Assessment of CAPEX and OPEX for Media Services in Cloud Enabled 5G Networks

Ioannis Neokosmidis,
Theodoros Rokkas

Incites Consulting
Strassen, Luxembourg
i.neokosmidis@incites.eu
trokkas@incites.eu

Pietro Paglierani,
Claudio Meani

Italtel
Milan, Italy
pietro.paglierani@italtel.com
claudio.meani@italtel.com

Karim M. Nasr,
Klaus Moessner

University of Surrey
Guildford, UK
k.nasr@surrey.ac.uk
k.moessner@surrey.ac.uk

Pouria S. Khodashenas

i2CAT foundation
Barcelona, Spain
pouria.khodashenas@i2cat.net

***Abstract*—A techno economic analysis for a C-RAN architecture in a Crowded Events (CE) offering immersive video services is presented. The analysis shows that investments for an IVS in CE relying on edge cloud resources are viable with an expected payback period of 6.5 years.**

***Index Terms*— Techno economic analysis, Immersive video services (IVS), Small cells (SC), Network planning, 5G, Cloud-enabled radio access networks (C-RAN).**

I. INTRODUCTION

FUTURE 5G networks promise a ubiquitous solution featuring aspects like extremely high data rates and capacities, multi-tenancy, convergence of fixed and wireless access networks, unconventional resource virtualization, on-demand service-oriented resource allocation and automated management [1]. These aspects call for a fundamental change in the telecommunication network infrastructures, shifting them from conventional data transport means to intelligent entities equipped with IT assets relying on compute and storage resources. Radio Access Networks (RAN) are an important part of the 5G PPP vision and have recently witnessed significant changes towards higher network capacities and flexibility. Network Function Virtualization (NFV) [2] and Software Defined Networking (SDN) [3] are two fundamental technologies that enable the exploitation of embedded resources at the mobile network's edge to offer added value services.

The capabilities offered by a C-RAN establish an excellent foundation to create new business opportunities for 5G vertical sectors. Among these sectors, innovative media (*e.g.* immersive and augmented reality video services) have gained a considerable interest recently. Despite successful technical demonstrations, clear economic incentives are needed to justify proper investments in a technology of interest. Factors including capital and operating costs (CAPEX / OPEX) as well as revenue generation potentials ultimately determine the viability of a solution to be deployed.

We present in this paper a techno economic assessment of IVS based on a Cloud-Enabled Small Cell infrastructure as proposed SESAME project [4]. The presented study assumes the natural interest of end users to upgrade their services over time. The paper is organized as follows: we first introduce the study framework in Section II. Section III presents the IVS technical details as an example of an innovative media service in 5G networks. In Section IV, the planning study is presented. Section V details the techno-economic analysis used in this study. Example results are presented in Section VI. Section VII concludes the paper and provides an outlook for investors.

II. THE STUDY FRAMEWORK

The main focus of this study is sporadic crowded event (CE) venues like a sport stadium or a concert hall. These venues are mainly characterized by their area and number of attendees. Fig. 1 shows an illustration of such a venue where a SESAME C-RAN has been deployed to offer connectivity and edge computing capabilities following the Neutral Host business model proposed by 5GCity project [5]. A Cloud-Enabled Small Cell (CESC) [4] is an enhanced SC that integrates a virtualised execution platform (micro server) equipped with IT resources (RAM, CPU, storage). Assuming CESC clustering, a distributed data centre, referred to as Light Data Centre (Light DC), can be created aiming to enhance the virtualisation capabilities and processing power at the network's edge. The technology used to link CESCs to a Light DC may vary from a wired to a wireless solution depending on the use case and scenario. The used clustering technology should be able to preserve the Quality of Service / Experience (QoS / QoE) to meet 5G performance targets such as ultra-low latency and high data rate requirements.

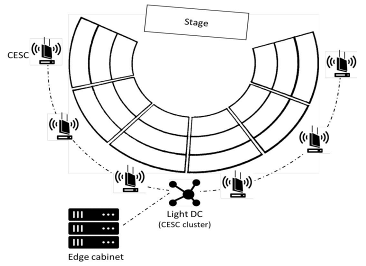


Fig. 1 Illustration of the case study framework

To enable multi tenancy and edge computing capabilities following the SESAME approach, it is essential to meet two main requirements:

- An adequate radio coverage at the event venue to support blocking free connectivity;
- Sufficient IT resources at the Light DC to run the needed SC Virtual Network Function (VNF). The VNF enables multi tenancy and utilization of edge

computing capabilities.

To offer innovative services at the network's edge, it is essential to enhance the Light DC by co-allocating an edge cabinet with extra IT resources and Hardware Accelerators (HWA) such as: Graphics Processing Units (GPU), Digital Signal Processors (DSP), and/or Field-Programmable Gate Arrays (FPGA), which can run the highly compute intensive workloads typically originated by media processing functionalities. We also assume that whenever extra IT resources and/or HWA are needed, they will be placed at the edge cabinet. In addition to conventional voice and data connectivity using the multi-tenant SESAME architecture, we consider in this study, IVS as an example of a 5G media service. We define three service bundles named bronze, silver and glold allowing different Service Level Agreements (SLA) with IVS as shown in Table I.

Another parameter of high importance is the share between the different bundles. This helps us to model the dynamic behaviour of end users over time. It is expected that an evolution in the end users' consumption profile will occur as 5G technology matures. Such a service penetration model will be used in section V for the techno-economic study.

III. INNOVATIVE MEDIA SERVICES

The 5G media sector is witnessing the emergence of many innovative services. In particular, the provision of IVS in Crowded Events (CE) is one of the most attractive cases under development by many important industrial players. Well-known examples are sport events or concerts in stadiums, concerts, exhibitions and international events spread over a university campus or in some cases an entire city. IVS enables the possibility of sharing HD video contents, anywhere, at any time and via any device, with the opportunity of (perceived) real-time interaction with the system and among users. In addition to traditional video content delivery systems in which users only play the role of content consumers, the IVS considered in this paper also offers the possibility to create and share video contents in real-time, within a pre-defined group of peers.

TABLE I
USERS AND TARGET DATA RATES

Service bundle	Data rate per user	Tariff (€/event)	Applications
Gold	7 Mbps	1	voice, text, images, streaming HD video
Silver	1.7 Mbps	0.5	voice, text, images, streaming SD video
Bronze	0.5 Mbps	0.25	voice, text, images and compressed video

To achieve IVS in a CE, the network infrastructure has to overcome several challenges namely: the high density of user devices (more than tens of thousands per km^2), high data-rates to enable HD video streaming (at least 7 Mbps per user) and low latencies (in the range 10-50 ms) to guarantee the expected level of perceptual quality and user experience (QoS/QoE). Moreover, HD video services require large IT resources, both in terms of compute and storage capabilities at the network's edge. Leveraging mobile edge computing capabilities and the potential offered by NFV and SDN, the C-RAN solution proposed by SESAME is well suited to cope with IVS requirements. It provides an infrastructure able to host IVS closer than ever to the end user.

A. *The IVS Provisioning Framework*

A simplified scheme of the overall framework for IVS provisioning is shown in Fig 2. The service is accessible from any browser through a web-service-based interface, or through an App, running on end-users' devices. This way, CE participants can register to the service and create ad-hoc groups of peers with other selected users. Within a group, peers can share live video streams through a Video Transcoding Unit (VTU) which is a VNF. In particular, a user can stream in real-time a created video content to the VTU or upload it as a pre-recorded file. Any other user in the group can concurrently receive this live content or access it offline at a later time. The VTU saves any created video sequence on a distributed storage system dedicated to a group of peers for successive content production and sharing. A common storage location is also dedicated to event managers to insert contents, e.g. event related information or advertisements, which will be offered to all users, thus bypassing group constraints.

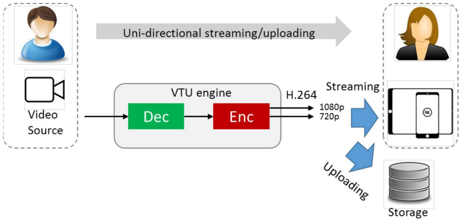


Fig. 2: Basic VTU model

Each received video file or live stream is processed by the VTU to obtain copies at different resolutions to match the various media capabilities of users' devices. The output files at the desired resolutions are finally stored in a distributed storage system ready for immediate streaming on demand. Moreover, the format of a live stream can be adjusted if the contents are shared in real-time between devices with different media capabilities. In this way, the IVS guarantees content accessibility by any registered device in a group.

Transcoding of video files and live streams is by far the most used and the most compute intensive workload executed by the VTU. Therefore, in the following we will focus on video transcoding functions only, which are the main consumers of IT compute resources.

B. *The VTU Model*

Generally speaking, the derived VTU model in this section is essential for IT resource dimensioning which is the focus of the following section. It is worth noting that we considered two operational modes for the VTU in this study, namely 1) off-line video transcoding process and 2) on-line transcoding for live streaming. Further details of each mode will be presented below.

1) *Off-line Video Transcoding*

The inputs to the VTU off-line video transcoding process are video contents produced by users and sent to the VTU as data files. This situation can frequently arise, for instance, in the case of CEs spread over an entire city or in a large venue where IVS are provided only at certain specific locations of interest, so that a video content produced elsewhere must be recorded, and then shared at a later time. This case also arises whenever a user decides to share the content after its production though having the possibility to access IVS while creating it.

For the purpose of the analysis of the off-line transcoding process, we model each single CE participant enabled to IVS as a video-data file generator, with a rate equal to λ_0 File per second (Fps). The superposition of video-file arrivals at the VTU can then be described as a single Poisson process with parameter $\lambda = N\lambda_0$, where N is the total number of users served by a specific VTU instance. For the sake of simplicity, we will also assume that all video contents are originated at the same frame rate. Moreover, we will make no assumptions related to the statistical distribution of the video-sequence duration (expressed in frames), except assuming that its mean is equal to N_{FILE} frames. Once an input video-data file is received, the VTU immediately starts a multiple transcoding session, consisting of n single-transcoding processes running in parallel, one for each of the target video resolutions. The VTU output is a set of n compressed video sequences at the desired resolutions obtained from the input file and saved in the VTU distributed storage system and ready for on demand transmission.

We assume that the ITU-T H.264 standard is adopted for video compression, and that n = 2 video resolutions are used, namely 720p and 1080p, corresponding to medium and high definition (HD) qualities respectively. Encoding is the most computationally intensive task as verified in [4]. For dimensioning purposes, each single-transcoding process can be effectively characterized by one parameter, namely its transcoding rate, expressed in frames per second (fps), independent of the input sequence format. The transcoding rate assumes a different value for each target resolution. Such values will be indicated as $\mu 0$ and $\mu 1$, and represent the transcoding rates achieved when processing the medium and high resolution contents, respectively. The VTU performance depends on the overall service rate μ of the multiple transcoding process.

The overall service rate can be written as:

$$\mu = \mu 0 \, \mu 1 \, / \, (\mu 0 + \mu 1) \quad \text{in fps} \tag{1}$$

and the overall service rate in Fps can be obtained as:

$$\mu_F = \mu \, / \, N_{FILE} \quad \text{in Fps} \tag{2}$$

Any received video data file is immediately processed by the VTU. In practice, however, the number of concurrent transcoding processes is limited by the amount of RAM assigned to the VTU. Thanks to the advantages offered by the SESAME C-RAN architecture, it is possible to instantiate several parallel VTUs and balance the load among them. Therefore, instead of having one VTU instance serving all the incoming files, a set of instances will be working together to serve end user requests. In cloud terminology, the process of having multiple VNF instances serving a single type of service is called scaling [7]. Having more VNF instances will result in more hardware resources and this is exactly how the change in the consumption behavior of end users affects capital costs (CAPEX). The derived model in this study is based on real life tests with a VNF running using a system with an eight core Intel Xeon CPU accelerated by an Nvidia M4000 Graphics Processor Unit (GPU) entirely dedicated to provide IVS [8].

2) *On-line Transcoding of Live Streams*

To analyze the live streaming case, we model each participant in a CE as a generator of live streams towards the VTU with rate equal to $\gamma 0$ streams per second and with an average duration equal to T seconds. The VTU can forward the received stream in real-time to all the other users in the group wishing to receive it through an ad hoc notification mechanism.

For the sake of simplicity, we assume that all video streams sent by the end users to the VTU are in HD format. Therefore, the VTU must only perform one real-time transcoding operation to adjust the resolution from HD to medium resolution (which is the interest of a silver bundle subscriber). Assuming that a single instance of the VTU can provide a transcoding rate from high to medium resolution with $\mu 1$ of 700 fps (as will be discussed in the following section) and that the frame rate at which video contents are created is $f0=25$ fps. Then, one VTU instance can perform up to $\mu 1/f0 = 28$ concurrent on-line transcoding sessions. If N VTUs are deployed, the maximum number M of available concurrent sessions is:

$$M=N \, \mu 1/f0 \tag{3}$$

This means that for every 28 concurrent online transcoding sessions, a dedicated VTU VNF is needed to guarantee a blocking free service as assumed in this study. Such a blocking free performance is at the expense of extra hardware resources mounted at the edge cabinet.

IV. PLANNING STUDY

The planning study intended to calculate the needed radio and IT resources to guarantee adequate service provisioning in an CE venue with an average number of attendees per event.

A. *Radio Planning*

To determine the number of SCs needed for a particular venue, two main factors are considered for radio planning purposes: 1) the maximum data rate that can be supported by a SC and 2) the coverage area of a SC. The current 4G LTE-A standard allows a maximum downlink data rate of 403 Mbps. However, as 5G technology matures aggregated downlink data rates of more than 1 Gbps are expected. For the purpose of the planning study in this paper, we are assuming a downlink scenario and a typical coverage area of 800 m^2 per SC. The radio planning strategy relies on calculating the minimum number of needed SC based on the largest figure obtained after considering the aggregate data rate of users in the venue and the coverage area per SC. In other words, it follows a worst-case planning strategy. Assuming the number of Gold, Silver and Bronze users to be U_G, U_S and U_B and the corresponding data rate per user to be D_G, D_S and D_B, then the aggregate data rate D_{tot} can be written as:

$$D_{tot} = (U_G \times D_G) + (U_S \times D_S) + (U_B \times D_B) \qquad (4)$$

If the maximum data rate supported by a SC is D_{sc}, then the number of needed SCs N_{SCd} using the data rate based design can be calculated as:

$$N_{SCd} = \text{round}\ (D_{tot} / D_{sc}) \qquad (5)$$

Assuming the area of the venue to be A and the coverage area of a SC to be A_{sc}, then the number of needed SCs N_{SCa} based on the coverage area design can be calculated as:

$$N_{SCa} = \text{round}\ (A / A_{sc}) \qquad (6)$$

In some cases, a single SC can only support a maximum number of users U_{max} (e.g. 128) irrespective of the individual data rate. This adds an additional constraint to the radio planning design and can eventually increase the number of needed SCs. If this is taken into consideration then the needed number of SCs N_{SCu} can be estimated as:

$$N_{SCu} = \text{round}\ (U / U_{max}) \qquad (7)$$

Finally, the number of needed SCs, Nsc can be obtained as:

$$N_{SC} = \text{maximum}\ (N_{SCd}, N_{SCa}, N_{SCu}) \qquad (8)$$

B. *IT Resource Planning*

In addition to radio planning, to offer different service bundles using a SESAME capable infrastructure, IT resources are needed. We assume that for each 128 users (the typical number of users supported by a single SC), an SC VNF should run at the Light DC. The required IT resources for a single SC VNF: $UR_{SC\ VNF}$ is a set of 2 CPU cores, 4 GB of RAM and 2 GB of HDD storage [8]. Therefore, the total required resources (R_{total}) to provide the basic service in a venue with N number of attendees is calculated as follows:

$$R_{total} = \text{round}\ (N / U_{max}) \times UR_{SC\ VNF} \qquad (9)$$

The calculated resources using (9) are placed at the Light DC as discussed previously. However to offer IVS, some extra resources are installed at the edge cabinet. The dimensioning of IT resources for IVS is presented below.

The bronze service bundle discus provides the users with standard voice services and data connectivity, without any added value IVS capability.

It is not possible to know in advance who will access a given content. Each received video file needs to be therefore processed by the VTU off-line multi-transcoding task to obtain all the possible resolutions. We assume that users create video-data files with parameter λ_0 = 5 x10e-4 and 7x 10e-4 Fps for Silver and Gold users respectively. We also assume that the average number of frames of the sent files is equal to 1000. Our experiments show that the VTU transcoding rates are $\mu 0$ and $\mu 1$ are 400 fps and 700 fps respectively. In this case, the service rate μ is 255 fps. The time D0 needed to transcode the average 1000 frame-file is $1/\mu F$ = 3.9 s. D0 can also be viewed as the minimum delay introduced by the VTU process when only one file is present in the system. When multiple files are concurrently processed, the delay D introduced by the VTU increases in comparison to D0. To guarantee an adequate level of user experience, such delay should be kept as low as possible. The average delay introduced by the VTU, i.e. the time between a video file arrival and the availability of the two output files at medium and high resolution, can be expressed as:

$$E[D] = 1/(\mu_F - \lambda), \qquad (10)$$

where E[.] is the expectation operator. To meet the delay requirements, we will put the constraint $E[D] \leq D_E$, where D_E is the expected average delay introduced by the VTU. The maximum number N of users served by one instance of the VTU, such that the constraint $E[D] \leq D_E$ is satisfied, can be evaluated as follows:

$$N(D_E) \leq (D_E\ \mu_F - 1) / (D_E \lambda_0). \qquad (11)$$

Using (11) with D_E equal to 5s, μF = 0.255 and $\lambda 0$ = 5x10e-4, then the number N of users served by one VTU instance is 110. However, if we increase D_E to 10s, N becomes 310. Further relaxing D_E to 15s or 20s provides values of N equal to 376 and 410 respectively. If the resources assigned to Gold and Silver users are separate, (11) can be used with different values of expected delay D_E to obtain different values for a gold user: N_G (D_{EG}) or a silver user: N_S (D_{ES}).

If the number of silver and gold users is U_S and U_G respectively, then the minimum number M_{VTU} of VTU needed to provide IVS services during a CE is:

$$M_{VTUOFF} = \textit{round}\ [(U_G / N_G(D_{EG}) + U_S / N_S(D_{ES}))], \qquad (12)$$

where $N_G(D_{EG})$, $N_S(D_{ES})$ are obtained using (11).

Once the number of servers has been obtained using (12), the RAM needed by each server for the off-line video transcoding function can be calculated. To this end, we first need to calculate the probability in the steady state, that i video files are being processed by the VTU. This can be written as:

$$\pi_i = \rho^i\ (1-\rho) \qquad (13)$$

where $\rho = \lambda/\mu_F$. If we now set the probability π_i to an arbitrarily low value, *e.g.* 10e-5, it is possible to obtain the corresponding number of concurrent files processed by the VTU as:

$$i = [\log(\pi_i) - \log(1-\rho)] / \log(\rho). \qquad (14)$$

with π_i value of 10e-5, N of 326 and using the above values for the other parameters, one can easily verify that the number of concurrently processed files i is 25. It has been verified that one instance of the VTU, with no transcoding sessions active, requires approximately 6 GB of RAM, and each multiple transcoding session requires 0.5 GB of RAM. As an example, the minimum quantity of RAM required to process 25 files concurrently is 18.5GB using the following equation:

$$\text{RAM (in GB)} = 0.5\, i + 6 \qquad (15)$$

The above analysis allows us to obtain the IT resources needed for the off-line transcoding of video contents. For the on-line transcoding process, an extra parameter namely the blocking probability E_m is needed to evaluate the resources in addition to the above presented analysis. The blocking probability is the probability that a user requiring transcoding finds all m resources already occupied. This blocking probability can be obtained using the well-known Erlang-B formula. A simple iterative way to evaluate the Erlang-B formula is as follows:

$$E_m = 1/I_m;\ I_m = 1+(m/A)I_{m-1};\ \ m=1,2,\ldots,M \qquad (16)$$

where E_m is the blocking probability, $A = N\, \gamma_0 T$ is the offered traffic stated in Erlang, m is the number of identical parallel resources and the iteration initial values are $E_0=1$ and $I_0=1/ E_0$ [9]. Finally, to estimate the storage requirements for IVS, we assume that the average duration of the video sequences originated by the users is equal to T seconds and that the data rates assigned to Silver and Gold users are equal to bS and bG bit per second respectively. Then, if the overall duration of the event is equal to Te, the needed storage capacity in bits is:

$$C= (\gamma 0+ \lambda 0)\ Te\ UG\ bG + US\ bS)\ T \qquad (17)$$

V. TECHNO ECONOMIC ANALYSIS

A. Methodology and Tools

The techno-economic methodology used for the assessment of 5G investments is based on the research made within TONIC and ECOSYS projects. The methodology and tools produced by these projects have already been adopted in numerous similar studies [10][11]. The core part of these models is in a database, which is regularly updated with network components, data collected from the largest European telecommunication companies and vendors as well as from benchmarks from the telecom market [10][12]. The study period is always adapted to the case under investigation. For the case of a 5G network deployment and considering the time a network or a service needs to reach market maturity to pay back investments, an eight to ten-year period is reasonable. The list of provided services is defined and their market penetration over the study period is calculated. Moreover, econometric and price forecast models are used to define service tariffs. By combining market penetration and tariffs, the received revenues for each service can be calculated.

To calculate the expenditures, the selected topology and the dimensioning rules for radio and IT resources described in the previous sections are used. It should be also noted that alternative topologies and rules could be easily incorporated in the tool. The output of the so-called "architecture scenario definition" is a shopping list containing all the required network elements (equipment, cables, racks, installation, etc.). To calculate the number of network components required throughout the study period, demand forecasting is carried out using existing methodologies and market data as shown in the following section. CAPEX is then calculated by combining the required number of components and their price for each year. A price evolution is calculated for all network components using the extended learning curve model [13]. Maintenance costs consist of two parts: 1) the cost of repair, calculated as a fixed percentage of the total investments in network elements and 2) the cost of repair work, calculated based on the mean time between failures (MTBF) and the mean time to repair (MTTR). Operating expenditures (OPEX) are also calculated in the techno-economic tool. For example, energy costs are evaluated based on the power consumption of components and the average cost of one kWh [14]. It should be highlighted that for the investigated CE case, it is assumed that network equipment is only used during the event and switched-off before and after the event. By combining service revenues, investments, operating costs and general economic inputs (e.g., discount rate, tax rate), the tool calculates the results necessary for Discounted Cash Flow (DCF) analysis such as cash flows, Net Present Value (NPV), Internal Rate of Return (IRR), payback period and other economic figures of merit. More details on the methodology are presented in [10].

B. Demand Forecasting

To forecast both the demand for subscriptions and the penetration of services, a four-parameter logistic model is used. This model is recommended for long-term forecasts and for new services and is used for both fixed and mobile networks [15].

$$Y_t = M / (1 + e^{a + bt})^c \qquad (18)$$

where Y_t is the actual or forecasted demand at time t as a population percentage; M is the demand saturation level as a population percentage; t is the time in years; and a, b, and c are diffusion parameters that can be estimated by a regression analysis using existing market data.

VI. RESULTS AND DISCUSSION

The selected study period is set to 10 years beginning in 2020 (the expected year of 5G introduction) and ending in 2029. The discount rate is assumed to be 10% while taxes are equal to 20%. It is also assumed that three mobile operators, with market shares of 50%, 30% and 20% respectively, have an agreement to access the small cells operators' network.

By combining market insights and 4G historical data along with (18), 5G demand is derived as shown in Fig 3a. The demand for 5G services is expected to grow much faster than that of 4G due to the provided advanced services and the higher number of heterogeneous devices to be supported.

The penetration for each service bundle is modeled using (18) under the following assumptions. During the first years when 5G services are introduced, the preferred packet will be the bronze bundle offering basic connectivity. However, for the following years, silver and gold bundles will prevail and will attract and increasing number of subscribers. Customers will be willing to pay higher subscriptions thanks to new innovative services and applications that will be available only to these bundles as illustrated in Fig. 3b.

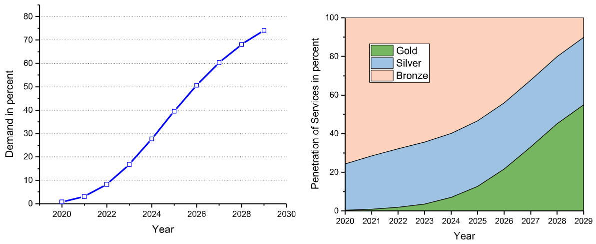


Fig. 3 a) 5G demand [Source: INCITES], b) Services penetration forecast

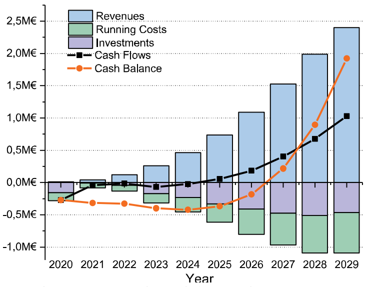
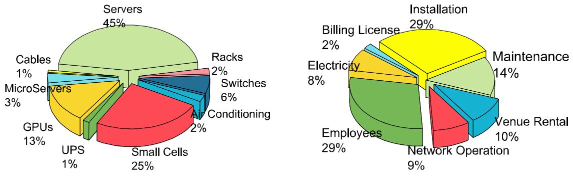


Fig. 4 Economics of the 5G investment

The basic economic indices are presented in Fig. 4 for a CE case in a stadium. The first observation is that the balance is initially negative. This is the usual case for telecom investments and can be attributed to the required high initial investments of the first years to actually deploy the network together with the relatively lower demand for 5G services. However, as the demand for 5G increases, the revenues increase making the investment profitable within the study period. Our calculations show that the payback period for the studied investment is expected to be approximately 6.5 years with an IRR equal to 27% and a NPV of ~705 k€.



(a) (b)

Fig. 5: Breakdown of (a) Investments and (b) Running Costs

To have a better insight of the expenditures, a breakdown of Investments and Running Costs (OPEX) for the whole project is illustrated in Fig 5. Regarding investments, it can be concluded that the major contributors to cost are: 1) servers (44.9%), 2) small cells (25.1%) and 3) GPUs (13.5%) that are used to accelerate video transcoding. It should also be highlighted that the analysis revealed that the cost contribution of micro servers is low (3%). This is in line with current trends of using general-purpose cost-effective servers (micro servers) to provide basic connectivity. The costs related to installations and employees are dominant and are equal to 58% of the total OPEX. Moreover, the need for revenues to make such an investment profitable should be highlighted. In this study, we assumed that the access fee should be paid by either mobile operators or venue owners to attract more attendees/subscribers. Alternatively or complementarily, revenues can be generated through advertising agencies.

VII. CONCLUSIONS

We presented in this paper a techno economic analysis to explore the viability of deploying IVS in future 5G networks. Our analysis shows that an investment needs approximately 6.5 years to reach a breakeven point. Considering the effective functional period of telecom infrastructures which is 15 to 20 years, the return on investment happens at a relatively reasonable point making it profitable.

ACKNOWLEDGMENT

The research leading to these results has been supported by H2020 5G-PPP SESAME (no. 671596) and 5GCity (no. 761508) projects

REFERENCES

[1] E. Hossein and M. Hassan, “5G Cellular: Key Enabling Technologies and Research Challenges” IEEE Instrumentation and Measurement Magazine, June 2015

[2] ETSI NFV white paper, “Network Function Virtualisation: An Introduction, Benefits, Enablers, Challenges and Call for Action,” (2012).

[3] R. Jain, S. Paul, “Network Virtualization and Software Defined Networking for Cloud Computing – A Survey,” IEEE Comm. Mag., vol. 51, no. 11, pp 24-31, (2013).

[4] I. Giannoulakis, et al., “The Emergence of Operator-neutral Small Cells as a Strong Case for Cloud Computing at the Mobile Edge,” Transactions on Emerging Telecommunications Technologies, vol. 27, no. 9, pp. 1152–1159.

[5] https://www.5gcity.eu/

[6] T. Wiegand, G. J. Sullivan, G. Bjontegaard, A. Luthra, "Overview of the H.264/AVC video coding standard," in IEEE Transactions on Circuits and Systems for Video Technology, vol. 13, no. 7, pp. 560-576, July 2003.

[7] “NFV Management and Orchestration - An Overview”, GS NFV-MAN 001 V1.1.1, ETSI 2014.

[8] SESAME D4.4 “Light DC Prototype”, June 2017, http://www.sesame-h2020-5g-ppp.eu/Deliverables.aspx

[9] M. Zukerman, "Introduction to Queueing Theory and Stochastic Teletraffic Models," [Available at: https://arxiv.org/pdf/1307.2968.pdf]

[10] T. Monath, N. K. Elnegaard, P. Cadro, D. Katsianis, and D. Varoutas, “Economics of fixed broadband access network strategies,” IEEE Commun. Mag., vol. 41, no. 9, pp. 132–139, Sept. 2003.

[11] T. Rokkas, T. Kamalakis, D. Katsianis, D. Varoutas, and T. Sphicopoulos, “Business prospects of wide-scale deployment of free space optical technology as a last-mile solution: a technoeconomic evaluation,” J. Opt. Netw., vol. 6, no. 7, pp. 860–870, July 2007.

[12] D. Katsianis, I. Welling, M. Ylonen, D. Varoutas, T. Sphicopoulos, N. K. Elnegaard, B. T. Olsen, and L. Budry, “The financial perspective of the mobile networks in Europe,” IEEE Pers. Commun., vol. 8, no. 6, pp. 58–64, Dec. 2001.

[13] L. Ims, “Broadband access networks introduction strategies and techno-economic evaluation,” in Telecommunication Technology and Applications, New York: Chapman & Hall, 1998.

[14] http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_price_statistics

[15] C. Michalakelis, D. Varoutas, and T. Sphicopoulos, “Diffusion models of mobile telephony in Greece,” Telecommun. Policy, vol. 32, no. 3–4, pp. 234–245, Apr.–May. 2008.