Techno-economic viability of integrating satellite communication in 4G networks to bridge the broadband digital divide

Asma Chiha
IDLab
Ghent University-imec
Ghent, Belgium
asma.chihaepharbi@ugent.be

Marlies Van der Wee
IDLab
imec- Ghent University
Ghent, Belgium
marlies.vanderwee@ugent.be

Sofie Verbrugge
IDLab
imec- Ghent University
Ghent, Belgium
sofie.verbrugge@ugent.be

Didier Colle
IDLab
imec- Ghent University
Ghent, Belgium
Didier.Colle@UGent.be

***Abstract*— Bridging the broadband digital divide between urban and rural areas in Europe is one of the main targets stated in the Digital Agenda for Europe. Though many solutions are proposed in literature, satellite communication has been identified as the only possible solution for remote rural areas, due to its global coverage. However, deploying an end-to-end satellite solution might be in some cases not cost-effective. In this paper, we propose a converged solution that combines satellite communication as a backhaul network with 4G as a fronthaul network to bring enhanced broadband connectivity to European rural areas. Therefore, a techno-economic model is proposed to analyze the viability of this integration. The model is based on a Total Cost of Ownership (TCO) model for 5 years, taking into account both the capital and the operational expenditures, designed for converged networks. This model aims to calculate the TCO as well as the Average Revenue Per User (ARPU) for the studied scenarios. We evaluate the suggested model by simulating a hypothetical use case for two scenarios. The first scenario is based on a radio access network connecting to the 4G core network via a satellite link. Results for this scenario show high operational costs. In order to reduce these costs, we propose a second scenario, consisting of caching the popular content on the edge to reduce the traffic carried over the satellite link. This scenario demonstrates a significant operational cost decrease (more than 57%), which also means a significant ARPU decrease.**

Keywords*— *Techno-economics, broadband digital divide, satellite, 4G

I. INTRODUCTION

While the ICT revolution continues exponentially with technologies such as Internet of Things (IoT), machine learning, block chain, etc., half of the people on earth are still without Internet connection. These disconnected users are mostly located in rural areas. On the other hand, broadband technologies and services create numerous socio-economic opportunities for users. In fact, broadband Internet is no longer seen as a comfort, but as a basic service. "Like electricity a century ago, broadband is a foundation for economic growth, job creation, global competitiveness, and a better way of life" [1]. Therefore, the public-policy focus on the Digital Divide is shifting towards broadband Internet access. In Europe specifically, only 53% of rural homes have next generation access compared to 80% of total EU households according to the European Commission [2].

Based on ITU [3], the most important global reasons for not having broadband Internet access are:

a) Internet service is not available;

b) Internet service is available but does not correspond to household needs;

c) Cost of service is too high;

d) Knowledge or skills needed to use the Internet are lacking.

Many solutions have been proposed to tackle the first reason, which is the absence of Internet infrastructure. A full wireless-based solution with the combination of WIMAX and Wi-Fi technologies was proposed in [4]. In another study, a fiber-based solution was developed to connect the rural areas in India [5]. A third suggestion was a converged optical-wireless architecture for interconnecting rural areas in Europe [6]. Though relevant from a technological perspective, these studies were focusing only on bringing the broadband connectivity to the unserved/underserved areas without taking into account the cost of the service, the third cause of not having broadband access.

It is not hard to find studies tackling these two important reasons of this gap, namely the lack of the network infrastructure and the cost of the broadband service. A techno-economic model that applies geo-based multi-objective optimization to find areas with the highest concentration of unserved/underserved users in the USA at the lowest cost to service providers was developed in [7]. A second techno-economic modelling method for choosing the adequate rural broadband access solutions was proposed by [8]. Nevertheless, these models did not take into consideration the willingness to pay of the end user, while we should bear in mind that in rural areas most of the inhabitants have a low income and the price of the service is crucial for its adoption.

Furthermore, aforementioned solutions were dealing with rural areas only from a low population density perspective. In reality, rural areas add more challenges towards choosing the right technology. Rural areas are characterised by clustered or sparse distribution of households, and their geography often consist of hard rock, mountainous or remote areas. For that reason, we suggest to use the satellite communication as a backhauling network to cope with these challenges. On the other hand, any proposed solution to bridge the broadband gap without taking into account deploying next generation networks (NGN), will rapidly be outdated and lead to deepening the digital divide between urban and rural areas even further. To this end, we choose the 4G network as an NGN technology to be deployed as a fronthaul and to provide mobile connectivity to rural inhabitants.

Within this paper, we seek a solution to provide broadband Internet access in a cost-effective way for both the network operators and the end users. To this end, we develop a techno-economic model to analyze the viability of integrating satellite communication with the 4G network to bring enhanced broadband connectivity to European rural areas.
The article proceeds by presenting the actual situation of broadband connectivity in Europe, in section II. In section III, the proposed converged satellite-4G solution is presented. Section IV highlights the cost model used in this study. A simulation of the model based on a hypothetical use case is presented in section V. The last section, section 0, summarizes the results and discusses the future work.

II. Broadband connectivity in europe

In this section, we examine the European policies towards the broadband digital divide as well as the penetration rate of this technology in European countries especially in rural areas, and we finish analyzing the price of, and demand for, the services.

A. Policies

The European Commission (EC) has adopted in September 2016 a new strategy towards its broadband program called "Connectivity for a European Gigabit Society 2025". The main targets announced in this agenda were [9]:
a) Provide gigabit connectivity for all of the main socio-economic drivers.
b) Guarantee an uninterrupted 5G coverage for all urban areas and major terrestrial transport paths.
c) Access to connectivity offering at least 100 Mbps for all European households.
The originally important investment allocated to achieve the third goal, was still insufficient, mainly because private network operators consider rural areas as a non-affordable market. Therefore, the EC has encouraged Member States to use public financing in line with European Union competition and State aid rules in order to achieve the speed, coverage and growth targets of the Europe 2025 agenda.

B. High-speed Broadband in rural areas

1) Penetration

Providing access to high-speed broadband connectivity for rural users is one of the main challenges facing the European countries to satisfy targets announced in the Digital Agenda for Europe. The rural EU average for NGA technologies, at 39.2% as presented in the figure below, continues to be considerably lower than the total NGA coverage (76.0%) [2]. However, as urban areas in previous years started to reach the saturation stage of NGA coverage, deployment should shift towards rural areas to bridge the gap.

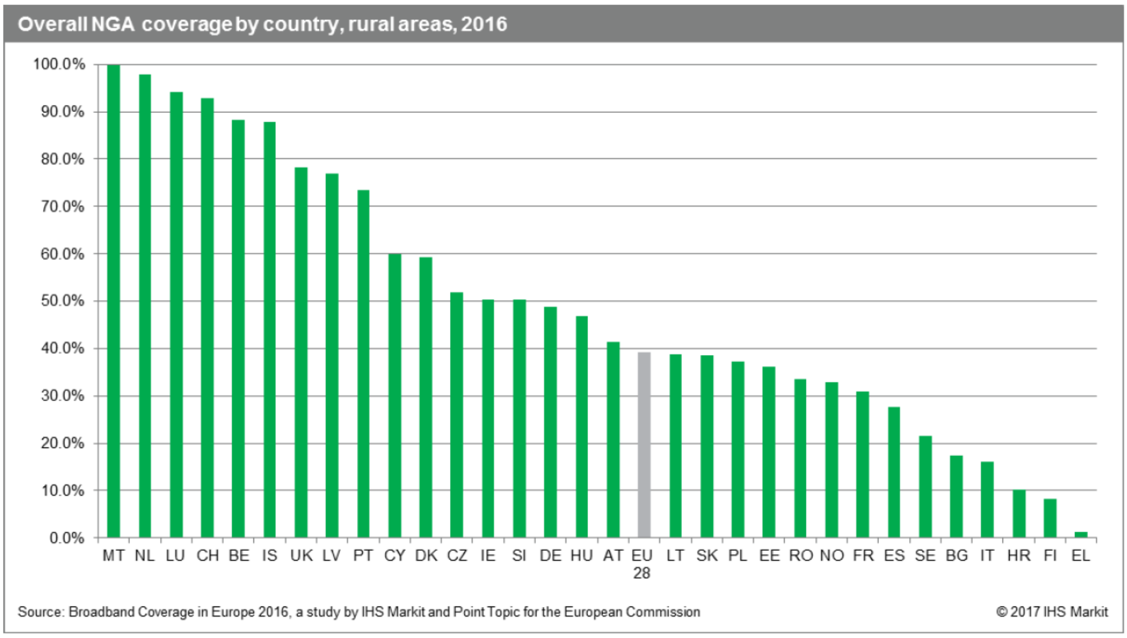

Figure 1: Overall NGA by country, rural areas 2016 [2]

As clearly shown in Figure 1, countries that rank among Europe's broadband leaders (the Netherlands and Malta) have particularly small rural populations (only 8.9% and 4.5% of the Netherlands and Malta population respectively are estimated to live in rural areas compared to 20.25% in, for example, France in 2016 [12]). As a conclusion from these results, rural areas are the main obstacle in the way of achieving the 100% of broadband coverage, and should receive more focus from operators and policymakers.

2) Demand

To reach the targeted broadband coverage, not only the network rollout should be considered but also the price of the service and the willingness to pay by the end user. According to [13], the average European price of a mobile broadband service (including 10 GB of data) is 21.77 euro per month. This price is valid for urban and rural areas. However, if we aim for a 100% of service adoption, this price should be decreased by 15% to be adopted by rural inhabitants as well as non-adopters in urban areas according to a wide survey carried out in the USA [14]. This results in a user willingness to pay of 18.5 euro per month.

To cover the European rural areas, many solutions have been proposed as presented in section I. However, designing solutions that optimizes for both technical (broadband technology) and economic (demand and willingness to pay) requirements for network deployment in unserved areas is, to the best of the authors' knowledge, not readily available in literature. In the next section, we present our solution that tries to consider both requirements.

III. Converged Satellite-Wireless architecture for interconnection of rural areas

This section presents first how satellite communication provides broadband access to remote areas, along with more technical details about the architecture.

A. Use of satellite for broadband connectivity

Using satellite for broadband connectivity has several advantages: it is the only readily available technology that has a worldwide coverage, while also being capable to provide high-speed capacity. For that reason, the EC has considered its first target, which is basic broadband for all citizens by 2013 as achieved [10]. However, using an end-to-end satellite solution may not be viable, for many reasons. First, the end users need to buy a satellite receiver (well known as VSAT) which is around 800 euro without counting the price of the installation [11]. In addition to that, the price of the broadband service itself is very expensive, about 215 euro for a volume of 7.5 GB, with a guaranteed speeds (Dl/UL) of 512 kbps/256 kbps [11] (which is way higher than the willingness to pay of the rural users (18.5 euro) presented in section II.B.2).

B. Proposed network architecture

The suggested solution takes profit of the satellite communication's global coverage and uses it as a backhaul network. In addition, the solution relies on a 4G access network, as one of the NGA technologies, to be deployed as a fronthaul network to provide broadband connectivity to the end user. The complete network solution is composed of:

1. A 4G core network that treats and processes the offered services,
2. A satellite gateway connected to the 4G core network via a fiber connection, which is responsible for forwarding the traffic from the core network to the radio access network (RAN) via a satellite link,
3. A satellite terminal installed near the RAN that receives the traffic from the satellite gateway via the satellite link and sends it to the RAN and vice versa,
4. Finally, a RAN which consists of eNodeBs (evolved Node B, i.e. mobile base stations), responsible of carrying out the traffic from the 4G core to the end user and vice versa.

The network architecture is presented as follows:

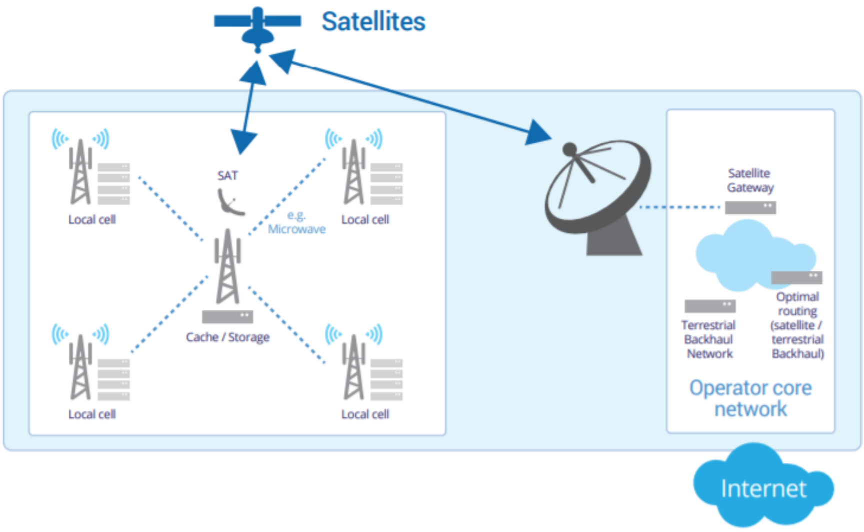

Figure 2: Network architecture of the integrated satellite-terrestrial solution [29]

To analyze the viability of the integration of satellite communication within the 4G mobile network, a cost model is defined and discussed in the next section.

IV. Cost Model

The proposed model takes into account both the Capital (CAPEX) and the Operational Expenditures (OPEX), designed for converged networks, and considers a planning horizon of 5 years. This model aims to calculate the Total Cost of Ownership (TCO) as well as the Average Revenue Per User (ARPU) for the studied scenario. In section A, we will discuss in more details the structure of the model. The mathematical formulation of the model is presented in section B. Finally, assumptions taken all along the modelling process are presented in section C.

A. Model structure

The main inputs of the model are the bill of materials (BOM), the number of users, the minimum bitrate per user, the average margin of profit of telecoms operators and the time horizon of the project. Those inputs feed into a cost model that consists of four sub-models in alignment with the network architecture components presented in the previous section. The first sub-model is designed for the edge site. It incorporates the CAPEX of the radio access network (RAN), the capex of the satellite terminal, the common capex and the OPEX of all edge components. The second one models the satellite network; both CAPEX and OPEX are taken into account. The third block builds the model of the costs for the 4G core network and the last block in the diagram englobes all overhead costs. After the calculation of the CAPEX and OPEX for all these blocks, the TCO can be derived. Hence, given the TCO as well as a margin of profit, the ARPU can be derived as an output of the model. The structure of the model is presented in Figure 3.

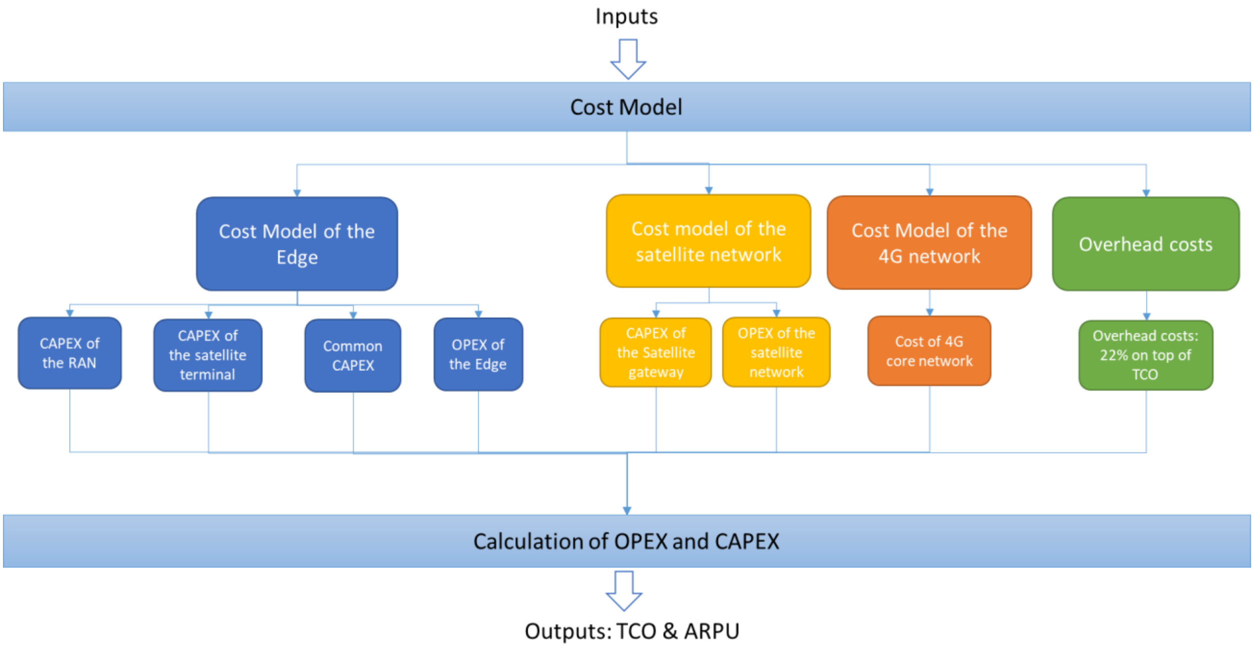

Figure 3: Model structure

B. Mathemathical formulation of the model

The previous section has presented, from a high-level perspective, the structure of the proposed cost model. In this section, we will detail each sub-model formula used to calculate both capex and OPEX parts. An overview of abbreviations can be found in Table 1.

1) Cost model of the edge site

The cost of the edge incorporates the CAPEX of the RAN, the CAPEX of the satellite terminal, the common CAPEX and the OPEX of all the edge components. The number of equipment needed depends on the dimensioning process of the site, which in turn depends on the bitrate to be provided in the site (Equation 1). The CAPEX of the RAN (Equation 3) depends on the number of eNodeBs to be deployed, which is the maximum of the number calculated based on the bitrate and the coverage area of the served site (Equation 2).

Equation 1 $$Br_s = N_u \times Br_u$$

Equation 2: $$N_{enb} = MAX(\frac{Cov_a}{Cov_{enb}}, \frac{Br_S}{Bw_{enb}})$$

$$\text{Equation 3: } Capex_{RAN} = N_{enb} \times C_{enb} + C_T$$

Furthermore, the CAPEX of the satellite terminal consists of the satellite terminal equipment, which is calculated based on its link capacity with the satellite. The common CAPEX incorporates all common capital costs needed to build the edge infrastructure. Finally, the OPEX of the edge consists of the cost of the power consumption of all the equipment as well as the maintenance costs, which is considered as 10% of the CAPEX of the overall edge costs [34].

2) *Cost model of the satellite network*

The cost model of the satellite network consists of two main parts. First, the CAPEX of the satellite gateway, which is the cost of the equipment and the building required to deploy the satellite gateway. Second the OPEX of the satellite network (Equation 5), which is the cost of the satellite capacity (Equation 4), in addition to the cost of the maintenance and the power consumption.

$$\text{Equation 4: } C_{satCapS} = (Br_S + Br_T) \times 12 \times C_{satMbps}$$

$$\text{Equation 5: } Opex_{sat} = C_{satCapS} + \left(\frac{P_{satGat}}{N} \times C_{watt}\right) + M$$

3) *Cost model of the 4G core network*

For modelling the 4G core network, an estimation of the cost of the core network per user should be made. Given this estimation in addition to the number of users, the cost of the 4G core network can be calculated. In our model, we use results found by [20], which calculate the cost of 4G core network deployed to serve 100,000 users (corresponding to about 100 base stations).

4) *Overhead costs*

In most cases, the overhead cost is defined as the cost of marketing, helpdesk, human resources, finance etc. According to [22], it is around 22% on top of the TCO.

Nomenclature	Designation	Nomenclature	Designation
$\mathbf{Br_u}$	bitrate per user	$\mathbf{H_u}$	average active hours per user
$\mathbf{Br_s}$	bitrate per site	$\mathbf{N_u}$	number of users
$\mathbf{Cov_a}$	coverage area	$\mathbf{C_{satMbps}}$	cost of 1 Mbps per month via satellite link
$\mathbf{Cov_{enb}}$	eNB coverage	$\mathbf{C_{satCapS}}$	cost of satellite capacity for a site S
$\mathbf{Bw_{enb}}$	eNB bandwidth	$\mathbf{Br_T}$	bitrate per site for traffic control and overhead
$\mathbf{N_{enb}}$	number of eNB	**M**	maintenance costs
$\mathbf{C_{enb}}$	cost of eNB	$\mathbf{P_{satGat}}$	power consumption satellite gateway per year
$\mathbf{C_T}$	cost of the tower	$\mathbf{Cs_{watt}}$	cost of energy
$\mathbf{N_s}$	number of servers	$\mathbf{N_{stg}}$	number of storage
$\mathbf{Mec_{mng}}$	cost of MEC software management	$\mathbf{C_{stg}}$	cost of storage
$\mathbf{C_s}$	cost of server	**N**	number of sites served by the satellite gateway

Table 1: Nomenclature

C. *Model assumptions*

The cost model is based on several assumptions that should be made to have as realistic results as possible:

- Hardware installation cost is 15% of the hardware costs [34].
- Maintenance cost is 10 % of the CAPEX costs [34].
- Overhead cost is 22% on top of TCO [22].
- Project horizon is 5 years.
- The average revenue per user (ARPU) is the average cost per user (ACPU) plus a profit margin of 11 % [23].

V. SIMULATION: HYPOTHETICAL USE CASE

To evaluate the proposed solution from a techno-economic point of view, we define a hypothetical use case, which will first be described. Inputs used to run the cost model are listed in the second section and finally results are analyzed in the third section.

A. Use case description

The case consists of a satellite backhaul connected to a cell tower located in a rural area in the EU covering two villages about 5km apart connected via a rural main road. The villages are home to 350 families, with an average of 3 users per home. The predominant traffic on the cell is eMBB (enhanced Mobile Broadband).

From the mathematical formulation of the model presented previously in section IV.B, we can conclude that the number of users as well as the minimum bitrate required per user are the main cost drivers of our model. First, they affect the dimensioning process, see Equation 1 and Equation 2. In addition, the OPEX costs (Equation 5) are directly driven by the bitrate per site.

In order to generate realistic results taking into account the bitrate per user cost driver, there are two ways to proceed. The first one is to forecast the average consumed mobile data traffic per user (i.e. monthly download volume) in the considered timeframe (2020-2024) and then calculate the bitrate per user that generates this amount of mobile data traffic. The second option is to set an initial average bitrate per user according to the broadband service requirement, namely 2 Mbps. We can assume that the first case corresponds to a conservative scenario and the second one to an aggressive scenario, and hereafter their description:

1) Conservative scenario

In order to have an idea about the future mobile data traffic, we refer to the well-known Cisco VNI report [28]. It forecasts that in 2021, the monthly mobile data traffic for Western Europe will be 6.5GB per user. To know the user bitrate needed to generate this amount of data we rely on the Analysis Mason data used in the BATS project report [24]. The calculation takes into account the number of hours during which the user is active, then it results that each 1GB per month corresponds to an average busy hour data rate of 7.8kbps. For our case, we have 350 families, of 3 devices each multiplied by 6.5 and by 7.8, make therefore totals of 53.2Mbps per site.

2) Aggressive scenario

In this scenario, we should stick to the EC requirements, which consider a service as a broadband if its speed is more than 2 Mbps [30], [31]. For our case, we have 350 families, of 3 users (hence 3 devices) each. If we consider that, the bitrate per household (HH) is 2 Mbps, only 80% of users are active users, and the number of active hours is 9, thus, it results in an average busy hour data rate of 210 Mbps per site.

For both scenarios, on top of the site bitrate, we might expect 10%-20% traffic and control plane overheads.

B. Model inputs

Inputs used to run the cost model are presented in the following tables. General inputs of the model for both the conservative and the aggressive scenario are described in Table 2. Table 3 contains parameters used for modelling the edge site, which consists of two parts: the RAN and the satellite terminal. Satellite network inputs as well as 4G core network are presented respectively in Table 4 and Table 5.

- **General inputs**

Parameter	Conservative scenario	Aggressive scenario
Simulation period	5 years (2020-2024)[1]	
Area	78.5 km^2 [1]	
Average busy hour data rate per site	53.2 Mbps [1]	210 Mbps [1]
Average active hours per user	9 [2]	
Active users rate (%)	80 [2]	
Cost of 1 kW	0.114 euro [17]	

Table 2: General inputs

- **Edge inputs**

Parameter	Value

[1] Use case definition

[2] These assumptions are derived based on Internet research, so may be realistic but not precise.

RAN	
Macro cell: 3 antennas, 1BBU, Software upgrades and maintenance	25-30K €
Macro cell bitrate	Maximal deployment is 5 * 3 sectors per eNB, (5*3*140= 840Mbps) [33]
building, rigging and materials (tower 10m)	10k $ [32]
Power consumption	18144 kWh par year [33]
Satellite terminal (ST)	
Cost of ST	4K $ [15]
Capacity of the satellite link/ST: Mbps	150 [15]
Satellite terminal power consumption	438 kWh per year
Air conditioning	~500 € [19]
Common power consumption: cooling etc...	30835 kWh per year
Edge maintenance	10% of CAPEX [34]

Table 3: Edge inputs

- **Satellite Network inputs**

Parameter	Value
Satellite capacity cost ($/Mbps/month)	15-7 (2020-2025) [32]
Satellite gateway infrastructure (€)	Cost of satellite gateway is included in the cost of satellite capacity
Satellite gateway power consumption	924480 kWh per year
Maintenance	10% of CAPEX [34]

Table 4: Satellite network inputs

- **4G core network inputs**

Parameter	Value
Cost of 4G core network (€)	2200K: deployed to serve 100 BS and each BS serve 1000 users [20]
Cost of 4G core per user	22 euro

Table 5: 4G core network inputs

C. Results and interpretation

1) Results for the baseline scenario

To implement our model, we rely on TESS (Techno-Economic Software Suite), a toolset developed in our techno-economic group [25] . As a first step, we simulate the proposed architecture for both the conservative, likely and the aggressive scenario based on collected inputs presented above and assumptions discussed in section IV.C.

Results of the conservative scenario and the aggressive scenario are shown below on the left-hand side and on the right-hand side respectively:

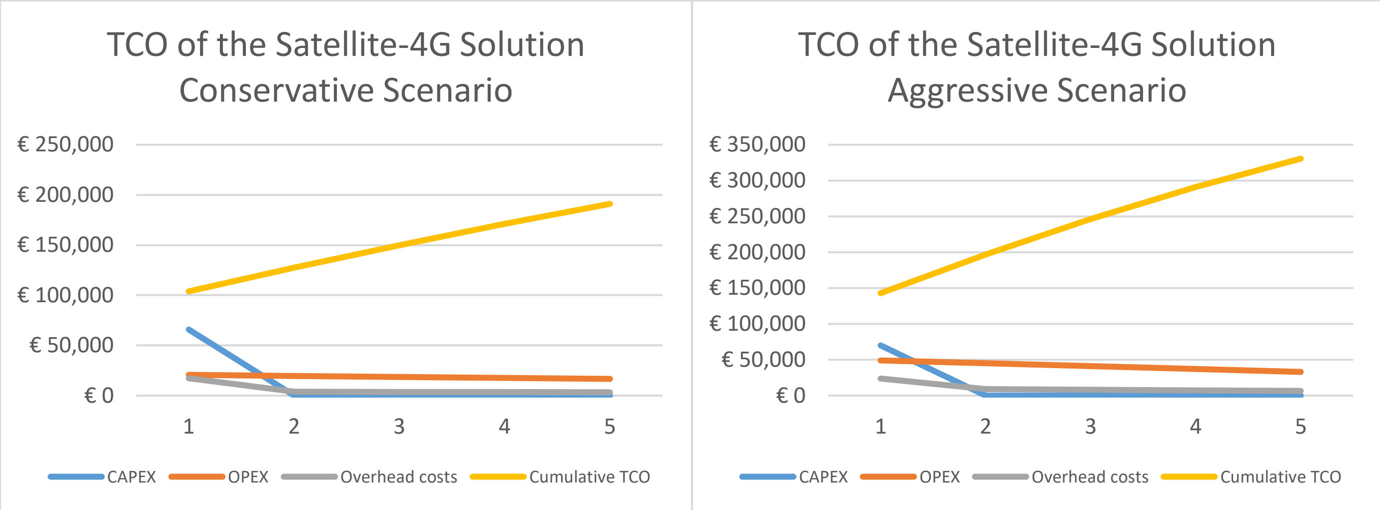

Figure 4 The total expenditures for satellite-4G solution

The monthly ARPU for the conservative for the aggressive scenarios are respectively 3.36 and 5.82. The ARPU both scenarios are not expensive comparing to the willingness to pay of the rural inhabitants (18.5 euro as discussed in section **Error! Reference source not found.**). Hence, the satellite-4G solution is viable for rural areas with a modest bitrate per user. In the view of optimizing these results, we examine the resulted cost components in more detail, we find that the OPEX costs are very high and this is due to the satellite capacity that should be paid monthly based on the traffic generated by the end users. One of the solutions proposed to decrease this cost is to cache popular content on the edge and by doing so we decrease the amount of traffic that needs to be carried out via satellite link, this solution should decrease the OPEX costs [21].

2) *Simulation with caching data on the edge:*

In the network architecture presented in Figure 2, we need to add multi edge computing (MEC) infrastructure on the edge site. The role of the MEC is to cache a percentage of the popular content locally on storages on the edge and to communicate with the base station to receive users' requests and send back the corresponding content. An intelligent algorithm is there to update the cached data according to the frequency of use and downloads of new content. In addition to changes in the network architecture of the proposed solution, there are also changes in the cost model structure (Figure 3). We need to take into account in the new model both the CAPEX and OPEX of the MEC deployment. Based on how much data can be cached on the edge, the number of storage equipment and servers required is calculated, and then the cost of the entire MEC infrastructure is derived based on the following equations:

Equation 6 $$Cost_{MEC} = capex_{MEC} + opex_{MEc}$$

Equation 7 $$capex_{MEC} = N_S \times C_S + N_{stg} \times C_{stg} + \frac{Mec_{mng}}{N}$$

The main difference between the two scenarios (without and with caching data on the edge) is the cost of the satellite capacity. Based on the rate number of user requests that will be served from the cached data R_{cd} the Equation 4 becomes Equation 8:

Equation 8 $$C_{satCaps} = ((1 - R_{cd})Br_S + Br_T) \times 12 \times C_{satMbps}$$

The model inputs related to this deployment are recapitulated in the table below:

Parameter	Value
Data Caching rate on the edge	20% - 80%: 20% of popular content will be stored and 80% of user requests are served from cached data.
Popular content volume	YouTube catalogue: 10ˆ9 MB as a total volume of popular content, which is based on 10ˆ8 MB YouTube movies, each having a size of 10MB [16]
MEC infrastructure costs: [18] • Server • TruDDR4 memory: 64 GB of RAM	~700€

• Physical storage: 10 TB of SAS disks on 14 disks • 8 vCPU at 2Ghz • Licence cost	~800€ 2800€ Free for VMWare 12k€
Management software: • 8 vCPU at 2,6Ghz, • 32 GB of RAM, • 600 GB of disk, with the licence	60 k€ to cover 50 sites 3
MEC infrastructure power consumption	3022.2 kWh per year2

Table 6: MEC inputs

When we re-run the model, while assuming that popular content is cached on the edge, results on the TCO for the conservative, likely and the aggressive scenarios are presented in Figure 5. A quick comparison between the TCO of the solution with and without caching (presented before in Figure 4), shows that the TCO with caching for the conservative scenario is slightly changed comparing the TCO without caching, and this because the amount of traffic generated is very low. However for the aggressive scenario the TCO for the scenario with caching dropped significantly comparing to the baseline scenario without caching. This comparison also shows an increase in the CAPEX costs in the case of using the cache due to the cost of the MEC infrastructure. To better compare between these two scenarios, we visualize their two OPEX costs for the aggressive scenario in the same graph, Figure 6. As a conclusion, the use of caching popular content on the edge with the assumed rate of 20% - 80% as explained in Table 6, proves a reduction of 57.9% in OPEX costs. This also generate an important decrease (35 %) in terms of ARPU. A comparison between the obtained ARPU for the aggressive and conservative scenarios for both cases with and without caching is recapitalized in Table 7.

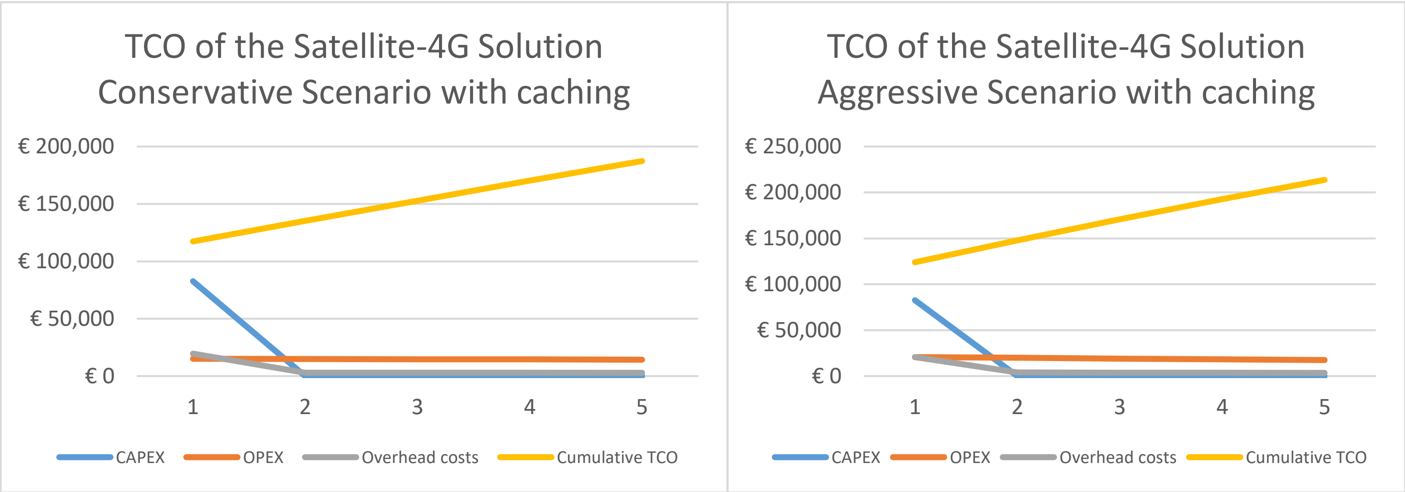

Figure 5 Total expenditures of satellite-4G solution with caching data on the edge

[3] These assumptions are derived based on Internet research, so may be realistic but not precise.

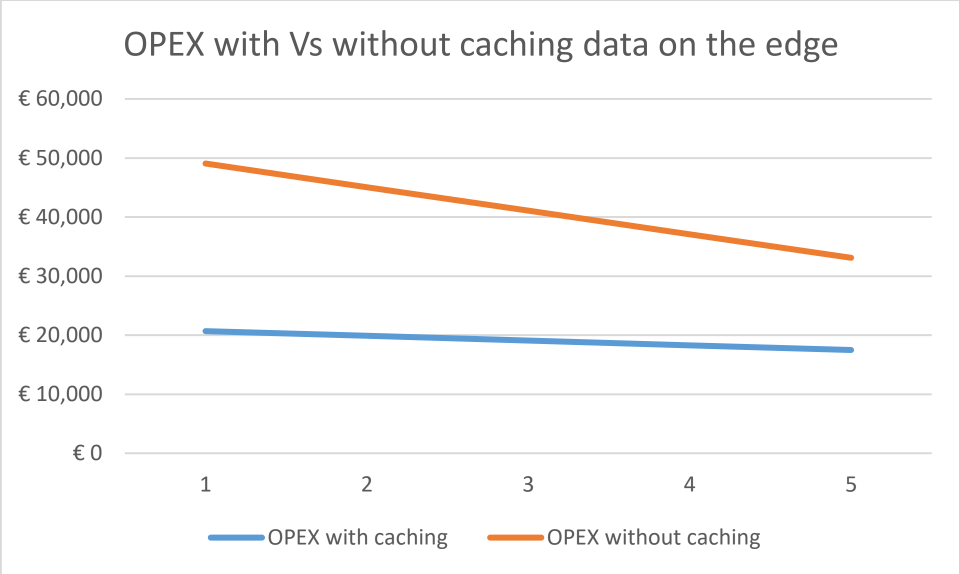

Figure 6: OPEX with Vs without caching data on the edge of the satellite-4G solution

ARPU	Conservative scenario	Aggressive scenario
Satellite-4G without caching	3.36 €	5.82 €
Satellite-4G with caching	3.30 €	3.76€
ARPU reduction rate	2%	35.5%

Table 7: ARPU with Vs without caching

As clearly shown in the table above, the use of caching technology has no significant effect on the ARPU when the bitrate per site is very low (53.2 Mbps). However, the ARPU reduction rate resulting from the use of the caching technology is more than 35% for the aggressive scenario (with a bitrate of 210 Mbps per site). In addition, the ARPU for both the conservative and the aggressive scenarios without caching are economically viable (if compared to the WTP discussed previously). Yet the ARPU for these two scenarios with the use of caching concept are very cheap. These results can give insights to the network operators on the deployment and pricing strategies that they can follow. For example, it might be that operators would start as a first step with a modest bitrate per user in order to provide basic Internet connectivity to these unserved areas (white areas) in the EU. By choosing the right margin of profit, operators can move forward smoothly to the aggressive scenario as a second step and finally to a good bitrate per user. Therefore, thanks to the use of the satellite communication as a backhauling network and the use of 4G networks as a fronthaul with the deployment of the caching technology, white areas are no longer a non-affordable market for the basic Internet service.

However, if the mobile operators want to offer full 4G speed for the end user, meaning 50 Mbps dedicated per user, the required ARPU without the use of caching is 271 euro, with caching data on the edge 73 euro. Hence, the ARPU reduction rate in this case is 72%. However, in both cases the ARPU remains very expensive comparing to the willingness to pay of the end user, namely 18 euro. The situation becomes worse if the operators aim to stick to the EC requirement for broadband services in term of speed (i.e. the Gigabit Society 2025, the required bitrate per user is at least 100 Mbps), then the required ARPU will be definitely be too high for the end user (540 euro without caching and 144 euro with caching). In this case, they should either opt for receiving subsidies from the government in alignment with the Digital Agenda suggestions or decrease the cost of the satellite capacity.

If none of possibilities aforementioned is achievable, we should bear in mind that offering broadband in rural areas will not only provide Internet connectivity to the citizens, but also open up opportunities for new and different services, such as tech-agriculture, farm business, e-services etc. This means new sources of benefits for the operators, which could make the use case more cost-effective than when providing only the Internet service. Offering diverse services could be more cost-efficient with the deployment of network slicing within the upcoming 5G networks due to the virtualization of network functions.

VI. CONCLUSION AND FUTURE WORK

In this paper, we proposed a cost model to study the feasibility of integrating satellite communications within the 4G mobile network to bridge the broadband gap in rural Europe. Results of this modelling approach shows that thanks to integrating satellite communication into 4G networks the basic Internet service can be provided to the white areas for an affordable price comparing to the WTP of remote areas inhabitants. These results are also able to give both the mobile and the satellite operators an overview of the feasibility of the proposed solution, and provide insights on the most cost-effective solution. Our results show that caching popular content on the edge can save significant OPEX costs and thus decrease the required ARPU based on the bitrate per site provided (57% of reduction in the case of the aggressive scenario, 210 Mbps). Results for conservative and aggressive scenarios can guide operators to fix good strategies for the deployment of broadband services in rural areas in such a way that guarantees both the service adoption by the rural inhabitants and to generate good revenues.

As the scenarios used in this paper only provide limited bandwidth, and as the evolution towards 5G (including virtualization and network slicing) opens up opportunities for service diversification and larger throughputs, we aim to model, as future work, the use of network slicing besides caching data locally on the edge, to prove its cost-efficiency towards the satellite use cases for enhanced mobile broadband (eMBB) [28]. Furthermore, the model suggested in this paper restricts on the cost part for 5 years, our intention in the future is to expand it to a cost-benefit model for 10 years to give insights to both mobile and satellite operators about the revenues of this solution.

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