Technologies and Architectures for Broadband Digital Divide Elimination

Spyros E. Polykalas[1*], Kyriakos Vlachos[2], George Ellinas[3]

[1]Department of Digital Media and Communication, TEI of the Ionian Islands, Greece
[2] Computer Engineering and Informatics Department, University of Patra, Greece
[3]KIOS Research Centre and Department of Electrical and Computer Engineering, University of Cyprus, Cyprus

***Abstract*— The provision of high speed connectivity to all citizens has been broadly accepted in the developed world, as one of the key elements for growth and innovation. Europe 2020 Strategy underlines the importance of the deployment of new network infrastructure, required for the provision of new innovative services, while in parallel sets ambitious targets in relation to the penetration of high speed broadband connectivity among European Citizens. In this paper, we examine the current situation, if broadband Digital Divide still exists, and propose a new paradigm for interconnecting rural areas and particularly islands complex. A techno-economic model has been developed for exploring the necessity of public aid funding or other cost sharing measure for the deployment of new fiber-optic transport networks.**

Keywords—digital divide, broadband networks, converged optical wireless, techno economic, state-aid, network sharing

I. Introduction

In 2010 the European Commission (EC) published its strategy for smart sustainable and inclusive growth [1] focusing on seven flagship initiatives. One of these initiatives was the promotion of the "Digital Agenda for Europe" aiming to speed up the roll-out of high-speed internet and reap the benefits of a digital single market for households and firms [2]. The overall aim of the Digital Agenda was to deliver sustainable economic and social benefits from a digital single market based on fast and ultra-fast internet and interoperable applications. The maximization of the social and economic potential of Information and Communication Technologies (ICT) and especially of the ultra-fast internet is expected to spur innovation, economic growth and improve the daily lives of citizens and businesses alike. Three of the main targets included in Europe 2020 Strategy related to the "Digital Agenda", are a) the availability of broadband access to all European citizens by the end of 2013, b) the availability of high speed broadband access (above 30Mbps) to all European citizens by the end of 2020 and c) the provision of internet connectivity with speeds above of 100Mbps to at least 50 % of European households. Bearing in mind these ambitious targets, it is evident that in most member states, especially in rural areas, the existing network infrastructures are inappropriate for the provision of high speed access broadband connectivity.

On the other hand, advances in optical networking technologies over the last two decades have provided tremendous growth in both backbone and MAN communication capacity, and at the same time, enterprise local-area net-works (LANs) have scaled tributary speeds progressively from 10 – 100 Mbps towards multi-gigabit speeds, (e.g., 1 and 10 Gb/s Ethernet, or GbE/10GbE). The last front of this evolution is the access technology so as to address the bottleneck in bandwidth and service quality between a high-speed residential/enterprise network and a largely overbuilt core backbone network. This, in turn will enable the support of more bandwidth-intensive networking applications, as well as the support of end-to-end QoS for a wide variety of applications, particularly non-elastic applications such as voice, video, and multimedia that cannot tolerate variable or excessive delay or data loss. However, these advances and actual network deployments concern only metropolitan area networks and not rural or other distant locations. To this end, these advancement will enhance rather than minimize Digital Divide.

The purpose of this paper is twofold. First, to evaluate European Union policies for the elimination of broadband Digital Divide and then to propose indicative solutions to bridge this divide. Several broadband indicators have been defined and their historic evolution is examined. In addition, we compare broadband digital development between the EU and countries outside Europe such as the USA, Japan, Korea and Australia.

II. European Union policies

It is commonly acceptable that for the achievement of the objectives for the bridging the Digital Divide between societies and/or European Union Member States (MS), hundreds of billions Euro for network investments in Europe are required [3],[5]. These investments are expected to primarily come from the private sector, mainly by providers offering broadband internet access services [16]. However, the private sector considers rural areas as being financially non-affordable and thus private initiatives to invest are almost non-existent. The lack of appropriate network infrastructure does not only prohibits the achievements of the goals set in the Europe 2020 Strategy [1], but also increases rather than decreases the Digital Divide between communities. Today, such a gap between people to access ICT technologies can be found between countries, regions, societies etc. For that reason, EC has published guidelines [4], [6], aiming to encourage Member States to use public financing in line with European Union competition and State aid rules in order to meet the coverage, speed and growth targets contained in Europe 2020 Strategy [7]. The EC has approved several proposals from Member States in relation to public funding for new broadband infrastructure deployment. In particular, during the last three years the EC has approved more than 60 relevant proposals

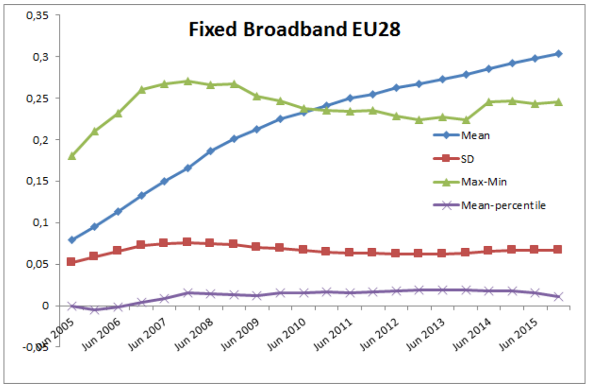


Fig. 1: Evolution of fixed broadband penetration in EU member states.

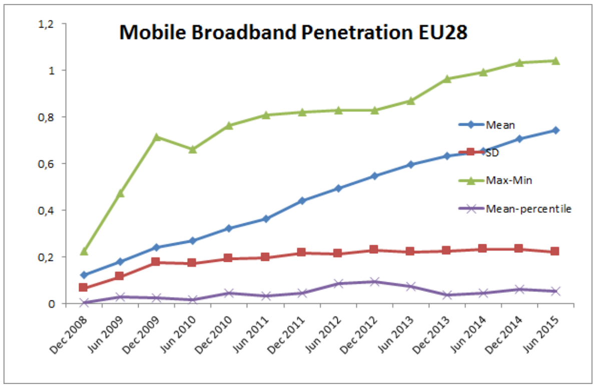


Fig. 2.: Evolution of mobile broadband penetration in EU member states.

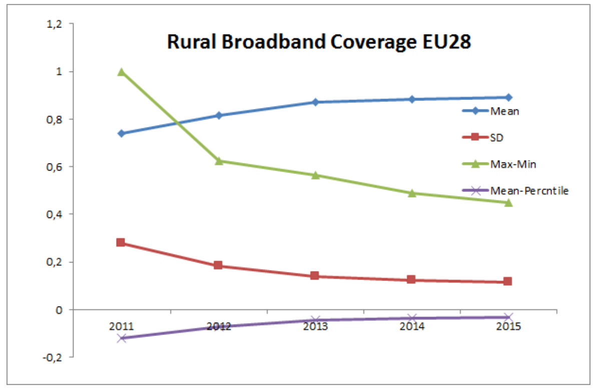


Fig. 3: Evolution of broadband coverage of rural areas in EU.

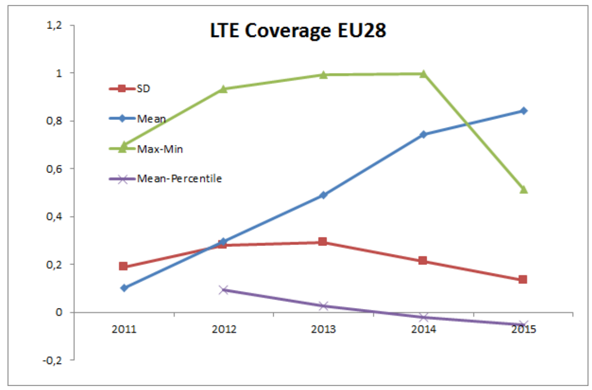


Fig. 4: LTE coverage in EU28.

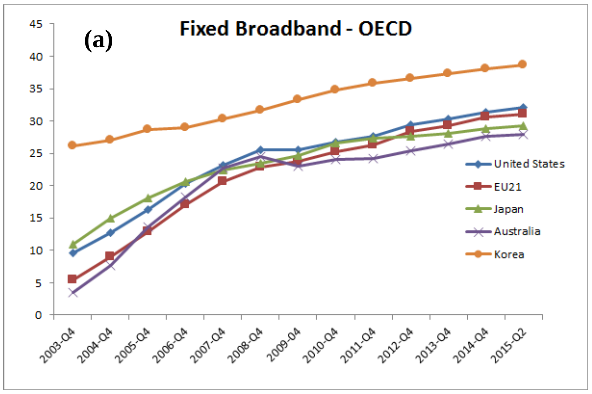
from Member States [8]. The majority of the proposed projects, encourage the deployment of a new network infrastructure that is able to provide ultra-high broadband access while in parallel will stimulate the demand for broadband services.

In addition, EC has published a Recommendation in relation to the access regulation for Next Generation Networks (NGN) [4]. The main aim of EC is to foster the development of the single market by enhancing legal certainty and promoting investment, competition and innovation in the market for broadband services. The Recommendation aims at promoting efficient investment for the transition to Next Generation Access Networks (NGA). For doing so, it takes into account the risks incurred by all investing undertakings and the need to maintain effective competition, which is an important driver of investment over time. An important aspect for the provision of ultra-high speed broadband connectivity remains access technologies. In particular, in many rural areas the existing access technology prevents the provision broadband access. Moreover in some cases, especially in rural areas, the lack for demand for broadband services has leaded to limited deployment of (high-speed) electronic communication network infrastructure even in the core part of the telecommunication networks.

III. Broadband Penetration and Network Investment in EU

In this section, we examine, some indicative indices for broadband penetration in EU. All data used for graphics generation have been gathered from Eurostat or OECD databases. Fig.1 displays the evolution of fixed broadband penetration in the 28 members of EU over the period 2005-2015. The displayed mean value shows a clear increase, albeit at a slower rate after June 2010. With respect standard deviation, denoted as SD, the relevant values present a slight increase from 5,2% in 2004 to 6,6% in 2015, but within the period of financial crisis, SD values demonstrate a slight decrease from 7,3% in 2008 to 6,6% in 2015. At the same period (2004-2015) the Max-Min increases from 18,1% (2004) to 24,5% (2015), while during the crisis increases from 22,3% (2013) to 24,5 (2015). Based on these findings, we may argue that penetration of fixed broadband lines continue to increase, albeit the economic crisis in many EU member states. Fig.2 displays the relevant penetration index for mobile broadband lines from 2008 to 2015. The mean value shows a significant increase, within the monitoring period, from 12,3% in 2008 to 74,2% in 2015. At the same time, the variance of Max-Min and Standard Deviation indicates that the disparities relevant to mobile broadband between EU28 have slightly increased. In specific, Standard Deviation has increased from 6,5% in 2009 has to 22,2% in 2015, while the Max-Min has increased from 22,4,% to 104,1% over the same period. It is obvious that during the financial crisis the mobile broadband Digital Divide, as expressed by the mobile broadband penetration has significantly increased.

Next, we examine broadband coverage of fixed broadband services and networks over rural areas. This concerns the



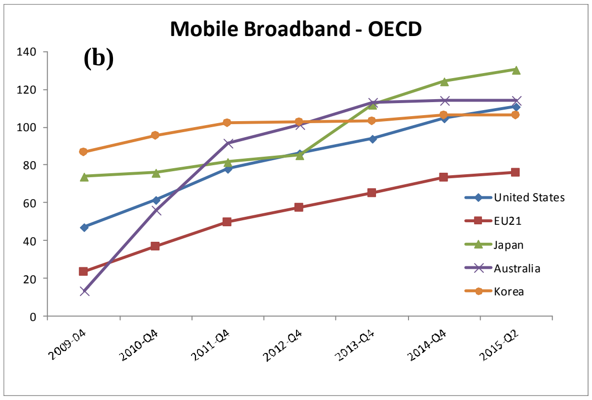


Fig.5: (a) Fixed) and (b) Mobile broadband penetration (OECD data).

deployment of broadband infrastructures only in rural areas. Low values of this index indicate low coverage of broadband networks. The lack of adequate broadband infrastructures reinforces the disparities between the communities relevant to digital divide, as expressed by the availability of broadband services. As seen in Fig.3, the Mean value of rural-broadband coverage has increased from 77,6% in 2011 to 89,1% in 2015. In addition, standard deviation has decreased from 25,4% in 2011 to 11,5% in 2015, while the Max-Min has decreased from 86,3% in 2011 to 45,1% in 2015. Standard deviation and Max-Min support the argument that during the crisis period, the disparity between the MSs of the EU, as regards the availability of broadband infrastructures in rural areas, has decreased. However, bearing in mind the increased ratio of broadband penetration (both of fixed and mobile lines), we may argue that digital divide between the less developed rural areas is stationary. Finally, Fig.4 displays LTE coverage in EU member states, which is tightly correlated with the deployment of new mobile network infrastructure, able to deliver new innovative mobile services. From Fig.4, it is clear that LTE coverage has been accelerated after 2012 reaching a mean value of over 80%. This may explain the increase in mobile broadband penetration ratio. Further, from Fig.4, we may also extract that disparities between member states are decreasing, bearing the clear decrease of all statistics, namely the standard deviation, Max-Min and mean percentile.

As a conclusion, it could be argued that mobile broadband penetration is rapidly increasing with investments on LTE networks becoming a reality. Further, the disparities between

Standard	Downstream	Upstream
BPON ITU-T G.983	622 Mbps 1480-1500nm	155 Mbps 1260 - 1360nm
GPON ITU-T G.984	2.488 Gbps 1480-1500nm	1.244 Gbps 1260 - 1360nm
GEPON IEEE 802.3av	1Gbps 1480-1500nm	1Gbps 1260 - 1360nm
10G-PON (XG-PON1) ITU-T G.987	9.95328 Gbps 1575-1580nm	2.48832 Gbps 1260 - 1280nm
10G-PON **(**XG-PON2) ITU-T G.987	10 Gbps 1575-1580nm	10 Gbps 1260 - 1280nm
10GE-PON IEEE 802.3av	10 Gbps 1575-1580nm	10 Gbps 1260-1280nm
NG-PON2 **(**TWDM-PON) ITU-T G.989.2	40Gbps (total) 1596 - 1602nm	40Gbps (total) 1524 - 1544 nm
WDM PON	True WDM 1524–1625nm	True WDM 1524–1625nm

Fig. 6: Wavelength allocation plan for Passive Optical Networks with backwards compatibility.

Member States and less developed areas do not indicate any sign of decrease. In order to compare the developments on fixed and mobile sector between Europe and other jurisdictions, Fig.5 (a) and (b) presents the penetration of fixed and mobile services in EU, Japan, Australia, USA and Korea. Although EU average curve seems to follow the trends of other countries, it should be noted that EU has the lowest mobile broadband penetration, while in the fixed broadband EU is in the middle. Thus, EU policies for implementing the so called "Digital Agenda for Europe" has not been a success till nowadays with respect the elimination of the disparities between Member states, and compared to other developed broadband jurisdictions.

IV. Converged Optical-Wireless architectures for Interconnecting Rural areas

Passive Optical Network (PON) technology has been proposed in the past as a last mile solution for broadband access, [11]. It bears two main architectures, namely TDM-PON and WDM-PON. Albeit today are not considered for access networks ("fiber-to-the-home" gains a higher momentum), mobile operators consider PON for backhauling wireless traffic. This is because, current backbone standards are expected to become less effective for building mobile access networks. Specifically, legacy technologies such as circuit-switched T1/E1 wireline or microwave used for existing 3G network infrastructures cannot scale to the capacity requirements of new 4G (and 5G) access architectures, [9]. Thus, mobile operators are looking for heavily investing in upgrading their backhaul infrastructure, with fiber-optic deployments to the LTE Base Stations ("Fiber To The Cell"). Among the different variants of optical networking, only Passive Optical Networks (PONs) meet the needs for such high-capacity access architecture. PONs have been proposed in the past 10 years as an access technology, bearing a) low deployment costs, avoiding active components in the field, b) bandwidth sharing between the end-users, c) scalability in

Fig. 7: Indicative fiber optical transport network for interconnecting Greek islands.

terms of users and points of presence, as well as d) bandwidth granularity. Further, with the recent standardization and technology improvements, PONs bear advantages concerning bandwidth utilization, flexibility in designing ring, tree or mixed architectures as well as long reach transceivers with a plethora of protocols supported. To this end, mobile operators consider "Next-Generation-PONs", the only future-proof solution to build mobile backhauls, which will scale to the increased capacity requirements of future NG-WBAN technologies. It will also alleviate the need of using expensive RF point-to-point links (i.e., 26GHz) or even the unlicensed 60GHz WiFi band. Apart from requiring additional RF circuits and antennas, they lack the high capacity, inherent resilience, and the ubiquity offered by optical fiber networks. Therefore, the implementation of an optical network supporting the fiber-enabled cell towers is the only viable solution.

A. Spectrum Allocation and PON variants

Fig. 6 illustrates the complete wavelength allocation plan for all PON standards, [10] denoting upstream/downstream speeds and wavelength usage. The allocation resembles frequency allocation in wireless networks, in the sense that there is a clear allocation (no overlap) of frequencies and wavelength bands, allowing protocols and existing access products to co-exist on the same fiber (backward compatibility). A technology solution that can serve rural and distant is the use of a converged optical wireless architecture utilizing a hybrid WDM-TDM long reach PON for both wireless backhauling and end-user connectivity, [12]. Broadband access will be provided either via a fixed connection to the PON (if possible) or wirelessly via an enhanced (4G/5G) Base Station with access to the high-speed PON. A PON-based mobile backhaul RAN must be capable of supporting a distributed architecture as well as distributed network control and management operations (4G LTE standard requires a distributed mobile backhaul radio access network-RAN for full meshing base stations).

A ring based PON architecture eloquently complies with this requirement via a purposely selected simple ring topology, which enables direct intercommunication/connectivity among the access nodes (combined Optical Network Unit/Base

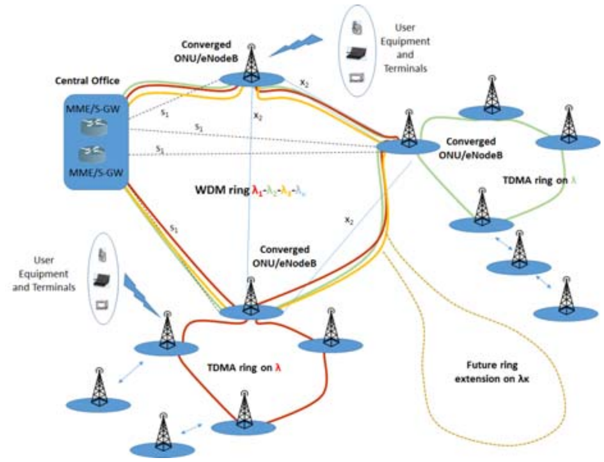


Fig.8: Architectural deign of a converged fixed wireless optical ring transport network Block level architectural design of the network.

Stations -ONUs/BSs-), allowing for the support of a distributed PON-RAN access architecture as well as for simply meeting the stringent requirement to fully meshing the ONUs/BSs. Thus, ring-based PONs may provide a simple and cost-effective mobile backhaul RAN solution. Further, the converged LTE wireless – PON network architecture can also be evolved to an all-packet-based converged fixed-mobile optical access networking transport infrastructure by simply interconnecting (overlaying) the ONUs with the 4G/5G BSs.

B. Converged Fixed Mobile Architecture for bridging Digital Divide – the case of Aegean Islands

Greece is characterized by the existence of more than 2000 islands from which more than 200 are habitable. Most of them are sparsely populated islands, while in parallel they are far away from the mainland. The deployment of a sub-marine cable infrastructure is much more expensive and time consuming compared to the deployment of a relevant infrastructure in the mainland. In an attempt to lower the cost, an alternative solution, which is used in the majority of the existing interconnections links between islands and mainland, is the use of wireless backbone technologies. Albeit, there are no huge upfront investments, the use of RF frequencies for backhauling traffic is inefficient for broadband access, while fees have to be paid annually.

Fig. 7 illustrates an indicative network topology deploying fiber optical links between Greek islands and Greek mainland, forming interconnected optical rings, while Fig.8 displays its top level network architecture, [13]. The basic principles for the design are the following, [14]:

- Design as many as possible interconnected fiber rings and employ one ONU per connected island (hub) over the ring.
- Unlike a typical WDM metro-access ring network, where the feeder fiber of a PON is replaced with a metro fiber ring that interconnects the hub and access nodes, the proposed architecture interconnects WDM ONUs via a distribution fiber ring in the local loop but allows them to share the feeder fiber for long reach connectivity to the OLT.

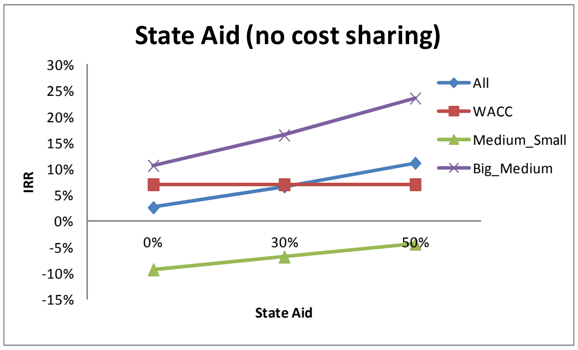


Fig. 9: IRR & State Aid variation (no cost sharing).

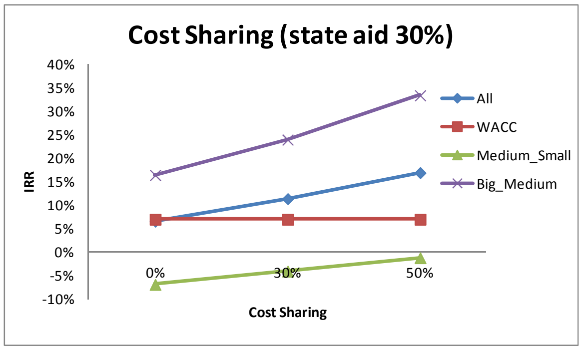


Fig. 10: IRR & Cost Sharing variation (State Aid 30%).

- Assign a separate wavelength per ONU and enhance ONUs capabilities to "evolved nodeBs" (eNBs).
- Extend the fiber rings linearly from each hub-island to distant small islands, either with optical or RF (i.e., 26GHz) point-to-point links.
- Allow ONU/eNB to directly communicate (prerequisite for full BSs meshing in LTE networks) with each other, adding a 2nd wavelength. This will create point-to-point optical links between all hubs islands.

V. Modeling Deployment and Operational Costs

In order to explore the viability of such an architecture, a techno economic model for the deployment of such a fiber optic transport network has been developed, [15]. The target area was the inhabited Aegean Islands (see Fig. 7). The inputs of such a model were related to (a) the existing, already deployed, fiber optic infrastructure between mainland and the islands, (b) the projections in relation to the expected bandwidth capacity per end-user, (c) the population of each habitant island, (d) the number of tourists per island on a yearly basis, (e) the cost of the implementation of sub-marine fiber optic cables, (f) the cost for the interconnection between sub-marine and landed fiber optic cables and (g) the average revenue per user for fixed and mobile electronic communication services. The model is based on Discounted Cash Flow (DCF) analysis and its results are related to financial indicators, which determine the level of the viability and profitability of each examined business case. More specifically, three indicators have been calculated: the Required Initial Investments (RII), the Internal Rate of Return (IRR) and the Net Present Value (NPV). Here, results only on IRR are presented. In economic terms, the IRR determines whether the examined business plan is profitable or not, by comparing the IRR of the business plan with the IRR of alternative business or with relevant market rates of return. The financial model takes as input two kind of cost parameters as follows.

- **Costs of infrastructure**: Provides the total cost of sub-marine cable deployment (€/Km), its operational expenditures cost (€/year), one-off costs for shore-end landing and plough launch operations expenditures (€) as well as theirs yearly operational expenditures (€/year).
- **Level of Infrastructure:** Length of required submarine cable (Km) and length of existing submarine cable (Km)
- **Revenues**: Monthly Average Revenue Per User (ARPU) for Fixed Line and Mobile lines (€).
- **Administrative**: Provides dynamic admin costs for required new infrastructure, percentage of ARPU, lifetime of investments, tourism population variance, market shares, island coverage, shore-end site cost, sub marine cable cost (€/Km), future revenues.
- **Cost sharing:** takes into account any infrastructure initial cost sharing with other operator (i.e. grid) or State aid co-financing.
- **Financial**: Weighted average cost of capital -WACC, yearly inflation.
- **Penetration:** Mobile and Fixed penetration in the relevant population.
- **Others:** Number of citizens per household, number of Sites per island, failures per year per Km, cost per failure (€), yearly failure cost per Km (€/Km).

Greek islands have been categorized based on their population, in the following groups: islands with population above of 30.000 ("Big size Islands"), islands with population between 5.000 and 30.000 ("Medium size Islands") and islands with population less than 5.000 ("Small size Islands"). Several scenarios have been examined in order to reveal the impact of each parameter to the viability of the relevant business case. In the first set of scenarios, the impact of state aid funding is examined without any cost sharing between telecom and other operator. In particular, Fig.9 displays the Internal Rate of Return of investments for different % of state aid for the cases where (a) "All" islands are interconnected, (b) a combination between medium and small ("Medium_Small") islands and (c) a combination between big and medium islands ("Big_Medium"). It is obvious that without State Aid funding only business plans related to big and medium islands interconnection are profitable with an IRR of ~12%. On the contrary, the other two scenarios return negative IRR or an IRR below of the relevant WACC. Any business plan with negative IRR or lower than the relevant WACC is not a profitable plan. However, in the case of a 30% state aid, the interconnection of all islands ("All") returns IRR greater than WACC, resulting in a profitable scenario. On the other hand, the third scenario (coverage of "Medium_Small") is not profitable even in the case that State co-funds a 50% of the required initial investment.

In the second set of scenarios, the impact of cost sharing between the telecom and grid operators is examined. Fig. 10 displays the relevant results. In all examined scenarios, a State

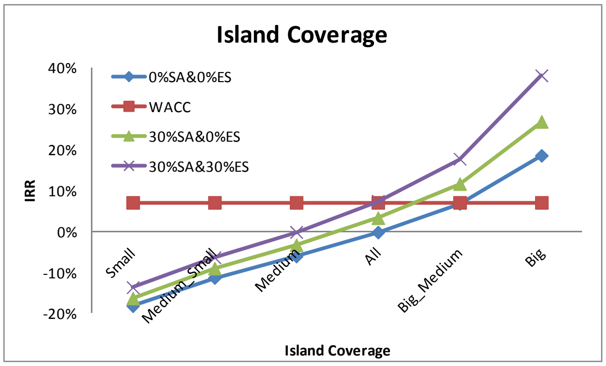


Fig. 11: IRR & State Aid and Cost Sharing variation.

Aid funding, at the level of 30% of the required initial cost, has been adopted. A scenario with State Aid funding 30% and Cost Sharing 20% means that, the 30% of the initial required investment will be provided by the State, while the 20%, by another the operator. From Fig. 10, it can be seen that a State Aid funding above of 30% in combination with a Cost Sharing above 15% returns profitable business cases for the islands' groups "Big-Medium" and "All". Indeed in the above scenarios the IRR of the examined relevant business plans is considerably higher than the relevant WACC values.

In order to determine the preconditions, in relation to State Aid and Cost Sharing parameters, for each selected group that designate a profitable business plan, Fig.11 summarizes results for: zero funding/zero sharing, 30% funding/zero sharing and 30% funding/30% sharing. For each group of scenarios, the IRR for each islands category is presented. It is obvious that for "Small", "Medium_Small" and "Medium" group of islands even with 30% State Aid and 30% Cost Sharing, the relevant IRR values are either negative or below the threshold set by WACC value. On the other hand for the other three islands categories ("All", "Big_Medium", "Big") IRR values indicate profitability. In particular for the "All" category a 30% funding from the State in combination with 30% sharing with another operator determines the preconditions for a profitable business case. As regards "Big_Medium" category, even with zero funding and zero sharing the IRR is slightly higher than WACC values. Finally, for "Big" islands category the IRR is much higher than WACC for all the examined scenarios.

Conclusions

In this paper, it is shown that Broadband Digital Divide between EU Member States has not been eliminated. Albeit, fixed broadband and mobile broadband penetration continue (on average) to rise, standard deviation and max-min statistics remain unchanged over the past 10 years (2005-2015). This is due to the fact that network operators are lagging behind from network investments to rural and distant areas, since these are considered of low business value. However, with the advent of optical network technology, new architectural designs that combine optical and wireless networking can be exploited to bridge that gap. Such designs combine the merit of a long-reach, high capacity fiber-optic network with the merits of LTE/LTE+ radio access networking (ease deployment, high bandwidth etc). Even though, and in order to expedite network investment and broadband coverage, a minimum cost sharing, either via state aid funding or infrastructure sharing with other telecom or grid operator is necessary. In this paper, a techno-economic model, that was developed for the Greek island complex, reveals that with 30% state aid funding and 30% cost sharing, all islands, independent of their size and number of inhabitants, can be interconnected over a converged high-speed fixed-mobile network. The results of the analysis strongly indicate that public funding by the State in combination with infrastructure sharing, is the only-way for the deployment of a NGN infrastructure in isolated and sparsely populated areas.

References

[1] European Commission communication to the European Parliament, the council, the European Economic and social committee and the committee of the regions "EUROPE 2020, A strategy for smart, sustainable and inclusive growth", COM(2010)2020, 3.3.2010.

[2] European Commission communication to the European Parliament, the council, the European Economic and social committee and the committee of the regions "A Digital Agenda for Europe", COM(2010)245, 19.05.2010.

[3] Wik Consult Study for ECTA. The Economics of Next Generation Access (NGA), 2008.

[4] European Commission recommendation on Regulated Access to Next Generation Access Networks, Recommendation 2010/572/EU.

[5] European Commission communication to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, European broadband: investing in digitally driven growth, COM(2010) 472.

[6] European Commission Guidelines "EU Guidelines for the application of State aid rules in relation to the rapid deployment of broadband networks", (2013/C 25/01).

[7] Linsey McCallum, Oliver Stehmann. The New EU State Aid Broadband Guidelines: What changes for electronic communication network operators, *Journal of European Competition Law & Practice*, 2013, 4,(4), 316-317.

[8] EC2014, European Commission decisions on State aid to broadband, http://ec.europa.eu/competition/sectors/telecommunications/broadband_decisions.pdf.

[9] E. Dahlman, S. Parkvall, J. Skold, and P. Beming, *3G Evolution: HSPA and LTE for Mobile Broadband*, 2nd ed., Academic Press, 2008.

[10] Kota Asaka and Jun-ichi Kani, "Standardization Trends for Next-Generation Passive Optical Network Stage 2 (NG-PON2)", Global Standardization Activities, NTT Technical Review, Vol. 13 No. 3, pp.1-5, Mar. 2015.

[11] L.G. Kazovsky, W.-T. Shaw, D. Gutierrez, N. Cheng, and S.-W. Wong, "Next-generation optical access networks", *IEEE/OSA J. Lightwave Technol.*, 25(11):3428–3442, 2007.

[12] M. Ali, G. Ellinas, H. Erkan, A. Hadjiantonis, and R. Dorsinville, "On the Vision of Complete Fixed-Mobile Convergence," *IEEE/OSA Journal of Lightwave Technology*, 28(16):2343-2357, 2010.

[13] K. Ramantas, K. Vlachos, A. N. Bikos, G. Ellinas, and A. Hadjiantonis, "A New Unified PON-RAN Access Architecture for 4G LTE Networks", *IEEE/OSA J. of Optical Communications and Networks*, vol. 6 , no. 10 pp.890 – 900, 2014.

[14] H. Erkan, et al., "Native Ethernet-Based Self-Healing WDM-PON Local Access Ring Architecture: A New Direction for Supporting Simple and Efficient Resilience Capabilities", *Proc. IEEE International Communications Conference (ICC)*, May 2010.

[15] S. Polykalas, "Bridging the Digital Divide in island countries – The case of Greece", in procedding of e-Case & e-Tech conference, Japan, 2014.

[16] A. Antonopoulos, C. Perillo, and C. Verikoukis. 2017, "Internet Service Providers vs. OvertheTop Companies: Friends or Foes? Short talk", SIGMETRICS Perform. Eval. Rev. 44, 3, January 2017.