Comparative Study and Techno-Economic Analysis of Residential Broadband Access Technologies: GPON and FWA

The focus of this paper is to compare and evaluate suitable access architectures and methods for delivering broadband services.† In particular, the paper presents a techno-economic analysis of two key broadband technologies for metropolitan networks: gigabit passive optical network (GPON) and fixed wireless access (FWA). Our studies are based on a modelling methodology for network value analysis that involves CAPEX and OPEX calculations, while the overall technology deployment financial assessment is based on techno-economic evaluation measures such as net present value (NPV) and internal rate of return (IRR). The results of a network value analysis can be of significant importance to various market players. For instance, such studies could be useful to equipment vendors to develop costing metrics (cost per customer, cost per megabit/s, cost per kilometre or area), support the business case of their solution or proposal, and prepare RFIs, RFQs and RFPs. Network carriers and service providers could benefit from using such results to assess market demand, compare different technological evolution cases, explore various equipment vendor solutions, forecast deployment costs and compare different roll-out scenarios. The objective is to identify and tailor strategies, such as investment, technology introduction or evolution strategies, for the deployment of broadband infrastructure and services.

Introduction

A number of alternatives exist for implementing broadband access and delivering broadband services: DSL, cable, HFC, FTTx, xPON, WiMAX, LMDS, UMTS, PLC to name a few. Some of them are already being exploited commercially while others are still in development phase. As it has been evident from other technologies, it is usually the various economic drivers, apart from the merits and shortfalls of each technology, that will finally shape the broadband market1. The offering of broadband services and applications will also play a dynamic role in the acceptance of broadband by the market (consider for instance the delivery of triple play by some operators or providers).

The inherent advantages of wireless technology (no wiring, easy deployment, mobility features), combined with the notable development in wireless technologies (electronics, efficient modulation techniques, advanced antenna technologies) during the past decades, has led the telecom market to introduce fixed wireless access (FWA) networks as a potential competitor to other broadband access technologies, such as digital subscriber line (xDSL) systems and emerging passive optical network (PON) systems. In particular, a promising broadband fixed wireless technology is WiMAX which could extend the reach of the Wi-Fi LAN systems. On the other hand, PON technologies are viewed also as a serious contender given that they can greatly capitalise on the huge benefits that optical networking brings (for example, immense capacity, longer-reach capabilities, improved performance) while they require very few active components (which means high reliability and very low maintenance costs).

The decision for a network provider or telecommunication operator to develop a broadband access network, and, hence, to commit substantial capital investment, has to take into consideration a number of factors and parameters. Therefore, a benchmark process is required that can recognise and compare the various technologies and architectures available based on a range of input data including

† The scope of this work is also within the scope and framework of the IST-3 project entitled ‘ReATH: Broadband e-Services and Access for the Home’.

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demographical and market figures including existing (for example, service penetration) and forecast information; costs involved (CAPEX and OPEX); projected revenues, etc. The results of this benchmarking exercise can assist a potential broadband service provider not only in assessing a technology but also in developing the appropriate market introduction strategy. Hence, the issue of examining existing and promising alternatives for developing broadband access is of paramount importance and a business imperative.

The techno-economic analysis methodology can be used to also assess emerging technologies while existing ones can be examined whereas potential evolution and upgrading scenarios can be devised.

The Broadband Market in Europe

The broadband market landscape in Europe is expected to change radically within the next few years as more and more users sign up for broadband access and with operators installing and offering a wider range of broadband services (IP telephony, triple play and WebTV in the future) at affordable prices. The European broadband markets are growing rapidly with an approximate 20 million subscribers by the end of 2005. It is expected that by 2008 close to half of the European households will have taken up broadband services.

The broadband challenge will enable new and emerging technologies aiming at delivering broadband services to a large spectrum of users and network scenarios: in urban, suburban, rural, remote/isolated areas. Hence, it is fundamental that a set of different technologies are considered. While customers (citizens, enterprises, government agencies, etc) will most certainly enjoy and exploit the benefits of the broadband revolution, service providers (and vendors alike) have to be ready to fully reap the rewards of this business opportunity by introducing strategies that are technically feasible and financially robust. In fact it will not be unusual to observe the deployment of a mixture of broadband architectures that could be identified and proposed for a particular network scenario or service area.

Access Network Technologies

For our comparative techno-economic study we consider two key emerging broadband technologies: PONs, with an emphasis on the emerging gigabit PON (GPON) standard, and the FWA WiMAX based on the 802.16a standard.

**PON technology**

The GPON technology is a very recent, promising and capable solution in the optical access market arena, offering unprecedented high-bit-rate support while it enables the transport of multiple services, data and TDM, in native formats and with extremely high efficiency.† PON technology and its species, GPON, Ethernet PON (EPON), broadband PON (BPON) are viewed as competitive solutions for the deployment of broadband access services for a wide range of customers and applications (Table 1).⁴, ⁵, ⁶.

Due to the high capacity and efficient use of bandwidth provided by PONs, a wide variety of user and network applications can be supported (Figure 1):

- flexible network configurations – PONs can support any FTTx configuration;
- flexible deployment – PON can be deployed as aerial networks, in trenches, in new conduit or existing conduit;
- legacy voice; and
- legacy data such as Ethernet/IP, frame relay and ATM.

The GPON architecture uses a broadcast TDM scheme for downstream access and for upstream access. In the downstream directions data are broadcast from the optical line termination (OLT) to the optical network units (ONUs) and only the intended ONU will accept the packet sent. In the upstream direction the ONUs use

† In January 2003, the GPON standards were ratified by ITU-T and are known as ITU-T Recommendations G.984.1, G.984.2 and G.984.3.

### Table 1 Comparison of main PON technologies

<table>
<thead>
<tr>
<th></th>
<th>BPON</th>
<th>GPON</th>
<th>EPON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driven by</td>
<td>ITU-T/FSAN</td>
<td>ITU-T/FSAN</td>
<td>IEEE EFM</td>
</tr>
<tr>
<td>Standards</td>
<td>G.983</td>
<td>G.984</td>
<td>802.3ah</td>
</tr>
<tr>
<td>Status</td>
<td>Standardised</td>
<td>Standardised in Q1, 2004</td>
<td>In draft</td>
</tr>
<tr>
<td>Max Line Rate D/S</td>
<td>1.25 Gbit/s</td>
<td>2.5 Gbit/s</td>
<td>1 Gbit/s</td>
</tr>
<tr>
<td>Max Line Rate U/S</td>
<td>622 Mbit/s</td>
<td>2.5 Gbit/s</td>
<td>1 Gbit/s</td>
</tr>
<tr>
<td>Max Split Ratio</td>
<td>1:32 typical</td>
<td>1:128 typical</td>
<td>1:16 typical</td>
</tr>
<tr>
<td>Payload Type</td>
<td>ATM</td>
<td>ATM, TDM, Ethernet</td>
<td>Ethernet</td>
</tr>
<tr>
<td>Network Interfaces</td>
<td>ATM, TDM, GbE</td>
<td>ATM, TDM, GbE</td>
<td>GbE</td>
</tr>
<tr>
<td>Access Interfaces</td>
<td>ATM, TDM, 10/100</td>
<td>ATM, TDM, 10/100</td>
<td>10/100</td>
</tr>
<tr>
<td>Distance</td>
<td>≈ 20 km</td>
<td>≈ 20 km</td>
<td>≈ 20 km</td>
</tr>
</tbody>
</table>

### Figure 1 Typical PON network deployment
preassigned time-slots which are synchronised. GPON’s 125 μs frame and native format transmission of legacy services guarantees deterministically the quality of service needed by the operators. Another advantage of GPON is its scalability in terms of rates that makes it more suitable, compared to EPON, in order to support any anticipated future growth and increased user demands.

GPON systems enable the service provider to support 2.5 Gbit/s converged data and voice services for the so-called ‘last mile’, in a cost-effective and bandwidth-efficient manner. It is noted that telecommunication carriers have a large installed base of TDM and traditional voice services. This base can be considered as a cash-generating source for the carriers, in terms of revenues and profits. Carriers are looking for an access solution that supports Ethernet services, yet at the same time, leverages the existing installed base and increases the revenue stream.

**WiMAX technology**

WiMAX and its 802.16a standard defines a MAC architecture which is based on a TDMA protocol scheduled by a base station (BS) allowing multiple subscriber stations (SS) to share the available bandwidth in a point-to-multipoint network configuration. On the uplink a SS can be allotted a variable length slot. The BS can service a radius of several miles/kilometres and does not necessarily have to reside on a tower. Quite often the BS antenna is located on a rooftop of a tall building or other elevated structure such as a grain silo or water tower. A customer premise unit, similar to a satellite TV set-up, is all that is required to connect the BS to a customer SS. The signal is then routed via standard Ethernet cable either directly to a single computer, or to an 802.11 hot spot or a wired Ethernet LAN.

IEEE 802.16a also supports mesh topology architecture, suitable for ad-hoc networks. In a mesh topology, the end-user terminals act also as routers for each other’s traffic. Base stations are also needed to provide connections to the core network. Mesh networks offer a way to improve the coverage of a wireless access network as each new subscriber can be effectively seen as a new BS serving subscribers nearby. At the same time, however, the capacity of some links in the network might be strained. The end-user terminals are also more complex, because of the routing functionality needed.

WiMAX has primarily several inherent advantages as a wireless broadband access technology over competing wireline-based broadband technologies; these include easy, fast and cost-effective deployment by avoiding costly and time-consuming wiring installation, and provision of coverage to areas where wired connection is not possible due to the physical limitations of traditional wired infrastructure (for example, in isolated areas, in transport).

WiMAX can provide support for very longer distances, at very high data rates, and support many users, while it can furthermore support true QoS for multimedia applications. Another major advantage is that WiMAX can very well serve as complementary technology to wireline-based broadband access, since it provides a flexible, cost-effective means of filling existing gaps in broadband coverage (for example, quickly satisfy the increased demand for broadband access in currently under-served on non-served areas), and creating new forms of broadband services not envisioned in a ‘wired’ world (for example, provision of broadband access to a site for a very limited time period; for example, to meet the increased bandwidth demand for a few-days conference or expo event). This advantage supports the vision that it will be firmly established in the market.

**Value-Analysis Modelling Methodology**

A complete value analysis for a network technology and service deployment involves the calculation of economical factors that will assist in evaluating whether a specific investment strategy is commercially feasible and financially viable; that is, profitable in the future (that is, positive cash flow). The analysis has to include a sensitivity study where the risk of the proposed investment is examined and assessed where uncertainty about some elements is appropriately measured (for example, differentiation in sales forecast, unanticipated economical moves, etc.). Our value analysis, which involves a techno-economic study performed using the aforementioned technologies, namely GPON and WiMAX, follows the functional model in Figure 2.

The demand for broadband access captures the current and forecast traffic and services demand as these can be further specified by the geographical and population characteristics (morphology, rural versus urban, etc) and distributions, user/customer profile (number of users, age, individual/enterprise/organisation), service attributes and penetration, type of application. Additional factors include the (existing) network topology and infrastructure (in terms of coverage, available duct/cabling, equipment, etc), the architecture scenarios to support the selected technologies and the associated costs for implementing (installation, labour) these technologies (collectively known as capital expenditure or CAPEX).

The costs of materials are based on available commercial prices while for emerging technologies price estimates can be considered. Apart from calculating the costs for the various (network and equipment) components in order to calculate metrics such as the total cable length, we need to model parameters such as the subscriber density, network configuration and the type of civil works. Furthermore, costs later in the project (subsequent years) are derived based on the relationship between price and time (and quantity).

† The initial model was developed within the European RACE project TITAN.
evolution. It should be noted that growth estimates have also to be taken into account in order to anticipate or meet any future demand.

Operational, administration and maintenance (OAM) expenditures are also taken into consideration since items such as personnel salaries, building/office expenses, advertising/sales costs and repair costs can often amount to a large portion of the total costs. OAM costs are typically based on estimates, reflect the project planning and often can be calculated proportionally to the capital investment. The OAM costs combined with the investment costs yield the life-cycle costs of the proposed (network) project; that is, the present cost (today’s prices) for implementing and running the project over a period of time.

Projected revenues based on the services to be offered, the customer base and the service (or product) pricing policy along with the forecast cumulative costs (CAPEX and OPEX) can determine the business project’s future cash flow figures. Based on these cash flows, and after taking into consideration any taxes to be paid, we can calculate the net present value (NPV), the internal rate of return (IRR) and the payback period of the investment. A favourable IRR (that is, higher than the opportunity cost of money) indicates that the project is not only profitable but also fiscally sustainable and viable.

Case Study: Athens Metropolitan Area (AMA)

For the purpose of our techno-economic evaluation we have chosen the Athens metropolitan area (AMA), a dense, urban environment, as a test case for our comparative study. For implementing the methodology described in the previous section, the VPIaccessMaker™ simulation and evaluation software package was used.

In general, the cost of a comprehensive implementation of a solution such as GPON or WiMAX includes the following items:

- manufacturing and component parts/equipment (chips, boards, backplane),
- software costs for software development tools (purchase, licences, maintenance),
- labour (civil works) costs, and
- indirect costs (managerial costs, marketing costs, infrastructure depreciation costs, derived part of the company expenditures for usage of electricity, facilities and infrastructure, facility services).

In case it is problematic to provide an accurate breakdown of the total cost into all the above listed cost components, an attempt can be made to estimate such costs based on information and data from previous or similar deployments; for example, in another area or country.

Both selected technologies were compared from a techno-economic viewpoint under the VPIaccessMaker™ tool. A moderate market scenario in terms of market penetration was evaluated for both FWA and GPON technology chains. The scenario assumes greenfield deployment for the FWA system, a reasonable network scenario for an emerging wireless access technology that cannot reuse any existing infrastructure. For the GPON network deployment scenario, a different approach was taken: its development assumed a mixture of leasing existing fibre plants and installing new ones. This was based on the fact that within the Athens metropolitan network the Greek incumbent PTT organisation OTE S.A. has already deployed a number of fibre cables during the preparations for the 2004 Olympic Games. Under these conditions, using a mixed scenario seems more realistic and since new installation of fibre incurs typically large labour costs, the economics between the two technologies will be more comparable.

In the following we present the technology deployment expenditures used in our simulation and evaluation experiments for GPON and WiMAX.

Network costs for GPON

The potential market for PON products is huge as PON brings the best of fibre optic technologies to the access channel and to the subscriber itself. For this study we consider a GPON that supports a Class C optical distribution network (ODN), which is in fact adopted by most service providers around the world. ODN Class C brings a major cost reduction: its tree PON topology allows the number of end-users to be doubled. On the other hand, the GPON requirement to handle ATM, Ethernet and TDM incurs additional complexity, which translates into increased cost. Recent chipset developments promise to bring the cost for CPE even down to less than €150.

The following logic was adopted: multiple customers who are connected to the PON share the OLT costs. Unlike point-to-point or rings networks, the TDMA-based PONs have only one optical transceiver at the OLT, which greatly reduces the CAPEX of the network. When the service providers consider the cost to deploy PON, the most important parameter is the price per optical ONT. The price per OLT is defined as:

\[
\text{Price per ONT} = \frac{\text{Price of OLT}}{\text{Max. number of ONTs}} + \text{Price of OLT}
\]

Therefore, the more ONTs that can be served from a single PON card at the OLT, the lower the overall price-per-ONT. We assume that the service (more particularly the interface) used can be POTS, E1, Ethernet, fast Ethernet, under the aim to serve a dense urban area with buildings. Furthermore, it is assumed that a maximum of four enterprises are served by a single (per building) ONT; 32 ONTs are connected to a single OLT serving the whole area. The various associated costs (OLT and ONU equipment and labour for a mixed deployment of leased and installed fibre) used in our study are shown in Table 2.

Network costs for FWA-WiMAX

The components of the WiMAX BS consist of the indoor unit (IDU), the outdoor unit (ODU), the antennas, the control and network interface units and any cable and installation materials (C&NIC) while the components of the WiMAX SS include the IDU and mounting box, the interface (I/F) modules, the ODU (with its transceiver, integrated antenna and mounting kit) and other cable and installation materials. Table 3 shows the total costs (all-components inclusive) for the BS and SS stations.

Service area:AMA

The geographic area selected for the simulations is the Athens metropolitan district (Figure 3), an area of around 215 km², including the core of the Athens city as we know it. This district was partitioned in 11 metropolitan sections – service areas – a quite hard and tedious task to complete manually, which however overcomes the lack of a real GIS map. The automatic measurement tool of VPIaccessMaker™ gave a quite

Table 2

<table>
<thead>
<tr>
<th>Type</th>
<th>Cost (euro)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OLT</td>
<td>35 000</td>
</tr>
<tr>
<td>ONU</td>
<td>1 500</td>
</tr>
</tbody>
</table>

(a) Equipment costs

<table>
<thead>
<tr>
<th>% fibre installed</th>
<th>Mix</th>
<th>Cost (euro/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>73 000</td>
<td></td>
</tr>
<tr>
<td>50%</td>
<td>1 000</td>
<td></td>
</tr>
</tbody>
</table>

Total fibre cost | 37 000 |

(b) Fibre installation costs

Table 3

<table>
<thead>
<tr>
<th>Type</th>
<th>Cost (euro)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS</td>
<td>35 000</td>
</tr>
<tr>
<td>SS</td>
<td>1 150</td>
</tr>
</tbody>
</table>
accurate estimation of the areas in square kilometres (tabulated). The final result, despite the lack of a GIS map, is quite realistic in the sense that the simulations are based on a real geographical area, segmented in service areas manually, but in a way that represents sufficiently the actual characteristics of the district.

Using *VPlaccessMaker™* the service area can be defined either (manually) by the user or by using raster or vector maps in a number of different formats including GIS. The market was modelled through user-defined service areas and customer densities. The technologies selected were modelled in terms of their architecture, capacity and performance characteristics and various cost metrics while time evolution coefficients were also taken into account. The simulator output provides an optimised network topology; that is, it can yield the optimum placement of equipment within the service area in order to maximise the financial aspect of the network deployment.

Table 4 shows the target customer base used. Average densities per km² were first taken for three basic area types (dense urban, urban and suburban). The European average values were downscaled for the Athens metro area business case by different factors for each area type, ranging from 20% up to 70%. Then the resulting densities were partitioned between large enterprises (LEs) and small medium enterprises (SMEs). The mix between the two categories was different for each area type with great emphasis in SMEs, which were assumed to outnumber LEs for the Greek market, even in the Athens metro area.

**Table 4** Analysis of target customer base for AMA business case

<table>
<thead>
<tr>
<th>Area Types</th>
<th>Dense Urban</th>
<th>Urban</th>
<th>Suburban</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>European Average Densities (Businesses/km²)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Businesses/km² per area type</td>
<td>1333</td>
<td>400</td>
<td>143</td>
</tr>
<tr>
<td><strong>Athens Average Densities (Businesses/km²)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greece downscaling factor</td>
<td>70%</td>
<td>50%</td>
<td>20%</td>
</tr>
<tr>
<td>Businesses/km² per area type</td>
<td>934</td>
<td>200</td>
<td>29</td>
</tr>
<tr>
<td>Business mix (LEs/SMEs)</td>
<td>30%</td>
<td>15%</td>
<td>5%</td>
</tr>
<tr>
<td>LEs Businesses/km² per area type</td>
<td>281</td>
<td>30</td>
<td>2</td>
</tr>
<tr>
<td>SMEs Businesses/km² per area type</td>
<td>653</td>
<td>170</td>
<td>27</td>
</tr>
<tr>
<td><strong>Athens Totals</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals of service areas (km²)</td>
<td>15.4</td>
<td>131.4</td>
<td>68.4</td>
</tr>
<tr>
<td>Total businesses per service area</td>
<td>14 350</td>
<td>26 274</td>
<td>1984</td>
</tr>
<tr>
<td>Total LEs per service area</td>
<td>4318</td>
<td>3942</td>
<td>137</td>
</tr>
<tr>
<td>Total SMEs per service area</td>
<td>10 032</td>
<td>22 332</td>
<td>1847</td>
</tr>
</tbody>
</table>

**Figure 3** The Athens Metropolitan Area (AMA) map with service segmentation (in km²)
These results can guide in the process of the project planning and determine the investment strategy and business development.

Examining Figure 4, the revenues are the same for both technologies (GPON and WiMax), since we have defined exactly the same services and tariffs for both. This is quite reasonable since telecom operators, usually pushed by demand and competition, do not differentiate substantially their tariffs, so as to protect their market share from competition. In such cases the important factor for financial performance is the cost. The initial high cost of GPON is mainly due to the high investment for fibre installation. Note also that in the year 2007 a significant increase for WiMAX cost is incurred due to a major network upgrade performed to meet the increase in demands. Taking this into account it is not surprising that the cash flow is much worse for GPON in the first year (2005), significantly affecting NPV and IRR indicators. The results were based on exactly the same market demand and revenue assumptions for both technologies, a particular market segmentation with differentiation only in technology chains and related cost assumptions. Key cost factors, including fibre installation costs for GPON and spectrum licence costs for WiMAX, were taken into account.

Additional interesting point is the fact that FWA network deployment reveals the need for quite dense base station placement for a broadband service operator to cover the expected demand of a metropolitan area. This fact, considering also that several operators normally service the same area, brings up a possible problem in WiMAX network deployments in terms of radio planning. This, in turn, supports the view of several decision makers today that WiMAX technology could become a complementary solution to wireline broadband access technologies such as PON-based, essentially covering non-dense areas (suburban, rural) and meeting dynamic demand increases in dense areas.

**Conclusion**

Our study results show that the WiMAX network deployment appears to present a better economic solution (based on the NPV and IRR indicators) compared to a GPON network deployment for the Athens metropolitan area. Thus, an investment in WiMAX presents improved prospects for a potential broadband access operator targeting the Athens metro area. The latter could also be attributed to the vast customer base adopted (Table 4). Nevertheless, it should also be mentioned that the economic analysis was based only on network deployment costs; in actuality an operator enterprise has numerous other costs such as operational and maintenance (for example, costs for personnel salaries, premises, advertisement) that should be also considered in order to estimate more accurately the various financial indicators.

**References**

Biographies

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Christos Kolias is an Assistant Professor at AIT. He was a senior research scientist and a founding member of Caspian Networks (USA), where he served as the company’s initial system architect. Caspian Networks designs and manufactures next-generation terabit routers. Dr. Kolias has been an adjunct faculty at USC and a visiting faculty at Stanford University and UCLA. He holds a Ph.D., an Engineer Degree and an M.Sc. in Computer Science from UCLA, and a B.Sc. in Mathematics from the University of Athens, Greece.

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