Final report on COCONUT project exploitation and dissemination activities

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Abstract:
This deliverable reports the actions taken by the COCONUT consortium in terms of dissemination and exploitation of the project results during the 3rd year of the project covering the period from November 2014 to February 2016 (including 4 months of extended period). It also summarises the opportunities for commercialisation, exploitation and standardisation identified by the industrial and academic partners at the end of the project.

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1 Introduction

In the final reporting period of the COCONUT project, a significant amount of knowledge and outcomes were generated in the specific topics related to the project. The key research outcomes of the project are:

- real time operation of 1.25 Gb/s prototype transceivers;
- narrow spacing (down to 6.25 GHz at 1.25 Gbs);
- low cost coherent detection scheme(s), implemented with cost–effective commercial available components;
- high power budget (35-40dB).

The consortium put significant effort to disseminate the project results to the scientific community and to the wider public. The project ended successfully by presenting the COCONUT system to the public. The COCONUT demonstration included 8 different experiments that presented the technologies developed in the project. Finally, the optical distribution network installed across the Pisa city center, was used to evaluate the transmission between the COCONUT OLT and the ONU.

This deliverable reports on: (a) the project's dissemination activities during the third year, (b) the exploitation plans of the consortium and (c) the situation in respect to the current technological standards.

The dissemination activities during the third year of the project have mainly focused on the promotion of COCONUT's important research outcomes to the scientific community. A key means of dissemination is the project web site, whose counter scored more than 23.000 visitors. The website content has been regularly updated with news and events related to the project. COCONUT was presented at relevant conferences, exhibitions and trade shows from the beginning of the project till now. The consortium published 56 (in total) scientific papers to the most prestigious journals and conferences in the field of the project. The consortium organized or participated in workshops, EU events, special sessions, seminars and other events, attracting a significant number of researchers in the field. Significant effort was given to organise the COCONUT demonstration and disseminate the actual working system to the wider public in the best possible way.

The current document gives an overview of the main business drivers that could use the COCONUT technologies. Different exploitation enablers are identified, which can make a business case for the COCONUT system. Three different business cases have already been identified i) Macrocell mobile backhaul ii) Small cell backhaul and iii) Fronthaul that could create new market opportunities for the COCONUT system.

All partners (industrial and academic) give their perspective of how they foresee the exploitation of the COCONUT technologies and comment on various commercialisation opportunities.

Standardization is fundamental for the success of any technology. The consortium follows the standardization process of the COCONUT technologies closely and has made efforts to influence the relevant fora and standardization groups that deal with the definition of the next

generation PON.COCONUT technologies were presented during a special FSAN workshop that was held in Atlanta in October 2015.

2 Market view and Business case for COCONUT system

In this section BT and Ericsson are presenting the current market view from their perspective. In particular BT gives the market overview in UK, by presenting the technologies that are currently used for FTTx. In addition, a forecast gives an insight of the traffic growth for the fixed data services in UK. In regards to the mobile services, Ericsson presents their view on how the mobile market is currently growing.

As BT starts the new NGA2 deployment in 2016, it is aiming at increasing the system capacities in the existing footprint and to increase the coverage to 95% of the UK by the end of 2017. While at the moment the technologies being used are VDSL2 using an FTTC physical architecture, and GPON using an FTTP physical architecture, it is expected that technologies being used in the future will be G.fast for FTTC, PON + G.fast in FTTN architectures, and eventually high capacity PON systems in future FTTP architectures. Future PON systems will be ITU standardized systems and could be XG-PON1, NG-PON2, G.metro, or even the new XGS-PON (currently under standardization in ITU).

2.1 Business Drivers

Open reach (a BT business division) are responsible for providing services over the local access network. More than 22m premises have now been passed using the fibre network (both FTTC & FTTP), which is more than 75% of households in the UK, 1.5m new connections in 2015. Net connections amount to 4.2m of homes and businesses, which represents 19% of those passed. Fig. 1 shows the evolution since 2011 of the number of premises passed and take-up during the roll out of BT's Next Generation Access (NGA).

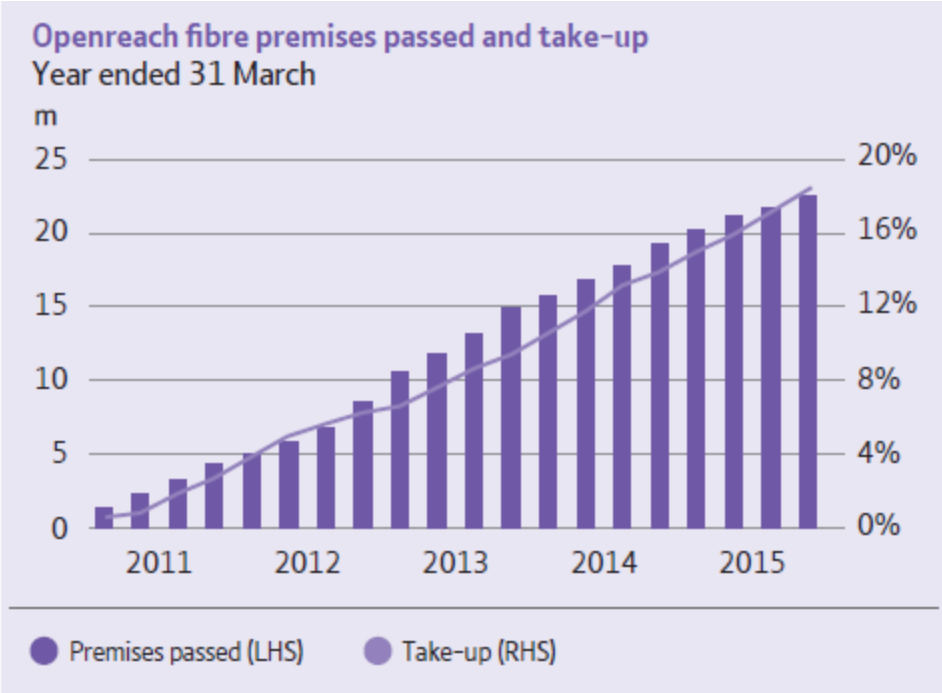


Figure 1. BT access fibre network deployment; premises passed and take-up

BT's programme is mirrored globally where deployments of broadband networks is gathering pace. Figure 2 shows the technology with highest growth are fibre based networks.

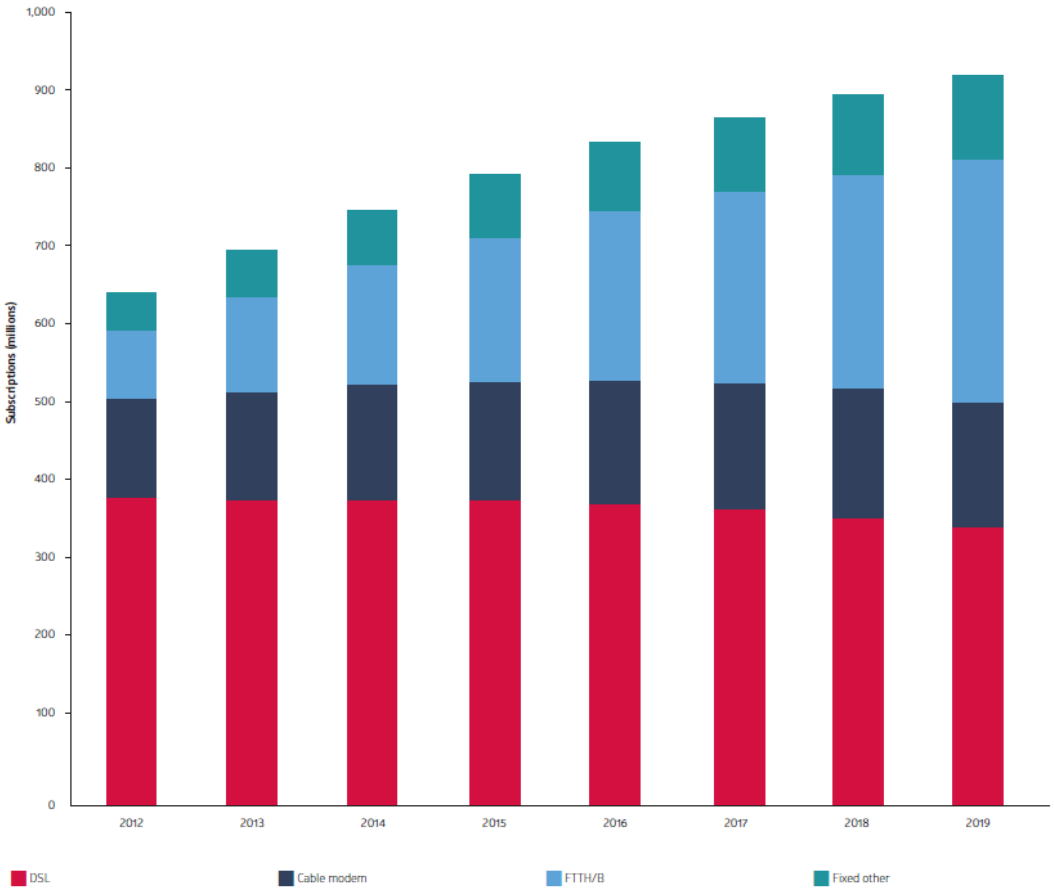


Figure 2. Global fixed broadband subscriptions by technology [Source: Ovum, "Telecoms, Media & Entertainment Outlook 2015"]

The business drivers remain the same as at the beginning of the project. Fibre roll out in the UK is progressing in both the commercially viable areas and in rural areas. Whereas the commercial deployment covers the areas where there is a market driven business case, the BDUK is part of the UK government with the aim of providing coverage to the rural areas via the Superfast Broadband (speeds of 24Mbit/s or more) Programme. This programme allocates public funding to stimulate private sector investment in the broadband roll out. The funding is allocated via public tenders in those targeted rural areas. BT bids for these tenders and uses the funding to complement its own means to build the fibre networks in the targeted rural areas.

The two tendencies of increased deployment footprint and higher bandwidth demand as shown in the forecast reported in the next subsection underpin the research of network technologies that can support the development of new access network systems that can enable the tendencies in a cost efficient manner.

2.1.1 Global traffic growth

The traffic demand has been increasing ever since Internet became the means for the delivery of services to businesses and residential customers.

Fixed Data Traffic growth

According to the Cisco VNI forecast, regarding the United Kingdom, traffic is expected to continue to grow. These estimations can be considered a good hint also for the global traffic growth in EU. The forecast indicate as follows

On internet traffic:

- It will grow 3.8-fold from 2014 to 2019, a compound annual growth rate of 30%.
- Busy hour traffic will grow 4.5-fold from 2014 to 2019, a compound annual growth rate of 35%.
- It will reach 7.0 Exa-bytes per month in 2019, up from 1.8 Exa-bytes per month in 2014.
- It will be 229 Peta-bytes per day in 2019, up from 60 Peta-bytes per day in 2014.
- In 2019 it will be equivalent to 92x the volume of the entire U.K. Internet in 2005.
- It will reach 107 Giga-bytes per capita in 2019, up from 29 Giga-bytes per capita in 2014.
- Average Internet traffic will reach 21 Tbit/s in 2019.
- Busy hour Internet traffic will reach 74 Tbit/s in 2019

On video traffic in the UK:

- It will grow 5-fold from 2014 to 2019, a compound annual growth rate of 38%.
- It will reach 5.6 Exa-bytes per month in 2019, up from 1.1 Exa-bytes per month in 2014.
- Total video traffic, i.e. business and consumer combined, will be 81% of all Internet traffic in 2019, up from 61% in 2014.
- Ultra HD will be 14.6% of Internet video traffic in 2019, up from 0.5% in 2014 (167.8% **C**ompound **A**nnual **G**rowth **R**ate, CAGR).
- High Definition will be 57.3% of Internet video traffic in 2019, up from 38.8% in 2014 (49.3% CAGR).
- Standard Definition will be 28.1% of Internet video traffic in 2019, compared to 60.6% in 2014 (18.5% CAGR).
- Consumer Internet video traffic will be 83% of consumer Internet traffic in 2019, up from 65% in 2014.
- Business Internet video traffic will be 68% of business Internet traffic in 2019, up from 37% in 2014.
- Internet-Video-to-TV traffic will be 15% of fixed consumer Internet video traffic in 2019, up from 19% in 2014.
- Internet-Video-to-TV traffic will increase 4-fold between 2014 and 2019 (29.2% CAGR).
- 118 billion minutes (223,586 years) of video content will cross the Internet each month in 2019, which is 44,717 minutes of video streamed or downloaded every second.
- Long form Internet video traffic was 56.0% of Internet video traffic in 2014, and it will be 73.9% of Internet video traffic by 2019

Finally, regarding residential users in the UK:

- The average Internet user will generate 108.0 Giga-bytes of Internet traffic per month in 2019, up 230% from 32.8 Giga-bytes per month in 2014, a CAGR of 27%.
- The average Internet household will generate 210.6 Giga-bytes of Internet traffic per month in 2019, up 231% from 63.5 Giga-bytes per month in 2014, a CAGR of 27%.
- There will be 21 million Internet households (86.5% of all Internet households) generating more than 50 Giga-bytes per month in 2019, up from 10 million in 2014.

- There will be 7 million Internet households (28.2% of all Internet households) generating more than 100 Giga-bytes per month in 2019, up from 4 million in 2014.
- There will be 4 million Internet households (16.6% of all Internet households) generating more than 250 Giga-bytes per month in 2019.
- There will be 1 million households (4.5% of all Internet households) generating more than 500 Giga-bytes per month in 2019.
- There will be 203,161 households (0.8% of all Internet households) generating more than a Tera-byte per month in 2019.

Using the same Cisco source, regarding mobile data in the UK:

- It will grow 9-fold from 2014 to 2019, a compound annual growth rate of 54%.
- It will reach 634 Petabytes per month in 2019, up from 74 Petabytes per month in 2014.
- It will grow 2 times faster than U.K. fixed IP traffic from 2014 to 2019.
- It was 3% of total IP traffic in 2014, and will be 8% of total IP traffic in 2019.
- In 2019 it will be equivalent to 7x the volume of the entire U.K. Internet in 2005.

Mobile Data Traffic (source: Ericsson[1])

According to the lastest mobility report issued by Ericsson, mobile data traffic continues to grow strongly, with a ten-fold increase forecast by the end of 2021 (see Figure 3). Data traffic is manly dominated by data from smartphones, followed by PCs, tablets, while voice remains flat.

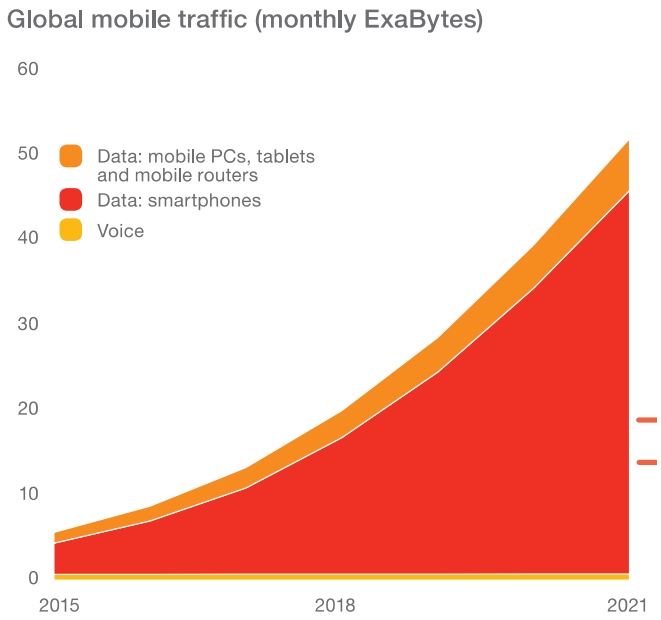


Figure 3. Global mobile traffic in ExaBytes.

As a reference, mobile data traffic in Q3 2015 was 65 percent higher than in Q3 2014, largely driven by increased video consumption on mobile devices. It is believed that almost 70 percent of all mobile data traffic will be from video by 2021.

This mobile data increase comes with an increase on the number of mobile subscriptions. Currently, there are as many mobile subscriptions as people in the world, and every second, 20 new mobile broadband subscriptions are activated. Global mobile subscriptions are

[1] Ericsson Mobility Report: "ON THE PULSE OF THE NETWORKED SOCIETY", NOVEMBER 2015

growing around 5 percent year-on-year. Smartphones accounted for close to 75 percent of all mobile phones sold in Q3 2015, compared to around 70 percent during Q3 2014. Today around 45 percent of all mobile phone subscriptions are associated with smartphones, compared with around 40 percent in 2014. By looking at the Figure 4 we see that the number of subscriptions exceeds the population in many countries.

For example we relate 1300 millions of mobile subscriptions in China compared to 1393 millions of people in China in 2014[2]. If we look at Western Europe the population for 2015 is 190 millions[3] to be compared to the 545 millions of mobile subscriptions!

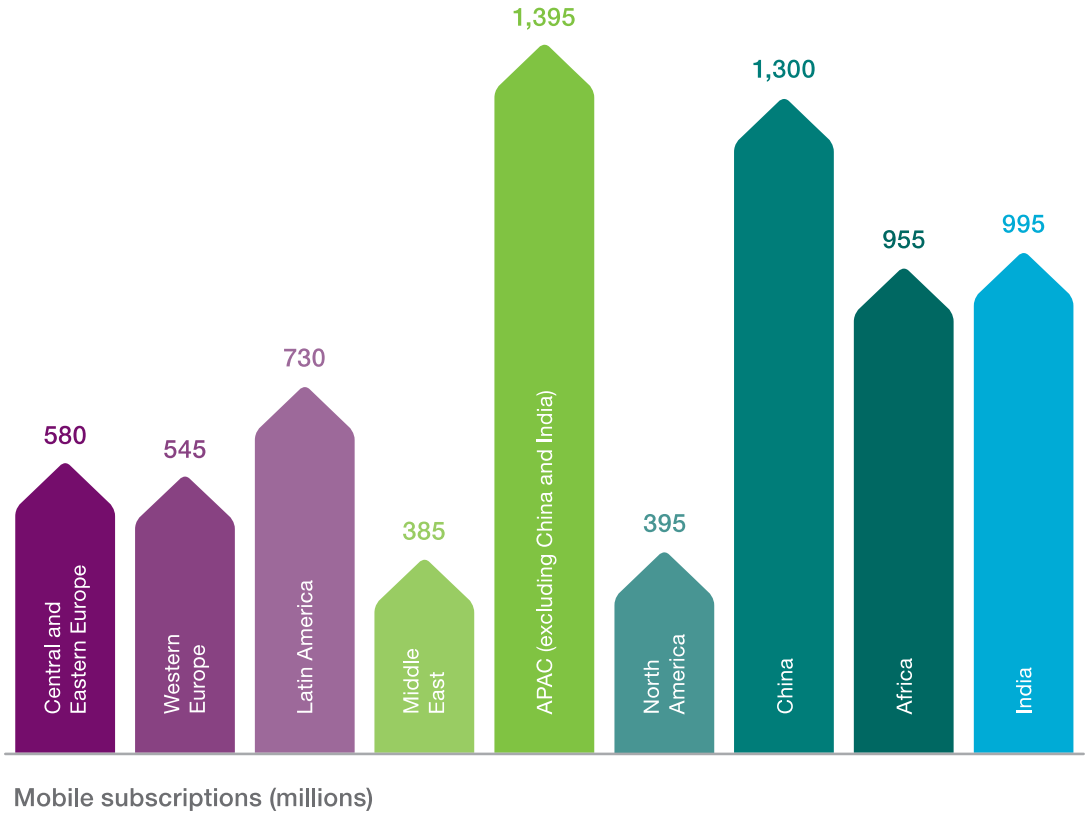


Figure 4. Number of subscriptions per country/region as of Oct 2015

This mismatch is largely due to inactive subscriptions and multiple device ownership, e.g. for business and private use, or to optimise pricing by using different operators for different calls (this is common for example in parts of Africa). In developed markets, users add devices such as tablets. This means that the number of subscribers is lower than the number of subscriptions. Figure 5 that there are around 4.9 billion subscribers versus 7.3 billion subscriptions.

[2] http://www.worldometers.info/world-population/china-population/
[3] http://populationpyramid.net/western-europe/

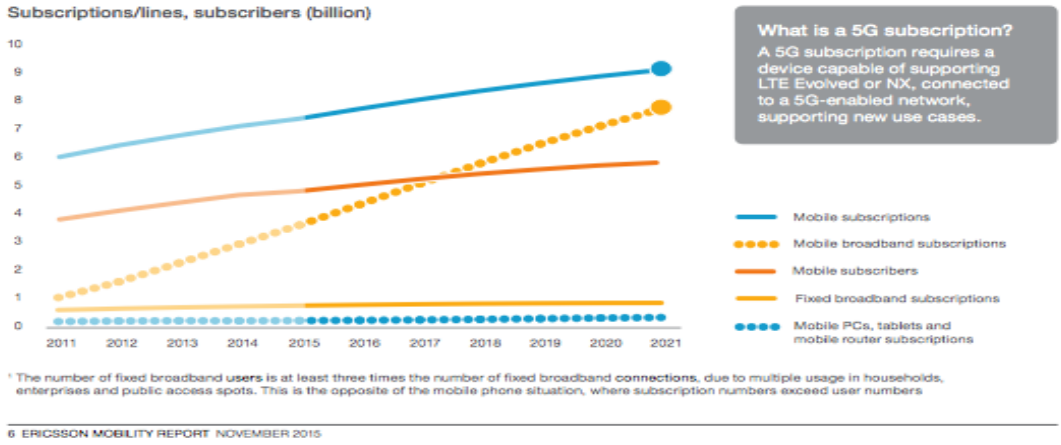


Figure 5. Number of subscriptions and subscribers in billions.

Apart from mobile phones, there will also be a multitude of other connected devices communicating. If we look at Figure 6 we see that out of a total forecast of 28 billion connected devices, more than 15 billion will be Machine-to-Machine (M2M) and consumer electronic devices by 2021.

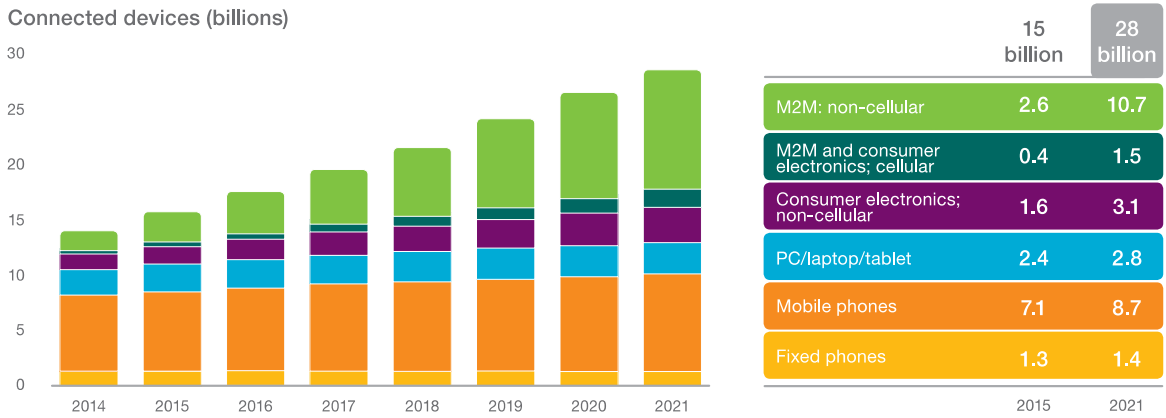


Figure 6. Type of different connected devices generating traffic. Traditional landline phones are included for legacy reasons. Examples of M2M: connected cars, machines and utility meters, remote metering. Note: A connected car is herein counted as one "thing" though it may have hundreds of sensors. Examples of consumer electronics devices include: smart TVs, digital media boxes, Blu-Ray players, gaming consoles, audio/video (AV) receivers, etc.

2.2 Exploitation Enablers addressed by COCONUT

In COCONUT, industrial partners have indicated various use-cases for the developed technology. In the following we report few selected examples of them.

Example 1. Macro cell deployment as a technology enabler.
Ericsson believes that the telecommunications network is evolving towards enabling the so-called networked society, or in other words towards 5G. 5G is not only a wireless technology evolution but it encompasses a new architecture, new business models and new use cases.

5G consists of a new radio access (NX), an evolved LTE access and an enhanced wireline and core network. It offers a wider range of services and will open up new industries and verticals. 5G networks, based on standards that will meet ITU IMT-2020 requirements, are expected to be deployed commercially in 2020. Pre-standard, pre-commercial networks are expected to be launched earlier in selected markets. 5G subscriptions will provide enhancements in mobile broadband services, as well as enable a wider range of use cases, e.g. for the Internet of Things (IoT). In 2021, South Korea, Japan, China and the US are expected to have the fastest uptake of 5G subscriptions. The three 5G use cases will be reviewed in the next sections, here we would like to point out some of the technology enablers for COCONUT.

2011 was the first year of 2G/3G/4G infrastructure deployment, 2015 is expected to see a plateau and it will follow a new disinvestment cycle expected to start in 2016, given current macroeconomic conditions. The major events during 2011- 2015 for mobile infrastructure equipment are:

- 2G: capacity upgrades and network modernization while reaching the end of life cycle 3G: network optimization and coverage expansion to ensure fallback when out of 4G coverage
- 4G: mobile broadband network rollouts; 2009-2011 marks the first wave of rollouts; 2012-2015 is the second wave
- 5G: definition, specifications, and requirements; the EU launched 5GPP on December 17, 2013, South Korea is actively working on it, and NTT DOCOMO set 2020 for commercial launch. In 3Q14, Russian operator MegaFon and Huawei recently announced they are planning to deploy 5G in time for the 2018 soccer World Cup

So if we look at the market (see Table 1[4]), after more than 2 decades of existence, the worldwide mobile infrastructure market has reached maturity and fluctuates between $31B and $47B depending on macroeconomic cycles and shifts in technology generations: 2G is declining, 3G is at maturity of its life cycle, 4G is in its 7th year of deployment and peaking in 2015 and defining 5G is a work in progress. The market is also shifting from macrocell-based coverage to small cell-based capacity upgrades. According to the table below, in 3Q15, the global macrocell mobile infrastructure market totaled $11.3B, down 1% from 2Q15, mainly dragged by Brazil, China, Japan, the Middle East, and Russia, and up 1% YoY, driven by strong 3G Wideband Code Division Multiple Access (W-CDMA) capacity projects in Europe, the middle-east and Africa (EMEA) and the end of LTE rollouts in China. As a result, LTE was flat quarter on quarter (QoQ) and up 9% (year on year) YoY; unlike last quarter, evolved packet core (EPC) was up 8% QoQ (up 15% YoY) while Evolved Universal Terrestrial Radio Access (E-UTRAN) was down 1% quarter on quarter (QoQ) and up 9% YoY. 2G/3G was down 1% QoQ, sustained by another strong W-CDMA quarter, up 4% QoQ and 13% YoY.

[4] Infonetics, mobile infrastructure equipment, 3Q2015

Table 1. Macrocell mobile infrastructure market revenue

Worldwide Markets	3Q14	2Q15	3Q15	QoQ	YoY
Total 2G/3G/4G	**$11.2B**	**$11.4B**	**$11.3B**	**-1%**	**+1%**
2G/3G	$5.6B	$5.2B	$5.2B	-1%	-8%
LTE*	$5.6B	$6.1B	$6.1B	-0.3%	+9%

The first wave of LTE rollouts (2009–2011) was characterized by a small number of mobile operators with large footprints (e.g., more than 10,000 eNodeBs). The early LTE adopters, those part of the 1st wave, are now busy implementing carrier aggregation-based LTE-Advanced to boost capacity in their network. There were a few LTE-A commercial launches in 2013, and as we expected, a serious ramp up occurred in 2014: 49 operators have commercially launched LTE-Advanced in 31 countries. Taking into account some additional deployments in progress, trials and studies, the Global mobile Suppliers Association (GSA) calculates almost 30% of LTE operators are currently investing in LTE-Advanced technology (see Figure 7[5]).

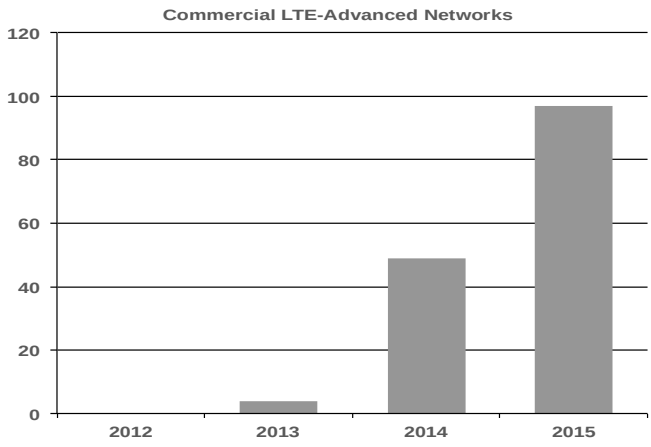


Figure 7. Number of LTE commercial networks launches

The second wave (2012-2015) of LTE rollouts continues and ramps up with a flurry of smaller footprints (e.g., less than 1,000 eNodeBs), with just one exception in China where China Mobile plans for 500,000 eNodeBs in 2015.

As of October 13, 2015, GSA (Global mobile Suppliers Association) confirmed that 442 commercial LTE networks had been launched in 147 countries. 657 mobile operators are currently investing in LTE in 177 countries, from which a big chunk of those 442 commercial LTE networks is already coming. This is because the major surge of LTE deployment in

[5] Infonetics, mobile infrastructure equipment, 3Q2015

developed countries will be over by the end of 2015, and beyond that, there could still be LTE site enhancement but neither greenfield sites nor large rollouts (see Figure 8[6]).

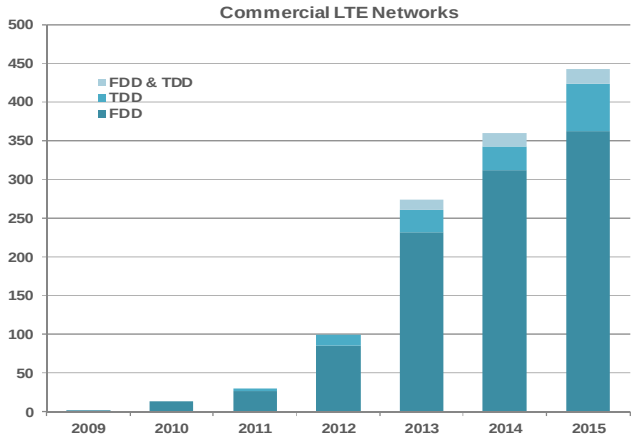


Figure 8. Number of commercial LTE networks per technology type.

LTE rollouts start with macrocells, and when the macrocell network is complete, it is augmented by a mix of low-power nodes such as microcells, picocells, metrocells and femtocells driven by the need to enhance existing saturated macrocellular networks that are struggling to maintain a decent mobile broadband experience, as well as to add capacity to existing LTE networks. So even if the macrocell networks market stops growing there is another fast growing small cell market that could provide single-digit YoY growth in the coming years.

Example 2. Small cell deployment as a technology enabler.

A small cell is a low power cell that: a) is used in order to add capacity (and extending coverage) in high traffic urban areas and/or b) to add coverage in rural areas. A small cell specifications comparison is found in the Table 2 (source Infonetics[7]).

[6] Infonetics, mobile infrastructure equipment, 3Q2015

[7] Infonetics Research "Small Cell Mobile Backhaul Equipment Biannual Worldwide and Regional Market Size and Forecasts: 2nd Edition" December 10, 2015

Table 2. Small cell specifications.

Specifications	Microcells	Picocells	Metrocells
Cell radius	2 km maximum	200 meters max	10-100 meters
Output power	33—36 dBm/2—5 W	250 mW—1 W	1 mW—250 mW
Number of users	More than 100	30 to 100	Less than 30
Controller signaling protocol	Iub	Iub	Iub
RRH/RRU option	Yes	Yes	No
DAS usage	Yes	Yes	No
Applications	**Microcells**	**Picocells**	**PA Femtocells**
Low power outdoor sites	Yes	Yes	Yes
Villages and road sites	Yes	Yes	Yes
City centers	Yes	Yes	Yes
Rooftop sites	Yes	Yes	No
Stadiums	Yes	Yes	No
Tunnel sites (e.g., subway)	Yes	Yes	No
In-building sites (e.g., buildings}	Yes	Yes	Yes
Shopping centers, malls	Yes	Yes	Yes

According to several industry analysts' reports, 2015 shows an increase of small cell activity, but service provider plans indicate rollouts are mainly tactical with modest small cell units in targeted areas. Mobile operators are testing, conducting field trials, and selecting technologies, products, and vendors for small cells and for small cell backhaul. Also, as new contracts are being signed, the number of small cell units shipped is gradually increasing. In the first 9 months of 2015, there have been several major deals and announcements; here are some examples:

- **Alcatel-Lucent** said in June 2015 it was helping AIS, Thailand's leading mobile service provider, to improve cellular services for residents and the country's substantial tourist economy with the country's first deployment of small cell technology. AIS is deploying small cells in popular tourist destinations and shopping malls in Thailand, as well as in urban environments and villages. This will help the service provider expand its data service faster and more economically than conventional cellular networks, which may be more costly and take considerably more time to install.
- **Ericsson** was selected by China Telecom, the first operator in Mainland China, to deploy Ericsson's Radio Dot small cell system. China Telecom has rolled out the LTE version of the Radio Dot in its offices in Zhejiang and Guangdong. The latter deployment saw China Telecom aggregate 20MHz of 1800MHz spectrum and 20MHz of 2.1GHz spectrum to achieve a theoretical maximum speed of 300M. Claro, MTS, SingTel, Telefónica, Verizon, and Vodafone have also deployed Ericsson's Radio Dot.
- **Nokia Networks** won a nationwide small cell deal with Ooredoo Qatar in August. The contract will see Ooredoo roll out Nokia's 3G and 4G microcells and 4G picocells to improve network capacity in areas such as cafes and restaurants.
- **Cisco** announced commercial availability of its Universal Small Cell (USC) 8000 Series designed for large enterprises and venues. This solution is the result of a strategic collaboration between Cisco and SpiderCloud Wireless and will be offered to Cisco's enterprise customers and channel partners. The global agreement includes Cisco reselling SpiderCloud's entire small cell portfolio under the USC 8000 Series brand. In addition, SpiderCloud will develop custom small cell technology for Cisco. Vodafone will be the first service provider to deliver the mobile service to its enterprise customers.

- **Cisco** announced that EE in the UK is deploying small cells to support its growing base of small, medium, and large enterprise buildings. EE's customers will be using standalone access points and a small cell solution that will support modules that plug into existing Cisco WiFi access points.

- **SpiderCloud Wireless** announced that Warid Telecom, a 4G mobile operator in Pakistan, has started deployments of scalable small cell systems to empower business and consumer customers in major cities of Pakistan with indoor and public space 4G mobile coverage and capacity. The first deployments are targeted for hundreds of different locations in the major cities of Pakistan with 4G Radio Nodes providing access using band 3* and Services Nodes that are securely connected to Warid Telecom's core network.
- **Telcel and América Móvil** said that they will be offering SpiderCloud's small cell in-building coverage system, following a successful trial in June 2014; together with its business partners in the region (Cisco, NEC, and one more major player), SpiderCloud will work with Telcel and América Móvil to bring in- building services to major metropolitan areas in South America.

Small cell deployment predictions are shown in Figure 9[8]. The expected total number of urban unit shipments to reach 447K by the end of 2015 and grow at a 5-year CAGR of 49.9% to hit 1.6M by 2019, delivering revenue of $482M.

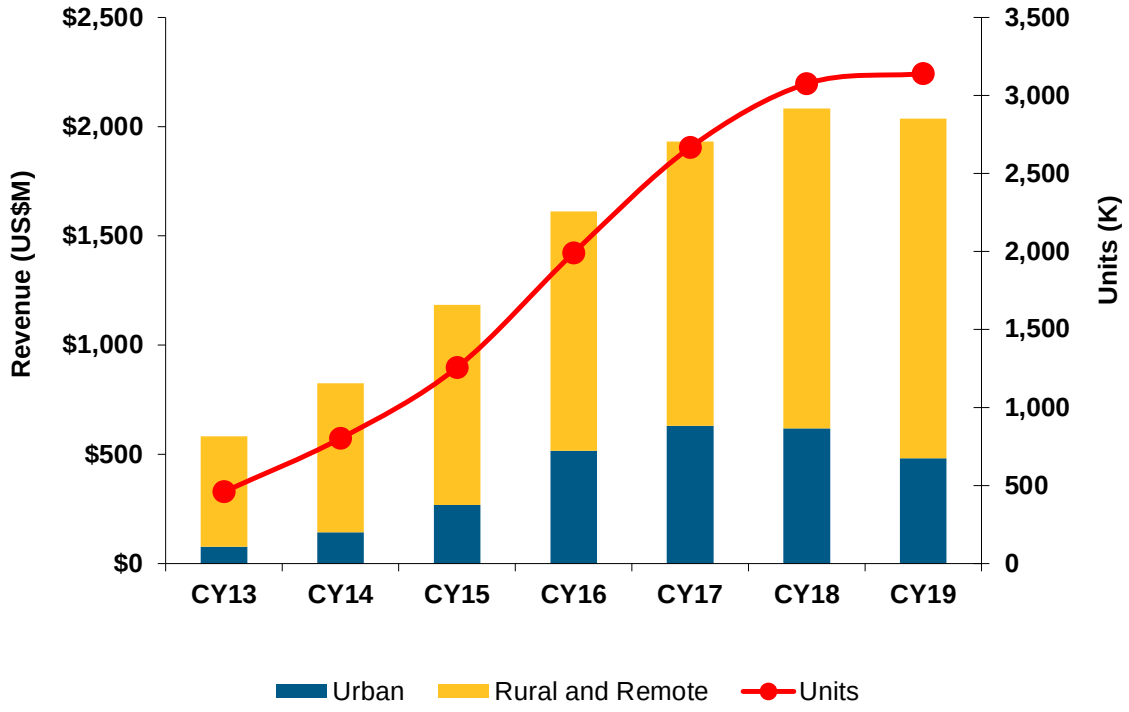


Figure 9. Small cell deployment predictions in revenue and units sold.

From the numbers presented in these two examples we deduce that an increase of deployed number of small and macrocells has a direct impact on the number of new backhaul connections being needed, which in turn has an impact on the potential addressable market for COCONUT. In the following section we evaluate the potential business opportunity for COCONUT.

[8] Infonetics Research "Small Cell Mobile Backhaul Equipment Biannual Worldwide and Regional Market Size and Forecasts: 2nd Edition" December 10, 2015

2.3 Market Outlook and business Opportunities

2.3.1 ERICSSON

COCONUT technology sees a business opportunity in the journey of building 5G networks for the networked society. 5G will allow new capabilities that are part of the ICT revolution to gradually evolve or disruptively change industries. Examples of these capabilities are:

- The shift from physical products to service delivery (think of Netflix or Spotify);
- The major influence from consumers before, during and after purchase (think of crowdsourcing, instant customer feedback etc.);
- Connected things with the possibility for everything in and around a value chain to be communicating (think of connected transport packages).

In fact, the very concept of these industries can be transformed. Think of transportation becoming mobility, retail to exchange and education to learning, healthcare moves from being perceived as a reactive treatment of illness to a proactive securement of wellness.

Like the pre-industrial and industrial worlds that preceded it, the Networked Society represents a fundamental paradigm shift for people, business and society.
The key enablers of growth and innovation come not from the physical assets and infrastructures themselves, but from the people, platforms and insights that are leveraged to reinvent them. We define these new assets in six key areas:

- **Digitalization – exponential and ubiquitous:** As digital assets rise in importance, and become primary sources of business value, we will see business process become faster, more relevant and cost-efficient.
- **Data – own, shared and open:** Big Data that is collected and analyzed from practically every aspect of life has tremendous potential to improve decision-making. As we continue to harness this data, whether it's owned, shared or open data, it will continue to become a powerful resource.
- **Things – connected and intelligent:** We are now entering a reality where billions of digitally connected objects are the equivalent of raw materials for much more dynamic products. They are in turn enhanced by a wealth of new services that improve product performance and achieve new levels of efficiency.
- **Users – participating and active:** In world defined by greater transparency and distribution of power, people will continue to become active contributors to the networks and communities in which they participate. This will lead to new forms of co-creation where products and services become more relevant and users are viewed as a vital asset for any public or private organization.
- **Platforms – economics and scale:** Technology platforms are transforming the idea of a product or service by opening up entire business processes to customers, developers, and partners to add value. This not only reduces transaction costs but has the potential to become an economic force with a logic of its own.
- **Capabilities – available and on-demand:** Starting a global business today requires little more than an idea, a user base and a network of collaborators. Funding can be crowd-sourced; factories can be rented and specialized skills, work spaces and digital infrastructures scale as needed. As a result, many more barriers to market entry and global scale will be lowered.

In 5G there will be diverse and extreme requirements: 10-100X devices, 1000X data volumes, latencies below 5ms, battery life in years etc. The way to achieve this is to build an

intelligently "sliced" network to allocate resources in the most optimal way and connect the devices to applications relevant to that device/app from the cloud.

Thus, in a 5G scenario there are three important use cases: extreme mobile broadband, massive machine-type communications and ultra-reliable machine type communications. **Extreme mobile broadband** is the most demanding service in 5G. It has to accommodate high mobility, high spectrum efficiency, excellent user experience, high peak data rate, high area traffic capacity, high efficiency, mid connection density and mid latency. **Massive machine-type communications** is characterized by a high connection density, mid network energy efficiency and low area traffic capacity, low peak and user experience data rate, low spectrum efficiency, low mobility and high latency requirements. **Ultra-reliable machine-type communications** is characterized by low latency and high mobility, while connection density, network energy efficiency, area traffic capacity, peak data rates, user experience data trates, spectrum efficiency remain low.

From the connectivity point of view, these three use cases will be enabled by wireline and wireless existing technologies, i.e., fibre, copper, microwave, etc. Thus COCONUT finds its niche in optical front and backhaul solutions.

Business opportunity 1: Macrocell mobile bakchaul

Macrocell backhaul is defined as the technology used for transporting mobile traffic between the macro base transceiver station (BTS)/NodeB and base station controller (BSC)/ radio network controller (RNC) or the eNodeB and the evolved packet core (EPC) site, including equipment used in hub points in the metro network in between.

- The 1st mile connection is from the macrocell site and any hub point—sometimes called Low radio access network (RAN) or LRAN, for example, an E1 from the macrocell site to a provider location where the E1s are aggregated onto an E3 or onto an synchronous optical networking (SDH) ring; in the case of a direct E1 to the BSC/RNC site, there is only a 1st mile; in the case of packet backhaul, for example, a set of Ethernet fibre 1st mile connections are aggregated by an Ethernet switch or a router to be transported on an IP/MPLS network (which typically rides across a metro on the existing metro transport network) to the BSC/RNC site. Many BSC/RNC controller sites reside at the same location as the MSC (mobile switching center).
- In the case where there is a hubbing point (e.g., macrocell site connection to a metro SDH ring, the next microwave link, or a metro Ethernet service), the 2nd mile, also called High RAN or HRAN, typically carries traffic aggregated from a number of cell sites at the hub across some transport network on to the BSC/RNC site; in the case of packet backhaul, the 2nd mile is typically an Ethernet service, which carries the aggregated IP/Ethernet traffic from a number of 1st mile packet connections. Figure 10 shows a possible connectivity of small and macro cells networks.

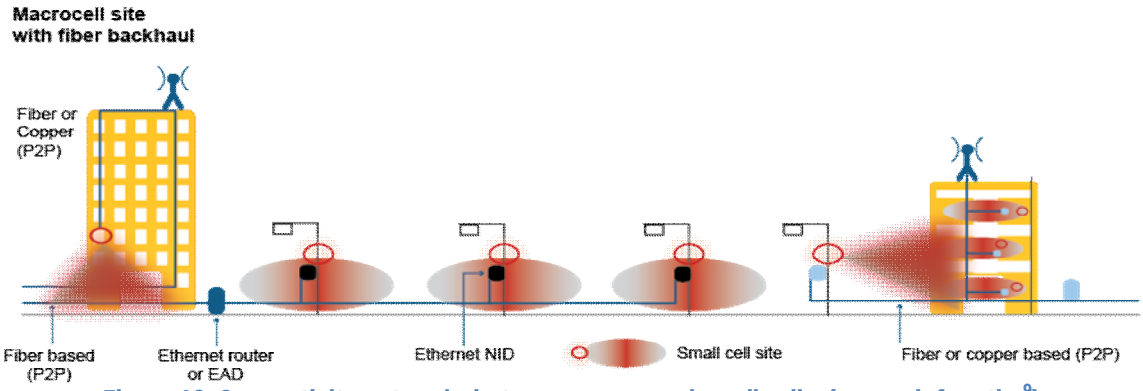


Figure 10. Connectivity networks between macro and small cells. (source infonetics[9])

Some of the deployment trends the analysts see are:

- Installed connections at cell sites rises as macro backhaul capacity demand grows
- Number of connections per macro site is increasing
- Average bandwidth per connection also growing:
  - Wireline
    - ~67Mbps in 2013
    - ~148Mbps in 2019
  - Wireless
    - ~46Mbps in 2013
    - ~168Mbps in 2019

In order to make a **quantitative analysis of the addressable market for COCONUT** we will focus on two parameters: i) the number of installed macrocell mobile backhaul connections by medium and ii) the revenue in dollars of macrocell site backhaul equipment.

Figure 11 (source Infonetics[9]) shows the historical and prediction of annual installed macrocell mobile backhaul connections by medium in number of units. As we can see from the figure Ethernet (wireline and microwave) is being added to, or replacing, the small portion of remaining TDM-only connections. We can see the installed backhaul connections mix change, with Ethernet / Ethernet microwave connections growing faster than the legacy TDM types.

[9] Infonetics Research "Macrocell Mobile Backhaul Equipment and Services Biannual Worldwide and Regional Market Share, Size, and Forecasts: 2nd Edition" October 21, 2015

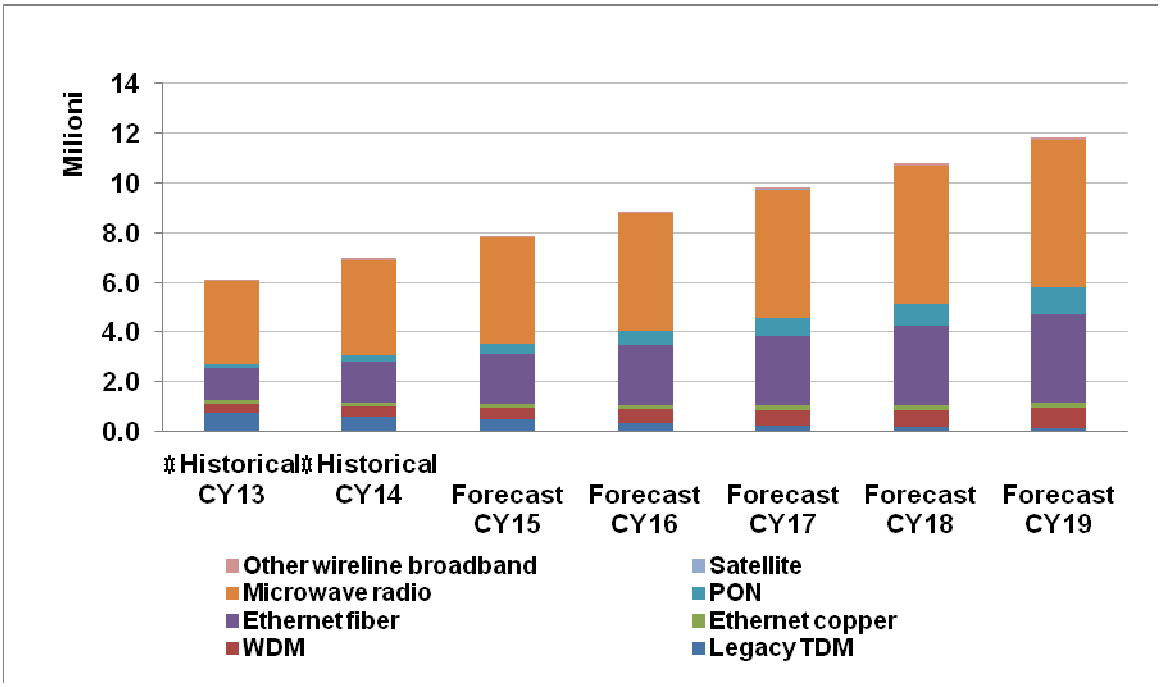


Figure 11. Historical and prediction of annual installed macrocell mobile backhaul connections by medium in number of units.

At the expense of copper, fibre makes up an increasing share of mobile backhaul installed connections, growing from 37% in CY14 to 40% in CY15 to 47% in CY19. Operators and transport providers prefer fibre to meet the capacity demands of the traffic increase driven today by LTE/LTE-A and in the future, 5G. Many cell sites will be copper-fed for years to come, and vendors of EFM bonded copper products—Actelis, Overture, ADTRAN, Huawei, and others—have been stretching the capacity of bonded copper. Alcatel-Lucent's VDSL2 Phantom Mode, for example, has been shown in the laboratory to provide 390M over a distance of 1,300 feet (400 meters) using 2 pairs and 910M over the same distance using 4 pairs. This is useful, but probably not enough to make it compelling enough for widespread deployment, so we could consider it a niche solution in the 4G to 5G era.

Zooming into the macrocell site backhaul existing fibre connections (Figure 12[10]) we will be able to tell the market potential for COCONUT. Fibre in this case includes PON, Ethernet fibre, WDM, and the fibre parts of legacy TDM. The number of installed macrocell mobile backhaul fibre connections has been increasing during 2013-2014 and the prediction is that it will increase over the coming years. In 2014 there were 2.6M number of installed mobile backhaul fibre connections and it is predicted that it will increase to 56M by 2019.

[10] Infonetics Research "Macrocell Mobile Backhaul Equipment and Services Biannual Worldwide and Regional Market Share, Size, and Forecasts: 2nd Edition" October 21, 2015

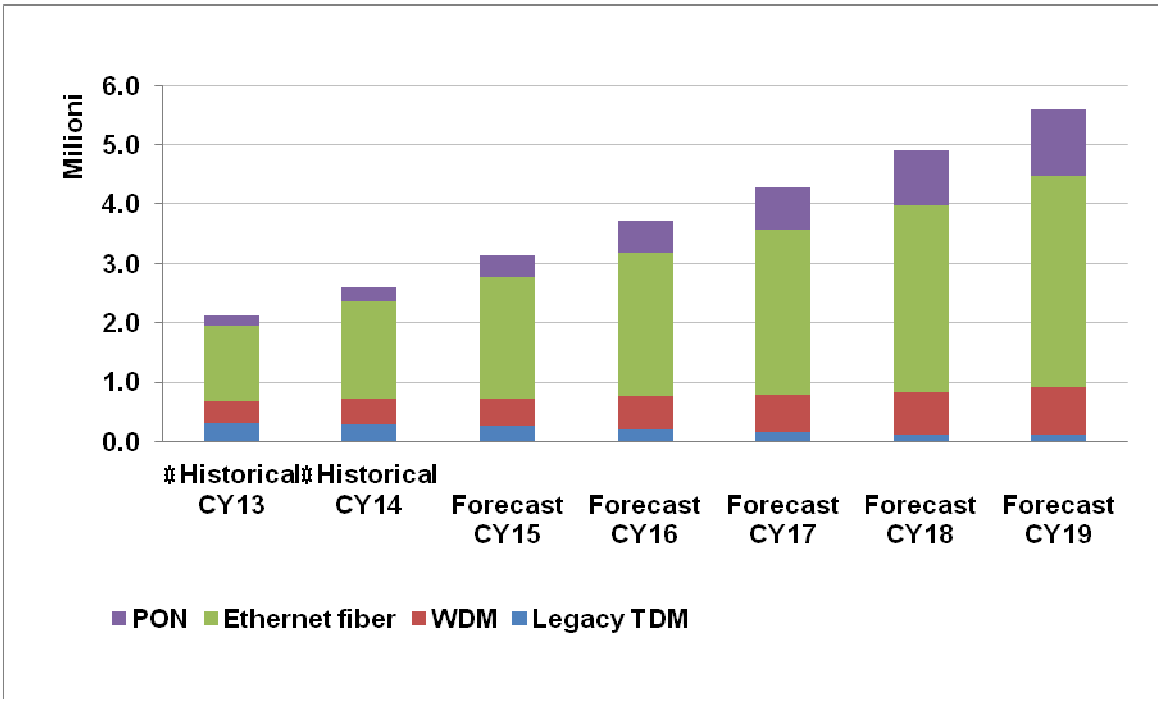


Figure 12. Number of small cell backhaul fibre connections

so we have a total number of 5.6 million of macrocell backhaul fibre connections where COCONUT technologies could be deployed.

The Figure 13[11] below shows the annual revenue in dollars of macrocell site backhaul equipment. The main contributors are microwave radi and IP edge routers. Smaller revenues are from Ethernet access devices (EADs) and WDM.

[11] Infonetics Research "Macrocell Mobile Backhaul Equipment and Services Biannual Worldwide and Regional Market Share, Size, and Forecasts: 2nd Edition" October 21, 2015

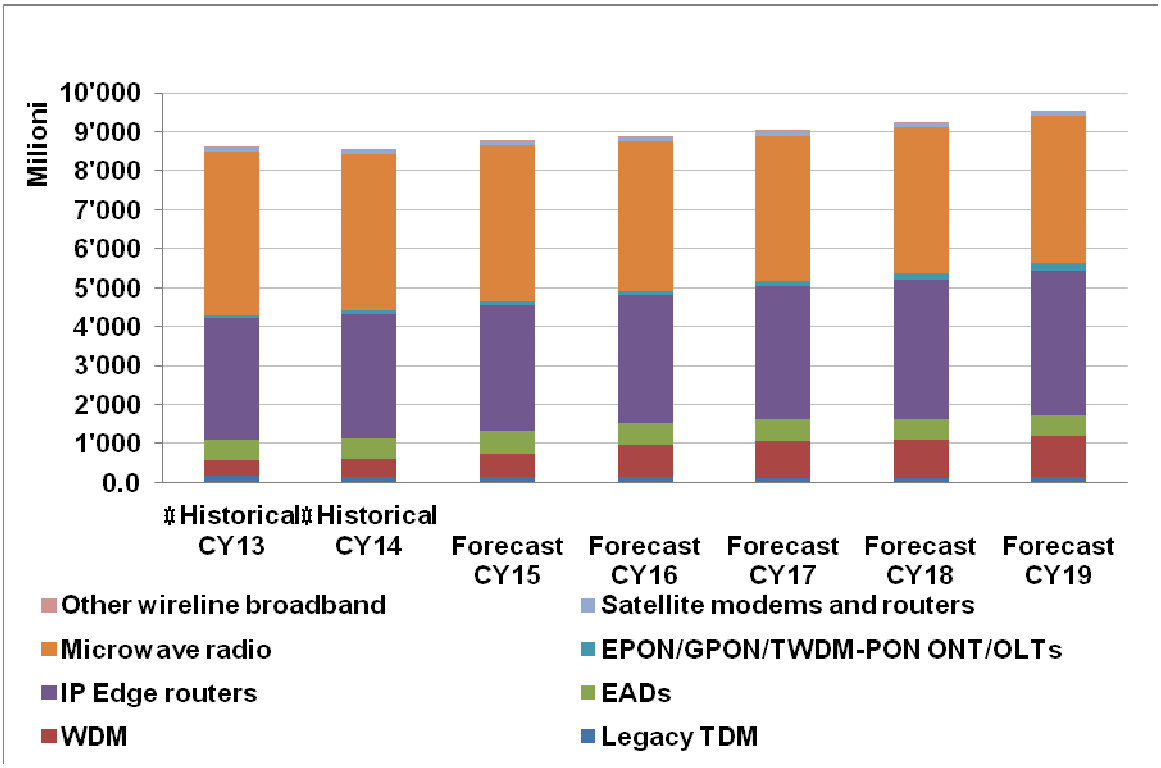


Figure 13. Annual revenue in dollars of macrocell site backhaul equipment.

Out of the total revenue per technology the potential market that is addressable by COCONUT is the one that includes WDM and PON networks. This is shown in Figure 14[12].

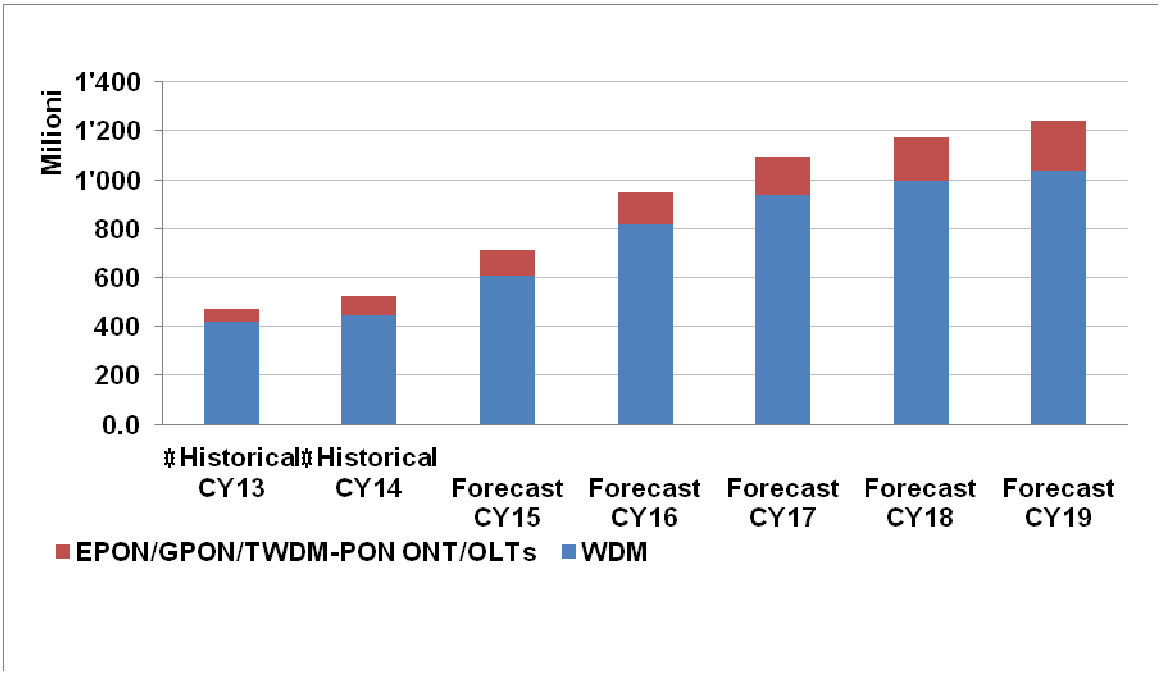


Figure 14. Annual revenue in dollars of macrocell site backhaul fibre equipment.

[12] Infonetics Research "Macrocell Mobile Backhaul Equipment and Services Biannual Worldwide and Regional Market Share, Size, and Forecasts: 2nd Edition" October 21, 2015

The revenue of these two technologies together used for mobile backhaul in 2014 was $522 million and predicted to be $1241 million by 2019, which means a potential market revenue for COCONUT of $1241 million. Another potential key enabling factor for COCONUT is the broadband access infrastructure re-use, which is an import piece of the 5G puzzle for operators.

Business opportunity 2: Small cell backhaul

Network operators are currently testing and field trialling many outdoor small cell and backhaul options in dense urban areas to choose technologies, products, and vendors, as well as to develop operational procedures. This started during 2013 and carried on into 2014 and continues still. Looking at 2015, the market is now underway, with a smattering of modest-scale deployments, but it is still an immature market. Though most deployments to date have been in urban and metro areas, there is life in the rural segment too: Vodafone and other operators are using small cells for outdoor coverage in rural areas, where the backhaul is not difficult and usually wireline. With these 2 main uses, total worldwide outdoor SBH equipment revenue hit $103M in CY14. The issues of urban deployments are gradually being resolved, and more mobile operators are now starting to make their initial deployments where Infonetics expects a revenue to increase of 143% from CY14 to CY15, reaching $250M. The prediction tells that the real ramp will begin in CY16, with steady growth throughout CY16–CY19 as outdoor small cell deployments proliferate.
Here again, in order to make a quantitative analysis of the addressable market for COCONUT we will focus on two parameters: i) the number of installed small cell mobile backhaul connections by medium and ii) the revenue in dollars of small cell backhaul equipment.

In Figure 15 (source Infonetics[13]) we show the worldwide installed outdoor small cell backhaul connections by technology: the network link between transporting traffic between the outdoor small cell site and either (1) the node connecting to a macrocell backhaul network, or (2) the node connecting to the WAN/Internet/metro network, whether over air, copper, or fibre.

[13] Infonetics Research "Small Cell Mobile Backhaul Equipment Biannual Worldwide and Regional Market Size and Forecasts: 2nd Edition" December 10, 2015

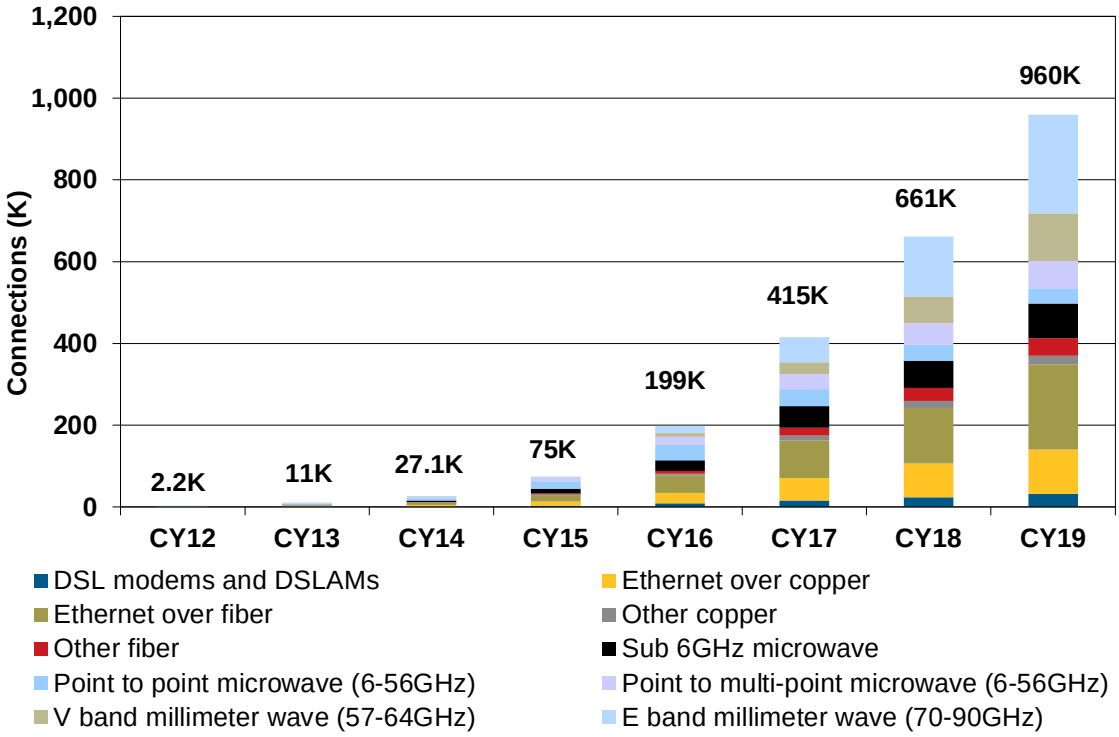


Figure 15. Worldwide installed outdoor small cell backhaul connections by technology.

Wireline technologies are led by Ethernet over fibre or copper. In city centers, sidewalk vaults are a source of copper and fibre connections, as well as some utility poles, some light poles, and a hole drilled in a building wall will suffice to use in-building wiring. The distance from the vault to the mounting locations on light poles, etc., may be short enough to run fibre or copper. On the other hand, it is more likely problematic or impossible for digging or drilling to reach the mounting location. Most light poles have electricity, but not extra copper, and certainly not fibre.
Operators will use fibre as much as possible, then copper. But the majority of planned outdoor small cell locations are in places where the microwave options are best.

If we take a closer look into the market figures addressable by the COCONUT (see Figure 16[14]) we observe that the number of small cell backhaul fibre connections was 6490 in 2014 and predicted to grow to 249600 in 2019. Here fibre includes the Ethernet, PON and WDM backhaul connections over fibre to small cells. Thus the potential number of connections that COCONUT technologies can address is 249600 by 2019.

[14] Infonetics Research "Small Cell Mobile Backhaul Equipment Biannual Worldwide and Regional Market Size and Forecasts: 2nd Edition" December 10, 2015

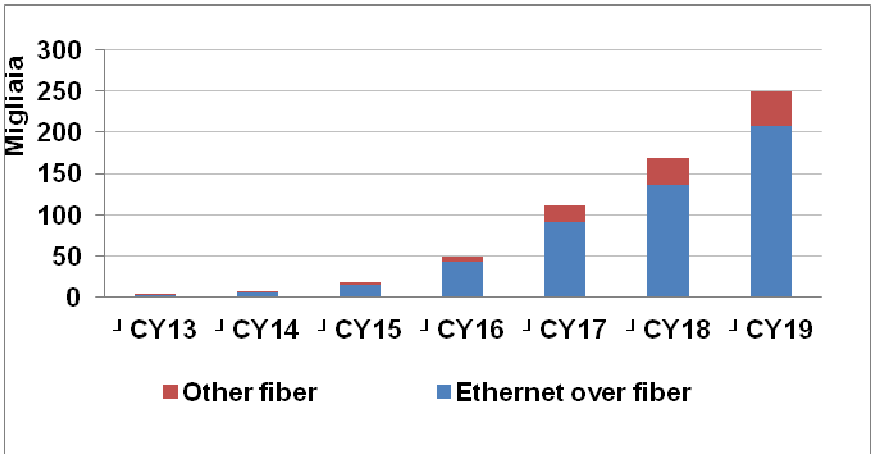


Figure 16. Number of small cell backhaul fibre connections.

Figure 17[15] shows the market revenue in millions of dollars for small cell backhaul equipment. The small cell backhaul market reached $103M in CY14, and Infonetics expects this market to grow at a 90% 5-year CAGR to hit $2.6B in CY19, mostly driven by the need to enhance existing saturated macrocellular networks that are struggling to maintain a decent mobile broadband experience. The chief objective is to complement and enhance the macrocell layer from a capacity standpoint with low power nodes.

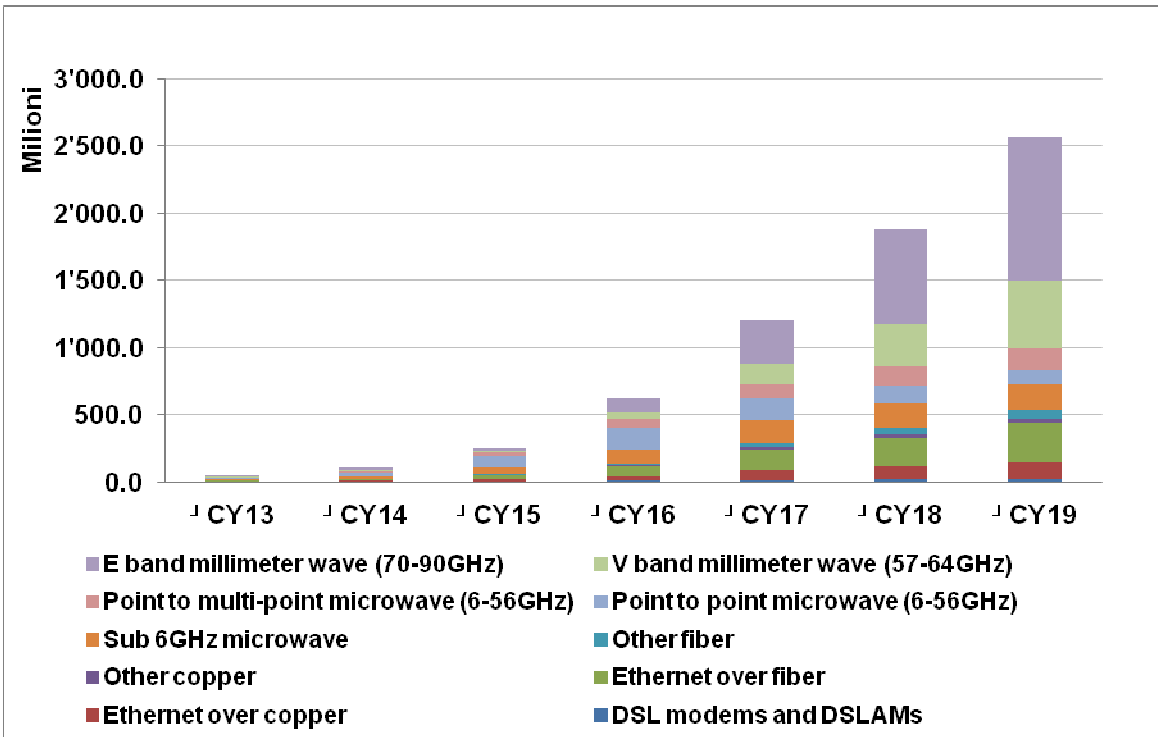


Figure 17. Market revenue in millions of dollars for small cell backhaul equipment.

[15] Infonetics Research "Small Cell Mobile Backhaul Equipment Biannual Worldwide and Regional Market Size and Forecasts: 2nd Edition" December 10, 2015

A closer look into the market addressable by COCONUT technologies (see Figure 18[16]) shows that 2014 recorded a revenue of $14M for fibre backhaul connections. The prediction is to reach $365M by 2019. Thus the potential market for COCONUT is $365M.

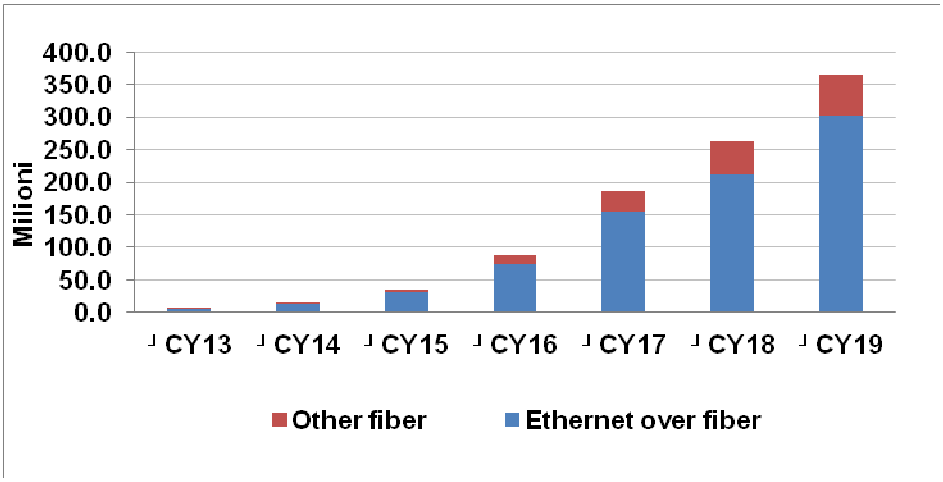


Figure 18. Annual revenue in dollars for small cell backhaul fibre equipment.

Note that we consider here that installed connections will be replaced by new COCONUT technologies. Also this forecast does not include in-building deployments, which are the bulk of current small cell volumes. Small cells include micro/pico and metrocells (formerly categorized as public access femtocells). For each outdoor small cell deployed, there is one backhaul connection though some connections will also aggregate traffic from several other small cells so may require higher bandwidth than single cell backhaul connections.

Business opportunity 3: Fronthaul

Mobile fronthaul is the transport of cellular traffic between a remote radio head and a baseband unit in a cellular network architecture.

Mobile network architectures have been evolving over the last several years from a legacy architecture where large radios are connected to antennas via coaxial cable to a new architecture that separates the RF portion of the radio from the digital portion, allowing the radio to be located closer to the antenna. The separation of the digital processing capabilities – also called baseband unit (BBU) – from the analog radio or remote radio head or unit (RRH or RRU) reduces the equipment footprint at the cell site and allows for more efficient network operations. In this architecture the connection between the BBU and RRU is provided via high-speed serial links over fibre-optic cable rather than a coax cable. These high-speed serial links use the Common Public Radio Interface (CPRI), Open Base Station Architecture Initiative (OBSAI), or Open Radio Interface (ORI) specifications. CPRI is the most common interface used for fronthaul. Due to the high bandwidth requirements, fibre is the preferred solution for fronthaul.

Fronthaul transmission of CPRI and OBSAI protocols is reach- and latency-sensitive, limiting the transmission technology options available to operators. Use of wireless technology is limited to millimeter wave radio systems that have high enough system throughput to support CPRI and OBSAI. Wireless technology will be used for fronthaul when fibre is not available,

[16] Infonetics Research "Small Cell Mobile Backhaul Equipment Biannual Worldwide and Regional Market Size and Forecasts: 2nd Edition" December 10, 2015

but distances must be short (<1km), and the technology only supports a subset of the CPRI line rates.

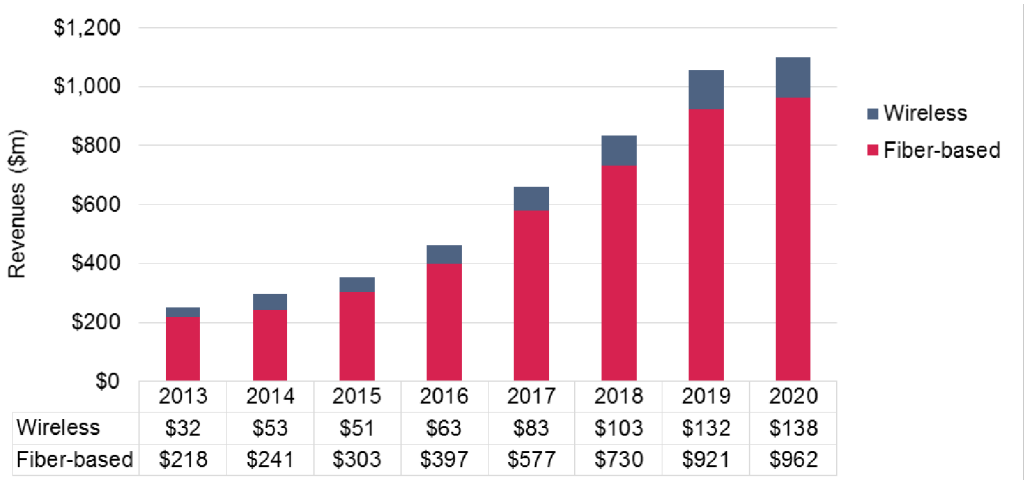
Early fronthaul deployments have been in regions with a very high penetration of fibre, most notably China, Japan, South Korea, and other Asian countries. Deployments are a mix of passive optics using fibre and SFP transceivers at RRU sites and access WDM equipment, particularly lower-cost CWDM gear. Ovum predicts that the deployment of traditional active WDM gear for fronthaul will increase through the forecast period as capacity requirements grow, latency is reduced, and pricing for systems declines. Table 3 details the advantages and disadvantages of various options for fronthaul transport.

Table 3. Transport options for fronthaul (Source: Ovum)

	Technology description	Pros	Cons
Dedicated fiber	Passive solution. CPRI signal is transported natively without encapsulation	No additional cost for transmission equipment; no need for power supply at radio site	Requires a lot of fiber. Each RRH requires a single fiber; multiple technologies each require own access fibers; extra equipment is required for monitoring
Passive CWDM	Uses colored SFPs (tuned to specific wavelength frequencies) at BBU and RRH locations combined with CWDM filters that channelize the fiber	Uses no active components; well suited for outdoor deployment; does not introduce latency and provides a highly reliable low-cost solution for CPRI transport	CWDM is limited to 8 or 16 wavelengths, which may not be enough in the future. Passive equipment offers no OAM capabilities
Active WDM	Uses active OTN/WDM gear to transport CPRI encapsulated in OTN frames	Provides CPRI transport over a standardized format; offers a high degree of OAM capabilities	CPRI transport requires careful consideration because the overhead processing required for OTN also adds latency and reduces reach. Since the OTN/WDM solution is active, it also requires power and costs more
Passive optical networking (PON)	Passive solution to support CPRI fronthaul transmission	PON is typically deployed in dense urban neighborhoods and by its nature has access to existing fiber in places where C-RAN is likely to be deployed.	If the OLT from the PON system and the BBU are not co-located, additional latency will be incurred that limits cell radius. PON is a passive solution and thus end-to-end monitoring of CPRI is an issue
Microwave/mm-wave radio	Wireless option when fiber is not available	Microwave incurs lower capex, particularly if fiber is not available; quicker time to market	Distances must be short (<1km), and the technology only supports a subset of the CPRI line rates. Multiple pairs of radios would be required to support a C-RAN architecture

Figure 19 shows the current mobile fronthaul forecast segmented by media type for the eight-year period 2013–20. The fronthaul forecast does not include copper technologies, only fibre and wireless (source Ovum[17]).

[17] Mobile Backhaul and Fronthaul Forecast Report: 2015–20, "LTE deployments driving operator spend" publication Date: 25 Sep 2015



	2013	2014	2015	2016	2017	2018	2019	2020
Wireless	$32	$53	$51	$63	$83	$103	$132	$138
Fiber-based	$218	$241	$303	$397	$577	$730	$921	$962

Figure 19. Mobile fronthaul forecast per media type.

From the figure above we observe a revenue of $241M for 2014 increasing to $962M in 2020. Thus the potential addressable fronthaul market for COCONUT is $962M.

Note that the COCONUT technology closest to production is the one for 1.25Gbit/s for which we have demonstrated real-time processing. This bit rate is not sufficient for fronthaul connections and bit rates of 2.5 and 10Gbit/s are expected to transport fronthaul bits. COCONUT aim for 10Gbit/s was to show an off-line processing solution, which means that there is some research and development to be done before it is considered for production. So the numbers given in this section are orientative as there is no real-time COCONUT 10Gbit/s prototype.

2.3.2 BT

BT uses Standardised access systems in their deployments. Only if coherent-type transceivers as developed by COCONUT are adopted in ITU Standards, may BT use them to target either areas where high power budgets are required, or as part of high capacity access systems. If the COCONUT technologies become part of ITU Standards, then it is very likely that operators all around the world to make use of them to a certain extend. It must be understood that, in principle, such technologies would not be part of the mainstream deployed systems, but used in certain circumstances where it would result cheaper than other options such as additional local exchanges, mid-span amplification, etc.

2.3.3 PROMAX

Promax main products include a wide range of telecommunications test instruments to provide testing solutions for cable, satellite, digital terrestrial television and optical fiber. We mainly manufacture test field equipment for installers, such as field strength meters, analyzers, light sources, etc. Lately we have had strong Asiatic competitors, who sell those products at extremely low price. Therefore we are trying hard to develop pioneer technology, advancing the market necessity, in order to launch cutting edge equipment.

In the past years Promax have carefully observed the strong tendency against coherent technology within optical networks - GPON seems to move forward ultra-dense channels, highly selective measurements, lambda multiplexing and complex modulations - , and we are betting on coherent solutions.

Promax have analyzed several business opportunities achieved following the COCONUT project. We firstly will exploit our high-resolution-OSA within the telecom market in both non-coherent (to compete with the actual optical channel analyzers) and coherent systems. Optical Channel Analyzers are the more common test equipment used in field applications for WDM systems and we believe that the consumer demand will rapidly improve, even faster than the standardization of coherent systems.

Additionally, Promax also contemplate the possibility to use the developed technology as core technology of medical diagnostic equipment by using optical spectrometry. The optical spectrum analyzer can achieve the high specificity and selectivity required by medical instrumentation.

2.3.4 OPTRONICS

OPTRONICS is very much interested in low cost coherent solutions, such as the one developed in the COCONUT project. From the beginning of the project Optronics disseminated the project to its clients. OTE (incumbent operator in Greece) is one of the clients that has seen on COCONUT the potential to upgrade its current services. During the second year of the project, Optronics made a provisional agreement with OTE to deploy COCONUT solution as a pilot program in the Marina of Rhodes, which is an ideal spot for deploying a PON system. The agreement will be implemented as soon as COCONUT system will be made available and Marina facilities will be ready. The success of such pilot programs will determine the way that Optronics could further exploit COCONUT solution for its clients.

Optonics is also interested in exploiting the transceivers developed in COCONUT. This has already been discussed with other partners. Optronics sees a potential business opportunity for the COCONUT transceivers in the local and the international market. This will be further investigated when the transceivers could be available as a product.

2.4 Risk Analysis

Turning a proof-of-concept into product requires time and money. The steps that have to be followed are:

1. Proof of concept: This takes from 2-3 years and it requires around €4M. Usually this is funded through EU or national projects.
2. Proof of performance: 2-3 years and €10-15M funding needed. Here is where a venture capital is needed.
3. Proof of product: Also 2-3 years and €10-20M needed to complete the step. Also a venture capital or risk investors are needed.
4. Proof of production: 2-3 years to accomplish and €20-40M needed. At this stage more funding from larger companies becomes available because the time-to-market is shorter.
5. Proof of profitability: Again 2-3 years to establish and needs €30-50M in funding. No problem for funding.

In this setup there is the so-called ‘valley of death’ where funding is difficult to find. This includes steps 2-4. After that, funding becomes more available since it becomes more interesting for large companies.

In parallel to this path-to-product there is of course the evolution of the technology, standardization, market need of the technology and cost of competitive solutions.

Low cost system solution based on coherent technologies can only be achieved if sufficient volumes can be attained so that the necessary investment in the production lines is justifiable. The only chance of achieving high volumes is by coherent systems being part of Standardised systems. Standardised access systems based on coherent technologies is a necessary step but it may not be enough. Acceptance of this system and deployments by operators will only be realised if they are lower cost than other options to achieve the same objectives.

New technologies tend to be accepted in Standards Recommendations only if there are a number of organisations supporting their inclusion. It is very important that Intellectual Property does not prevent a number of manufacturers producing equipment so source diversity exists for system vendors who supply network operators.

Note that when the technology is brought into standardisation technical details of the components and functionality of the system are revealed and from that moment on, any system vendor is able to manufacture the said technology. The IPR protecting the technology is valid in certain countries, regions but not worldwide, so there is a risk that other companies not subject to Europe or US patent laws will develop the same technology at a much lower cost, making the solution worthless for EU manufacturers.

Other two risks are market needs and cost of off-the-shelf technologies. If the market pull is strong that allows for a proprietary solution then the standardization is not a risk anymore, it will come as a natural step of the deployed technology. Another risk factor for point to point Ethernet fibre links is the price competitiveness. If COCONUT is to be successful in this market it has to beat the price and performance trade of CWDM SFP at 1G and DWDM SFP+ at 10G.

3 Dissemination Activities

3.1 Website

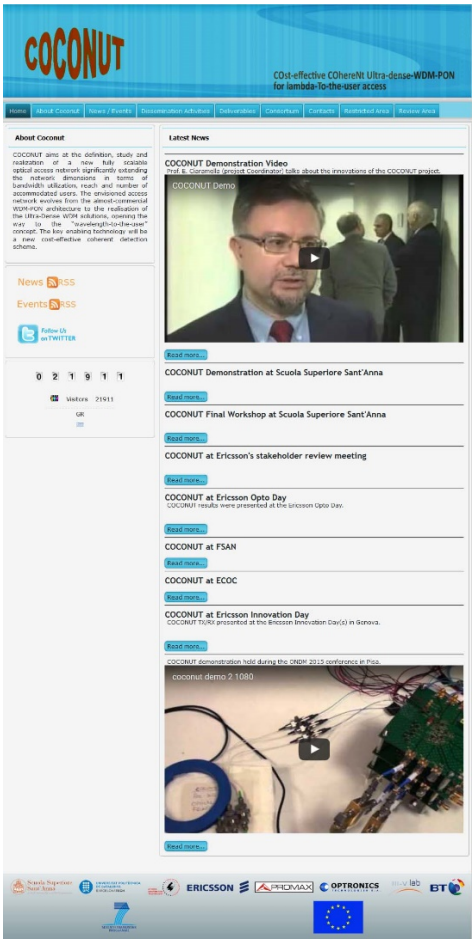


Figure 20. Screenshot of the COCONUT website

The COCONUT website (http://www.ict-coconut.eu/) was established within the first month of the project's lifetime. Till now the project is updated regularly with all project news. The COCONUT website contains a public area with

- ✓ News and events
- ✓ Publications
- ✓ Public Deliverables
- ✓ Information about the consortium etc

and a restricted area with access only to the COCONUT partners. This area enables the Consortium to manage the diffusion of the information and to file sharing all relevant to the project files of the

- ✓ Deliverables
- ✓ Milestones
- ✓ Plenary Meeting Information
- ✓ Project time line (Gantt Chart)
- ✓ Templates etc

The website has currently counted almost 23,000 visitors and this number is expected to increase due to the recent dissemination activities. In particular after the final demonstration of the COCONUT system at Pisa, the daily number of users has been significantly increased. In average the daily number of visitors, before the project demonstration, was 15 visits per day, while after the demo and till the end of the project this number increased to 56 visits per day. Figure 21 presents the accumulated traffic (pageviews) of COCONUT website, where the traffic for the different reporting periods is presented by different colours. The figure also includes the traffic forecast for the third reporting period based on the second year data (dashed line). In general the website traffic during the final reporting period is increased in comparison with the forecasted traffic. Moreover, the date of the COCONUT demo is marked in the figure highlighting the significant effect of the event to the website traffic.

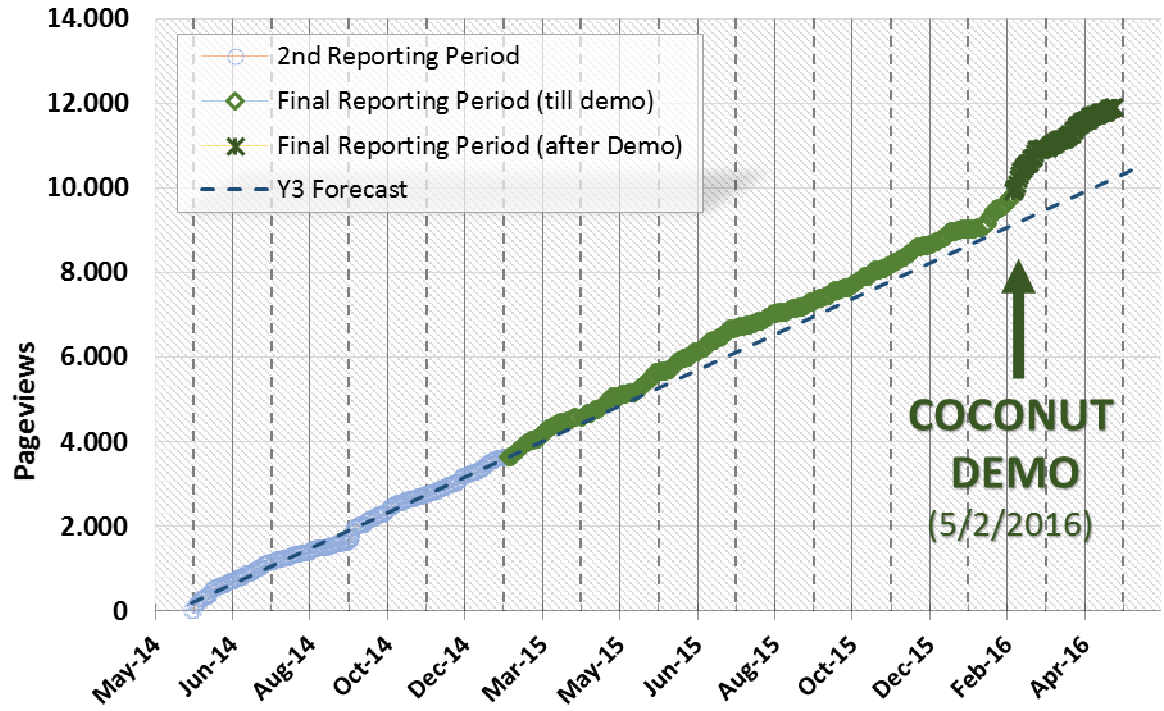


Figure 21. Acumulated traffic of COCONUT website

In figure 22 the daily trafic of COCONUT website is presented. Note that the most important scientific confereces/events, where the COCONUT project has been presented, are marked with different colours. The figure also includes the total average of the pageviews (red dashed line) and the weekly average (brown solid line). Although it is not easy to colerate the effect of the various dissemination activities on the website traffic, the weekly average traffic most times have peaks very close in time to important scientific events. A good example is the COCONUT demo event, where the weekly average traffic is well above the total average for almost two weeks before and two weeks after the actual event date.

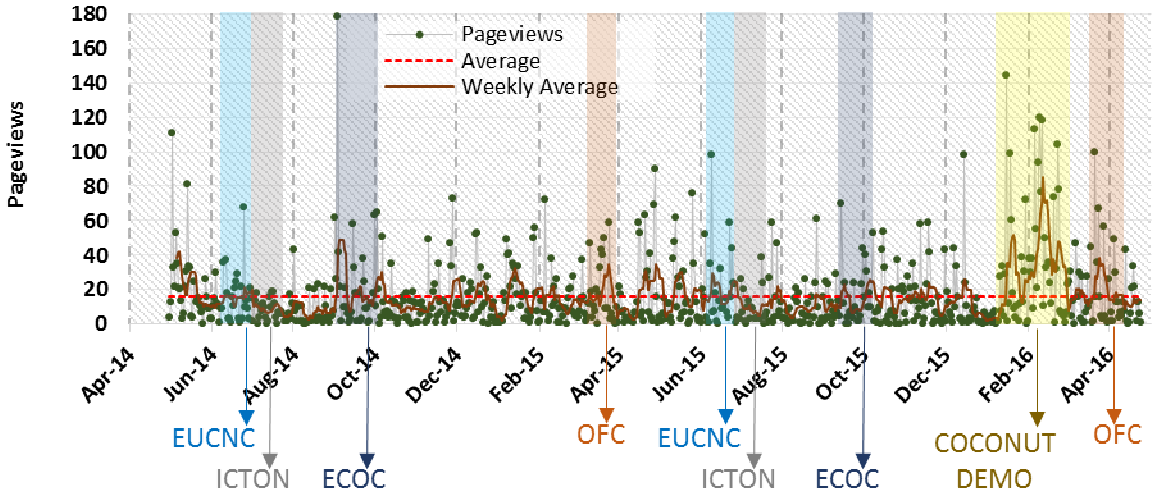


Figure 22. Daily trafic of COCONUT website

Figure 23 presents the country origin of all unique users visited the website during the second (Y2) and the final reporting period (Y3) of the project. The results indicate that there is an international interest to the project technologies (Brazil, India, Japan, South Korea etc). In addition, there is interest to other European countries not direct related to the consortium members (Germany, Portugal, Ireland etc).

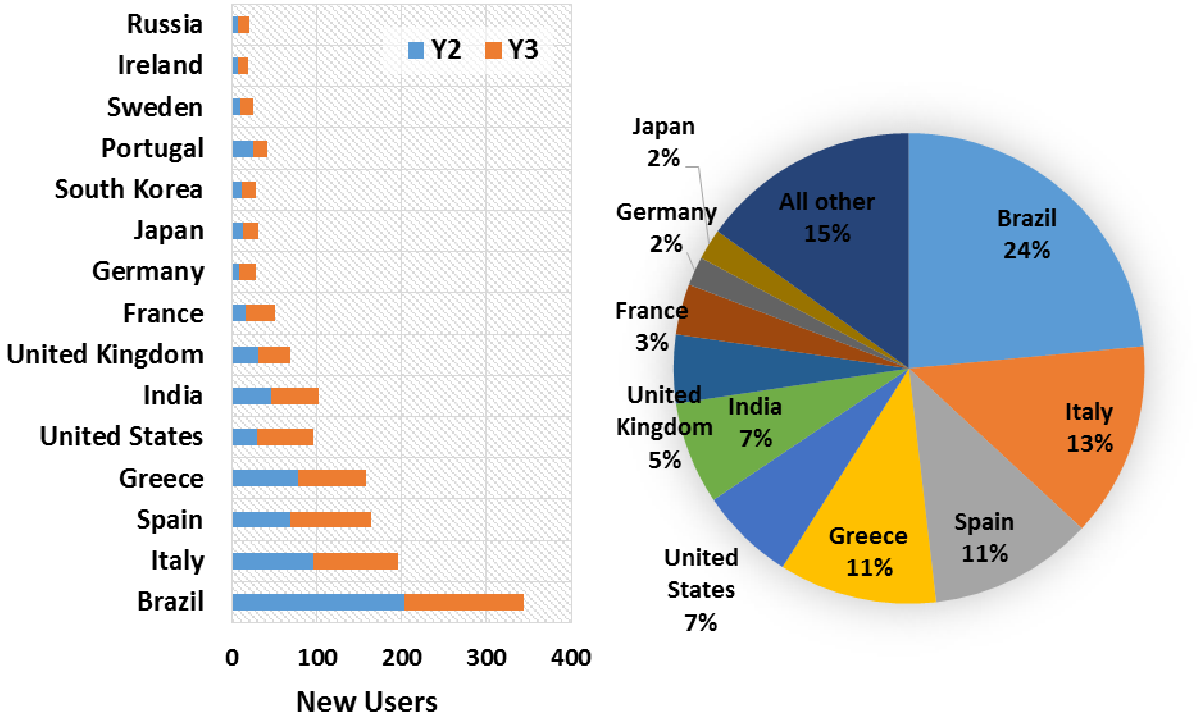


Figure 23. Visitors Origin Country. The left figure presents the total number of new visitors for the top 15 origin countries. The right figure presents the persentace distribution of visitors in the different countries.

3.2 Dissemination activities to the scientific community

3.2.1 Publications

The consortium during the total duration of the COCONUT project had published a total of 64 scientific articles in peer-reviewed international journals and conferences, acknowledging the project. Figure 24 presents the number of COCONUT publications per year, followed by a detailed list of all project publications.

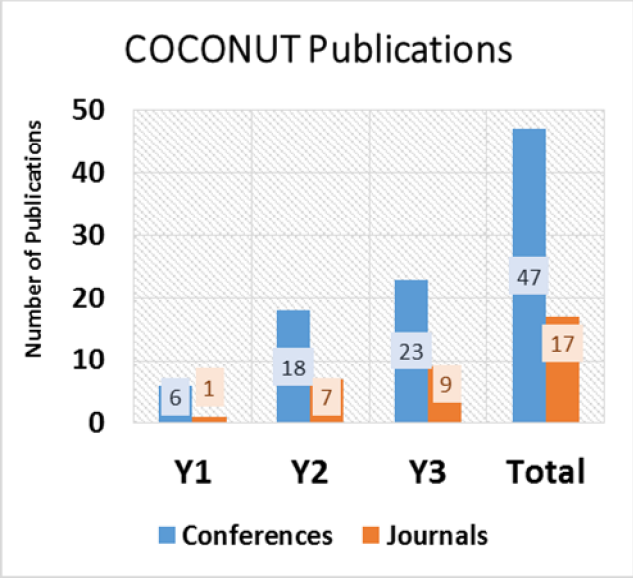


Figure 24: Number of Publications per reporting period

During the 3rd and final reporting period of the project, the consortium has published a total of 24 scientific articles in peer-reviewed international journals and conferences, acknowledging the project.

Journals

1. M. Artiglia, R. Corsini, M. Presi, F. Bottoni, G. Cossu, and E. Ciaramella "Coherent Systems for Low-Cost 10 Gbit/s Optical Access Networks," Journal of Lightwave Technology, Vol. 33, No. 15, June 2015.
2. M. Presi, R. Corsini, M. Artiglia, and E. Ciaramella "Ultra-dense WDM-PON 6.25 GHz spaced 8×1 Gb/s based on a simplified coherent-detection scheme," Opt. Express vol. 23, pp. 22706-22713 (2015)
3. M. Artiglia, M. Presi, F. Bottoni, M. Rannello, E. Ciaramella, "Polarization-Independent Coherent Real-time Analog Receiver for PON Access Systems," Journal of Lightwave Technology, Vol. PP, No. 99, January 2016.
4. J. A. Tabares, V. Polo, I. Cano, J. Prat, "Automatic l-control with offset compensation in DFB intradyne receiver for udWDM-PON" IEEE Photonics Technology Letters, vol. 26, pp. 443-446, (Feb. 2015)
5. G. Y. Chu, V. Polo, A. Lerín, J. Tabares, I. N. Cano, J. Prat, "1.25-3.125 Gb/s per user PON with RSOA as phase modulator for statistical wavelength ONU," Optics Communications, vol. 357, pp. 34 -40 (Dec. 2015).
6. I. N. Cano, A. Lerín, J. Prat, "DQPSK directly phase modulated DFB for flexible coherent UDWDM-PONs," IEEE Photonics Technology Letters, vol. 28, issue 1, pp. 35-38, (Jan. 2016).
7. J. Prat, I. Cano, M. Presi, I. Tomkos, D. Klonidis, G. Vall-llosera, R. Brenot, R. Pous, G. Papastergiou, A. Rafel, E. Ciaramella, "Technologies for cost effective udWDM-PONs," IEEE Journal of Lightwave Technology, vol. 34, no. 2, pp. 783-791 (Jan. 2016)
8. G. Y. Chu, I. N. Cano, V. Polo, C. Kazmiersky, R. Brenot, J. Prat, "Monolithically integrated dual-output DEML for full duplex DPSK-ASK and DPSK-SSB ONU in ultra-dense channel spaced access networks," IEEE Journal of Lightwave Technology, vol. 34, no.8, pp. 2042-2048 (Apr. 2016)

9. G. Y. Chu, A. Lerín, I. N. Cano, V. Polo, J. Prat, “Coherent ONU based on 850 μm long cavity reflective semiconductor optical amplifier for next generation ultra-dense access network,” Chinese Optics Letters, accepted for publication.

Conferences

1. G.Y. Chu, V. Polo, A. Lerín, I.N. Cano, J. Prat, “Optimizing Reflective Semiconductor Optical Amplifier as Phase Modulator for Low Cost Colorless ONU with 3x3 Homodyne Detection,”, proc. ACP 2014, paper AF2B.5, Shanghai (China)
2. J. Prat, "Technologies for a Cost-effective Coherent udWDM-PON," in Proc. OFC 2015, Th3I.3, Los Angeles, (USA)
3. R. Corsini, C. Kazmierski, M. Presi, S. Faralli, J. G. Provost, R. Brenot, and E. Ciaramella, "1.4 mA (70 mV) Peak-to-Peak Drive of 1.25 Gb/s Frequency Modulated Laser for WDM Coherent Access Networks," OFC 2015, W2A-22, Los Angeles, (USA)
4. M. Presi, R. Corsini, M. Artiglia, F. Bottoni, G. Cossu, and E. Ciaramella, "Low-Cost 6.25 GHz UDWDM-PON based on Direct Intensity-Modulated Transmitters ," OFC 2015, Th3I-1, Los Angeles, (USA)
5. F. Bottoni, M. Presi, M. Artiglia, J. Prat, and E. Ciaramella, "Real-Time Coherent ONU for λ-to-the-user Based on Fully Analogue Processing of OOK Signals ," OFC 2015, Th2A-59, Los Angeles, (USA)
6. V. Sales, J. Segarra, J. Prat, "An improved dynamic wavelength assignment in statistical UDWDM-PONs," in Proc. ONDM 2015, Mo2.3O, Pisa (Italy)
7. G. Y. Chu, I. N. Cano, C. Kazmiersky, R. Brenot, J. Prat, "First demonstration of monolithically integrated dual output DEML for full-duplex UDWDM-PON ONU," proc. ECOC 2015, paper Th.1.3.1, (Valencia)
8. A. Lerín, G. Y. Chu, V. Polo, I. N. Cano, J. Prat, "Chip Integrated DFB-EAM for Directly Phase Modulation Performance Improvement in UDWDM-PON," proc. ECOC 2015, paper P7.10, (Valencia)
9. I. N. Cano, A. Lerín, V. Polo, J. Prat, "Directly Modulated DFB with Phase Diversity in Time Polarization Independent Intradyne Receiver for UDWDM-PON," proc. ECOC 2015, paper Th.1.3.4, (Valencia)
10. I. N. Cano, A. Lerín, V. Polo, J. Prat, "Flexible D(Q)PSK 1.25-5 Gb/s UDWDM-PON with Directly Modulated DFBs and Centralized Polarization Scrambling," proc. ECOC 2015, Th.1.3.7, (Valencia)
11. E. Ciaramella, F. Bottoni, M. Rannello, M. Artiglia, M. Presi "Coherent PON System with High-Sensitivity Polarization-Independent Receiver and no ADC/DSP," ECOC 2015, Th.1.3.2, (Valencia)
12. N. Liakopoulos, G. Menoutis, I. Patronas, A. Foteas, C. Kachris, D. Klonidis, "Design of Optical Network Unit (ONU) for Hybrid TDM/WDM NG-PON," IEEE International Conference on Electronics, Circuits and Systems (ICECS) 2015 (Cairo)
13. M. Artiglia, F. Bottoni, M. Camera, R. Corsini, G. Cossu, M. Presi, M., ... & E. Ciaramella, "SImplementation and testing of a ASK polarization-independent coherent receiver for UDWDM-PON," ICTON 2015, pp. 1-4, Budapest (Hungary)
14. M. Presi, R. Corsini, M. Artiglia, E. Ciaramella, "Applications of narrow-filtering based on optical coherent detection," ICTON 2015, pp. 1-4 (Budapest)
15. I. N. Cano, A. Lerín, G. Yong Chu, V. Polo, J. Prat , "Performance comparison between direct phase modulated DFB and RSOA for cost-effective user transmitter in udWDM-PONs," proc. ICTON 2015, paper Mo.D2.2, Budapest (Hungary)

16. I. N. Cano, F. Bottoni, J. Camilo V. Micolta, M. Presi, E. Ciaramella, J. Prat , "Bidirectional Coherent PON with ONU Based on Reused Direct-Modulated LO," OFC 2016, paper M3C.7, Anaheim (US)
17. M. Presi, M. Rannello, M. Artiglia, I. Tomkos, I. Cano, J. Prat, E. Ciaramella, "Hitless Dynamic Wavelength Allocation for WDM Coherent PONs," OFC 2016, paper W2A.63, Anaheim (US)
18. E. Ciaramella, F. Bottoni, M. Presi, M. Artiglia, R. Corsini, M. Rannello, M. Valvo, "4x10 Gb/s Coherent WDM-PON System over 110 km Single Mode Fibre and with 55 dB ODN Power Budget," OFC 2016, paper W2A.66, Anaheim (US)
19. I. N. Cano, J. Camilo Velásquez, J. Prat , "7.5 Gb/s direct DFBphase modulatin with 8-dDPSK for 6.25 GHz spced coherent UDWDM-PON", OFC 2016, paper M3C.4, Anaheim (US).
20. G. Vall-llosera, A. Rafel, N. Parkin, M. Angelou, D. Klonidis, I. Cano, M. Presi, G. Papastergiou, I. Tomkos, J. Prat, E. Ciaramella, "COCONUT cost, power consumption and migration analysis: A route towards NG-PON3," Proc. of ICTON 2015, Budapest, Hungary, paper Mo.D2.1 (July 2015).

Invited

1. M. Artiglia, F. Bottoni, M. Camera*, R. Corsini, G. Cossu, M. Presi, M. Rannello and E. Ciaramella " Low cost coherent receivers for UD-WDM NRZ systems in access networks," Invited, ICTON 2015 paper FRII1 (Budapest)
2. J. Segarra, V. Sales, V. Polo, J. Prat, "Dimensioning OLT architectures for UDWDM-PONs employing coherent transceivers",(invited) in Proc. ICTON 2015, Mo.D2.5, Budapest (Hungary)
3. M. Artiglia, F. Bottoni, R. Corsini, M. Presi, E. Ciaramella "Simple and effective solutions for low-cost coherent WDM-PON", Invited, Photonics in Switching, Florence

3.2.2 Workshops and conference sessions

SSA organized the final workshop of the COCONUT project at Pisa on February 5, 2016. The workshop started with the welcome address by a representative of the Pisa town council, supporting the initiative. The workshop was a full-day public event started with various talks (in English) for technical and non-technical audience:

Figure 25. Final COCONUT workshop at Pisa

- A. Sorsaniemi (European Commission), "High speed broadband access – EU strategy and future targets"
- J. Prat (Univ. Politecnica Cataluna, Spain), "Research and Development in FTTx technologies and architectures"
- E. Ciaramella (Scuola Superiore Sant'Anna, Italy), "Ultra-dense WDM-PONs solutions in COCONUT"
- A. Rafel (British Telecom, United Kingdom), "British Telecom's perspective on access networks"
- G. Vall-llosera (Ericsson AB, Sweden), "Optical technologies for 5G"
- I. Tomkos (AIT, Greece), "Benefits of Broadband Networks and why Europe is not reaping them of?"

- M. Presi (Scuola Superiore Sant'Anna, Italy), "Introduction to the COCONUT demo"

After the workshop, the participants had a tour to the laboratory, where the COCONUT network was demonstrated to public. The project demonstration was successful and was covered by the local media. 19 different websites published articles about this event, informing the public about the COCONUT project and its innovations:

- ANSA.it
- askanews
- Corriere Della Sera
- Firenze Rebubblica
- intoscana.it
- Toscana24
- gonews.it
- controcampus.it
- PisaInforma
- tom's HARDWARE
- Corriere Comunicazioni
- Smart World
- tiscali.it
- tiscali
- TECHNOANDROID
- agenziaimpress
- MeteoWeb
- Diario del Web
- La Prima Pagina

Figure 26. Video of the Final Demonstration of COCONUT system

Moreover, an interview was given and broadcasted on a local TV, to promote the project and the event. The video shows highlights of the Workshop and System Demonstration, while prof. Ciaramella explains the basic concept of the COCONUT and its innovations.
Later several interviews were also given on Italian radio channels

- RADIO POPOLARE NETWORK http://www.santannapisa.it/it/multimedia/radio-popolare-network-arriva-la-banda-ultra-larga-con-coconut
- RTV38 http://www.santannapisa.it/it/multimedia/rtv-38-fibra-ottica-con-il-turbo
- Radio 24, http://www.santannapisa.it/it/multimedia/radio-24-banda-ultra-larga-con-il-progetto-coconut

News in Spain about the COCONUT Pisa field trial demo

- 22/03/2016 Data Center Market : La UPC desarrolla una nueva red de acceso de fibra óptica
- 21/03/2016 ADSL Zone : Proyecto Coconut, así es la iniciativa europea para mejorar la red de fibra óptica
- 20/03/2016 Cuentamealgobueno : Nuevo proyecto de fibra óptica
- 18/03/2016 Redes Telecoms : Investigadores de la UPC desarrollan una nueva red de acceso por fibra óptica
- 18/03/2016 InterEmpresas Net : Investigadores de la UPC mejoran la red de acceso por fibra óptica aumentando la velocidad y el alcance

- 17/03/2016 Lo Campus Diari : Investigadors de la UPC milloren la xarxa d'accés per fibra òptica augmentant la velocitat i l'abast
- 17/03/2016 Instituto de la Ingeniería de España : Un proyecto europeo multiplica la capacidad de la red actual de fibra óptica
- 17/03/2016 Revista de Ingeniería Dyna : Mejoran la red de acceso por fibra óptica aumentando la velocidad y el alcance
- 01/03/2016 DIGITAL TV Pág. 26 : PROMAX: "NUESTRAS REDES DE FIBRA ÓPTICA SE QUEDAN PEQUEÑAS Y EUROPA YA TRABAJA EN LA SOLUCIÓN"

3.2.3 Other Dissemination activities

ONDM 2015

The 19th edition of the Optical Networks Design and Modelling (ONDM 2015) conference was held in Pisa on May 11-14, 2015. The conference was organized by Scuola Superiore Sant'Anna (SSSA) and Consorzio Nazionale Interuniversitario per le Telecomunicazioni (CNIT). During the conference the SSA group organised, for the first time, a lab tour and a preliminary demonstration of the COCONUT technologies. The demonstration presented mainly one of the COCONUT transceiver transmitting a HD video in real time through a Gigabit Ethernet link.

Figure 27. Preliminary demonstration of COCONUT technologies during ONDM 2016

ECOC 2015

ECOC 2015 was held in Valencia, Spain on September 28-30, 2015. As part of the promotion of the project activities to the photonic community OPTRONICS participated in the ECOC Exhibition at the ECOC booth 756. Among its other research activities, OPTRONICS advertised COCONUT with a summary poster, leaflets and a constantly-rolling overview presentation. The technical personnel of OPTRONICS were available for information to the interested attendees. Optronics counted many visitors including the project officer (Dr. Ari Sorsaniemi) accompanied by the Head of Unit Network Technologies (Dr. Thibaut Kleiner), prof. Ciaramella and prof. Prat.

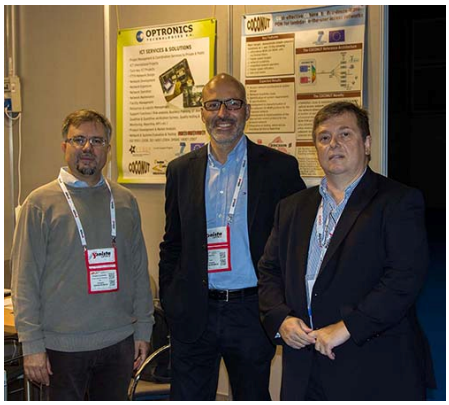


Figure 28. COCONUT project at ECOC 2015

Ericsson Innovation Day

This event was organised by Ericsson in Genoa on September 2015. During the event the COCONUT transceiver developed by SSSA was presented to a selected number of Ericsson's customers.
Members of the SSA group attended the event and presented a poster with the project's latest results. The real-time eye diagrams of the COCONUT system can also be seen in the figure.

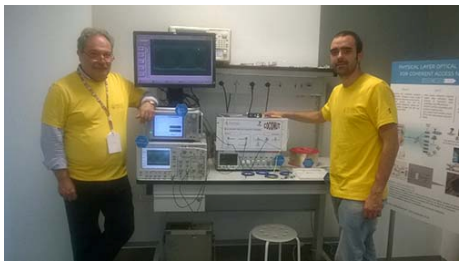


Figure 29. COCONUT TX/RX presented at the Ericsson Innovation Day(s)

Ericsson Opto Day

The results of the COCONUT project were also presented at the Ericsson Opto Day. The Opto day is an internal event organised by Ericsson Research and one of the product development units. It is intended for any Ericsson employee with an interest in photonics or wanting to know more about the role of optics in Ericsson products and in the research labs. The event was held at Ericsson on November 17, 2015. The feedback was very positive (many participants were asking if this was already a product).

Figure 30. COCONUT project at the Ericsson Opto Day

FSAN workshop

COCONUT was invited to a workshop organized by FSAN, which is currently working towards producing a PON system roadmap.

FSAN held a workshop to hear from specialists about the new technologies that may come about. The Workshop was held in Atlanda, USA on October 7, 2015. Attendance included representative of all main operators and system manufactures worldwide.

Figure 31. COCONUT technologies presented at FSAN

Prof. Ciaramella attended the workshop and presented the Tx/Rx solutions that had been developed in COCONUT project. Presentation was very well-received and acknowledged.

Ericsson's stakeholder review meeting

Ericsson on on January 29, 2016 organized the small cell transport stakeholder review meeting. The purpose of the meeting was to show to the internal Ericsson stakeholders the results of the previous year work and discuss how to continue the research so it can be integrated in the product roadmap. The COCONUT project was reviewed by the stakeholders during this meeting.

Figure 32. COCONUT project reviewed by the Ericsson's stakeholders

Special issue on netweek online magazine

Netweek magazine published a special issue on the Research centres in Greece. In the article AIT presented their current research activities including COCONUT project.

Interview on Fibre System magazine

Fibre Systems, one of the leading publications for the optical communications industry, covering technology, applications, business and regulation, has published a long article covering current evolution of passive optical networks and most interesting project results. The views and results of COCONUT were presented largely.

FEATURE
RESEARCH & DEVELOPMENT

Future passive

What will passive optical networks look like in future? **Robert Roe** explores some promising new research directions

The evolution of fibre networks has led to increased bandwidth, which in turn has enabled new services, but this growth in the network has not translated into a proportional growth in revenue for operators. To attempt to remedy this unsustainable situation, several European research projects have been set up to investigate new technologies for optical access networks.

'Effectively revenues and usage of network capacity are becoming decoupled over the last decade or so. That is really demonstrated by the flat rate charging regime where you buy a bundle of capacity and services, and how much you use them does not affect how much you pay for them. That is a problem for the future because providing more bandwidth isn't free,' commented Professor David Payne from Trinity College Dublin.

Payne is coordinating a European-Commission-funded project called DISCUS, which is a charmingly imprecise acronym for 'DIStributed Core for unlimited bandwidth supply for all Users and Services'. The project's aim is ambitious – the researchers want to develop an entirely new architecture that will allow the access network to scale economically – but it is not impossible. At the European Conference on Optical Communications (ECOC) exhibition last autumn, the project team showed their first demonstrator: a software-reconfigurable, DWDM long reach passive optical network (LR-PON) test bed.

Does DISCUS show us the future of optical access? Certainly it may be one future, but it's not the only possibility. To address the challenges facing optical access networks, a number of European research projects were created under the European Commission's 7th Framework Programme, which awarded funding between 2007 and 2013. These projects are now beginning to report results. At least three major projects have presented their findings at high profile telecoms conferences and meetings in the past year. Interestingly, these projects have taken contrasting approaches.

The direct approach

A project called CEEOALAN (Cost and Energy Efficient Optical Access and Local Area Network) was highlighted by systems vendor ADVA Optical Networking at ECOC 2015. Taking a nearer term view, this project has focused on designing next-generation access networks around direct-detection methods, with particular attention on the modulation formats that will be needed for high bit rates. The European funding allows a post-doctoral researcher from the University of Bristol to work with ADVA for two years, and devote himself to the project – which runs until August 2016.

'Most people, and that certainly includes us at ADVA, agree that it is worth following a direct detection approaches for next-generation access, even for bit rates beyond 10Gb/s,' asserted Klaus Grobe, director of global sustainability at ADVA Optical Networking. 'At least, somebody has to look at the possibility of implementing higher bit rates beyond 10Gb/s cost efficiently. We expect that with the proper implementation it [direct detection] will be cheaper compared to coherent solutions and that is exactly what the CEEOALAN project set out to prove.'

Specifically the project team will carry out a theoretical analysis and comparison of key criteria – such as optical power budget, cost and power dissipation – for different modulation formats including pulse amplitude modulation (PAM), optical dashinary, carrierless amplitude and phase (CAP) modulation and discrete multitone (DMT), a form of orthogonal frequency division multiplexing (OFDM). Experimental demonstrations of one or two variants are also planned before the end of the project.

'It is clear that the higher the bit rate the more problems that will face direct detection,' said Grobe. 'This is why alternative modulation schemes are required. However, the characteristics of the access network, which tends to operate over limited distances, will help alleviate some of the technical challenges. A standard reach class of 20km is typical in commercial PON systems. Even in a site consolidation scenario, where operators bypass some of their central offices, then the upper bound for the reach of next-generation access is expected to be in the region of 50km, according to ADVA's estimates.

'That will of course solve many things because it eases the aspects of dispersion and also possibly

A doctoral student working on an experiment as part of the COCONUT project in the laboratory at Scuola Superiore Sant'Anna at the University of Pisa

FIBRE SYSTEMS Issue 10 • Winter 2016

Figure 33. Article published by Fibre Systems

4 Exploitation Activities

The following section describes the exploitation plans and activities per consortium partner. The plan of each partner for the exploitation of the COCONUT results was reported in detail in the COCONUT DoW. Following the end of the project in M40, this deliverable summarizes the up-to-date status and any performed activities.

4.1 Patent Applications and Innovations

SSA
Inventor: E. Ciaramella, M. Presi
Title: " *Polarisation-independent coherent optical receiver* "
https://patents.google.com/patent/WO2015079400A1/en
Status: Patent granted by Italian Patent Office, and currently being extended internationally.

35L
Inventors: C.Kazmierski, A.Garreau
Title: "*Integrated semi-conductor IQ modulator and transmitter without phase modulation and control*"
Status: Patent filed in Europe, and is now extended to US.

PRO
Inventors: C.Vilà, R.Pous, G.Azcárate
Title: "*Coherent optical spectrum analyser for monitoring a spectrum of a fibre link*"
Status: Submitted at European Patent Office.

AIT
Patent rights owner: Ericsson
Inventors: Christoforos Ververidis and Ioannis Tomkos
Title: "*Activation Process for ONUs with non-calibrated tunable lasers in TWDM-PON networks*"
Status: filed in USA (provisional patent application PS54888US00).

UPC
Inventors: Josep Prat, Ivan Cano, Maria Concepción Santos.
Title "*Method for reducing interference in passive optical networks*"
Status: Granted in Spain.

4.2 Exploitation plans per industrial partner

4.2.1 BT

BT only deploys network technologies that have been standardised. The main Standards body is the ITU. BT is promoting the technologies developed in COCONUT within the FSAN group such that they might be part of future defined systems.

4.2.2 ERICSSON

We can evaluate the exploitation plans with three key performance indicators: i) penetration of COCONUT technologies, ii) time scale of COCONUT technologies, iii) exploitation of intellectual property.
In agreement with the results reported in the previous sections, the potential level of penetration of the COCONUT technologies in the market is estimated to be 249600 small cell backhaul connections by 2019 and 5.6 million macro cell backhaul connections within the same timeframe.

Another of the exploitation factors is the time scale of implementation of the COCONUT technologies. The implementation could be following the market predictions for small and macro backhaul connectivity deployments but there is a risk factor that can play a big role: standardisation. If the market pull is strong and allows for a proprietary solution then we could see the COCONUT technologies before 2020. If a standard solution shall be reached before there is a market pull then we would face a much longer time frame. Right now backhaul radio connections are based on CWDM SFP transceivers or using SFP+ when moving to 10G.So the timescale will also be determined by the potential of COCONUT to become comparable in price to a CWDM SFP or SFP+.

The third exploitation KPI is the usage of generated IPR. Any solution that is considered for product implementation has to be protected. So we are working on the generated intellectual property together with the consortium partners with the purpose to initiate a potential commercialization of products.

From Ericsson's point of view COCONUT technologies are relevant for mobile front and backhaul connections, to substitute the current WDM, Ethernet fibre point-to-point links, and to reuse the PON fibre deployed. As an internal exploitation plan, the COCONUT prototype will be shown at the relevant product development units in a review meeting on January 29th. The goal is to introduce the results to the product development unit, discuss possible new products and a possible implementation roadmap.

Ericsson stakeholders (Sandor Albrecht, ER; Mats Johansson, CT Office, Stephane Lessard, ER) visited the field trial that was carried out in Pisa. The trial provides first hand feedback on system performance in real service deployment. This experience will be utilized in products and future roadmap developments.

4.2.3 OPTRONICS

Optronic's primary goal is to maintain a leading position in the Greek market by staying at the forefront of technological developments concerning Photonics, Fibre Optic Networks and Optoelectronics. Innovation is the force that drives our company forward and determines our growth strategy through 2020.

Optronics identified 3 main directions for exploiting the project results:

- use the generated knowledge to provide consulting services to its clients;
- establish new collaborations with other SMEs, Universities and Research centers;
- enrich the company's product list with new and innovative products.

The first two bullets have been successfully achieved during the project's lifetime. Optronics has gained significant knowledge on the coherent technologies developed by the COCONUT

project and at the same time established new collaborations that have the potential to lead to new business opportunities. The identified business cases (see section 2.3.4) depend on the availability of the COCONUT system as a final product.

4.2.4 PROMAX

Although coherent WDM market is still far from standardization and commercial exploitation, knowledge and development carried out in COCONUT offer us an opportunity to exploit two instrumentation equipment needs: (1) a hand held coherent OSA and (2) a cost-effective tunable laser within C and L bands.

Moreover, high-resolution-OSA development is the basis for new projects that require high-resolution spectral analysis, such as medical devices based on optical spectrometry. PROMAX R&D department is working on that and will try to evolve in that direction.

4.2.5 35L

Within the COCONUT project, we have evaluated the potential of our industrial technologies for coherent access. In particular, we have benefited from the partners ideas and request to propose innovative low-cost phase modulators.
The main outcome for 35lab is the validation of the following devices for phase modulation:

- Semiconductor Optical Amplifier, in transmission or reflective scheme.
- EAM-based phase selectors.
- Frequency-modulated lasers

COCNUT was a great opportunity to identify the advantages and disadvantages of these devices.
In particular, we have filed a patent on the EAM-based phase selector.
Besides, we have demonstrated that our EML-SOA and DFB-SOA were able to generate simultaneously the LO signal for detection on one facet, and the phase (and/or) amplitude modulated signal on the other facet.

Based on all these results, there are several possible exploitation plans:

Direct exploitation:
If standardization activities and market needs lead to a special request of any of these devices for the targeted application, we will be able to fabricate the devices in small to moderate quantities, or to transfer our technological process to a larger device manufacturer for big volumes (> 10000 / year typically).

Indirect exploitation:
Due to the large amount of generated ideas, we believe the proposed architectures might also find outcomes for other applications, in particular for data-center interconnects.

4.3 Exploitation plans per academic partner

4.3.1 SSA

SSA, being an Academic organisation, does not directly exploit the know-how it creates, but it gives directions for further development and exploitation, typically licensing its own patents to industries. As far as COCONUT know-how is concerned, the main exploitation path is about the original solutions developed by SSA about subsystem implementations allowing low-cost polarization-independent coherent detection of intensity-modulated signals. SSA

developed an original concept for **polarization independent coherent receiver of ASK signal**, which was implemented in **two twin transceiver prototypes**, shown during the COCONUT demo operating at 12.5 Gbit/s in real-time. They are capable of high sensitivity (-48 dBm), with no special requirement of wavelength stability and allow for very narrow channel spacing (6.25 GHz). The concept was also proven at 10 Gbit/s (also shown during the demo by means of offline processing).

The solution of the SSSA Receiver was filed as a **international patent** (see sect. 4.1, https://patents.google.com/patent/WO2015079400A1/en), which is now being extended. After the successful demo, SSA now collected at least two declaration of interest in acquiring the patent rights, which are at the present stage confidential.

Of course the key application is in both cases in the **optical communication industry**. Besides WDM-PONs, as discussed at length in this document, SSA foresees also that both Low-Cost solutions for 5G front-haul and for Metropolitan Area Systems can be possible areas of exploitation of its COCONUT.

With the advent of **5G** and the explosion of portable mobile terminals market, most of the traffic between data-centres and customers will be concentrated in the metro area and its access edges. Therefore the need for powerful and cost-effective systems serving this network segment is arising and compelling, as witnessed by the new ITU Recommendation G.metro, currently under study in SG15, which addresses a first typology of such systems, still based on direct detection. COCONUT technology can provide the next generation of such systems the relevant advantages of high sensitivity and high spectral density where needed, allowing the implementation of new metro-access network architectures more efficient in exploiting the existing infrastructure, more flexible in terms of service provision and with higher capacity.

Another important aspect of **next generation metro-access network** is that they will be based on a mix of wireless and wired technologies. SSA believes that COCONUT low-cost coherent technology can provide a powerful tool for implementing high capacity front-hauling of the wireless edge in C-RAN architectures, allowing a large number of antenna sites to be served by low latency high speed links (also on existing ODNs) thanks to the improved sensitivity; moreover the excellent spectral resolution of COCONUT receivers will also allow to pack more channels into the allotted spectral region, thus more efficiently exploiting the spectral resource.

About new EU funding opportunities, SSA will seriously investigate the potential of the technology developed in COCONUT and plans to participate to the **November H2020 calls** related to optical solutions for 5G networks, mostly for the access segment (i.e. front-haul) but also supporting the metro scenario where the system solitions may allow for higher capacity and flexibility.

At national level, SSA is also seeking collaborations with major operators and industrial partners, especially considering the national and regional initiatives that are eventually starting, in Italy and Tuscany, respectively (as example, see http://www.bandalarga.telecomitalia.com/toscana/eventi/ministero-dello-sviluppo-economico-regione-toscana-infratel-e-telecom-italia).

SSA analysis also indicates that, based on existing literature and preliminary investigations, the COCONUT receivers are compatible with miniaturization and eventually integration on a

Photonic Integrated Circuits (PICs), No fundamental limitations are foreseen. This is a very important point in view of a full industrial exploitation, which could allow for evolution of the COCONUT towards small footprint and low-energy consumptions devices, suitable for mass production.

Finally SSA believes that a **low-cost integrated coherent receiver** of the type described above can find a variety of applications also outside the field of telecommunications. In fact high sensitivity detection with high frequency selectivity is a very interesting feature for many types of optical fibre devices. A first application area could be high speed interconnection in data centres. This is a rapidly growing market where connection, cost and capacity density in Gbit/s per cm of front panel are crucial parameters: the sensitivity advantage of low cost coherent receivers could be exploited over short distances for example to significantly increase the transmission rate per port. Another promising application may be for example using COCONUT-like technologies to improve the sensitivity of optical remote sensor networks, that will play a role in the potentially vast market opened by the advent of the Internet of Things.

Finally, SSA, in the final stage of the project, proposed and demonstrated new concepts to extend the COCONUT **multi-wavelength dynamic allocation** in a flexible network environment. At same time evolution towards a mixed TDM/WDM solution, similar to what is being promoted by NG-PON2 standard, is being carefully investigated. The above areas will be discussed with other members of the COCONUT consortium after the conclusion of the COCONUT project.

4.3.2 UPC

UPC has developed WP6 susbsystems that in the last months have been semi-engineered as prototypes able to be adopted for production by COCONUT partners or future clients; specifically:

- a low cost **coherent heterodyne ONU** using DPSK modulation at 1.25 GBit/s with 2.5 GHz up/down spacing and 12.5 GHz channel spacing, and full duplex real time operation *(see Appendix*).

- a low cost **coherent homodyne ONU** using DPSK modulation at 1.25 Gbit/s at 6.25 GHz channel spacing, and full duplex real time FPGA DSP operation, supporting with 50 dB power budget ODN.

- a **wavelength-manageable low cost laser unit**: with non-preselected statistical wavelength and limited tuning for coherent systems, in collaboration with Promax. A single board includes TX laser and LO laser, adapting butterfly and/or TO/CAN packages, analogue electronics and microprocessor with the control software, that also handles the signalling communication with the OLT udWDM Spectrum Manager.

The complete udWDM PON solution may be able to be deployed in a practical scenario, after some required engineering, offering 256 1G Ethernet connections (homes or antennas) with a single feeder fibre. UPC worked closely with partners to assemble the COCONUT demonstration test-bed in practical conditions, in terms of simplicity, cost, operation, consumption, environmental tolerances and scalability. The demonstrations have had wide

disseminations to maximize the project visibility and impact in the European industry. UPC is in discussions with the industrial partners to produce the subsystems.

On the other hand, UPC, with other partners, have performed theoretical and experimental tests validating the compatibility of COCONUT with previous PON generations coexisting in the same ODN. This has lead to produce guidelines for a possible contribution to standardization bodies by the representative partners.

4.3.3 AIT

AIT identifies 3 areas for the exploitation of the COCONUT research results that are closely related with the main research activities undertaken in the project:

a. FPGA based implementation of MAC protocol
b. Network design and techno-economic evaluations
c. Low-cost transceiver technologies and new application areas

AIT has gained significant expertise in the area of MAC protocol design and evaluation from previous FP7 projects, SARDANA and ACCORDANCE. The added value from the work carried out within COCONUT is the implementation of the MAC functions in an FPGA. The developed platform includes all the critical parts of the ONU such us synchronization and FEC implementation as well as the PLOAM (header) processor and the GEM queue (payload) extraction. The OLT functions were emulated so that the ONU part of the MAC that includes the registration and the DBA functions is successfully tested. Also it is important that a design compatibility with the existing XGPON and NGPON2 standards was maintained for the implemented MAC design, thus keeping it close to the current industrial interests. This development work is a significant asset for AIT as it opens new collaboration opportunities, both direct ones with the industry sector and through new national or EU research projects.

Regarding the industry sector, AIT is currently seeking the establishment of targeted research collaborations (in the form of an industrial research project) in the area of MAC design, protocol implementation/extension and MAC layer testing for optical access networks. For this reason one major vendor and one operator have been contacted and relevant discussions are on progress. Regarding new EU funding opportunities, the major focus is shifted on the November call related to 5G backhaul solutions where a redesigned MAC is explored to include integrated functions from heterogeneous network segments.

The network design and techno-economic evaluation studies performed under Task 2.2, enriches further AIT's expertise and use cases including now that of coherent technologies for access. AIT exploits its knowhow in network deployment and cost evaluation studies through consultancy services offered to operators and the public sector. A major study has been offered a few years ago to one of the largest operators in Greece, while the previous year a related study was performed in collaboration with the incumbent operator of Greece. The exploitation efforts in this area are currently targeting projects for large municipalities seeking the establishment of open access network infrastructures or extension of their services to citizens.

Finally, AIT has identified some new application areas to extend the COCONUT multi-wavelength allocation and low-cost processing concept. These areas include primarily potential applications in intra data center networking and extensions for the support of sensor networks and secured network infrastructures. The new areas are currently under study, and

will be discussed with members of the COCONUT consortium after the completion of the project.

An additional area of focus for AIT is the licencing of its intellectual property on the relevant COCONUT topics by companies (with priority and first-access rights given of course to the COCONUT partners). As an example of such exploitation activity, we highlight the agreement established with Ericsson that is the patent rights owner for the provisional patent application (PS54888US00), where the inventors are AIT researchers.

5 STANDARDISATION EFFORTS

5.1 Current Situation – Year 3

The COCONUT project developed technologies and solutions that could be used for the next generation optical access. The success of the project, in terms of market penetration, is directly related to the standardization process. During the 3rd year of the project a significant effort was given to follow up standardization bodies and influence the relevant fora and standardization groups that deal with the definition of the next generation PON such as FSAN, IEEE and ITU-T. The main updates regarding the standardization situation during the 3rd year of the COCONUT project and the relevant consortium achievements are listed below:

- Recommendation ITU-T G.989.3: Transmission convergence (TC) layer specification (draft in progress)
  - It was consented in July 2015.
- Discussed in the FSAN Group first and then again within ITU-T Q2/15, it was finally decided in July 2015 to start a new recommendation on a fixed single wavelength (one per direction), symmetrical 10G system.
  - G.9807.1 (XGS-PON) is based on the XG-PON optics (G.987.2), and the TWDM-PON TC Layer (G.989.3) minus all the wavelength related functionality.
  - G.9807.1 was consented by the ITU-T in February 2016
- BT was able to influence the FSAN Group to allow the Project COCONUT to present some of the technologies developed during a special workshop that was held in Atlanta in October 2015.
  - Ernesto Ciaramella (SSA), Josep Prat (UPC), and Albert Rafel (BT) prepared the slides that were presented by Ernesto Ciaramella.
  - The presentation was well received
- The FSAN Group is working on the new System Roadmap
  - BT will promote the acceptance of the Coherent Technologies in future systems.

List of abbreviations

BBU	Coexistence Element
BTS	Coexistence Element
CAGR	Cost-Effective Coherent Ultra-Dense-Wdm-Pon For Lambda-To-The-User Access Networks
CE	Common Public Radio Interface
COCONUT	Description Of Work
CPRI	Differential Phase Shift Keying
CPRI	Digital Subscriber Line
CWDM	Dense Wavelength Division Multiplexing
DoW	European Conference On Optical Communications
DPSK	Element Management System
DSL	European Semiconductor Laser Workshop
DWDM	European Union
ECOC	European Conference On Networks And Communications
EMS	Fiber Infrastructure Management Systems
EPC	Field-Programmable Gate Array
ESLW	Full Service Access Network
EU	European Union
EUCNC	European Conference On Networks And Communications
FIMS	Fiber Infrastructure Management Systems
FPGA	Fiber To The Distribution Point
FSAN	Fibre-To-The-Home
FTTC	Fibre-To-The-X
FttDP	Gigabit Passive Optical Network
FTTH	High Resolution Optical Spectrum Analyzer
FTTN	International Conference On Communications
FTTP	Information And Communication Technology
FTTx	International Conference On Transparent Optical Networks
GPON	Institute Of Electrical And Electronics Engineers
GSA	Intellectual Property Rights
HR-OSA	International Telecommunication Union
hr-OSA	Itu - Telecommunication Standardization Sector
ICC	Knowledge Transfer
ICT	Letter Of Intent
ICTON	Media Access Control
IEEE	National Fiber Optic Engineers Conference
IMT	International Mobile Telecommunications
IoT	Next Generation Passive Optical Networks
IP/MPLS	Network Management Systems
IPR	Optical Code-Division Multiple-Access System
ITU	Optical Coherent Tomography

ITU-T	Optical Distribution Networks
KT	Optical Fiber Communication
LOI	Optical Line Termination
LRAN	Optical Network Unit
LTE	Physical Medium Dependent
M2M	Passive Optical Network
MAC	Point-To-Point
NFOEC	Research And Development
NGA2	Rich Site Summary
NGPON	Superposition Coded Modulation
nms	Transmission Convergence
OBSAI	Time Division Multiplexing
OCDMA	Time Division Multiple Access
OCT	Technical Report
ODN	Time And Wavelength Division Multiplexing
OFC	Ultra Dense Wavelength Division Multiplexing
OLT	Uniform Resource Locator
ONU	Wavelength Division Multiplexing Passive Optical Network
ORI	Working Texts
PMD	Wavelength To The User
PON	10 Gigabit PON
PtP	Point-To-Point
QoQ	Quarter On Quarter
R&D	Research And Development
RAN	Quarter on Quarter
RRH	Quarter on Quarter
RRU	Quarter on Quarter
RNC	Radio Network Controller
RSS	Rich Site Summary
SCM	Superposition Coded Modulation
SDH	(*base transceiver station*
SPF	Small Form-Factor Pluggable
TC	Transmission Convergence
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TR	Technical Report
TWDM	Time And Wavelength Division Multiplexing
UDWDM	Ultra Dense Wavelength Division Multiplexing
URL	Uniform Resource Locator
USC	Universal Small Cell
VDSL2	Very-High-Bit-Rate Digital Subscriber Line 2
WAN	Wide Area Network
W-CDMA	Wideband Code Division Multiple Access
WDM PON	Wavelength Division Multiplexing Passive Optical Network

WT	Working Texts
WTTU	Wavelength To The User
XG-PON	10 Gigabit Pon
YoY	Year On Year

Annex I

Publications

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Patents

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