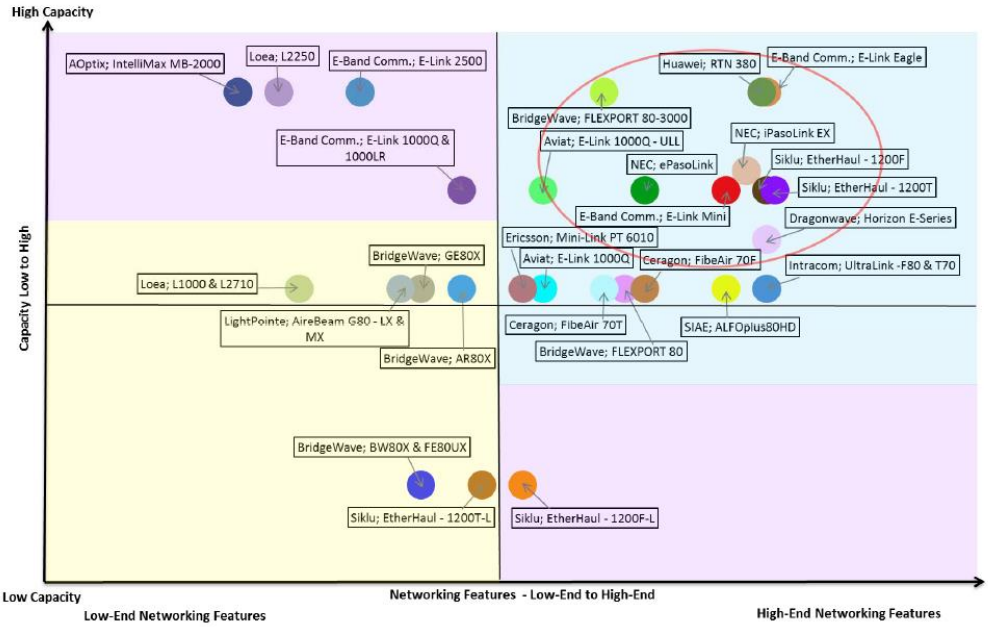


**Figure 5- Millimetre-wave Radio Ranking Matrix**

Current picture is showing few radio solutions, transporting few hundred Mbps, in line with traditional Microwave solution, a second class of solution transporting about 1Gbps and an upper class able to transport up to 2.5 Gbps.

These three macro classes can also be subdivided according to the networking features embedded into the solution. The networking aspect is not part of the E3NETWORK project and so not relevant to our discussion.

### 1.1.4. Application in E-Band solution

A non-exhaustive list of potential applications that can be addressed using a millimetre-wave radio solution operating in E-band is listed in this section. In order to identify the potential applications that can be covered by a radio solution in E-Band, we will first summarize the main peculiarities of E-Band compared to traditional microwave frequency bands:

- Larger channels size
  - E-Band channel up to 5GHz
  - Microwave: channel up to 56MHz (rarely 112MHz)
- Scalable channels size
  - E-Band from 62,5; 125; 250 and n x 250 MHz up to 5 GHz
  - W-band and D-band n x 250 MHz
  - Microwave from 3.5; 7; 14; 28; 56; 112 MHz
- Licensing fees (usually the higher the frequency, the less the fees/MHz)
  - E-Band – usually less than Microwave and in some cases no fees at all
  - W-band and D-band – today unknown
  - Microwave – defined on National basis, usually based on n*MHz
- Propagation conditions very similar to 32 -38 -42 GHz

Since the channel spacing is strictly related to the data rate that can be transported, it appears evident that the E-Band is a natural way to increase the data rate in a radio link.

The primary applications for a millimetre-wave radio solution will be:

**Backhaul:**

- Traditional mobile backhaul network
  - Solution able to transport capacities up to 500Mbps over short haul distances (few Km) where traditional Microwave bands are not congested or licensing costs are in favor of E-band.
- Emerging new mobile backhaul network called Front-haul/C-RAN
  - This solution is required to interconnect the remote radio unit with the remote radio Head, requiring huge data rate, up to 10Gbps
  - Part of this Market will derive by the conversion of traditional mobile backhaul and part from a possible arrangement of Small Cell Backhaul
- Small Cell backhaul
  - All the stakeholders are today convinced that massive deployment of small cells will need a huge quantity of frequency spectrum not available in traditional Microwave bands and then an E-Band backhaul link solution will be needed.

**Vertical:**

- This market accounts for applications like Enterprise, Defense Military, TV and others. Enterprise dominates, according to OFCOM [2][5] the existing UK use of the E-Band so far.

## 1.2 Market Competition analysis

### 1.2.1. E3Network Solution Competitor

At the time being, the only product present on the market that can be considered in competition with the E3NETWORK solution is the product from FUJITSU, a Japanese manufacturer. This product is called BroadOne GX4000.

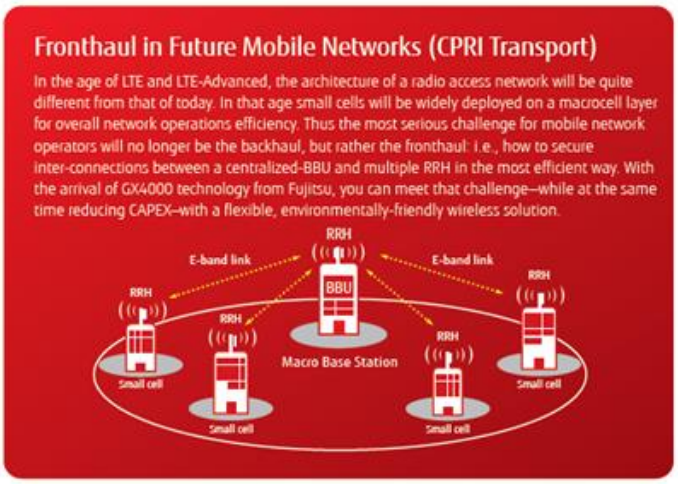


**Figure 6- Front-haul in future mobile networks**

This product is a classic full-outdoor system with integrated antennas. It is positioned in the market of CPRI transportation for Front-haul in future Mobile Networks.

The main characteristics are shown in the following table:

**Table 2- Main characteristics of the BroadOne GX4000**

| | |
|---|---|
| Frequency | 71–76/81–86 GHz, FDD |
| Channel Size | 4,500 MHz |
| Modulation | "Impulse Radio" method |
| Ethernet Throughput | 3.0 Gbps |
| Traffic Interface | Optical (10 GbE/CPRI-2.4576G, 3.0720G) Electrical (1 GbE) |
| Latency (one way) | Less than 50 µs (Ethernet)<br>Less than 20 µs (CPRI) |
| Antenna Size | Parabolic antenna<br>1 ft (30 cm) or 2 ft (60 cm) |
| Tx Output Power | 0 to +10 dBm (ATPC, MTPC) |
| Temperature | –27 to 131 °F (–33 to +55 °C) |
| Humidity | 4 to 100% |
| Power Supply | –48 VDC or 110 VAC (50/60 Hz) |
| Power Consumption | 25 W |
| EMC, EMI | FCC compliant<br>ETSI EN 301 489-1, 4 |
| Dimensions | 9 x 9 x 2.2"<br>(23 ×23 × 5.6 cm) |
| Weight | 6.6 lb (3 kg) |
| Management | NETSMART 1500, SNMP, HTTP, in-band management |

Compared with the E3Network requirements, we observe that:

- The channel size needed is 4.5GHz much bigger than the 2GHz bandwidth of E3NETWORK.
- The employed modulation is “impulse Radio”, which has very low spectral efficiency.
- It is not clear from the specifications of this product if a capacity of 10 Gbps is reached.

Moreover, similarly to the specifications of E3NETWORK:

- It uses FDD as E3NETWORK.
- It has very low latency: i.e.: 20 µs.
- The transmitted power is up to 10 dBm.
- It presents very low power consumption.

The very low power consumption is really impressive. However, a real comparison needs to compare also the receiver threshold, which unfortunately is not disclosed.

### 1.2.2. E-Band Overview on commercial solution

The table below depicts the most relevant E-Band solutions present today on the market.

**Table 3- Commercial solution in E-band**

| | SIAE | Ceragon | Dragonwave | Huawei | NEC | NEC | Ericsson | Aviat | Fujitsu |
|---|---|---|---|---|---|---|---|---|---|
| name | ALFOplus80HD | FibeAir IP-20E | Harmony Eband | RTN 380 | iPASOLINK EX | iPASOLINK EX CPRI | PT6020 | WTM 3300 | BroadOne GX4000 |
| date | 2013 | 2013 | 2014 | 2013 | 2013 | 2014 | 2013 | April 2014 | 2014 |
| CS [MHz] | Up to 500 | Up to 500 | Up to 500 | Up to 500 | Up to 500 | Up to 500 | | | 5000 |
| Modulation [QAM] | Up to 256 | Up to 256 | Up to 256 | | Up to 256 | | | | Impulse radio |
| PTx in QPSK | 18 dBm | 14 dBm | 15dBm | 15 dBm | 18 dBm | ? | 15dBm | 14 dBm | 10dBm |
| Rx in QPSK 250MHz | | -74 dBm | -69.5 dBm | | -71dBm | | -71dBm | -73dBm | |
| Consumption | 50W | 45 W | 34 W | | 55 W | | 45W | 37W | 25W ? |
| Data Ports | 2 | 3 | 4 | 3 | 3 | | 2 | 1 | |
| Weight | 4,5kg | 6,5 kg | 3,4 kg | 5,5 kg | 5,5 kg | 4,5kg | 5,7 kg | 2,4 kg | 3kg |

Apart from the FUJITSU solution, which has been presented before, it is observed that the current solutions address the capacity needs up to 2.5Gbps.

In fact, the modulation schemes adopted are up to 256-QAM and channel spacing up to 500MHz. Moreover, we observe some first attempts to provide a solution with CPRI interface, and, thus, for the Front-Haul application. In particular, NEC has already such a solution, but others are in the phase to provide a solution for the Front-Haul application.

### 1.2.3. Alternative solutions to E3NETWORK approach

The purpose of this section is to identify possible alternative wireless solutions, which can be considered in competition with the approach of E3NETWORK.

There is today a growing interest in a Front-haul solution that uses radio technology. Among these solutions, which differ from the E3NETWORK approach, it may be worth to point out the following two:

- The adoption of LOS MIMO technology
- The EBlink solution

#### 1.2.3.1. LOS MIMO

MIMO is a spatial diversity technique where multiple antennas, all transmitting and receiving at the same carrier frequency, are able to provide a greater throughput compared to the conventional Single-In Single-Out (SISO) radio transmission channel.

4x4 LOS (Line-of-Sight) MIMO is a technique that potentially permits a two-fold increase of the traffic capacity for the same spectrum occupancy, at the cost of doubling the antennas and transmitter / receiver equipment. Under the **Line-of-Sight** condition (i.e.: no scattering, no reflections, only geometry), best performances are obtained under the constraint of minimum optimal antenna spacing.

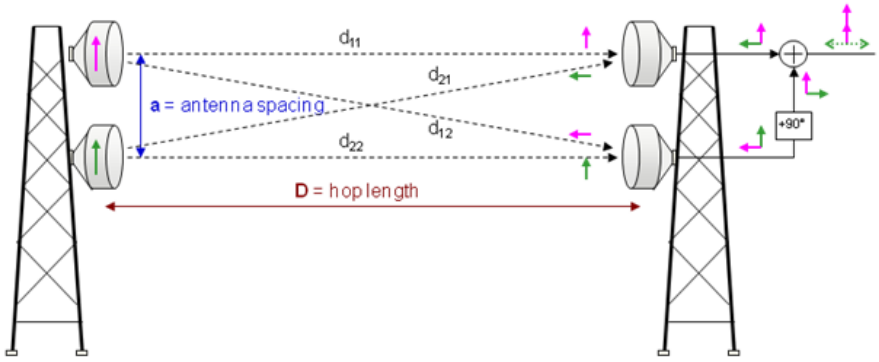


**Figure 7- LOS MIMO solution**

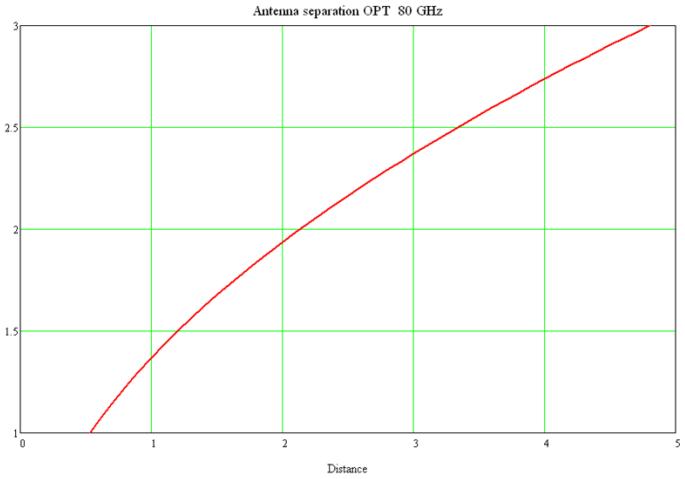


**Figure 8- LOS MIMO Antenna separation**

So, in principle, using LOS-MIMO, it would be possible to transport the same capacity as with E3NETWORK, using just one 500MHz channel instead of 2GHz. As intermediate solution, the frequency reuse (XPIC) is also considered. Assuming that all is perfectly working, a comparison is provided in the following table:

**Table 4- Comparison of LOS-MIMO, XPIC AND E3NETWORK**

| 10 Gbps solution | LOS-MIMO | XPIC | E3NETWORK |
|---|---|---|---|
| **Max Modulation scheme** | 64 QAM | 64 QAM | 64 QAM |
| **Channel size** | 500MHZ | 1000MHz | 2000MHz |
| **Numbers of antennas** | 4 dual polar | 2 dual polar | 2 single polar |
| **Polarization** | H and V | H and V | H or V |
| **Number of Transceiver** | 8 | 4 | 2 |
| **Power consumption** | Xx [Watt] *8 | Xx [Watt] *4 | Xx [Watt] *2 |
| **Deployment** | Very Complex | Quite Standard | Standard |
| **Maturity** | Very very Low | Low/Medium | medium |
| **Frequency bands applicable** | E-band only | E-band only | E-band only |

### 1.2.3.2. EBlink solution

Founded in France in 2005, EBlink [7] is a wireless start-up revolutionizing the mobile network market with a new standard for the industry: wireless front-haul. Based on the founders' vision of evolving mobile network architecture, EBlink's technology gives operators an immediate solution to the demands of mobile multimedia applications and the increasingly high-speed service they require.

EBlink solution is FrontLinkTM 58 allows up to three independent channels on a single Wireless Front-haul link supporting 3-sector site configurations or tri-band remote sectors, i.e a total of 7.2Gb/s CPRI signal, carried over less than 70MHz.

In the following we present the main features of their solution, according to a public presentation [6]:

**Table 5- Main characteristics of FrontLinkTM 58 from [8]**

- Supports up to 3 RRHs on a single link
- Multi-techno access: UMTS and LTE
- Transparent to RAN frequency band
- Line Of Sight (LOS)
- Regulation : FCC & CE Compliant
- Link range : up to 400m (depend local regulation
- Bandwidth : 5725-5875MHz
- Capacity : Up to 3x20 LTE carrier 2x2 MIMO and up to 3x(4x5MHz) UMTS

The main peculiarities of this solution are:

- It works in 5GHz band
- It needs a channel size of 70MHz, only
- It is able to transport up to about 7 Gbps - Future version up to 10 Gbps
- Its maximum hop length is about 400 meter

At the time being, there is no additional public information we can use for a fair comparison with E3NETWORK. Anyway, disregarding pure theoretical speculations, what we can observe today is:

- An impressive spectral efficiency when compared with other solutions in the market
- A quite short hop length achieved.

## 1.3 E3NETWORK positioning

In an attempt to position the E3NETWORK system in the Millimetre-wave radio ranking matrix picture showed above, we can say that E3NETWORK will be positioned very above the line of today considered Very High capacity, since E3NETWORK will provide x4 capacity with respect to the actual 2.5Gbps radio ready on the market.

It is outside the scope of E3NETWORK solution to address networking features, but it is evident that the E3NETWORK solution is totally transparent to that, allowing to add on top of the transceiver, any level of Networking features, in such a way that it can be placed anywhere on the x-axis reference.

From this analysis, it appears clear, according to the following Figure 7, that results from E3NETWORK can be wider exploited for covering the entire Millimetre-wave segment, whichever the application or use case considered.

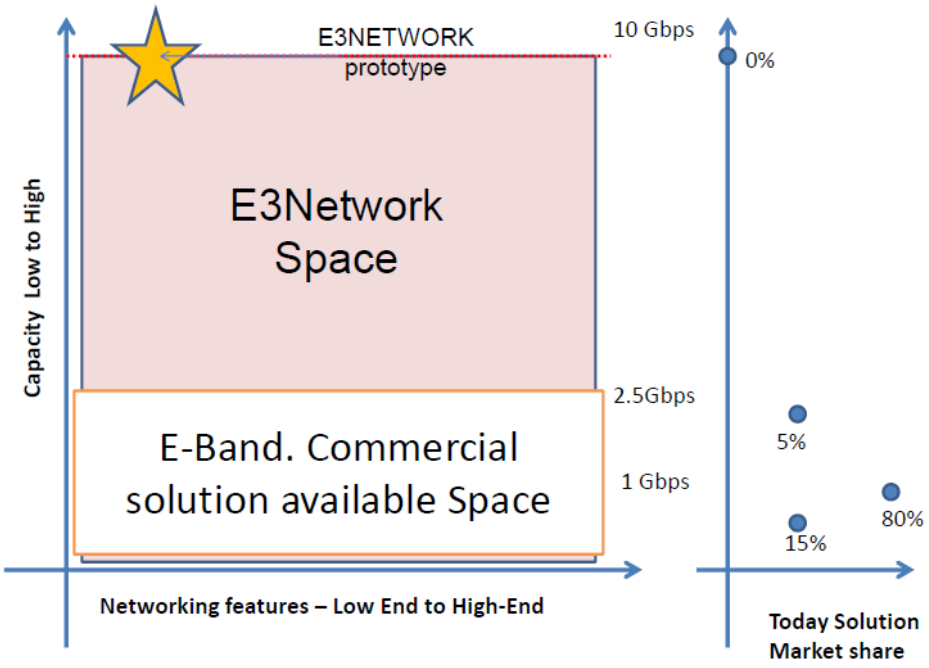


**Figure 9- E3Network positioning**

It may be worth also noting that results and components from E3NETWOK solution will be exploited in solutions requesting:

- Less than 10Gbps
- Similar channel spacing in a different frequency bands (i.e.: the forthcoming W and D Band)
- Narrow channel spacing
- Huge frequency agility capability benefits in mass production
- Better performances, i.e.: System Gain
- Operating in closer frequency bands
- Different application in closer frequency bands (i.e.: Anti-collision system in 76 GHz)

- Multi-gigabit systems in 60 GHz frequency bands, for indoor and outdoor applications
- Any wireless System requiring10Gbps Ethernet interface

## 1.4 Potential Market estimation

This chapter is trying to give an answer to the question, "How big E-Band Market is going to be" is, without any doubt, a tough task. In the following, an attempt to estimate the potential market is provided, considering only the Telecom market. Other market segments, like consumer, Automotive or others are outside the scope of this document.

To carry on this estimation, in the following, we have identified:

- Market sectors
- Use cases
- New link arrangement

That can be addressed or can benefit from an E-Band solution.

For each of these points, we have then provided the market performance obtained in the period from 2013-2015, and we have assumed as forecast for 2016, the same value of 2015.

After that we have estimated, the market's quote addressable by an E-Band solution.

To carry on this analysis, we have considered, plenty of different trusted sources of information in this field, then mainly, our internal data and intelligence, the info from specialized press and last but not least the sharable outcomes of specialized Analysts that are able to grooming the information coming from the most world-wide equipment manufacturers and the data from most of the Network Mobile Operators (NMOs). We have considered as well the info coming from some National Administrations, when publicly available and the information circulating among several regulation and standardization bodies. The general sentiment derived from the analysis of all this information, is for a positive common forecast view. In general all stockholders forecast a massive use of E-Band in the near future. Here below some quotes.

According to recent OFCOM UK research [2]:

> *"Network evolution from 3G to 4G and beyond with the need for reliable high capacity data: network evolution to deliver 4G mobile services has placed a greater requirement for increasing capacity to support the demand for high capacity mobile data. Macro layer requirements of 1 Gbit/s and above, which can be challenging in conventional microwave bands can effectively be delivered by using 70 / 80 GHz spectrum where the fibre alternative is not available or is not a cost effective solution."*
>
> *" …the urgency and importance of this issue being connected with the observations above that the bands (E-Band) have a key role to play in the provision of high capacity backhaul required for 4G mobile networks"*

According to Heavy Reading 4G/LTE Insider [4]:

> *E-Band will play the major role in Wireless Backhaul for small Cells - "This is because it supports very high capacity of more than 1Gbps over distances up to 3 Km"*

According to Sky Light Research (SLR) [3]:

> *"Currently, it can be defined as a market with much near-term and long-term potential (thanks to a newly defined killer application: rapidly increasing mobile data backhaul), but is still on the front side of the demand curve"*
> *"The killer application: The need for ultra high capacity backhaul alternatives to fiber is critical as mobile data continues to proliferate."*
> *"The opportunity is ripe, and SLR believes that the total millimeter-wave market (60-90 GHz) could reasonably surpass the half Billion dollar mark in the next five years.*

Looking at the rough data market from the period 2013-2015, we can anyway observe that the market is not taking off as fast as expected at the beginning of the project, but the number of E-Band equipment required by the market is steadily gaining ground.

Main reasons for that could be identified mainly into:

- The MNOs have not yet started to invest in deploying outdoor small cell and this is stalling the rollout mainly for E-Band.
- The E-Band equipment price definition, is suffering from lack of a main and clear use case which has to be addressed: manufacturers are still in doubt whether to develop an E-Band equipment addressing the new multi-gigabit use case or to adopt the approach to complement conventional microwave solution. This uncertainty can only lead to confusion in the market, because it provides two products for different scope and with different price levels.

### 1.4.1. E-Band as a complement to MW in Mobile Backhaul

This section presents a first attempt to estimate the E-Band market when mobile backhaul is concerned. It is a matter of fact that considering the installed Worldwide Macrocell Mobile Backhaul Connections, at least 50 % of them are using radio, instead of fiber or copper. The preference for using radio, observed mainly in some parts of the world, is due to lower cost and the easy and fast deployment of a radio solution.

The big role played by and that will be played by radio solution, against other media, fibre and copper is reported usually by all stockholders. See the following picture [10]

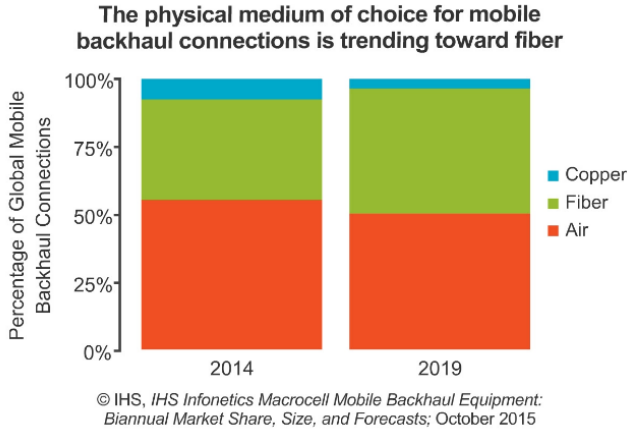


**Figure** 10**- Mobile Backhaul connection breakdown**

As reference, according to these IHS studies, Microwave and Millimetre-wave solution dominated the mobile backhaul market with more than 50% of installed backhaul connections worldwide in 2014 and they forecast that such a radio solutions will maintain this predominant role in the next future.

An updated situation, respective to what was reported in our former deliverable [12] and now based on what the market has actually done, is here reported.

In the following picture we have summarised how the market performed in 2013-2015, considering the part addressed by microwave solution only, so using frequency bands from 6 to

42 GHz and the part addressed by millimetre solution only, then E-Band mainly since V-Band counts for less than 10% in this segment.

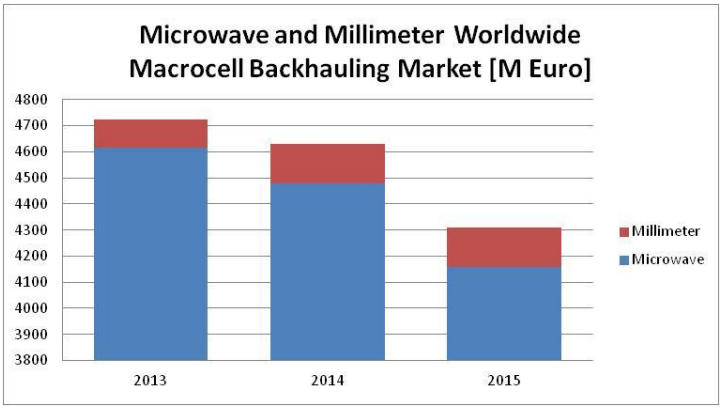


**Figure** 10**- Macrocell Backhauling Market**

While the global macrocell backhauling market decreased by 9%, the millimetre segment has improved its weight from less than 2% up to 3% of the total market in 2015. Considering the millimetre market segment alone, from 2013 to 2015 it has obtained a compounded annual growth rate of 11%. Then, even if in a period when the global market declined, -9% over 3 years, the millimetre segment is steadily gaining ground.

In order to estimate the amount of the potential market that could be addressable by an E-Band solution, and then a potential market for E3NETWORK results and solutions, an estimation of the actual hop length distribution among frequency bands is considered. According to the next figure, taken from ECC Report 173 [5], the frequency bands above 25GHz, present, as typical value for actual hop lengths, figures below 4 Km.

Then we can conclude that, considering that a hop length up to 4 Km can be easily addressed using an E-Band equipment, we can foreseen that, as soon as E-Band equipment will be widely available on the market, it can potentially address all the new link population with hop length below 4 Km. The main advantages of an E-Band solution compared to a solution in lower frequency bands can by listed as:

- E-Band solution can provide more capacity than lower frequency bands
- E-Band has a huge number of channels and is today practically empty
- Using E-Band for these links will resolve the congestion problems some lower frequency bands are suffering
- E-Band solution will provide a lower TCO since in most cases spectrum fees are lower than traditional frequency bands.

Further investigation considering the ITU-R F.2086-0 [11] dealing with the “Deployment scenarios for point-to-point systems in the fixed service” extend World-Wide the validity of our considerations .

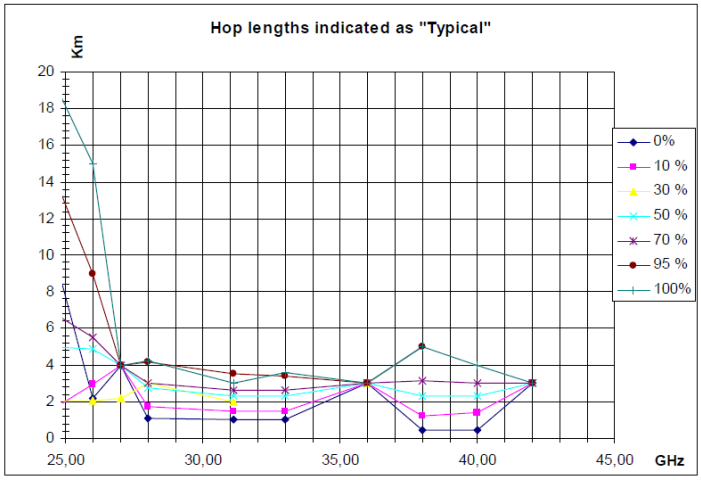


**Figure** 11**- Typical hop length for frequency bands above 25GHz**

Moreover, according to this ECC Report, the links deployed in frequency bands above 25GHz is representing almost the 20% of the total links deployed today.

The ALU internal data base, reporting WW ALU installed links in last 5 years, provides practically the same result: an E-Band solution is suited in almost 20% of current installed Microwave connections.

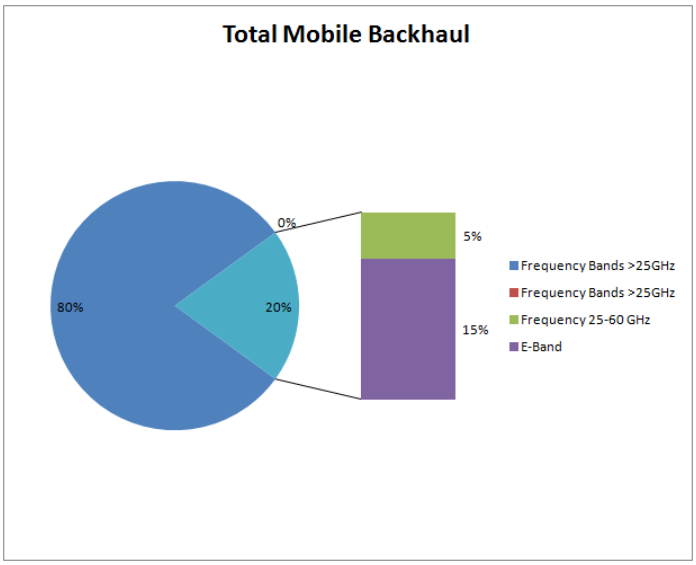


**Figure** 12**- Forecast 2016 - Breakdown Mobile Backhaul vs Frequency Bands**

According to the above consideration, we can assume that, conservatively, a range of 10-15% of the future Mobile Backhaul Market can be addressed with an E-Band equipment.

Under this assumption, the forecast for E-Band market 2016 can be estimated close to 650M€. This result is obtained considering the Mobile Backhauling market totally flat from 2015 to 2016, considering then 15% of microwave market forecast in 2016 adding the 100% of the millimetre market part foreseen for 2016.

### 1.4.2. Backhaul option for Centralized Base Band Unit Architectures

The C-RAN like architecture, described in [13], requiring Ultra High Capacity (UHC) data rate systems is a possible and promising future variant of Mobile Backhaul, in both scenarios, for Traditional Mobile Backhaul (Macro-Cell) and Small Cell Backhaul. Since the UHC systems, reaching up to 10Gbps, can be feasible only in E-Band, the UHC market can be estimated as a percentage of traditional mobile Backhaul in E-Band only. We believe that, since C-RAN will still be at early stage in 2016, this market will be not more than 8-12%.

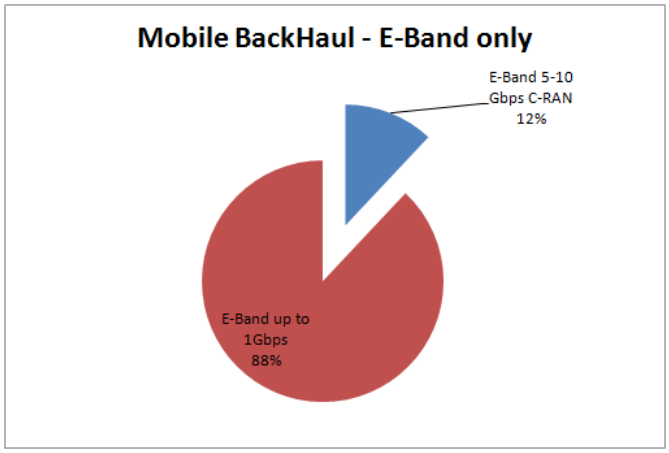


**Figure** 13**- Forecast 2016 – Breakdown vs data rates**

### 1.4.3. Backhaul option for small cells

One of the most promising markets, for E-Band radio solutions, is the Backhaul for Small Cell. The next figure shows the global Small Cell Backhaul connection breakdown for different technology types in 2015.

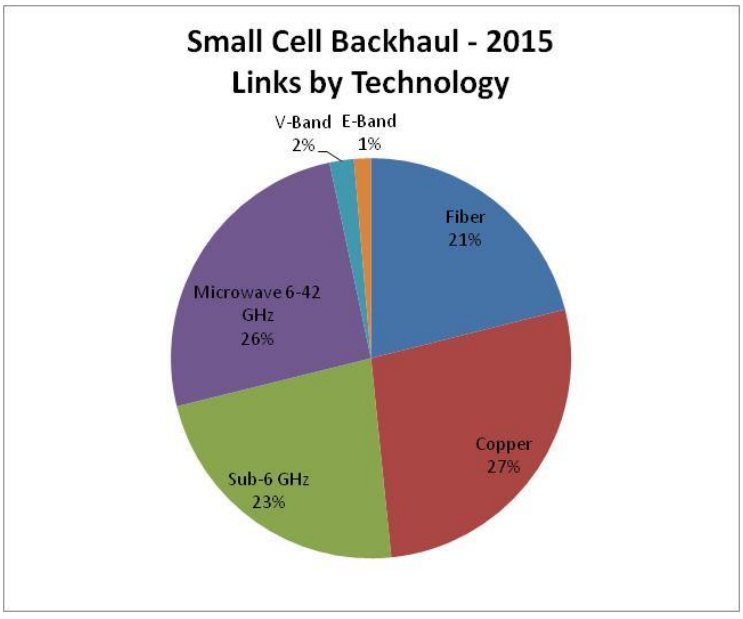


**Figure** 14**- Breakdown for connection type. Situation 2015**

Our assumption to estimate this part of the market is: A solution using an E-Band equipment, can be exploited in all areas covered by V-Band, E-Band and Microwave. In fact, since Small Cell Backhauling needs connections with a length that rarely exceed 1-1.5 Km, we can, safely assume that the Microwave LoS parts can be, potentially, addressable with a solution operating in E-Band, for the same reasons explained above. In addition concerning the V-Band solution, MNOs complain that, a V-Band solution, due to the uncoordinated regulation of the band, cannot guarantee any level of availability, but just a sort of "best effort" operation, not considered today enough, for most of the Small Cell use cases. For this reason MNOs are looking to E-Band as the candidate solution for most of the Small cell Backhaul radio interconnections.

The following table shows how the Worldwide Small Cell Backhaul market performed in 2013-2014 and 2015.

| **Small cell Backhauling Market per Frequency Band segment [M Euro]** | | | |
|---|---|---|---|
| Frequency Band | **2013** | **2014** | **2015** |
| Sub-6 GHz | 97.9 | 113.3 | 221.4 |
| Microwave 6-42 GHz | 163.8 | 233.0 | 396.8 |
| V-Band | 8.8 | 14.4 | 42.2 |
| E-Band | 5.5 | 10.0 | 30.1 |
| Total | 276.0 | 370.7 | 690.6 |

**Table 6- Small Cell Backhauling WW Market**

The Small Cell Microwave and Millimetre-wave LoS backhaul market grows at 38% CAGR from 2013 to 2015 reaching a value of almost 470M€ in 2015, up from only 178M€ in 2013.

The E-Band millimetre-wave part only grows at 71% CAGR from 2013 to 2015 reaching a value of almost 30M€ in 2015, up from only 5.5M€ in 2013.

These values are in absolute lower and lower respective to what was forecasted in our former deliverable[12]. It may be observed that, all stakeholders are today more positive in forecasting this market, but we prefer to stay linked to 2015 actual figures and forecast the 2016 at the same level of 2016.

In a conservative way, we can assume that, in 2016, almost 60% of the Whole Small Cell radio backhauling market will be addressed with an E-Band equipment.

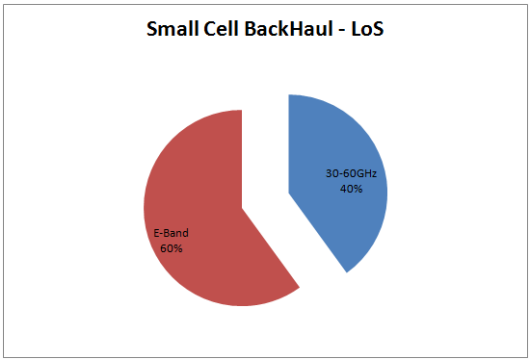


**Figure** 15**- Forecast 2016- Breakdown Small Cell LoS Backhaul vs Frequency Bands**

Under this assumption, our forecast for E-Band market in 2016, derived by Small Cell backhauling application can reach 415 M€.

### 1.4.4. Vertical

This segment accounts for all the applications outside the Macro-cell and Small Cell backhaul application. Here, we consider the Enterprise, Defence Military, Backhaul of TV network and so on. The market share of this segment represents usually 15-20% of the whole radio Backhaul market.

The amount of this segment that can be addressable using an E-Band solution, can be estimated into 30-35%.

Under all the above assumptions, the Vertical market contribution for 2016 can reach a value close to 50M€.

### 1.4.5. W-band (92-114.5 GHz) and D-band (130-174.8 GHz).

These two bands, are currently under discussion, mainly in ECC area for small cell backhauling. As already said, current frequency arrangement are based on 250MHz channels with the possibility to aggregate xN channels to reach the necessary bandwidth, This approach makes the E3NETWIORK solution in a position to be exploited for what is concerned the whole digital parts, from Network interface up to ADC/DAC converter.

It is no possible today to provide any forecast for these bands, but for sure in 2016 the market can be considered negligible.

### 1.4.6. New Carrier aggregation approach.

Last novelty in mobile network backhauling is based on the carrier aggregation approach. This approach tries to exploit the fact that future network requirements are indicating an huge quantity of traffic composed by plenty of different services requiring different levels of availability. Levels of availability ranging from 99.999% for CBR traffic with voice to a 99.x %, corresponding to up to few days per year of aggregate time windows of unavailability for services not so demanding. This implies that the given link, from two points it is requested to provide a relative small quantity of capacity with high level of availability, i.e.: 99.995% and in addition a huge capacity with less availability.

Former solution adopted implied a link design for the most demanding availability for all capacity, and the resulting in an overdesigned link with a lot of waste in terms of valuable spectrum (low frequency bands) and power consumptions.

The following simple example will explain better the concept.

The use case is: Spain, region where, according to the ITU table we can assume as rain rate for designing the link a value equal to 42 mm/h.

The customer asking for:

- To connect two points 7.7 Km far.
- At least 800Mbps of capacity with the following availability
    - At least 150Mbps capacity @ 99.999% for traditional voice services
    - At least 650 Mbps of capacity @ 99.9% for generic internet connection

Traditional approach would design this connection using 5 parallel links operating at 18GHz, 128QAM in 28 MHz channel with 1.2m antennas.

In fact commercial 18GHz, 128QAM in 28 MHz with 1.2 meters antennas in rain rate 42mm/h is able to provide among 160Mbps of capacity @ 99.999% of availability. Some optimization in network design, for the 4 links has to provide less availability are possible saving for instance some power, or dealing with the numbers of the antennas or the size with some different arrangement using couplers. The table showed few examples.

| Case | EQUIPMENT | Capacity | Antenna | Number of Couplers | Number of parallel link | Total Numbers of antennas | Total Number of equipment | Total capacity | Capacity @ 99.999% | Capacity @ 99.9% | Total spectrum used |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 18 GHz- 128QAM - 28 MHz | 160 | 1.2 | 0 | 5 | 10 | 10 | 800 | 800 | 0 | 140 |
| 2 | 18 GHz- 128QAM - 28 MHz | 160 | 1.2 | 3 | 5 | 4 | 10 | 800 | 160 | 640 | 140 |
| 3 | 18 GHz- 128QAM - 28 MHz<br>E-BAND- QPSK - 500 MHz | 160<br>670 | 1.2<br>0.6 | 0 | 2 | 4 | 4 | 830 | 160 | 670 | 528 |

**Table 7- New approach comparison**

The new approach consists of putting one 18 GHz link, as per the above example providing the 160Mbps capacity @ 99.999%, with in parallel a single E-Band link, operation in 500MHz channel in QPSK. With this equipment the link at E-Band can provide up to 670Mbps with more than 99.9% of availability.

The above table provides a comparison. What may be worth to point out is the fact that, with the new approach, only two links have to be deployed, and we have saved 4x28MHz spectrum, in a valuable frequency band (18 GHz) for a link that would require long hop and high availability capacity. Moreover we have enabled the use of the E-Band spectrum, for application over longer links than expected. For the solution cost, we need to consider that:

Case 1: 10 equipment plus 10 antennas plus fees for 10 channels @ 18 GHz

Case 2: 10 equipment plus 4 antennas plus fees for 10 channels @ 18 GHz

Case 3: 4 equipment plus 4 antennas plus fees for 2 channels @ 18 GHz plus 2 channels @ 80GHz.

A rough estimation, considering as per most of the cases we know, fees for 28 MHz channel in 18GHz can be considered close to the fees for 500MHz channels in E-Band, the equipment and the antennas cost the same for the two frequency bands. The coupler cost is similar to antennas cost. For sure installation cost and rent of the side for antenna installation will penalise a lot case 1 mainly.

According to what said above, the case 3 will result, in average among different places can that have an impact on spectrum fees, the most convenient in term of solution cost.

We can then conclude to say that, an E-Bnad based solution, perfectly matches the above use cases, enlarging, in this way, the E-Band potential market.

An estimation performed for this case, has preliminary forecast in 10-15% of the total market starting from 2016 and more in a close future, the potential market addressable using an E-Band solution.

This means that, assuming the adoption of this new arrangement starting from the beginning of 2016, our forecast for E-Band market in 2016 with, this new approach has a contribution estimated in almost 645M€.

### 1.4.7. Total E-Band Market

The following figure is trying to depict the whole situation. At the time being, only the telecom market has been considered. The abscissa represents the capacity and the ordinate the hop length.

With E3NETWORK, we enlarge the potential Backhaul Market via radio, covering the application needs for Ultra High Capacity (up to 10 Gbps) and short hop.

The area above of the figure, with Ultra High Capacity and hops length of more than 3Km, is today not feasible with a single radio equipment solution. However, bounding more transceivers together, providing that there is enough frequency spectrum free, capacity up to 1-2Gbps at more than 3Km can be transported.

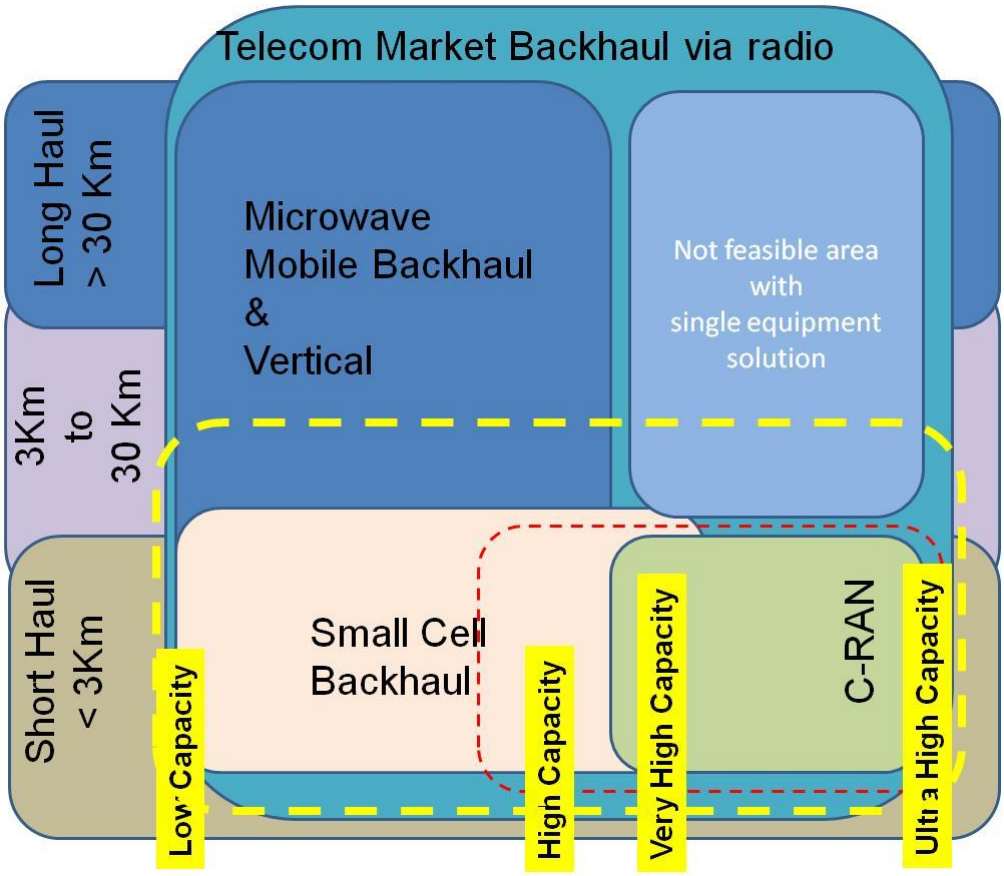


**Figure** 16**- Radio Backhauling Market segmentation**

We have now introduced the carrier aggregation arrangement, not considered before, as a new way to extend the hop length range of applicability of an E-Band solution. This new region is depicted with a yellow line.

According to the above analysis, we can conclude that a first rough estimation, for 2016, considering now the actual market values obtained in 2013-2015, for a potential market for E-Band based solution, represented then in the above picture by the highlighted yellow area, is estimated the range of 1.2-1.5 Billion Euro.

For E-Band and Ultra High Capacity market, driven mainly by C-RAN (Green area) mainly part of Traditional Mobile Backhaul, we can estimate for 2016, a 8-12% of this market, and then around 50 Million Euro.

# 2. EXPLOITATION PLAN

This plan focuses on the promotion and the exploitation of the obtained research results during the project.

The exploitation plan shall provide a response to three questions; Who, What and When. The following picture provides an overview of the E3NETWORK exploitation plan.

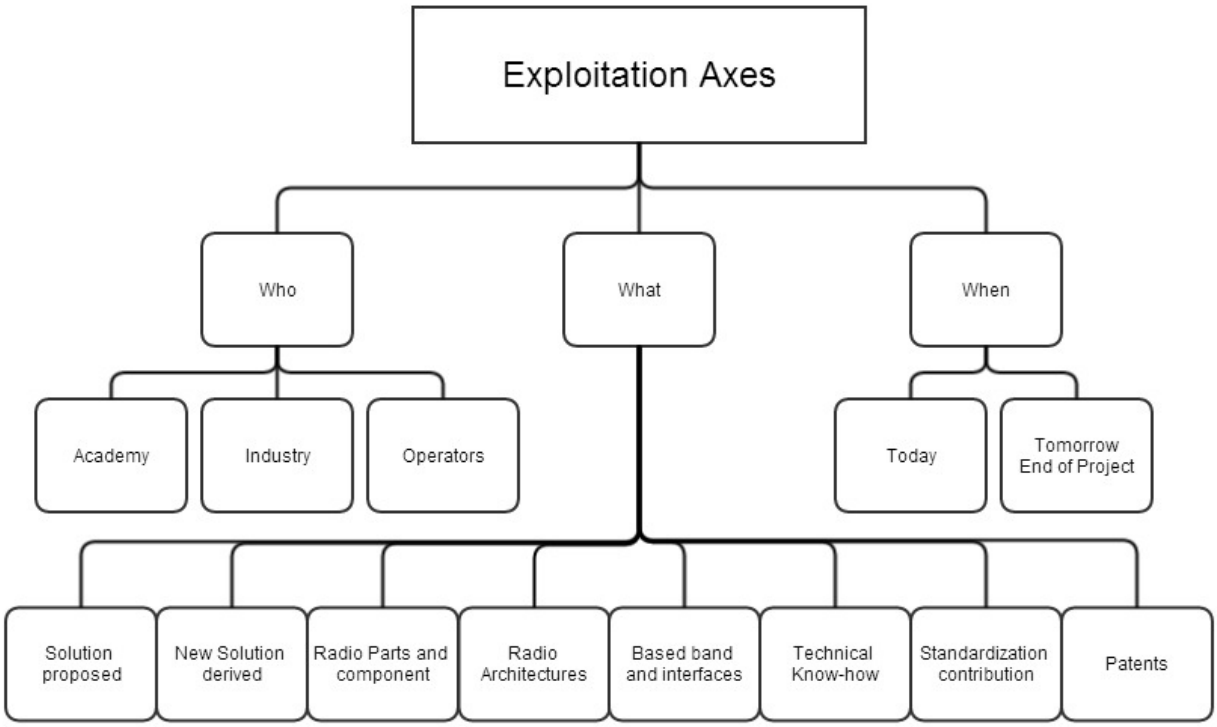


**Figure** 17**- Exploitation axes.**

According to the previous figure, the main actors, who provide an answer to the question - Who in the E3NETWORK, can be subdivided into 3 categories, with different scopes, Academy, Industries and Operators.

"What" can be exploited in the E3NETWORK project is the more complex answer, because of the very complexity of our project, ranging from a complete set of millimetre radio interconnection, passing throughout the design of a single transceiver's component up to the design of a suited radio architecture, able to comply with actual market rules. Under the voice "What", we have foreseen, today, up to seven voices. The list should be considered, at the time being, provisional.

Here is a brief description of the voices mentioned:

- Solution Proposed

  We are referring to the potential exploitation, as part of Manufactures portfolio of the E3NETWORK solution itself or a close derivation, for transporting 10Gbps in 2000MHz channel spacing in E-Band frequency bands

- New solutions derived and Radio Parts and component

Here we have in mind, different solutions that can be derived using single component alone or subsystems parts, studied and developed under E3NETWORK. These parts can be for instance:

- The Modem with or without the network interfaces, used with different radio parts to address different frequency bands, above (i.e.: The forthcoming W and D Band) or below (i.e.: V Band) the current 71-86GHz.
- The radio parts, used for different type of equipment, transporting less capacity over longer links, or in different configuration, such as Point to multipoint, TDD configurations or others.
- The Local oscillator groups, for different radio architectures in the same or different frequency bands.
- All radio parts, for different applications, such as automotive systems, operating in the middle of 75 to 81 GHz

- Radio Architecture

  The transceiver architecture, whole or in parts, can be reused for transceiver in frequency band above E-Band

- Base band and interface

  Can be used in all the cases, a 10Gbps shall be transported over air or similar medium

- Technical know-how

  This project will give opportunity to all the partners to acquire know-how and the possibility to exploit results to introduce new commercial products, not necessarily similar to the main object of E3NETWORK, according to its peculiarity position, academy, industries and Operator.

- Standardization contribution

  Contributions to regulatory bodies showing the limits of current technologies in such a way to define the achievable correct limits (i.e.: spectrum mask and transmitter noise floor) will be provided.

- Patents

  A possibility to submit patents, derived by the attempt to resolve the problems that will be faced during the project, is foreseen.

According to this subdivision, each of the partners will focus their exploitation plan in its own relevant areas of interest.

The next figure presents a first attempt to define these areas:

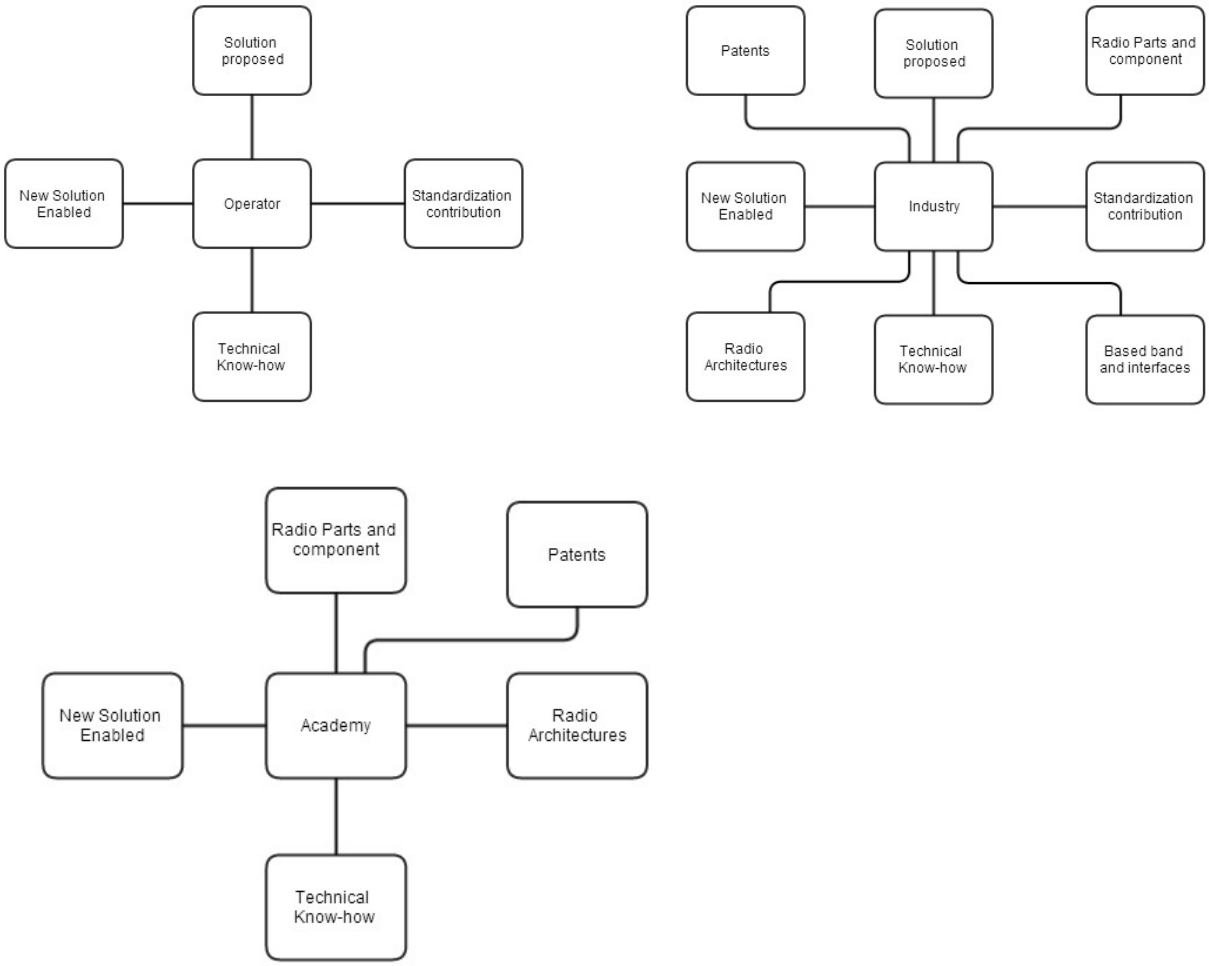


**Figure** 18**- Areas in which the exploitation plan will be focused.**

## 2.1 Partners Individual Exploitation Plans

Paving the way for E-band adoption and industrial exploitation is a “core” priority for the full E3NETWORK effort. One of the major goals is a timely adaptation of proposed solutions by stakeholders and a viable commercialisation of results by the consortium. This shall have a positive impact on environmental and economic developments in Europe.

All partners are committed in exploiting E3NETWORK expected results into future networks and businesses. Industry partners, operators and SMEs will investigate new business opportunities based on the project outcomes. Academia and Research Institutes are interested in exploiting project-based results for their future research activities.

Interested partners (i.e., network operators, SMEs) will give priority in order to exploit the expected results/findings by further enhancing their competence in the field of the wireless communication networks market sector. For operators or SMEs in particular, the innovative features of the expected project-based findings may strongly affect further their market-related policies, by offering them significant benefits for a more effective use of existing -*or planned to be developed*- facilities or applications.

Industrial exploitation of the Project can be achieved, in a first stage, by the “reinforcement” of cooperation between the members of the Project consortium (i.e.: academic partners-universities, network operators, manufacturers and SMEs) in order to “transfer” the Project-based results into new, enhanced services and products.

## 2.2 Individual Exploitation Plans for ALU

### 2.2.1. Partner profile

Alcatel-Lucent, and here in particular the Microwave transmission business line, offers a portfolio of microwave products to address the backhaul needs of 2G, 3G, 4G/LTE mobile backhaul, high-capacity long-haul, and mission-critical networks for industries, including Wi-Fi® small cells. In this contest Packet Microwave Mobile Backhaul solution is a key component in the Alcatel-Lucent/NOKIA end-to-end mobile backhaul solution, which provides the flexibility, scale and operational simplicity to lower the total cost of ownership and simultaneously enhance the mobile service experience. Alcatel-Lucent’s microwave transmission portfolio sets the standard for innovation in delivering faster, more efficient microwave links with flexible networking and simplified operations. Proven in more than 500 networks worldwide, the portfolio has been deployed in a wide range of applications.
Alcatel-Lucent’s microwave solutions are based on the Alcatel-Lucent 9500 Microwave Packet Radio (MPR) portfolio. Microwave access to cell sites is an important building block for the delivery of mobile services. Today, more than 50 percent of the world’s cell sites are connected to the network over microwave access. Several types of wireless cell site connection options are required to support mobile network capacity and coverage expansions. Alcatel-Lucent’s 9500 MPR solutions support a full suite of wireless frequency options including 5.8 GHz to 42 GHz solutions for macro cell backhaul, 80 GHz millimeter wave (e-band) solutions for both macro and small cells, unlicensed 60 GHz millimeter wave (v-band) and sub-6 GHz solutions that are typically used to support the backhaul of small cells.

### 2.2.1. General Exploitation strategy

The Alcatel-Lucent portfolio takes particular care of the radio spectrum, as scarce resource, using innovative techniques to maximize payload capacity to support the evolution to LTE and heterogeneous networks. For this reason, Alcatel-Lucent is continuously making strategic

investments necessary to evolve their microwave systems to cover efficiently current and future network needs, exploiting at its best the frequency spectrum currently available. In this contest the Alcatel-Lucent is proud to participate in this project where a complete solution for providing a 10 Gpbs wireless solution exploiting a quite new high frequency band has been assessed. In particular because this project that has tried to address the whole scenario behind the introduction on the market of a new solution, taking into account all the processes a solution's manufactures has to face on, so starting from a real use case defining the network requirements and then deriving the suited radio architectures considering as well the components technology assessment.

### 2.2.2. Exploitation activities, achievements and technologies

As said above, we particularly appreciated to participate in this project because E3NETWORK has tried to address the whole scenario behind the introduction on the market of a new solution, taking into account all the processes a solution's manufactures has to face on, so starting from a real use case defining the network requirements and then deriving the suited radio architectures considering as well the components technology assessment. This approach has produced a broader view in understanding all the process related to real product development, given the chances to touch a lot of different and interdisciplinary aspects/activities.
Here a not exhaustive list of the main activities and achievements we are particular interested in exploiting are:

- Solution and architecture for wireless system 10 Gbps capable
- 10 Gbps Network interface for wireless system
- Digital base band for data rate up to 10 Gbps in up to 2 GHz bands
- AD and DA converters for data rate up to 10 Gbps
- Chip set solution based on SIGE components for Transceivers in E-Band and beyond
- Front end solution and architecture for Millimetre-wave Frequency bands up to 170GHz
- Wireless Energy Efficiency solution as part of green approach to the future network
- Defined the standardizing radio profile up to 10 Gbps profile for frequency band above 70GHz

These points are now considered part of the Alcatel-lucent know-how, consolidating our expertise in Microwave and Millimetre-wave backhauling network ecosystem. We gained as well, new skill in measurement techniques at millimetre-wave frequencies, in ultra high capacity data rate and in general in all millimetre-wave area application.
Alcatel-Lucent is convinced that its activities in E3NETWORK will have a direct impact on the future Alcatel-Lucent's Microwave Transmission activities with concrete effects for our future business and products portfolio.

### 2.2.3. Product Roadmap

Alcatel-Lucent currently has an E-band solution, with a data rate up to 2.5Gbps to cope with current network backhaul needs. The next step we have in mind, driven by E3NETWORK research as well, - is to evolve our portfolio and solution able to provide up to 10 Gbps solution, as per E3NETWORK demonstrator, in such a way to be ready to address the future demands of point-to-point and point to multipoint wireless solutions capable of at least 10 Gbit/s. On regard, thanks to the achievements obtained in E3NETWORK work, today we have a more clear picture, for what is regarding:

- the World Wide regulations among different places and administrations , impacting feasibility of a real business case

- The list of the mandatory requirements that a wireless solution has to be meet to become a real commercial product

In addition, we are starting to consider the W-Band and D-Band frequency bands, as well, as possible complement solution for wireless 10Gbps solution, reusing as much as possible the E3NETWORK results and achievements obtained

## 2.3 Individual Exploitation Plans for OTE

### 2.3.1. Partner profile

Hellenic Telecommunications Organization (OTE S.A.) is the incumbent telecommunications provider in Greece, and together with its subsidiaries forms one of the leading telecom groups in South-eastern Europe. Its aim is to deliver increasing value to its shareholders while improving the quality and value of its services to customers. To this end, OTE seeks to be the first choice of consumers in the markets in which it operates.

OTE's key strategic priorities are to optimize all processes by means of sustainable cost reductions, while making ongoing improvements in flexibility and productivity; expand broadband penetration in the domestic market, while safeguarding OTE's leading role, with maximum utilization of the Company's competitive advantages through the provision of innovative products, services and integrated solutions; make the most of technological convergence by creating commercial proposals, and constantly improve customer care; and focus on domestic and international activities with the best growth potential.

OTE's capital expenditure program currently focuses on mobile services, Internet Protocol services and broadband, expanding backbone network capacity using DWDM and network dimensioning to maintain quality. The primary aim of OTE's research and development activities is to introduce new technologies and services to its network in a systematic and efficient manner, to examine and test new technologies and products and to maintain active testing grounds of the technologies used in its network.

### 2.3.2. General Exploitation strategy

Under this scope, and taking into consideration that over the last years the Company has been investing in enhancing the capability of its telecommunications networks, OTE's increased interest for active participation in promising, ambitious research initiatives becomes evident. Promotion, implementation and deployment of innovative research ideas in cooperation with distinguished partners from the academic and business world, lies within the priorities of OTE's strategic plans. Such a collaborative effort is in fact the only way to achieve a targeted, integrated, successful outcome, through the united expertise of variant scientists from different sectors.

### 2.3.3. Exploitation activities and achievements

The overall goal of the E3NETWORK project has been to exploit E-band frequencies for providing energy efficient backhauling to future networks. E-band potential applications regarding backhauling as well as contiguous solutions in the same or adjacent bands are of great interest for an operator such as OTE. These technologies can improve the current core networks in terms of capacity, flexibility, and network design optimization, which can lead to relevant CAPEX and OPEX reduction. Except for the capacity and performance improvement, OTE is also interested in exploiting the outcomes of the project in order to apply a better environmental-friendly network design process.

E3NETWORK's approaches shall affect OTE's market related policies and lead to a more effective use of both existing and developed facilities, aiming at the realization of a green strategy.

### 2.3.4. E3Network technologies

The project results are taken into consideration in forming the company's strategy regarding the provision of future backhauling, in order to improve current core networks in terms of capacity, flexibility, performance, energy efficiency, operational and capital expenditures.

OTE plans to investigate the possibility of deploying the E3NETWORK solution in a number of exploitation scenarios, since millimetre-wave backhaul is particularly attractive for the new small cell movement in high density environments.

Other potential areas of exploitation include the last mile gap between the fiber backbone and commercial buildings not accessible by fiber, redundant networks to fiber for mission critical data, networks that need to be deployed quickly, and short distance mobile backhaul.

DSLAM (*digital subscriber line access multiplexer*) backhaul may also be investigated to connect mini DSLAMS on the field inside KVs in the neighbourhood to the Central Office (CO), instead of using optical fibres.

E-band small cell backhaul links have recently been tested and deployed by the mobile branch of OTE Group in three urban regions of Greece (Athens, Thessaloniki and Corfu) with capacity 1-2 Gbps for distances less than 2km. E3NETWORK solution is expected to bring a whole new perspective to this backhauling portion of the network, regarding higher data rate achievement.

The progress of the project has been regularly disseminated to the relevant internal corporate functional units, so as to ensure optimum exploitation against upcoming network challenges.

## 2.4 Individual Exploitation Plans for Silvers IMA

### 2.4.1. Partner profile

Sivers IMA AB is a Swedish company (SME) that develops, manufactures, and markets microwave products within three areas:

- Frequency converters for mm-wave transceiver applications
- Sensors (mainly FMCW RADAR front ends)
- Frequency generation (wideband VCO)

The company is owned (100%) by Sivers IMA Holding AB, which is a publicly traded company at NGM Nordic-MTF and has been active since 1951.

### 2.4.2. General Exploitation strategy

Sivers IMA currently manufacture and market E-band front-end transceivers for the telecom point-to-point market. The specification of these transceivers reflects the need of today's E-band point-to-point links with data rates in the low Gbit/s region. The need of even increased data-rate is evident with the ever increasing number of smart-phones. In order to remain competitive in the business, Sivers IMA needs a comprehensive understanding of the technical challenges and needs of these new links with data-rates as high as 10 Gbit/s. That involves both "hard" facts such as output power, noise figure, etc, and more "soft" facts as suitable new technologies that allows for on overall reduced cost and improved performance compared to today's existing transceivers.

The cross disciplinary cooperation in E3network will be beneficial for all participants and not the least for SME-s like Sivers IMA, since many areas in a 10 Gbit/s point-to-point link will be under consideration. The understanding from a system perspective is crucial in the future product development of Sivers IMA.

Thus, E3network will be of utmost importance for Sivers IMA to be continuously successful in the area of competitive E-band transceivers that meet the needs of the future.

### 2.4.3. Exploitation activities and achievements

Sivers IMA continuously follows the worldwide markets for E-band point-to-point links. Sivers IMA has also participated in the discussions within E3network to determine a specification of an E-band point-to-point link capable of 10 Gbit/s data transfer. These important insights are fed back to our product development.

The experience gained, and the insight in future possibilities also strengthens Sivers IMA's position in marketing discussions concerning the technology roadmap of mm-Wave products.

### 2.4.4. E3Network technologies

Important technology developed within E3network for Sivers IMA includes:

- System specification of an E-band point-to-point link capable of 10 Gbit/s data transfer
- Low cost building practice suitable for E-band frequencies and BiCMOS dies
- Insight into the key challenges when designing baseband and IF circuitry capable of transmitting and receiving a 10 Gbit/s data stream

### 2.4.5. Product Roadmap

Sivers IMA currently manufacture and market E-band front-end transceivers for the telecom point-to-point market. These products need to be updated to meet the demands of future E-band point-to-point link capable of 10 Gbit/s data transfer.

## 2.5 Individual Exploitation Plans for ST-I

### 2.5.1. Partner profile

The RF Business Unit of the MPD division within ST-I addresses two business areas: the RF Front End Module of Mobile Devices and the RF Products for Wireless Infrastructure applications.

The RF BU is responsible for the ST COT business based on the H9SOI process technologies. This ST H9SOI process technology allows a full monolithic integration of all key function of RF Front-end module of mobile devices offering the industry's best in class figure of merit for antenna switch and antenna tuning devices.

The shift from GaAs to SOI CMOS process technologies combined with the need to support multiband and multi-standard creates growing opportunities in the Cellular phones and WiFi markets.

For the Wireless Infrastructure market the RF BU provide products for Macro to Small cells as well as for mobile Backhauling application. This includes both standard products and ASIC products. COT business is also supported providing advanced BiCMOS process technology to customers developing RF products. The wireless infrastructure, due to the exponential increase in mobile data traffic, is undergoing significant changes toward Heterogeneous Architecture creating new opportunities. The RF BU target is to grow the revenues of the existing standard products and to drive the development of new ones for the emerging opportunities.

### 2.5.2. General Exploitation strategy

The exponential grow of data traffic sent over the mobile networks, with the advent of 3G and now LTE and, thus, the proliferation of distributed RAN (Radio Access Network) architectures and RRHs, (Remote Radio Heads) are the causes why ST-I is considering adding the E-band transceiver related products to their portfolio as an additional opportunity of increasing their available market by developing a proper CMOS based low cost and low power technology well working within the MMW frequency range. In this way, ST-I should offer to customers involved in MMW backhauling market both a proper high RF performance CMOS-Based technology allowing to develop their own E-band transceiver front end architecture solution or a complete ASSP (Application Specific Standard Product) chip set making easy the development of their RRH products as well. Furthermore, ST-I is planning to extend their System-on-Chip (SoC) portfolio to both the control and data plane layers of the baseband, taking advantage of the latest advances in multicore SoC technology as the nano-scale FDSOI CMOS technology.

ST-I could also expand its available market by including solutions for small cell backhaul in its portfolio – a market area that is likely to scale up with the increasing demand for data capacity. According to the Global Mobile Suppliers Association LTE is the fastest developing mobile system technology ever, with (in March 2012) 57 commercial networks in operation in 32 countries. Additionally 242 operators from 81 countries have committed to LTE and a further 59 operators from 14 countries are in pre-commitment trials. The development and deployment of distributed base stations and the rollout of LTE are two important factors driving wireless infrastructure hardware. From 2012 to 2017, the CAGR of RRH revenue will be 33.7%, with sales increasing to $3.6 billion by 2017 and Active Antennas could near US$500M for 2017 if all

the drivers fall into place. Macro base-stations receive much attention as technologies transition from 2G to 3G and 4G/LTE. Changing RAN architectures evolving from macrocells to small cells and HetNets also add complexity and variety to the equipment market. With such rapid growth in the number of macro, micro, pico, and femtocell base-stations, the backhaul, which connects them to the core of the network and interconnects them to each other, becomes a critical piece of the network design Spending on backhaul services by will grow to reach US$24.2 billion in 2018.

With new metrics required for the next generation compact single box base stations, chipset suppliers are using different approaches to achieve those metrics. The two key approaches in use are the DSP/Field Programmable Gate Arrays (FPGA)/network processor, and the SoC approaches. Depending on the supplier, these approaches will integrate one or several of the OSI layers in the on-chip design. ST-I believes that several leading OEMs are using ASICs in the baseband of their base station designs as a means of preserving their competitive advantages. These ASICs are either designed by the OEM in-house, or jointly designed by the OEM and its ASIC supplier as ST-I, following the OSI model based partition described below.

Typically, DSPs and FPGAs handle uplink and downlink processing for Layer 1. Then, multicore Reduced Instruction Set Computer (RISC) MPUs handle the Media Access Control (MAC) and data path processing, hardware acceleration, and network interfaces for the RF and backhaul transmission ends. Networks can also use FPGAs for high-end processing tasks such as turbo decoding, Discrete Fourier Transform (DFT), Fast Fourier Transform (FFT), Random Access Channel (RACH), and so forth. RISC processors or Multicore DSPs are used for Layer 2 and higher such as MAC scheduling, Radio Link Control (RLC), and control plane processing.

While this approach is the most common, bottleneck issues occur when transferring data between the DSP, FPGA, and Network Processor elements, especially when dealing with processing intensive technologies like LTE that use MIMO or have higher bandwidths, and is an incentive to the semiconductor manufacturer to integrate multiple OSI layers on chip as an SoC.

### 2.5.3. Exploitation activities and achievements

The approach followed by ST to exploit the RF IC design could be summarized by the following, where three kinds of business models could be achieved through the project by both the technology and the design developments as well.

1. COT/Wafer Foundry: Customer fully owned design tailored on their needs.

   ST takes care of production and eventually the industrialization. Customers are in charge of design, DRC and LVS. ST is in charge of silicon diffusion to untested/tested wafers or finished goods packaged IC.

2. ASICS: Customer owned specification tailored on its need.

   The design is shared (or delegated to) with ST. The customer is in charge of the design. ST covers DRC and LVS. ST is in charge of silicon diffusion to tested/untested wafers or finished goods

3. ST owned design and specification.

   The product is fully made by ST

The COT business model allows ST Customers to access to the MMW technology as the BiCMOS9MW or the BiCMOS55 getting the proper IC fabrication process for their devices. The ASIC model allows the Customers to design and implement together with the ST support their application specific IC to be integrated within their own system. The ASSP model sees ST to design and fabricate an application specific standard chip set which will enrich its own product portfolio. A very large application market, including:

- the cellular base stations and network accessories,

- the microwave communications and point-to-point links,
- the professional radio, railway security and surveillance,
- the satellite, cable modems and audio-video distribution
- the test & measurements, medical, space/avionic and defense

could be envisaged by exploiting the know-how, the experience and the above mentioned business models acquired and defined during the E3Networks project.

### 2.5.4. E3Network technologies

ST has proven excellent technology for RF and, thus, it makes available to the project partners the following silicon based IC process technology:

- BiCMOS7RF/6G widely adopted on Cellular Base Stations
- BiCMO9MW (& B55) for microwave RF & Optical
- CMOS65RF for Small Cells base Station

In particular for the design and implementation of the E-band transceiver front end chip set and IPs the very advanced B55 or BiCMOS55 process is provided. Below the performance feature comparison between BiCMOS9MW and BiCMOS55 has been briefly listed:

SiGe HBT: Reduced power consumption and/or increased speed

- fT/fMAX : 220/280GHz (B9MW) ~ 300-350/400-450GHz (B55)
- Similar transistor architecture as used in B9MW

CMOS: 55nm is a good compromise between performance and cost

- High Speed: ~715kG/mm² @ 100% (~575kG/mm² @ 80%)
- High Density: ~945kG/mm² @ 100% (~755kG/mm² @ 80%)

Copper back-end: 7 Metal Layers dedicated BEOL balancing performance & cost

- 6ML from digital BEOL preserving gate density
- Top thick copper metal layer (and thick via) to improve performances of transmission lines & inductors

The ST development path towards the very advanced MMW BiCMOS technologies started at the end of the nineties with the BiCMOS6G based on the 0.34mm CMOS process and then passing through the BiCMOS7RF in the first years of the two thousands, arrived to the BiCMOS9MW in 2007, which is based on a 0.13mm CMOS and got a bipolar transistor transition frequency ($f_T$) around 230GHz and a cut-off frequency of the bipolar transistor power gain ($f_{max}$) of 280GHz. Exploiting also the R&D activities allowed by the E3Network project, it's currently within the development phase the new BiCMOS55 process, based on the shrinking of the 65nm CMOS process lithography, which is getting an $f_T$ of 300GHz and a $f_{max}$ around 450GHz and it will reach the complete maturity towards the reliable high volume production at the end of the 2014.

### 2.5.5. Product Roadmap

IC functional IP foreground

The exploitation foreground that ST-I is planning to create in order to be consistent with both the higher added value business model ASIC or ASSP, by proper license agreements with

the project partners involved in E-band transceiver functional block design, is summarized in the following table:

**Table 8- Exploitable foreground according to ST-I**

| Exploitable Foreground (description) | Exploitable product(s) or measure(s) | Sector(s) of application | Timetable, commercial / scientific use | Patents or other IPR exploitation (licences) | Owner & Other Beneficiary(s) involved |
|---|---|---|---|---|---|
| E-band IP cell library and know-how | ADC | High speed Analogue-to-Digital conversion | 2016 | CAD IPR cell licensing | ST |
| E-band IP cell library and know-how | VGA | Communication link analogue base band channel | 2016 | CAD IPR cell licensing | ST |
| E-band IP cell library and know-how | BB Filter | Communication link analogue base band channel | 2016 | CAD IPR cell licensing | ST |
| E-band IP cell library and know-how | DAC | High speed Digital-to-Analogue conversion | 2016 | CAD IPR cell licensing | ST |
| E-band IP cell library and know-how | PA | MMW communication link front end power amplification | 2016 | CAD IPR cell licensing | ST |
| E-band IP cell library and know-how | VCO and frequency divider | MMW communication link RX and TX frequency synthesizer | 2016 | CAD IPR cell licensing | ST |
| E-band IP cell library and know-how | MMW mixers | MMW communication link RX and TX up and down conversion | 2016 | IPR licensing | ST |
| E-band IP cell library and know-how | Miniature antenna array | MMW communication link front end | 2016 | IPR licensing | ST |

The above mentioned circuit functional IP, developed during the project timeframe and related to the E-band transceiver analogue front end enrich the ST standard IP cell portfolio in order to allow the Customers who prefer to approach the ASIC model, to concentrate their efforts mainly towards the application specific system aspects where their know-how give the stronger added value.

Technology foundry service foreground

The new BiCMOS technology offer will provide to the key Customers a full foundry service for COT design of optoelectronic and RF IC for up-to-millimetre wave frequency applications.

A full Design Platform including the Design Kits for both the digital design flow and the analogue one as well, is developed and is provided to the Customers for mixed signal high speed and high frequency applications.

The BiCMOS55 process will consist of a core mask set of 53 mask levels and +5 to 7/8 masks for the process options. The BiCMOS55 available device summary will include:

*LP/GP HVT & SVT CMOS w/ 2.5V IOs*

*SRAM LVT + HVT*

*High Speed Si/SiGe:C HBTs*

*Natural NPN & PNP bipolar transistors*

*Natural DC resistors (active, poly & metal)*

*Natural DC capacitor (poly, plate)*

*RF MOM capacitors*

*Single & Differential varactors*

*MMW Inductors*

*µstrip transmission lines*

*MV Si/SiGe:C HBTs*

*RF LP SVT NMOS & PMOS*

*RF GO2 SVT NMOS & PMOS*

*RF Resistors*

The process options will include:

| | |
|---|---|
| *CMOS LVT (LP+GP)* | *+ 2 masks* |
| *6kΩ/sq. HIPO resistor* | *+ 1 mask* |
| *5fF/µm² MIM capacitor* | *+ 2 masks* |

*High Voltage Si/SiGe:C HBTs*

*RF Low Power Low Voltage Threshold NMOS & PMOS*

*RF MIM capacitors*

*RF HIPO resistors*

The BiCmos55 process is currently available for risk prototyping while the effort to bring it towards the full mass production maturity levels is still in progress and should be conclude within the project timeframe.

## 2.6 Individual Exploitation Plans for SiR

### 2.6.1. Partner profile

Silicon Radar (SiR) is a technology oriented company that gains a competitive advantage through the application of advanced and cost-efficient IC-design and fabrication technologies. Silicon Radar develops and delivers advanced, SiGe-based millimetre-wave integrated circuits (MMIC) for wireless communications and radar applications. The main areas of expertise are: single-chip radar systems, 60GHz communication systems, X-band phased array RF-frontends, and Terahertz circuits for communications and imaging.

Silicon Radar has developed a number of standard components - mainly for radar and communication applications. The products range from standard components for customized discrete circuits to highly integrated single-chip-frontends in frequency range of 10GHz up to 200 GHz and above. In addition to standard products, Silicon Radar offers design services for customer specific RF-ICs.

### 2.6.2. General Exploitation strategy

Silicon Radar was founded as a spin-off company by employees of the Leibnitz Research Institute IHP GmbH in June 2006. Preferably Silicon Radar developed circuits based on IHPs world leading Silicon Germanium technologies SG25 and SG13.

In the course of E3Network project, SiR is going to transfer its design concepts and development approaches to the advanced SiGe technologies of ST Microelectronics for the first time. Within the consortium of E3Network, the company will be able to improve its communication system know-how and design methodology and will benefit from cooperation with European design and system experts. This competence will directly improve the competitive position of SiR in the area of communication IC design services and IP portfolio.

Silicon Radar plans to make use of the methodologies developed in E3Network in mm-wave IC design projects for external customers as well as for their own radar and communication IC product offerings. It is planned to use the E-band receiver building blocks as basis for future commercial product developments. As a part of its future roadmap Silicon Radar plans to develop novel electronic components for the mixed-signal and RF markets. Silicon Radar will utilize the know-how acquired throughout the project to prepare future IP cores. It will allow for extending Silicon Radar actual markets towards new fields and help find new customers in the future. Additionally, the project enables closer cooperation among the partners and help gain deeper knowledge in RF IC technologies.

### 2.6.3. Exploitation activities and achievements

Exploitation activities undertaken so far:

- Evaluation of ST Microelectronics cost model for MPW and serial production and benchmarking with IHPs cost model for midrange and high volumes
- Evaluation and specification of an E-band ASIC chipset with potential customer
- Participation in definition of business model of beamconnect - the current IHP spinoff project

### 2.6.4. E3Network technologies

Silicon Radar considers the access to the advanced SiGe technologies (55nm node) of ST Microelectronic as a foundation for the commercial realization of later low-cost and high-volume millimetre-wave ASICs.

It is planned to establish an elementary design flow based on LaySuite tool of TexEDA and ADS Momentum.

### 2.6.5. Product Roadmap

The main target of E3Network for Silicon Radar is to acquire know-how in the fields of ST Microelectronics advanced SiGe technologies as well as in the field of E-band standardization requirements. From the developed building blocks of E3Network other more generic IP blocks could be derived.

Possible commercial projects in sight are:

- Customized E-band high data-rate communication frontend chips
- Derivational building blocks and IP blocks for frequency ranges close to E-Band (79GHz VCO and receiver, LNA and VGA for in-tank-applications).

## 2.7 Individual Exploitation Plans for INCIDE

### 2.7.1. Partner profile

INCIDE, SA is a fabless company dedicated to the design and industrialization of mixed-signal and RF integrated circuits. INCIDE has a long time expertise in the design of general-purpose analogue-to-digital and digital-to-analogue converters.

### 2.7.2. General Exploitation strategy

High speed analogue-to-digital and digital-to-analogue converters can be used in different applications apart from communication transceivers, such as data acquisition systems (including oscilloscopes and ATE), RADAR, light detection and ranging (LIDAR), set-top box, … The combination of a growing market and high-added volume makes it an accessible market for a company like INCIDE.

The developments done in the frame of E3NETWORK project could be exploited at different levels as stated below:

1. Exploitation of the **intellectual property (IP)** generated both for the ADC and DAC. In such an exploitation model, the layout is provided to the customers (in gds format), who can then integrate the design in a bigger chip. The resulting IPs for such high speed ADC and DAC are strongly related to the technology and process in which they were designed. Therefore, in a first step, the exploitation of the IPs in CMOS65 and/or CMOS55 and/or BiCMOS55 by ST-I has to be explored.

2. Exploitation of the high speed ADC and DAC as individual packaged chips. A short overview of similar products is shown in the tables below.

**Table 9- References for high-speed ADC**

| Mnfr | Model | Resolution [bit] | Max $f_s$ [Gsps] | Input channels | SNR [dB] | $f_{max}$ [GHz] | Consumption [W] | Origin |
|---|---|---|---|---|---|---|---|---|
| TI | ADC12D1800 | 12 | 3.6 | 2 | 58.6 | 1.4 | 4.4 | EEUU |
| TI | ADC12D1600 | 12 | 3.2 | 2 | 58.5 | 1.4 | 3.8 | EEUU |
| TI | ADC10D1500 | 10 | 3.0 | 2 | 56.8 | 1.4 | 3.1 | EEUU |
| Maxim | MAX109 | 8 | 2.2 | 1 | 44 | 0.8 | 6.8 | EEUU |
| Maxim | MAX108 | 8 | 1.5 | 1 | 47 | 0.4 | 4.8 | EEUU |
| Maxim | MAX104 | 8 | 1.0 | 1 | 47 | 0.3 | 4.8 | EEUU |
| E2V | EV12AS200 | 12 | 1.5 | 1 | 48.5 | 0.5 | 3.2 | UK |
| E2V | EV10AQ190A | 10 | 5.0 | 4 | 48 | 0.6 | 5.6 | UK |

**Table 10- References for high-speed DAC**

| Mnfr | Model | Resolution | Max $f_s$ [Gsps] | Input channels | $f_{max}$ [GHz] | Consumption [W] | Origin |
|---|---|---|---|---|---|---|---|
| Analog | AD9129 (1) | 14 | 5.6 | 4 | 1.4 | 1.3 | EEUU |
| Analog | AD9119 (1) | 11 | 5.6 | 4 | 1.4 | 1.3 | EEUU |
| E2V | EV12DS130ACZPY | 12 | 3.0 | 2 | 1.5 | 1.3 | UK |
| Maxim | MAX19693 | 12 | 4.0 | 1 | 2.0 | 1.2 | EEUU |
| Maxim | MAX5879 | 14 | 2.3 | 1 | 1.15 | 2.3 | EEUU |

(1) It is important to consider that the maximum sampling frequencies for some DACs are obtained in a second or third Nyquist zone, which can't be used for applications for baseband digital signals, as for instance in E3NETWORK project.

3. Development of expansion boards for ADC and DAC. This expansion boards help system designers to improve the time-to-market in system design, providing them with a solid starting point for development. These boards would use the chip designed by INCIDE. Apart from being a product in themselves, they will also help as evaluation board for potential customers for the chip and/or the IP.

**Table 11- References for high-speed ADC expansion board**

| Mnfr | Model | Resolution | Input channels | Max $f_s$ [Gsps] | $f_{max}$ [GHz] | Interface | Origin |
|---|---|---|---|---|---|---|---|
| **Delphi** | ADF-2500 | 10 | 1 | 2.5 | 0.5 | FMC | EEUU |
| **Delphi** | ADF-D1600 | 12 | 2 | 3.2 | 1.4 | FMC | EEUU |
| **4DSP** | FMC125 | 8 | 4 | 5.0 | 0.625 | FMC | EEUU |
| **4DSP** | FMC126 | 10 | 4 | 5.0 | 0.6 | FMC | EEUU |
| **Nutaq** | ADC5000 | 10 | 4 | 5.0 | 0.6 | FMC | EEUU |

**Table 12- References for high-speed DAC expansion board**

| Mnfr | Model | Resolution | Input channels | Max $f_s$ [Gsps] | $f_{max}$ [GHz] | Interface | Origin |
|---|---|---|---|---|---|---|---|
| **4DSP** | FMC176 | 14 | 2 | 5.6 | 1.4 | FMC | EEUU |
| **4DSP** | FMC110 | 16 | 2 | 1.0 | 0.44 | FMC | EEUU |
| **Delphi** | DAC-D2500 | 14 | 2 | 2.5 | 1.125 | FMC | EEUU |
| **Digilent** | AD9739A | 14 | 1 | 2.5 | 1.125 | FMC | EEUU |

Following the project evolution, it has been decided to prioritize the exploitation activities focused on the high speed converter boards. The efforts have been focused in identifying other potential applications apart from the communications based on E-band.

It has been realized that, for example, the military market combines the need for high-speed converters with possible needs for customization to their specific demands, which allows finding a clear differentiator from other competitors.

### 2.7.3. Exploitation activities and achievements

To start the promotion of the board for a wider market, a preliminary datasheet has been prepared. It has been uploaded to the website, and it is ready for review for potential customers.

A generic presentation of the kind of products and services designed during E3NETWORK project is included in our presentation for general customers.

A list of more specific customers potentially interested in the high speed converter boards has been prepared. For these customers face-to-face meetings will be prepared in order to understand their specific requirements concerning these boards.

### 2.7.4. E3Network technologies

Important technology developed within E3network for IXYS San Sebastian (former INCIDE) includes:

- ADC and DAC specifications for a E-band point-to-point link capable of 10 Gbit/s data transfer
- ADC integrated circuit architecture, suitable to provide high conversion speed
- DAC integrated circuit, suitable to provide high conversion speed

- Design of a FPGA Mezzanine ADC board, based on widely used ADCs, easy to interface with the FPGA board and with extended analogue bandwidth (including low frequencies) to satisfy the requirements of high bandwidth baseband processing

### 2.7.5. Product Roadmap

As stated above, the intention is to start with the marketing of high speed FMC ADC boards.

The architectures and techniques developed for the high speed integrated converters are valuable. At a later stage, it could be replace the commercial converters used in the FMC boards by integrated converters developed by IXYS San Sebastian, exploiting the circuits and architectures developed during E3NETWORK project.

# 3. CONCLUSIONS

Due to the growing adoption of data-hungry devices a huge increase of data traffic in backhaul network is expected. To cope with such high data rates, the backhaul network will be upgraded accordingly. The traditional solution based on Microwave radio shall be changed in such a way to be able to transport data rates of 5-10Gbps.

The adoption of millimetre-wave radio operating in E-band with the larger channel sizes here available is recognized as the feasible solution when data rates will go beyond Gbps.

For this reason, 71-76 and 81-86 GHz frequency spectrum, is recognized as the place where the most attractive future radio solutions, providing connection at Ultra High Capacity, for the needs of the 4G and 5G network backhaul, will find space.

In this document, a first attempt to identify the potential market size behind E3NETWORK millimetre-radio solution is carried out.

A full description of E-Band is provided, in terms of actual frequency arrangement and frequency licensing regime. Current E-Band radio solution already present on the market is also provided.

In chapter 3, the exploitation plane areas have been identified, subdivided also among the E3NETWORK actors. Commercial and not commercial, academy and standardization areas are considered. At the end, individual exploitation plans of each industrial partner are reported.

# 4. REFERENCES


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# 5. ABBREVIATIONS

| | |
|---|---|
| ADC | Analogue to Digital Converter |
| ASIC | Application Specific Integrated Circuit |
| ASSP | Application Specific Standard Product |
| ATE | Advanced Test Equipment |
| BEOL | Back End Of Line |
| BH | BackHaul |
| BiCMOS | Bipolar CMOS |
| CAGR | Compound Annual Growth Rate |
| CAPEX | Capital Expenditure |
| CEPT | European Conference of Postal and Telecommunications Administrations |
| CMOS | Complementary Metal Oxide Semiconductor |
| C-RAN | Centralized RAN |
| DAC | Digital to Analogue Converter |
| DFT | Discrete Fourier Transform |
| DRC | Design Rule Check |
| DSP | Digital Signal Processor |
| ECC | Electronic Communications Committee |
| ETSI | European Telecommunications Standards Institute |
| FDSOI | Fully Depleted Silicon On Insulator |
| FFT | Fast Fourier Transform |
| FMCW | Frequency Modulated Continuous Wave |
| FPGA | Field Programmable Gate Array |
| GaAs | Gallium Arsenide |
| IC | Integrated Circuit |
| IP | Internet Protocol |
| IP | Intellectual Property |
| ITU | International Telecommunications Union |
| LIDAR | Light Detection and Ranging |
| LNA | Low Noise Amplifier |
| LoS | Line of Sight |
| LTE | Long Term Evolution |
| LVS | Layout Versus Schematic |
| MAC | Media Access Control |
| MIMO | Multiple Input Multiple Output |

| | |
|---|---|
| MMIC | Millimeter Wave Integrated Circuit |
| MMW | Millimeter Waves |
| MPU | Micro Processor Unit |
| MPW | Multi Project Wafer |
| MW | Micro Waves |
| NMO | Network Mobile operator |
| OEM | Original Equipment Manufacturer |
| OPEX | Operational Expenditure |
| OSI | Open Systems Interconnection |
| R&D | Research & Development |
| RACH | Random Access Channel |
| RAN | Radio Access Network |
| RF | Radio Frequency |
| RISC | Reduced Instruction Set Computer |
| RLC | Radio Link Control |
| RRH | Remote Radio Head |
| SiGe | Silicon Germanium |
| SLR | Sky Light Research |
| SME | Small Medium Enterprise |
| SoC | System on Chip |
| TDD | Time Division Duplex |
| UHC | Ultra High Capacity |
| VCO | Voltage Controlled Oscillator |
| VGA | Variable Gain Amplifier |
| WiFi | Wireless Fidelity |
| WiMAX | Worldwide Interoperability for Microwave Access |
| WW | World Wide |