Techno-Economic Aspects of 5G Transport Network Deployments

I. Mesogiti[1](✉), E. Theodoropoulou[1], G. Lyberopoulos[1], F. Setaki[1], K. Filis[1], A. Di Giglio[2], A. Percelsi[2], and Anna Tzanakaki[3]

[1] COSMOTE Mobile Telecommunications S.A., Athens, Greece
{imesogiti,etheodorop,glimperop,fsetaki,cfilis}@cosmote.gr
[2] Telecom Italia, Turin, Italy
{andrea.digiglio,alessandro.percelsi}@telecomitalia.it
[3] University of Bristol, Bristol, UK
anna.tzanakaki@bristol.ac.uk

Abstract. 5G networks will comprise multiple, versatile infrastructures at finest granularity consisting of multiple disaggregated pools of network, compute and storage resources. To support the 5G network architectures and satisfy the access network demanding performance requirements, transport networks consisting of various converging technologies shall provide mechanisms to support deployment flexibility and scalability. The deployment of the complementary or alternative transport network technologies in real network deployments shall take into account various factors such as area specifics, technologies' deployment feasibility, traffic/usage forecasts considering long-term services roadmaps and certainly, the implicated costs. Thus, transport network planning and dimensioning shall be tightly accompanied by the techno-economic analysis of the various deployment alternatives. This paper provides insights on the techno-economic aspects of 5G transport network technologies and its applicability on the architectural concepts of 5G-XHaul and 5G-PICTURE 5G-PPP projects.

Keywords: 5G · Transport network · Wireless-optical convergence · Techno-economic · Fronthaul · Backhaul

1 Introduction

5G access network deployments will pose stringent requirements to the transport network, to support high capacity Macro Sites (MS), dense layers of high capacity Small Cells (SCs), as well as versatile Distributed and Cloud-based Radio Access Networks (C-RAN/Cloud RAN), D-RAN (Distributed-RAN), DA-RAN (Dis-Aggregated-RAN) [2]) setups in coexistence with the traditional architectures. To support the 5G networks/services' requirements, the transport network shall be equipped with mechanisms to support flexible and scalable access network deployments, to converge fronthaul (FH) and backhaul (BH) traffic of various functional splits (FS) over a single infrastructure consisting of various wireless and optical technologies [3, 4].

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A number of research projects addresses the development of next generation transport network technologies while all major infrastructure vendors focus on enhancing their products to meet the 5G access network requirements. In this context, the 5G-XHaul project [1] has proposed a converged optical-wireless network solution capable of delivering BH and FH connectivity for versatile 5G access network deployments. Leveraging on this, the 5G-PICTURE project [2] aims at delivering a paradigm shift, from D- and C-RAN to the DA-RAN approach, by "disaggregating" hardware and software components across wireless, optical and compute/storage domains. To support this approach, 5G-PICTURE focuses on advanced optical and wireless transport network technologies.

However, the actual deployment of the complementary or alternative transport network technologies meeting the 5G requirements is not a straightforward task. In practice, lots of factors shall be taken into account, such as reuse of legacy networks/infrastructures, area specifics, deployment feasibility, long-term services delivery roadmaps, traffic forecasts and, last but not least, the implicated costs. This paper proposes a methodology for the techno-economic evaluation of large-scale transport network deployments aiming at indicating cost optimal network deployment solutions while various technological aspects and critical related parameters can be investigated. The methodology is based on a fully parameterized expandable techno-economic analysis tool that can reflect the architectural concepts of 5G-XHaul and 5G-PICTURE by modeling the network segments under study which are then cost for a desired time period and a specific geographical area. Initial results from the applicability of the tool in the 5G-XHaul project confirm the capabilities and its usage potential.

The paper is organized as follows: Starting from the 5G networks physical architecture overview, the 5G-XHaul and 5G-PICTURE transport network technologies are identified in the various network segments, while access network aspects are touched upon. In the next section, a methodology for 5G transport network cost analysis is described, based on a techno-economic tool which performs network modeling and dimensioning –based on practical rules and deployment aspects- and allows for cost assessment of various deployment scenarios. A number of transport network deployment alternative scenarios are identified and evaluated from a techno-economic perspective. Finally, potential enhancements of the techno-economic tool are presented before conclusions are drawn.

2 5G Network Physical Architecture Overview

The common set of principles underpinning the 5G network architectures, as proposed by SDOs (Standards Developing Organizations) [4–7], 5G-PPP projects (e.g., [1, 2]), infrastructure vendors and mobile operators roadmaps, consider 5G networks comprising multiple network and compute infrastructure setups [7], at finest granularity, including multiple disaggregated pools of network, compute and storage resources as proposed by the 5G-PICTURE project [2]. The baseline of the physical architecture of these resources has been introduced in [3], and in more detail in [8] and [15] – further elaborated in Fig. 1.

More specifically, the 5G data-plane architecture considers an integrated optical and wireless network topology and infrastructure to support jointly backhauling of SCs/MSs,

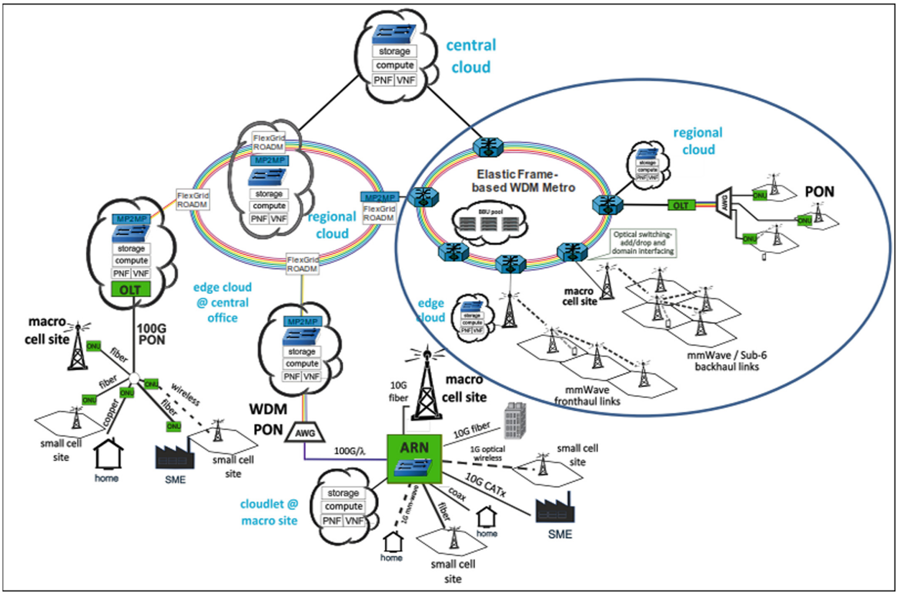


Fig. 1. Physical architecture - converged fixed-mobile 5G network

fronthauling of various FSs (as defined in [7]) of Remote Radio Heads (RRHs) as well as fixed network access. The wireless domain comprises a dense layer of SCs to serve the high traffic demand which is complemented by a MS layer for maximizing coverage. Due to the high capacity requirements, MSs can be considered as predominantly attached to the optical transport network. SCs can be wirelessly backhauled to MSs using a combination of wireless technologies (mmWave and Sub-6). Alternatively, SCs can be directly connected to a central office (CO), using either optical or wireless network technologies.

Compute resources are present at various physical and logical locations of the network for hosting network services and/or applications. These are indicated as edge (close to the location of or collocated with a MS), regional (at COs), or central clouds (at core network), where Virtual Base Band Units (vBBUs) considered as "network services" are hosted.

The access transport links are aggregated using optical network technologies and the traffic is forwarded to the backbone optical transport network. A dynamic and flexible/elastic frame or time-based optical network solution is considered for aggregation and transport core network segments.

2.1 5G-XHaul and 5G-PICTURE Transport Network Technologies

Considering the 5G-XHaul and 5G-PICTURE transport network technologies the identified deployment options are:

- mmWave transceivers for last mile transport BH and/or FH links providing 3.5 Gbps average data rates per link, taking into account the link capacity achieved in 5G-XHaul [12]; depending highly on the spectrum (frequency, bandwidth), the distance between the two nodes and the radio environment.
- Sub-6 transceivers for last mile transport BH links providing 500 Mbps average data rates per link as achieved in 5G-XHaul [13].
- Point-to-Point optical or WDM-PON connections (ONUs/OLTs) for last mile transport BH/FH links providing data rates of 10 Gbps (for the 10 G interfaces) and 25 Gbps (for the 25 G interfaces) and 40 Gb/s for aggregating transport network interfaces [14].
- Ethernet type connections (denoted as Flex-E in [17, 18]) aggregating various Ethernet PHY (cable, optical, wireless, etc.) and MAC interfaces into a high speed Optical Ethernet trunk reaching 100GE or 400GE in the future [17, 18]. This technology can be considered as a substitute of WDM-PON, complementary to Optical Ethernet G.698.4-based for aggregating wireless transport links, or even complementary to TSON (Time-Shared Optical Network) components at transport core segment with the future 400GE release.
- Optical Ethernet (G.698.4-based) type connections at aggregation transport network segment; aggregating 10x10GE (Gigabit-Ethernet) optical links to an optical 100GE channel link [16–18]. This can be considered as a substitute of WDM-PON or another aggregation layer.
- TSON edge nodes, aggregating 4 × 10 Gbps Optical Ethernet interfaces in the context of 5G-XHaul [19], especially for optical backbone transport segments. The TSON

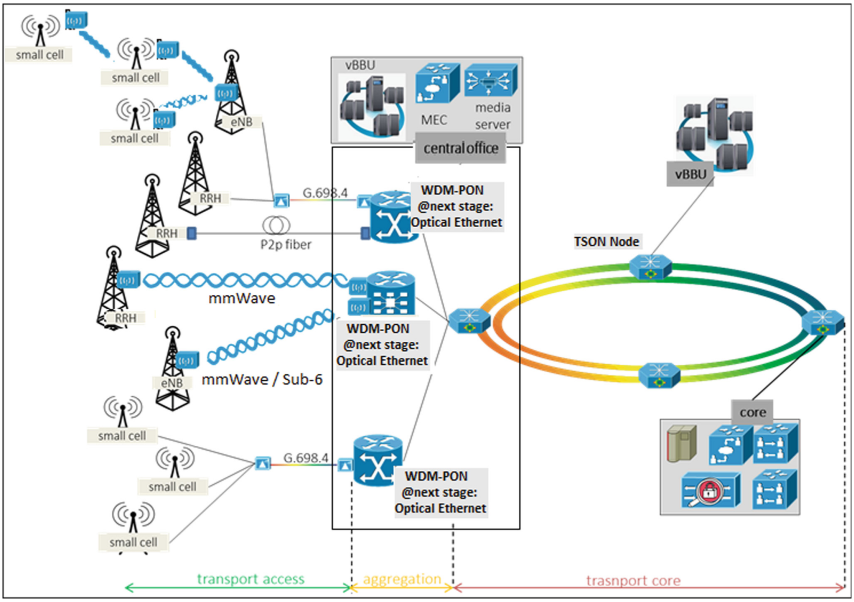


Fig. 2. 5G-XHaul and 5G-PICTURE technologies applicability

release developed in 5G-PICTURE, incremental aggregation of up to 12 × 10 Gbps interfaces to 100 Gbps optical Ethernet while allowing for 100 Gbps pass-through traffic can be considered.

It is obvious that these technologies can be deployed alternatively or complementarily at different network segments (last-mile transport, aggregation, backbone), as depicted in Fig. 2.

3 Methodology for Techno-Economic Analysis

3.1 Techno-Economic Tool Description

In the context of 5G-XHaul [19], a fully parameterized tool has been developed, to be further expanded in 5G-PICTURE, mainly to support cost analysis and cost efficient deployment of 5G-XHaul solution (FH/BH/BB transport networks) in a selected area, for a desired timeframe, by running various scenarios of: coverage area and traffic, usage of various optical/wireless network technologies (i.e. WDM-PON, mmWave, Sub-6), FS for FH/BH and various MIMO schemes. In addition, the tool can assist in performing comparative analysis and concluding on technologies' utilization and deployments by flexibly modifying the input.

The innovation of the tool lies in the modeling of the 5G transport network technologies and architectural/deployment options, as defined in the 5G-PPP general architecture and refined in the 5G-XHaul and 5G-PICTURE physical network architectures, based on rules and assumptions resembling usage/operation conditions (technology restrictions, loading factors, fiber deployment, etc.) in the most realistic way.

The usage methodology of the tool includes: (i) definition of the scenario under evaluation, (ii) introduction of assumptions, input parameters and network dimensioning rules based on network modeling, and (iii) the Cash Flow Model which leads to automatically calculated CAPEX/OPEX breakdown, using separate cost models and pricing information for each type of technology/equipment.

More specifically, on an annual basis for a specific area of interest and a definable deployment period, the usage of a tool comprises the following steps:

- Definition of various access network deployment scenarios; either manually or based on coverage, traffic, services and resources utilization;
- Modeling of the transport network segments and technological options (BH/FH, FS, MIMO in relevant grades of adoption), thus reflecting the 5G-XHaul/5G-PICTURE architectural concepts;
- Transport network dimensioning, considering:
  - technologies' capabilities/restrictions and their inherent, default dimensioning rules - tightly related to their incremental cost models,
  - nodes' loading factors (either technology-specific or operator defined),
  - fiber infrastructure deployments ranging from Greenfield scenarios (implying costs for digging, trenching, permits, personnel costs, etc.) to Brownfield scenarios (assuming existing fiber infrastructure owned or provided/leased by a 3rd party).

- CAPEX/OPEX breakdown, taking into account:
  - equipment costs based on cost models specific to each type of equipment and pricing (considering purchase, installation, maintenance/service costs, and estimated annual prices erosion or escalation). Since the cost models are technology- and vendor- specific and adhere to specific commercialization policies, they have been made modifiable and expandable to adapt to other technology implementations and commercial offerings as well. Indicative cost models are the following:

    for wireless links: the cost of the link equals the cost of the set(s) of transceivers required calculated by the BH/FH traffic to be served divided by the average datarates achieved per technology, adjusted accordingly to the number of hops (for the multi-hop cases). Once the maximum link datarates are reached, the incremental cost equals to the cost of the additional set(s) of transceivers required for serving any additional traffic.

    for WDM-PON links: the cost model takes into account (1) the initial cost of an OLT and the initial number of provided interfaces, (2) OLT's incremental cost based on the additional interfaces to be provided at second stage, as well as (3) the cost of the ONUs. Both the number of OLTs and the provided interfaces are related to the OLT loading factor decided by the network operator. Similar is the cost model in the case of the Optical Ethernet technologies' equipment.
  - fiber deployment specific costs; for the Greenfield scenario (that is, there is no previously deployed infrastructure) not only the necessary hardware has been taken into account but also aspects such as digging and trenching, permits, necessary personnel etc., and the costs are calculated on the basis of average fiber deployment cost per Km (country/area-specific parameter), while for the Brownfield scenario as a percentage of the Greenfield deployment cost, accounting for the extra mile that an existing deployment needs to be extended to reach a certain number of SC sites.
  - labor costs for network deployment, operations and maintenance,

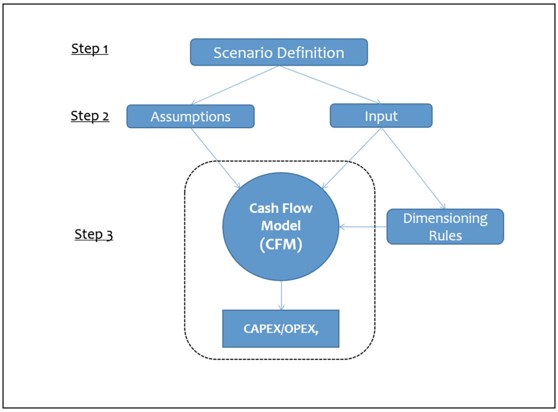


Fig. 3. Stepwise methodology of the techno-economic analysis tool

– other financial figures of extra costs such as Weighted Average Cost of Capital (WACC) and Tax Deduction (% of Equipment Cost).

3.2 Network Modeling, Dimensioning and Deployment Aspects as Input to the Tool

Access Network Deployment Dimensioning. The 5G access network deployment for a specific geographical area (dense urban, urban, suburban, rural) refers to the locations of MSs/RRHs, SCs, fixed network nodes serving corporate users and aggregating traffic from residential users and the dimensioning, according to broadly and well-established access network planning principles:

- Targeted coverage (for the calculation of MSs) and capacity (for the calculation of MSs and SCs);
- Actual and forecasted traffic patterns and services, especially with regard to the maximum traffic requirements (based on the concurrent services mix) for the 5G mobile and fixed access network. Leveraging on ITU's IMT-2020 and 3GPPs' 5G services' and verticals' identification, forecasted patterns and services for 5G networks have been studied in [9–11];
- Existing aggregation sites of mobile network and fixed access nodes (e.g., corporate users, COs).

5G Transport Network Deployment Modeling. The 5G transport network deployment shall be based on the access network requirements and technologies, taking also into account the following practical rules:

- The MSs that are fronthauled (Remote Radio Head, RRH) have no associated SCs, while the vBBUs preferably reside at edge or regional cloud (i.e., at COs' locations).
- SCs will be mainly backhauled with wireless technologies or optical links: the traffic of the former is eventually transported over the optical aggregation and backbone network by hops of backhauled SCs (usually not more than two to satisfy latency requirements), while the traffic of the latter over the optical aggregation network.
- For the corporate fixed network users, one or more optical network components (ONUs) are deployed on premises; therefore, their dimensioning is based on the number of users.
- The residential users' traffic is summed at first level at ONUs (residing at centralized locations) and then at optical aggregation network; thus, dimensioning is based on the aggregated traffic.
- Aggregation and backbone transport network will reuse (part of) existing COs.

However, besides the technological aspects (interfaces, performance, etc.), in real network deployments the actual implementation highly depends on the cost, provided that the quality of services offered is guaranteed.

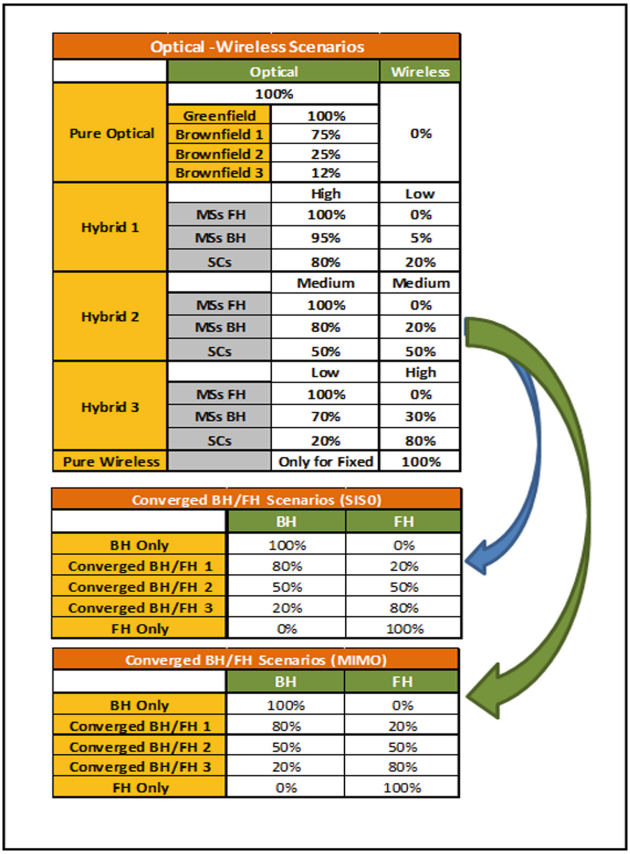
4 5G Transport Network Deployments' Techno-Economic Evaluation (Scenarios and Results)

Considering the 5G-XHaul technologies (BH/FH/BB), a number of transport network deployment scenarios for a specific dense area in Barcelona have been assessed with the tool in terms cost. Preliminary cost information has been used since some of these technologies are at pre-commercial product Technology Readiness Level (TRL), while the pricing information accuracy varies depending on the development and commercial maturity of the technologies.

The evaluated transport network deployment scenarios (depicted in Fig. 3) consider optical and wireless deployments, ranging from purely optical (Greenfield, and Brownfield of various legacy fiber network penetration) to hybrid ones (with varying level of MSs/SCs deployment) to purely wireless, combined with converged BH/FH scenarios with varying level of BH/FH adoption from BH only to FH only, assuming either SISO or MIMO schemes.

These scenarios have led to a set of results and conclusions regarding the cost efficient utilization of the 5G technologies especially in large scale deployments. Some of them are not straightforward, while others refer to technologies not commercialized yet. The tool can assist in defining the factors that influence significantly the transport network deployment cost and in making the best decision on selecting 1. wireless vs. optical techs, 2. alternative FSs (for BH/FH), 3. MIMO configurations; as well as investigating possible relationship between these options. Indicatively:

- From the techno-economic point of view there are marginal differences among the various hybrid optical-wireless transport network deployment options, irrespectively of the degree to which each type of technology is utilized (Fig. 4).
- The cost raises significantly -almost doubles- in case of a pure wireless Brownfield deployment due to the increased usage of the wireless equipment cost (high cost vs. low capacity and cost of optical equipment). Therefore, in the area under study, deployment shall be based primarily on optical technologies especially for the MSs BH/FH, complemented with wireless links (where fiber is not in place) along with a mix of optical and wireless links for SCs backhauling. In practice, we can consider the 2nd hybrid solution as the most viable deployment.
- For a converged scenario (i.e. Hybrid 2), the selection of BH or FH highly depends on the actual FS option for FH, but it seems that there are marginal differences between the various FH/BH deployment options, when leaving aside CPRI as a choice, and considering that all FH traffic is transmitted over optical connections due to the significant capacity vs. cost advantage they exhibit in all scenarios.
- Provided the current price estimations of optical interface and Sub-6 transceiver components, in extreme deployment scenarios, a FH-only deployment over optical links can be even more cost efficient than a BH-only using a significant number of Sub-6 links. At the same time the capacity vs. cost for mmWave is higher than that for optical links which implies that FH traffic over optical links can cost marginally the same as if backhauled over mmWave, depending on the air-interface overhead. For SISO links, the cost in all converged scenarios options is almost the same (Figs. 5 and 6).



Optical -Wireless Scenarios			
	Optical		Wireless
Pure Optical	100%		0%
	Greenfield	100%	
	Brownfield 1	75%	
	Brownfield 2	25%	
	Brownfield 3	12%	
Hybrid 1		High	Low
	MSs FH	100%	0%
	MSs BH	95%	5%
	SCs	80%	20%
Hybrid 2		Medium	Medium
	MSs FH	100%	0%
	MSs BH	80%	20%
	SCs	50%	50%
Hybrid 3		Low	High
	MSs FH	100%	0%
	MSs BH	70%	30%
	SCs	20%	80%
Pure Wireless		Only for Fixed	100%

Converged BH/FH Scenarios (SISO)		
	BH	FH
BH Only	100%	0%
Converged BH/FH 1	80%	20%
Converged BH/FH 2	50%	50%
Converged BH/FH 3	20%	80%
FH Only	0%	100%

Converged BH/FH Scenarios (MIMO)		
	BH	FH
BH Only	100%	0%
Converged BH/FH 1	80%	20%
Converged BH/FH 2	50%	50%
Converged BH/FH 3	20%	80%
FH Only	0%	100%

Fig. 4. 5G transport network deployment scenarios

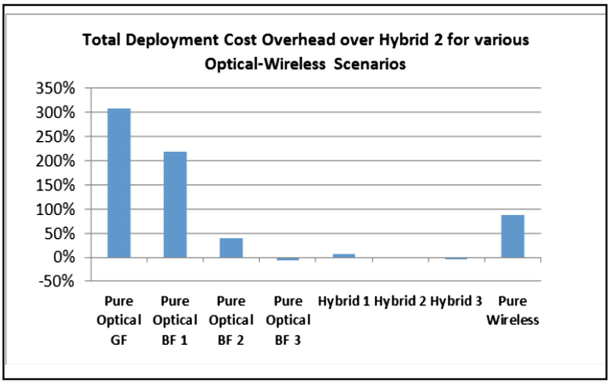


Fig. 5. Comparative cost for various optical-wireless transport network deployment scenarios

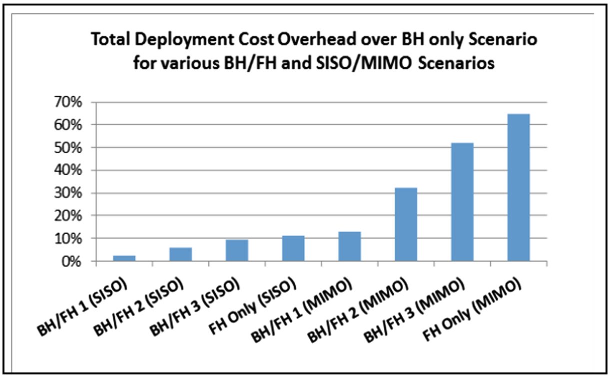


Fig. 6. Comparative cost for various BH/FH and SISO/MIMO transport network deployment scenarios

- Considering the effect of MIMO schemes at the access network, when using 4 × 4 MIMO for interference cancellation the total cost escalates with greater steps for FH compared to SISO, leading to more than 60% of additional cost for FH-only deployment compared to BH only. Therefore, MSs operating with higher order MIMO schemes for interference cancellation shall be backhauled.
- OPEX is a very small fraction of total cost compared to CAPEX. To sum up, the main factors that affect the total cost are: the trenching/civil works/etc. for the optical network, the usage of Sub-6 network equipment, the usage of MIMO schemes for FH, a BH-only deployment of numerous Sub-6 links.

5 Potential Future Expansions of the Tool

Although the tool has been developed for the needs of a specific 5G-PPP project, it could be tailored to "assess" more technological and architectural concepts, and provide insights on the relative cost efficiency and the investment viability of alternative deployments. Indicatively, the tool could incorporate:

- Additional deployment options, such as the placement of vBBU pools, the adoption of edge-computing, cloud-computing for specific services' hosting, other wireless/optical technologies, etc.
- Business aspects, such as licensing, and/or revenues coming from 5G transport service offerings, and additional financial calculations (e.g., RoI, NPV, IRR, Profitability Index).

The tool can be also used in the opposite manner, that is, for a given investment provide the deployment options to support the maximum possible traffic in a certain area. In the mid-term, the tool is planned to accommodate the architectural evolution of 5G-PICTURE, while the business factors still remain out of the 5G-PPP projects scope.

6 Conclusions

In this paper, a methodology framework for the techno-economic analysis of the prominent, highly converged, 5G transport networks is presented. A fully parameterized techno-economic tool, developed for the needs of the 5G-XHaul and 5G-PICTURE 5G-PPP projects enables the cost evaluation of various transport network technologies and deployment options, by modeling, dimensioning and costing while taking into account a plethora of critical technology-related parameters. Initial results from the applicability of the tool in indicative (5G-XHaul) deployment scenarios provide interesting conclusions on the potential utilization of 5G technologies achieving higher cost efficiency. Flexible by nature, the tool can be further expanded to include additional technologies, more complex deployment options as well as business factors, to enable the investigation of cost efficient high performance 5G network solutions' deployments as well as deeper understanding and familiarization with the yet unknown 5G ecosystem.

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