Techno-economic Analysis of NGNs Implementation in Rural Areas Based on the Geographic and Socio-demographic Characteristics of Serbia

MIRJANA R. RADIVOJEVIĆ, University Union, School of Computing Science, Belgrade
PETAR S. MATAVULJ, University of Belgrade, School of Electrical Engineering, Belgrade

This paper presents a comprehensive techno-economic evaluation of the hybrid fiber-coax (HFC) networks and the multichannel Ethernet passive optical networks (EPONs) as two main next generation broadband technologies. The focus within this study is the comparison of these technologies in the case of their deployment in the rural area. Moreover, this paper analyzes how these technologies could be profitably deployed and what could be the optimal migration path for the operators in Europe.

Key words: HFC, Multichannel EPON, Techno-economic analysis.

1. INTRODUCTION

In the last decade the role of broadband infrastructure has been revised and it is widely considered that the existence, or absence, of this infrastructure is parameter that is used to classified certain area as developed or underdeveloped. As a result, last few years almost all EU countries have launched different strategic plans for enroll the broadband infrastructure but most of these plans are related to urban/suburban areas since the investment costs in these areas are much lower in comparison to rural areas [1]. However, in general the most of this growth is related to the infrastructure development in urban and suburban areas. Namely, the investment costs in urban/suburban areas are much lower in comparison with rural areas since the amount of needed fiber and related work (which influence the cost of the network in greatest extent) is significantly lower. Consequently, today the urban and suburban inhabitants have the possibility to choose among variety of broadband access technologies (both wired and wireless) while in the same time the majority of the rural users do not have broadband services at all. Moreover, the number of end users in rural areas is significantly smaller, and their need for bandwidth is much lower. As a result, the return of investment is much slower and raise the question that still remains unanswered – what is the future of broadband access networks in rural areas?

This paper present techno-economic analysis of the Hybrid Fiber-Coax (HFC) network, based on Data Over Cable Service Interface Specification (DOCSIS) 3.0, and hybrid multichannel Time/Wavelength Division Multiplexing Ethernet Passive Optical Network (TDM/WDM EPON) as the most competitive technologies which are able to deliver supreme service to end users [2]. In order to make the analysis as much realistic as possible authors consider the two generation of both systems. In the case of the HFC network the analysis is based on DOCSIS 3.0 with integrated cable modem termination system (I-CMTS) and the following generation called modular CMTS (M-CMTS) [3]. In the case of the multichannel solution authors provide analysis of hybrid TDM/WDM EPON based on Dynamic Wavelength Priority Based Algorithm (DWPBA), and its successor DWPBA with Fine Scheduling (DWPBA-FS) [4].

Analysis of both systems rely on socio-demographic infrastructure of Serbia in which the broadband access in rural areas is under-develop and should be improved in future period. For presented analysis authors used currently available information elated to HFC systems.

Since this type of data is generally considered private we provide only relative measures and available and well known information. For the evaluation of multichannel EPON system and related costs we
refer to previous works and built the hypothetical network model in order to evaluate all key points.

The rest of the paper is organized as follows. Section 2 presents system architecture of both analyzed systems, Section 3 provide input data and framework, while Section 4 presents the techno-economic analysis. The obtained results are discussed in Section 5 and Section 6 concludes the paper.

---

**Figure 1 - HFC architecture and characteristics**

**2. SYSTEM ARCHITECTURE**

**2.1. HFC Architecture**

Figure 1 shows the HFC architecture analyzed in the paper. I-CMTS architecture has all of its building blocks contained within one chassis that could be single box with all components on one card, or larger chassis with multiple line cards. On the other hand, M-CMTS separates the CMTS core from the radio frequency part (Edge-QAM) that, among other, allows sharing of video and DOCSIS services, and addition of multiple downstream RF channels without any additional upstream channels. This independent scaling of downstream channels makes the modular solution more cost effective. However, integrated solution is still widely deployed [3] due to its simplicity (all building block on the same line card), chassis efficiency (one line card in a CMTS can protect all other line cards), and high availability (with all components in a single chassis, DOCSIS failure detection and recovery is limited to that one chassis). Hence, in the rest of the paper we discuss both solutions.

**2.2. Multichannel EPON Architecture**

Figure 2 shows the architecture of the analyzed hybrid TDM/WDM EPON system in which OLT and ONUs are equipped with four fixed-tuned transceivers, one for each operating wavelength channel in order to enable simultaneous transmission of traffic in one station on different wavelengths and thus maximize the resources of a multichannel system. Both presented models, DWPBA and DWPBA-FS, implement a new approach in the Quality of Service (QoS) analysis in which wavelength assignment per traffic class and not per ONU, as usual approach in literature, is used [2].

---

**Figure 2 - Hybrid TDM/WDM model**
Traffic classes are defined in accordance with DiffServ framework as Expedite Forwarding (EF), Assured Forwarding (AF) and Best Effort (BE) class and traffic from each traffic class is transmitted on the defined wavelength. Furthermore, in the DWPBA model one wavelength is reserved for the control messages transmission and other three wavelengths are used for the transmission of each traffic class.

In order to improve system efficiency in the DWPBA-FS model all wavelengths are used for data transmission (control messages are transmitted together with data on all wavelengths). Additional wavelength is allocated for the data transmission (various video applications), too.

3. FRAMEWORK AND INPUT DATA

Analysis of both systems relies on socio-demographic infrastructure of Serbia in which the broadband access in rural areas is underdeveloped. In order to achieve ‘win-win’ situation from end-users perspective and their own perspective as well, ISPs must understand current service usage trends, socio-demographic structure of considered area and end user’s needs. Hence, the analysis presented in the rest of the paper takes into account current market situation and trends and provide an insight in the future of NGNs and their further in-field implementation in order to analyze and evaluate the main characteristics related to implementation and/or migration strategy of discussed solutions and give an insight in the further access network development.

As a representative, a rural part of the municipality Backa Topola (Vojvodina) is chosen. The observed rural area has population of 34000 inhabitants living in 22 settlement [5], and 596 km² surface (‘flat’ terrain, and evenly spaced houses in the ‘row’ and therefore is suitable for digging and deployment of physical infrastructure). The authors assumed that broadband infrastructure is deployed in the whole area since the analysis ‘settlement by settlement’ would not provide results able to give insight in the future development.

Table 1. Equipment costs for techno-economic analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Cost (€)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber cable (€/m)</td>
<td>CFC</td>
<td>0.3</td>
<td>For both technologies</td>
</tr>
<tr>
<td>Coax cable (€/m)</td>
<td>C_{CC}</td>
<td>1.69</td>
<td>For both technologies</td>
</tr>
<tr>
<td>Duct (€/m)</td>
<td>CD</td>
<td>3</td>
<td>For both technologies</td>
</tr>
<tr>
<td>Trenching(€/m)</td>
<td>CT</td>
<td>10</td>
<td>For both technologies</td>
</tr>
<tr>
<td>I-CMTS</td>
<td>C_{CMTS,I}</td>
<td>6000</td>
<td></td>
</tr>
<tr>
<td>M-CMTS</td>
<td>C_{CMTS,M}</td>
<td>30000</td>
<td></td>
</tr>
<tr>
<td>Fiber node (FN)</td>
<td>CFN</td>
<td>12500</td>
<td>2-4 branches per FN; 250-1500 households per FN</td>
</tr>
<tr>
<td>Power supply</td>
<td>CPS</td>
<td>7000</td>
<td>Power supply in outdoor cabinets</td>
</tr>
<tr>
<td>RF splitter</td>
<td>CRF</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Coax Amplifiers (last mile)</td>
<td>C_{AMP}</td>
<td>70</td>
<td>4-15 amplifiers in cascade</td>
</tr>
<tr>
<td>CATV taps</td>
<td>CTAP</td>
<td>2/3/4</td>
<td>per user connected</td>
</tr>
<tr>
<td>Cable modem</td>
<td>C_{CM}</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>Set-top box</td>
<td>C_{STB}</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>DWPBA OLT</td>
<td>COLT-DWPBA</td>
<td>26880</td>
<td></td>
</tr>
<tr>
<td>DWPBA-FS OLT</td>
<td>COLT-DWPBA-FS</td>
<td>32256</td>
<td></td>
</tr>
<tr>
<td>DWPBA ONU</td>
<td>CONU-DWPNA</td>
<td>220</td>
<td>without installation</td>
</tr>
<tr>
<td>DWPBA-FS ONU</td>
<td>CONU-DWPNA-FS</td>
<td>260</td>
<td>without installation</td>
</tr>
</tbody>
</table>

Namely, in practice service provider would decide to build new infrastructure and make investment only in the case that there is possibility to connect several settlements and establish significant user database i.e. achieve return of investment in acceptable period of time.
For the HFC deployment analysis authors use currently available information (year 2014 and first half of year 2015) gathered from cable operator working in similar areas, Table 1 (all information about company’s network installment, traffics, equipment and involved costs are considered private; only relative measures without any absolute reference are provided).

For the evaluation of multichannel EPON system and related costs authors refer to previous work [6] and built the hypothetical network model [4]. The prices of the new WDM EPON units are calculated under assumption that new technology will increase the costs for at least 20% [7]. The infrastructure costs for all systems are defined on the basis of the research presented in [6] and average labor-related costs in Serbia (Table 1).

4. TECHNO-ECONOMIC ANALYSIS

In order to estimate the cost of the access network deployment as well as its sustainability over time the following costs are taken into consideration [8]:

- Capital Expenditure (CAPEX) include the initial costs of network installation and network equipment (network infrastructure) and network management system.
- Service Provisioning (SP) includes costs of end user equipment, types of installation and administrative costs. The presented analysis assumes that during 0th year (2016) will be build network architecture hence there will not be any active customers.
- Operational Expenditure (OPEX) cover costs associated with the network operation, administration, and maintenance (OAM).

The details of all parameters and their count are presented in Table 1, Table 2 and Fig 1.

Capital costs of the HFC network infrastructure cover the costs of laying physical infrastructure (both fiber and coax) and costs related to network equipment:

\[ C_{HFC} = C_{total\_fiber\_ coax} + C_{equipment} \]  

(1)

Costs of physical infrastructure are calculated as:

\[ C_{total\_fiber\_ coax} = L_{HE\_ FS} C_{fiber} + L_{FS\_ CM} \sum C_{coui} \]  

(2)

\[ C_{fiber(coax)} = C_{FC(CC)} + C_D + C_I \]  

(3)

Cost of related equipment is calculated as follows:

\[ C_{equipment} = C_{CMTS, I(M)} + \sum C_{FS} + \sum (C_H + C_P) + \sum C_{AMP} + \sum C_{TAP} + \sum (C_{CM} + C_{STR}) \]  

(4)

The multichannel EPON deployment costs are calculated based on the network geometric model that defines two-layered structure with distribution level (DL) that connects households with passive optical splitter (POS), and feeder level (FL) that connects POSs with central office (CO) [8, 9], Figure 3. Total network cost can be now calculated as sum of total infrastructure costs and equipment costs in the following way [10]:

Figure 3 – Geometric model

- Service Provisioning (SP) includes costs of end user equipment, types of installation and administrative costs. The presented analysis assumes that during 0th year (2016) will be build network architecture hence there will not be any active customers.
- Operational Expenditure (OPEX) cover costs associated with the network operation, administration, and maintenance (OAM).

The details of all parameters and their count are presented in Table 1, Table 2 and Fig 1.

Capital costs of the HFC network infrastructure cover the costs of laying physical infrastructure (both fiber and coax) and costs related to network equipment:

\[ C_{HFC} = C_{total\_fiber\_ coax} + C_{equipment} \]  

(1)

Costs of physical infrastructure are calculated as:

\[ C_{total\_fiber\_ coax} = L_{HE\_ FS} C_{fiber} + L_{FS\_ CM} \sum C_{coui} \]  

(2)

\[ C_{fiber(coax)} = C_{FC(CC)} + C_D + C_I \]  

(3)

Cost of related equipment is calculated as follows:

\[ C_{equipment} = C_{CMTS, I(M)} + \sum C_{FS} + \sum (C_H + C_P) + \sum C_{AMP} + \sum C_{TAP} + \sum (C_{CM} + C_{STR}) \]  

(4)

The multichannel EPON deployment costs are calculated based on the network geometric model that defines two-layered structure with distribution level (DL) that connects households with passive optical splitter (POS), and feeder level (FL) that connects POSs with central office (CO) [8, 9], Figure 3. Total network cost can be now calculated as sum of total infrastructure costs and equipment costs in the following way [10]:
\[ C_{\text{WDM EPON}} = C_{\text{equipment}} + C_{\text{total fiber}} \]
\[ C_{\text{equipment}} = 2C_{\text{total OLT}} \]
\[ C_{\text{total fiber}} = (L(N^2 - 1) + I(n^2 - 1))C_{\text{fiber}} \]

The input parameters of geometric model are defined in the following table (Table 2).

### Table 2. Parameters of Geometric model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area surface (km²)</td>
<td></td>
<td>596</td>
</tr>
<tr>
<td>Population</td>
<td></td>
<td>34,000</td>
</tr>
<tr>
<td>Number of houses in row at Distribution level</td>
<td>n</td>
<td>8</td>
</tr>
<tr>
<td>Number of Distribution level 'cells' at Feeder level</td>
<td>N</td>
<td>23</td>
</tr>
<tr>
<td>Distance between two house (m)</td>
<td>l</td>
<td>10</td>
</tr>
<tr>
<td>Distance between two POS (m)</td>
<td>L</td>
<td>1,000</td>
</tr>
</tbody>
</table>

5. RESULTS

The evaluated reference scenario is based on a planning horizon of 10 years although the EU recommends planning horizon of 15 years for large telecom projects [1]. However, political/economic situation in Serbia together with investment environment makes the planning horizon of 10 years more favorable option both for investors and operators.

The analysis also assumes that variable take rate (the percentage of homes connected that subscribe to the service) reaches its maximum value of 20% in the fifth year (worst-case scenario but consequently the obtained results provide more realistic insights into the development of broadband infrastructure).

The Fig. 4 presents the total cost of ownership (TCO) of the whole infrastructure (modeled as the summation of both CAPEX and OPEX and SP costs [11, 12]). As expected infrastructure cost i.e. CAPEX dominate the TCO value for all technologies. CAPEX of HFC models is significantly higher in comparison with WDM EPON since the HFC deployment includes implementation of coaxial cables, power cabinets and range of passive elements.

M-CMTS however has lower CAPEX due to the better scalability and possibility to connect more customers on one device. Nevertheless, M-CMTS solution has 1.8 and 1.4 times higher CAPEX in comparison with DWPBA i.e. DWPBA-FS. On the other side, DWPBA-FS model has 1.25 times larger CAPEX value in comparison with its predecessor DWPBA since price of OLT and ONU components are higher due to more complex scheduling algorithm (physical infrastructure costs are the same for both models). Both OPEX and SP costs follow the same reasoning, and results show that HFC solutions have larger values in comparison with WDM EPON solutions due to increased costs related to the maintenance and monitoring of active equipment, and its higher power consumption, Figure 4.

![Figure 4 - CAPEX, OPEX, AND SP costs](image)

The value of the total cost per household is shown in Fig 5. In accordance with previous analysis the highest cost is in integrated CMTS solution (765 €), decreased for modular solution (612 €), and evidently more competitive in DWPBA-FS (430 €) and DWPBA (344 €) solutions.

![Figure 5 - Cumulative costs per household (HH)](image)

In order to calculate needed revenue per connected home and evaluate the feasibility of the analyzed deployment besides TCO values it is necessary to also evaluate cost recovery (CR) curve. Namely, the revenues needed per subscriber/per month can be calculated based on the known TCO as [11, 12]:

\[ TCO(CAPEX + SP + OPEX) = \sum_{i=1}^{10} 12iN(i)d(i) \]

where \( R \) presents the monthly fee for each subscriber, \( N(i) \) number of users per year and \( d(i) \) is defined as discount rate of 5% (based on the reference discount rate for large infrastructure investments, as set out by the EU [4]). Consequently, Fig. 6 shows TCO and CR curves for ten years period and defined parameters.

Based on Table 1 and Figs. 5-6 the following values for monthly fee are obtained: DWPBA (29 €/month), DWPBA-FS (36 €/month), M-CMTS (51 €/month), and I-CMTS (64 €/month).
The techno-economic analysis presented in this work is based on geographic and socio-demographic statistics of one rural area in Serbia. However, the presented framework can be, with minor modification, used for techno-economic analysis of broadband systems in most European countries. From the obtained results it is clear that in the case of the green-field investment, WDM EPON systems (DWPBA) require significantly less investment per user than most competitive DOCSIS solutions i.e. M-CMTS.

However, the evolution of DOCSIS from I-CMTS to M-CMTS shows a strong investment reduction in the analyzed zones and accordingly brown-field investment should be considered as the most optimal solution for the already existing I-CMTS based networks. Further, the obtained results show that the deployment of multichannel EPON in rural area is justified from the economical point of view as well as service and technical aspects. The comparison of WDM EPON models shows that the DWPBA model is more economical solution having in mind the total cost of ownership and cost per household.

Nevertheless, the DWPBA-FS model should not be overlooked since it could be optimal solution for implementation in more urban environments with a large number of business customers and residential users that demand more bandwidth and more advanced services. Moreover, this model could be also deployed on per-need basis in the rural areas, when technology mature and prices of the involved components decreases.

7. ACKNOWLEDGEMENT

This work was supported by the Serbian Ministry of Education, Science and Technological Development under contract No. 171011.

REFERENCES


REZIME

TEHNOEKONOMSKA ANALIZA IMPLEMENTACIJE MREŽA SLEDEĆE GENERACIJE U RURALNIM SREDINAMA ZASNOVANA NA GEOGRAFSKIM I SOCIODEMOGRAFSKIM KARAKTERISTIKAMA SRBIJE

Ovaj rad predstavlja detaljnu tehno-ekonomsku analizu hibridnih optičko-koaksijalnih mreža (HFC) i višekanalnih Ethernet pasivnih optičkih mreža (EPON) kao dve vodeće širokopojasne tehnologije nove generacije. Fokus predstavljene studije je poređenje ove dve tehnologije u slučaju njihove implementacije u ruralnim oblastima. Pored toga, ovaj rad analizira na koji način se ove tehnologije mogu profitabilno implementirati i koji bi mogao da bude optimalan migracioni put za operatore u Evropi.

Ključne reči: HFC, Višekanalni EPON, tehno-ekonomska analiza