Comparison of Techno-Economic Solutions for 5G Networks and beyond

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***Abstract*—5G envisions a society that is constantly interconnected with a large number of devices, anywhere and anytime. The developed technologies play an important role, allowing low latency, a large data traffic, and improved quality of services. 5G encourages providers and investors to develop innovative services that meet consumer demands. However, the viability of a new service is being investigated from an economic perspective. This paper analyzes 5G technologies and evaluates them from a techno-economic point of view and pricing models. In particular, the main factors used to estimate the cost are CAPEX and OPEX, which compare the viability of the investment. 5G is proved to be a profitable investment due to its low cost and the increase in the average data consumption of each consumer. Finally, reusing existing sites is less costly in developing a dense macro-cell network.**

***Index Terms*—5G, models, IoT, CAPEX, OPEX.**

I. Introduction

5G will play a vital role in the transmission of mobile data to provide higher capabilities to individual mobile radio cells. On the other hand, mobile data are not used appropriately by users due to reckless usage and increased demand. Due to this increment in data traffic, mobile providers are fighting to normalize the massive demand with high-speed and multi-site data links providing a faster and wide-ranging wireless network.

The 5G technology is based on Orthogonal Frequency Division Multiplexing (OFDM) using various technologies such as Multi-user Multiple-Input Multiple-Output (mu-MIMO), Distributed Antenna Systems (DAS), Femtocells, Network Function Virtualization & Software Defined Network (NFV & SDN), Cognitive Radio (CR), Millimetre Wave (mmWave). Also, 5G enables support for almost infinite innovations and uses. It is undoubtedly the network of the future supporting more new services, besides digital communication and wireless Internet. 5G is a communication standard and not just a wireless standard. Since the digital relationship between humans and machines is evolving rapidly, robust infrastructure and appropriate networks are required. Increasing data volume requires faster data transfer. Therefore, the 5G network needs to face the enormous and complex range of requirements.

The current mobile standard is known as Long Term Evolution (LTE). The present technology satisfies almost all the requirements of the subscribers for various applications.However, the advent of 5G does not mean that LTE has come to an end, but rather it will be an upgrade that will expand the existing network resulting in the simultaneous operation of both technologies that will lead to higher capacities and internet speeds. In addition to the billions of people already using mobile internet, more than 100 billion connected devices will connect and the 5G network is a solution to the demands of digitalization.

The development of 5G mobile broadband technology will have a significant impact on the future economy according to several techno-economic studies. Adapting to the IoT means that remarkable changes will occur in the current communication networks. According to [1], crucial factors that will radically affect the dimensioning of the network must be considered and are the coverage, range, capacity, and data rate. Furthermore, it is important to indicate the cost and energy consumption of the base stations that will be used for the needs of the network coverage, for example, an urban or rural area [2]. Also, according to [2], which refers to an analysis made between macro and femtocell, it appears that Operator Mobile Network (OMNs) need to formulate the appropriate strategies to adapt to future business developments. Finally, it is important to mention the CAPEX and OPEX costs associated with BS strategy carried

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out in urban areas where traffic demand is high [3].

The remaining part of this paper is structured as follows: in Section II, the characteristics of 5G technologies are presented. Section III refers to compare & contrast the aforementioned technologies. Section IV refers to cost analysis and needs for upgrading to 5G network. In Section V, conclusions are summarized and future research is proposed.

II. Synopsis of 5G Technologies

In this section will analyze the features of technologies such as mu-MIMO, DAS, Femtocells, NFV & SDN, Cognitive Radio, mmWave.

A. mu-MIMO

MIMO technology utilizes limited resources to meet user demand, but due to the insufficient number of antennas at the MIMO system base station, system performance problems are caused. It constitutes the fundamental technologies of the future 5G, MIMO technology must meet the requirements of wireless companies, improve the effectiveness of the spectrum, the capability of the system communication, the reliability of the connections, and the data rate. If the number of antennas is equal to 4, 8, or 16, then the technology is called MIMO. In case there is a enormous number of antennas in each transceiver, for example, 128, 256, or more, then it is called mu-MIMO or Massive MIMO [1]. Figure 1 describes the concept of mu-MIMO architecture.

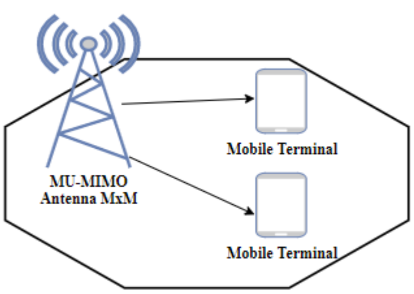

Fig. 1: mu-MIMO architecture scheme.

B. DAS

The Distributed Antenna System (DAS) contains several antennas that are considered as nodes and are connected to a transmission medium, for example, optical fiber. As mentioned in [1], at least two antennas must be per floor of a building, so that they adequately cover the floor of an apartment complex or a non-densely populated building. Also, the DAS includes two basic structures. The first basic structure is a base station (BS) and a distributed system (DS - Distributed System). The second basic structure is several antennas representing the DS along with many transceivers that facilitate the transmission.

C. Femtocells

Femtocells are known as Femto Access Point (FAP) or Home NodeBs (HNBs) and the transmission of base stations consumption is around 100 mW, which is installed indoors. Femtocells use the licensed range and provide services like voice and data to mobile subscribers. Subscribers using femtocell technology enjoy high-quality voice dialing and peak data rates because of improved Radio Frequency (RF) coverage. Furthermore, mobile providers benefit from the low cost of infrastructure development, considering coverage improvements and capacity upgrades. Also, to expand coverage, femtocells minimize the movement of a macrocell network and significantly increase network capacity by using the same range many times over smaller pieces. That helps to achieve higher efficiency, as fewer subscribers share valuable resources macrocell [4]. Figure 2 describes the concept of Femtocell architecture.

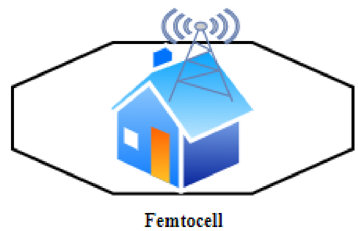

Fig. 2: Femtocell architecture scheme.

D. NFV & SDN

Network and telecommunications applications that use NFV technology currently operate exclusively from specific platforms on NFV cloud infrastructures. The devices that the user uses increase, because of the requirements of the users increased. That results in limitations such as expensive equipment and complex control protocols. At the same time, it has an impact on the innovation of new services, the creation of new architectures and technologies in general. Networking is defined by SDN and NFV, which are critical tools for the future of the IoT [5].

Utilizing both SDN and NFV technologies for dynamic Virtual Mobile Network (VMN) development is fundamental. SDN and NFV technologies are being developed with the goal of control, reliability, scalability, cost-effectiveness, and flexibility for VMN [5], [6] development. Also, these technologies allow VMN to flexibly control the virtual core of their mobile network by considering traffic load, Radio Access Network (RAN), and Evolved Packet Core (EPC). Figure 3 describes the concept of SDN architecture.

E. Cognitive Radio

Cognitive Radio Networks (CRNs) make greater use of the spectrum because they exploit the points of a spectrum

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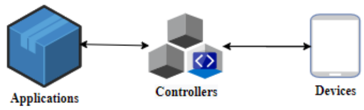

Fig. 3: SDN architecture scheme.

that are used less or not at all. Unauthorized users are given access by the spectrum if their interference is negligible. The operation of CRN is based on the Cognitive Radio Devices (CRD), which can automatically adjust some parameters such as bandwidth, waveform, and transmission power depending on the environment, avoiding bottlenecks, exploiting parts of the spectrum. The Cognitive Process (CP) is known to contribute to gathering relevant information, machine learning, reasoning, and decision making. There are regulated radio platforms such as Software Defined Radio (SDR) software to execute the decisions of the CP [7].

It is necessary to clarify the difference between the terms cognitive communication system based on SDR and CR software. SDR consists of a group of radio frequencies, in which most of the intermediate radio frequencies are converted to digital format, to be compared with the classic radio technology, providing greater flexibility in radio operation. On the other hand, CR is related to the control that contributes to the SDR to determine the mode of operation as well as the necessary parameters that will be applied in the specific networking mode [7].

Cognitive communication devices (CRD) are designed to respond to complex wireless environments which are [7]: Multi-band, Multi-channel, Multi-mode, Multi-standard and Multi-service.CRDs and CRNs are characterized as complex and designed to operate in these situations. The functions used for management are four and are [7]: spectrum detection, spectrum management spectrum sharing and spectrum mobility. Figure 4 describes the concept of CR architecture.

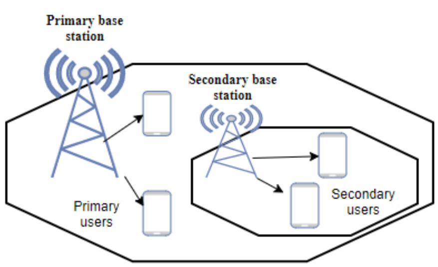

Fig. 4: Cognitive Radio architecture scheme.

F. mmWave

MmWave cellular systems operate in the 30-300 GHz band and are candidates for 5G cellular systems supporting high speeds. An innovative technology consisting of millimeter-wave (mmWave) communications and providing two advantages [8]: 1) proper management of unlicensed additional spectrum bands and 2) huge bandwidth up to 1GHz to provide high data rates for demanding subscribers.

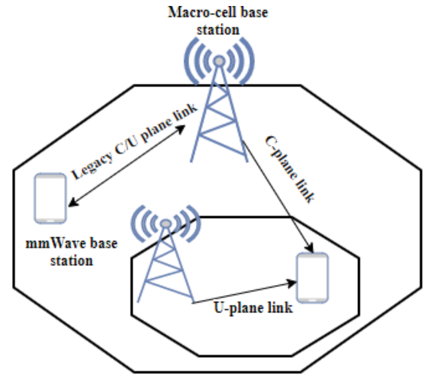

Fig. 5: mmWave C-/U- plane architecture scheme.

However, the use of mmWave presents some propagation barriers, which are [8]: loss of travel due to a high carrier frequency, reduced dispersion, which helps to reduce the available diversity, increased blockage, atmospheric absorption and rain, and noise power due to the use of the high bandwidth.

To address the prior issues, mmWave can be combined with other technologies such as Massive MIMO, SDN and femtocells, which help to achieve an optimal system [8]. Such as: massive MIMO and Beamforming, Ultra-Dense Networks (microcell development), a cellular architecture that supports heterogeneous layers and integrates the SDN standard and the functional split between the user layer (U-level) and the control layer (level-C), and a geographical database, that will include information related to the environment of each geographical area to increase the efficiency of cell functions, which will support the ability to store and process information related to previous cell discoveries. Figure 5 describes the concept of mmWave architecture.

III. Compare & Contrast

In this section, a comparative analysis of the technologies will be performed based on the characteristics explained below, (see Table I [9]):

Adoption: Each technology has its degree of adoption. Low means that its adoption rate is not widespread enough. High means that its adoption rate is quite widespread. Future means that it will be presented in the future.

Appeared: The first introduction of each technology according to research studies.

Bandwidth: Some of the previous technologies need more bandwidth to increase their efficiency, while others directly reallocate the existing bandwidth. Table I presents the technologies, which are characterized as reallocate, in need, and virtual.

Capacity: Each technology offers the appropriate capacity.

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TABLE I: Comparison of 5G Technologies.

Factors	5G Technologies					
	mu-MIMO	DAS	Femtocells	NFV & SDN	CR	mmWave
Adoption	High	High	High	Low	Future	Future
Appeared	2018	1987	2010	2012 / 2011	1999	2017
Bandwidth	Need	Need	Reallocate	Virtual / Reallocate	Reallocate	Reallocate
Capacity	✓		✓	✓	✓	✓
Coverage	✓	✓	✓	✓	✓	
Cost	High CAPEX High OPEX	Low CAPEX Low OPEX	Low CAPEX Low OPEX	Low CAPEX Low OPEX	Low CAPEX Low OPEX	High CAPEX High OPEX
Efficiency	✓	✓	✓	✓	✓	✓
Heterogeneous	✓		✓	✓	✓	
Interference	✓	✓		✓ NFV only		✓
Power Consumption	✓	✓		✓	✓	✓
Scalability	✓		✓	✓	✓	✓
Standardization	IEEE	IEEE	IEEE	Many / OpenFlow	IEEE	IEEE

Coverage: Each technology must meet the needs of the network, either by redistributing or by purchasing more resources.

Cost: The development of each technology has a specific valuation. The cost-valuation for each technology is characterized by CAPEX and OPEX. CAPEX is the capital expenditure relating to the initial purchase or investment in new equipment, a service, or a product. OPEX is the operating costs relating to the costs of maintenance, operation, and energy consumption e.t.c.

Efficiency: The continuous development of technologies offers increased efficiency and better resource management in a network.

Heterogeneous: Heterogeneity exists between some technologies, for example, they can corporate together.

Interference: In some technologies, interferences are resulting in signal distortion.

Power Consumption: Each technology consumes electricity according to its requirements for functionality.

Scalability: Scalability is an vital feature for many technologies and means whether it is possible to expand a network by adding the right resources.

Standardization: The standardization of technologies means a description of the core functions they perform. According to Table I, some technologies are standardized, while others are not.

IV. Cost analysis and needs for upgrading to 5G network

A. *Prediction and assumptions of cost analysis in Shanghai.*

It is a fact that OMNs are considering ways in which migrating to a 5G network will be profitable or not. First, in [2], a high-level model is examined, which describes the factors on which it depends whether it is worth investing in 5G networks. The factors that contribute to the completion of the investment are the forecast of the number of users, the churn rate, the pricing model, and the cost forecast. Regarding the prediction of the number of users, a Bass forecasting model has been chosen, which explains well the market forecasting system for the types of products or services. It is achieved according to the formula [10]:

$$N(t) = M * \frac{1 - e^{-(t-t_0)(p+q)}}{1 + \frac{q}{p} * e^{-(t-t_0)(p+q)}} \quad (1)$$

where M is the Market Capacity, $p > 0$ is the innovation factor and symbolizes the probability of starting a service and is related to the initial size of the adopters, $q \geq 0$ is the imitation coefficient which refers to the size of the potential future subscribers or adopters' imitators. N(t) is the number of subscribers at time t and t_0 the initial time. From formula (1) and setting the appropriate coefficients p=0.009, q=0.42 and M=50000000 [2]. It appears that the number of adopters or subscribers until 2021 will remain low and then will increase exponentially until 2025, as shown in Figure 6.

The churn rate or transfer rate from provider to provider is used to calculate lost and new revenue. Also, the transfer rate from provider to the provider must be of the order of [4%, 10%] where the four represents the best case and ten the worst case [2], so it is concluded that when a user leaves not only the future revenue is lost, but also the resources acquired for the needs of the investment are spent.

About the pricing model, a volume-based pricing strategy is currently being used, which is not efficient for the 5G mobile network [11]. That is why a hybrid pricing strategy has been developed that is a combination of volume-based and value-based and aims at profitability. The volume-based pricing strategy includes parameters such as location, usage time, and content. The value-based pricing strategy includes parameters such as time, speed, and data. In addition, a prerequisite for OMNs is to find the optimal service price which has been approached in two perspectives and is transparency and PED.

OMNs collect information related to the cost of their services to properly assess subscriber behavior. Therefore, to minimize risk and uncertainty, two economic concepts are proposed, which help to predict the sales of volume-based data and to determine their prices. The first concept is Price Elasticity of Volume $E_V(P)$ and proportional to the price elasticity of demand and is defined as the percentage change in actual volume V per percentage change in unit price P. So, the following formula applies [2]:

$$E_V(P) = \lim_{P'-P \to 0} \frac{\frac{V'-V}{\frac{1}{2}(V+V')}}{\frac{P'-P}{\frac{1}{2}(P+P')}} = \frac{P \cdot \Delta V}{V \cdot \Delta P} \Rightarrow \frac{\Delta V}{P} = E_V(P) \cdot \frac{\Delta P}{P} \tag{2}$$

The second concept is Volume Elasticity of Revenue $E_R(V)$: defined as the percentage change in revenue R (charge) per percentage change in actual volume V. So, the following formula applies [2]:

$$E_R(V) = \lim_{V'-V \to 0} \frac{\frac{R'-R}{\frac{1}{2}(R+R')}}{\frac{V'-V}{\frac{1}{2}(V+V')}} = \frac{V \cdot \Delta R}{R \cdot \Delta V} \Rightarrow \frac{\Delta R}{R} = E_R(V) \cdot \frac{\Delta V}{V} \tag{3}$$

The two formulas (2) and (3) apply the following [2]: 1) for the subscriber, if $E_V(P) < 1$ means that the increase in volume demand contributes to the reduction of service prices, otherwise there is an increase in service prices. 2) For the provider, if $E_R(V) > 1$ means that that the increase in volume demand affects the increase in profits. In addition to the above, the following applies to PED:1) When the $|PED| < 1$ means that it is inelastic, specifically changes in price have little impact on the volume of service required. 2) When $|PED| > 1$ the means that it is elastic, specifically changes in price have a crucial impact. 3) When PED = 1 subscriber and the provider are benefitted.

Based on the results reported [2], the hybrid pricing model uses subscriber contents (usage time, content, location) and according to formulas (2) and (3) it is concluded that if the price of services decreases then the demand for subscribers increase and vice versa. Therefore, the ideal solution is when the PED is equal to one where both the user and the provider are benefitted. Finally, another conclusion that emerges is the effect of value and volume on profit at 5G, specifically 5G technologies are more beneficial than 4G, due to low cost and increased average data consumption.

Then, two scenarios have been developed for cost forecasting and estimation [2]: The first scenario concerns the creation of new Radio Access Technology (RAT) technology by replacing the previous BS equipment. The second scenario concerns the addition of new carriers and equipment to the existing RAT to reuse the previous BS equipment in conjunction with the latest equipment and a software upgrade.

Based on the results from [2], which relate to the predicted CAPEX and OPEX values, the scenario two is more efficient due to lower CAPEX, but for OPEX the two scenarios do not show a significant difference.

It is known that the demand for network traffic is proportional to the population density since the volume of data per subscriber does not depend on the growth scenario. According to [12], the estimamtion of the traffic demand for 1 km^2 in Shanghai shows that the level of demand corresponding to the average user data rates is 2.59 Mbps, which was obtained during the eight working hours. However, the formula (2) shows that it needs an output of 20 Gbps / km^2 [2].

A key issue is the modeling of indoor network investments using various scenarios to achieve the rate of 20 Gbps per 1 km^2. The main features to consider are cost, coverage, and capacity for each BS category. However, for all of these scenarios there are penetration losses due to a specific wall barrier, so to address this issue two possible solutions have been proposed: creating a denser 2.6 GHz network or developing a network using 10 MHz and 0.8 GHz bands within the zone in order to maximize internal coverage [2] [13].

Based on the results reported in [2], it appears that developing many new sites is costly as opposed to reusing existing sites, which are less expensive even if the sites are equipped with a new RAT. Also, the 5G mmW Pico Base Station (PBS) strategy provides the lowest cost but is limited in terms of network coverage, which results in that if the network is expanded, it will have a high overall CAPEX [14]. In addition, a more efficient strategy with low base station density is to use the LTE-A RAT carrier aggregation. Also, the option to develop new carrier aggregation sites is a more cost-effective solution than new site development scenarios, and the development of Femto Base Station (FBS) and Wi-Fi IEEE 802.11ac becomes more cost-effective when FBS deployment can support a large number of users. Finally, the above concludes that the main disadvantage of the 5G network is that the limited coverage resulting from the use of small cells such as femtocells, picocells developed with 5G mmW and Wi-Fi, and the lack of capacity limited by macro-cell sites and one solution is to combine Macro Base Station (MaBS), femtocells, 5G mmW PBS or Wi-Fi to achieve the right balance between cost, capacity, and coverage.

B. Prediction and assumptions of cost analysis in three cities.

The study carried out in Indonesia to upgrade the network to 5G includes the following cities Jakarta, Surabaya, and Medan. As mentioned above, using the Bass model which predicts the number of users of a market and applying the appropriate rates in formula (1), based on the data taken from [2], [3] where p=0.0267, q=0.3356 and M is 15000000 for Jakarta, 3500000 for Surabaya and 2500000 for Medan. The

TABLE II: Needs in BS and in Bandwidth per km^2 for each city.

Cities	BS Strategy						CAPEX (k$)	OPEX (k$)
	MaBS (4G LTE-A)		MetBS (5G mmW)		PBS (5G mmW)			
	Number	Band (MHz)	Number	Band (MHz)	Number	Band (MHz)		
Jakarta	35	40	6	400	6	400	4352.4	1094.4
Surabaya	16	40	3	400	3	400	1996.2	502.2
Medan	14	40	3	400	3	400	1756.2	442.2

accruing forecast results are shown in Figure 6, where the forecast number of subscribers is being increased by 2025 for all cities.

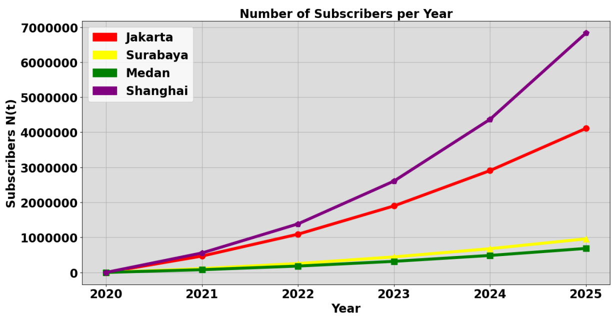

Fig. 6: Forecast of subscribers for six years for four cities [2], [3].

Besides, the different strategies used for the development of the 5G network are MaBS, Metro Base Station (MetBS), and PBS. The design of the network was carried out by dividing areas into three categories of network requirements based on the total demand, in high, medium, and low. According to [3], the results are summarized in Table II and relate to the needs of each city in BS, bandwidth, and used for the evaluation of CAPEX and OPEX. Therefore, Jakarta is the dominant city concerning the rest in terms of network needs and investments related to the development of 5G networks.

V. Conclusions & Future Work

Today there is a relatively large number of 5G IoT technologies. But to use a communication technology must be considered whether it is cost-effective and whether it is a solution to be implemented by providers. In this paper, the characteristics of 5G technologies are introduced and a comparison between them in numerous terms was studied. A forecast model for the development of a 5G mobile network in Shanghai was also studied, which includes the estimation of subscriber numbers, the churn rate, a hybrid pricing model, the estimation of traffic demand, the capacity, the CAPEX cost for the FBS, WiFi IEEE 802.11ac and the macro site's strategy with carrier aggregation and wall losses compensation. Finally, a high-demand model for the development of a 5G mobile network in the cities of Jakarta, Surabaya, and Medan was studied, in which the number of subscribers, the total CAPEX and OPEX costs for the BS strategies MaBS, MetBS, and PBS were estimated.

For future study, based on the above, further research is needed on energy consumption and the impact it will have on the profit and the further improvement of the 5G network. Also, there is a need for research for improving the heterogeneity, scalability, efficiency, and cost of 5G cellular technologies.

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