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Business Models for the Next Generation of Mobile Communications

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Abstract: The advent of 5G, the next generation of mobile networks, promises a seismic shift in telecommunications services, addressing the challenges posed by the exponential rise in mobile traffic demand and declining profitability in the mobile broadband market. Operators must strategize to deploy 5G networks post-2020, leveraging business analysis and mathematical modeling to devise effective plans. A novel pricing model aligned with mobile broadband growth is proposed. Findings indicate that 5G offers significant advantages, not only in cost reduction compared to 4G LTE but also in accommodating higher data consumption and expanding user base. Analysis of Price Elasticity of Volume (PED) underscores its importance. Reusing existing infrastructure significantly lowers costs, especially with denser macro network deployment. Nonetheless, challenges persist, such as limited capacity in macro sites and coverage gaps addressed by small cell solutions like femtocells, picocells, 5G millimeter-wave systems, and Wi-Fi.

Keywords: 4G, 5G, Benefit, CAPEX, Cost, OMN, OPEX, Prediction, Techno-economic.

Introduction:

The mobile communication industry is swiftly advancing toward the fifth generation (5G) of mobile technology, expected to meet the demands for ultra-high traffic volume density, connection density, mobility, and quality of service (QoS) requirements for multimedia applications well into the 2020s. Projections suggest that 5G could deliver data rates of up to 10 Gbit/s over the air and latency as low as 1ms, while also enabling Internet of Things (IoT) devices to operate on battery power for up to a decade. Despite these advancements, the landscape of the telecom service market is evolving. In 2015, the global telecom service market was valued at $965.3 billion USD, with voice service anticipated to decline at a Compound Annual Growth Rate (CAGR) of -4.9% by 2020, while data service is forecasted to grow at a CAGR of 8.3%. Notably, data service has surpassed voice service since 2015 and is expected to constitute 65.7% of the entire telecom service market by 2020.

However, Operator Mobile Networks (OMNs) are actively seeking enhancements to their networks to expand coverage, boost capacity, and deliver superior quality of service in a cost-effective manner. OMNs face scenarios where network costs could outstrip revenues if proactive measures are not implemented. Hence, the imperative lies in minimizing costs while maximizing revenue.

This paper conducts a comprehensive business and financial analysis to assess the deployment of 5G mobile networks, employing a mathematical model to project revenue and predict costs over a six-year period from 2020 to 2025. Our focus lies on a set of techno-economic indicators essential for evaluating the necessity of network upgrades.

Comprising four sections, Section 2 provides a survey of pertinent literature. In Section 3, we detail our modeling approach, outlining key techno-economic indicators crucial for analyzing and predicting the pricing and revenue of 5G networks. Additionally, we estimate Capital Expenditure (CAPEX) and Operative Expenditure (OPEX), comparing these costs with expected revenue to ascertain the profitability of operators during the analysis period. Notably, this work represents a pioneering effort in analyzing the commercial launch of 5G networks utilizing Price Elasticity of Volume (PED) and Volume Elasticity of Revenue ($E_R(V)$) to assess traffic volume and benefits, offering valuable insights for pricing, revenue, and traffic prediction. Furthermore, we propose a novel pricing model aimed at enhancing OMNs' revenues. The final section delves into the analysis of traffic demand and network investment.

Review of Research:

In recent years, techno-economic studies in the field of telecommunications have gained increasing importance due to the rapid evolution of technology and the exponential growth of mobile devices and IoT connections. Lingjie Duan et al. (2014) examine cellular operators' timing of network upgrades and model user behavior regarding operator and service switching, highlighting the balance between market share increase and increased risk or upgrade costs as 4G technology matures. Yanjiao Chen et al. (2015) analyze how operators manage cash flow and plan 4G deployment within finite time horizons, emphasizing financial considerations. Conversely, Filipe Vazl et al. (2013) conduct economic and environmental comparative analyses on macro and femtocell technologies, aiming to align OMNs' business models and deployment strategies with sustainable trends.

Markendahl et al. (2010) compare the cost and capacity performance of femtocell and macrocellular networks, advocating for femtocells as a means for operators to reduce mobile broadband network costs. Meanwhile, Miroslaw Kantor et al. (2010) outline a general framework for the economic analysis of various access network technologies and architectures, highlighting specific challenges in techno-economic evaluations of next-generation networks.

In contrast, our study focuses on cost and benefit analysis to aid OMNs in determining the financial viability of migrating to 5G networks over the analysis period. As there is limited research on techno-economic and cost issues in mobile networks, our model represents a novel contribution. By utilizing real datasets, we aim to facilitate operators' identification of key parameters for deploying new technology on a broader scale, employing a mathematical model for revenue description and cost prediction.

Modeling of Cost-Benefit Predicting:

To analyze the necessary marketing parameters, this paper adopts a specific geographical area as its focus. Illustrated in Figure 1, the initial phase of the analysis entails assessing the number of subscribers within this area. Subscribers are defined as individuals who have acquired services from an Operator Mobile Network (OMN) via a Subscriber Identity Module (SIM card) to access voice and data services within the designated region.

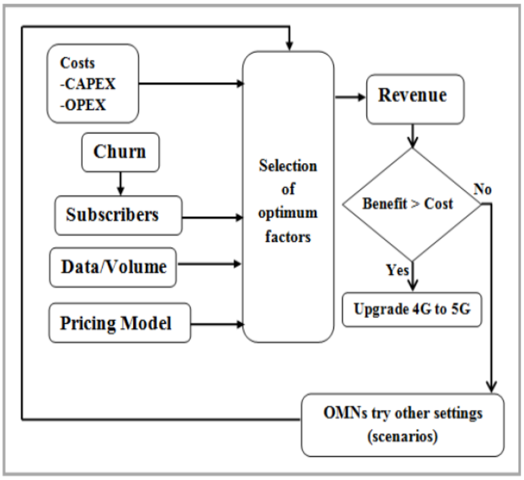

Figure1. High level study of business model.

At the core of the decision-making process lies the comparison between the total cost of ownership (TCO) and the forecasted revenue over the analysis period. Naturally, if the return on investment (ROI) exceeds the TCO, the investment is deemed profitable. Additionally, while Operator Mobile Networks (OMNs) aim to maximize benefits through favorable terms and pricing, users seek services at minimal costs. For analysis and deployment purposes, Shanghai, China, with its 6,340.5 km^2 area and population of 25 million at a very high density of 3,854/km^2 according to, is selected. It's noteworthy that while the analysis focuses on Shanghai, its applicability extends to regions with similarly high population densities. In Shanghai, 95% of the population resides in urban areas, with the remaining 5% in rural areas. Moreover, as reported, the city boasts 30 million subscribers, surpassing its citizen count of 25 million. This discrepancy can be attributed to the significant presence of foreigners and migrant workers in Shanghai, many of whom utilize mobile phones with dual SIM cards. The analysis of this area is segmented into three parts: predicting the number of users, conducting a pricing strategy analysis aligned with the next generation of Mobile Broadband (MBB), and evaluating Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) for various base station classes across multiple scenarios.

Predicted number of users:

In our paper, we have opted to utilize the Bass model for predictive analysis, as it effectively captures the market dynamics of products or services with diffusion-like characteristics, such as those in the mobile telecommunications sector. This choice is substantiated by the nature of telecom industry development, which often exhibits diffusion characteristics due to the network externality effect, as highlighted by Zhu et al. (2006). Accordingly, we assume that the projected number of future users will be contingent upon factors such as population potential, growth rate, innovation, and imitation coefficients. This estimation can be expressed as:

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

In the equation, M represents the market capacity, where p (>0) denotes the innovation coefficient, signifying the probability of initial purchase at the onset of the service's life cycle, and is correlated with the initial critical mass of adopters. Meanwhile, q (≥0) represents the imitation coefficient, indicating the size of the group of potential future adopters who imitate the behavior of current users. N(t) represents the number of subscribers at time t. For this study, we set M = 50 million. Additionally, adhering to the new regional classification for mobile telecommunications diffusion policy in China, we assign p = 0.009 and q = 0.42 for Shanghai. The graphical representation of modeling the number of mobile users based on equation (1) is depicted in Figure 2.

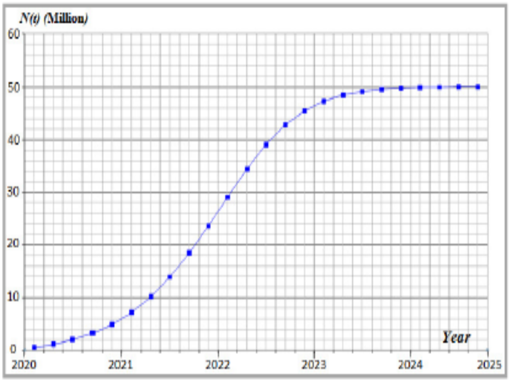

Figure 2. Mobile users prediction for 6 years.

Our findings exhibit an S-shaped curve, indicating that following the launch of 5G technology, there is initially a low number of adopters by 2021. However, as innovators begin to embrace the new technology, the adoption rate gradually increases. Subsequently, the number of imitators follows an exponential trajectory. Consequently, after experiencing exponential growth in adoptions, the rate of new adopters starts to decline beyond 2024.

However, our results, as depicted in Figure 3, illustrate the sales of operators. It is evident that initially, when the number of imitators is relatively small compared to the number of innovators, there is an acceleration in sales. With time, as more adopters come on board, there is an increase in users, leading to higher sales of the new technology. As the number of adopters approaches N(t) (50 million), the market nears saturation, resulting in a decline in sales.

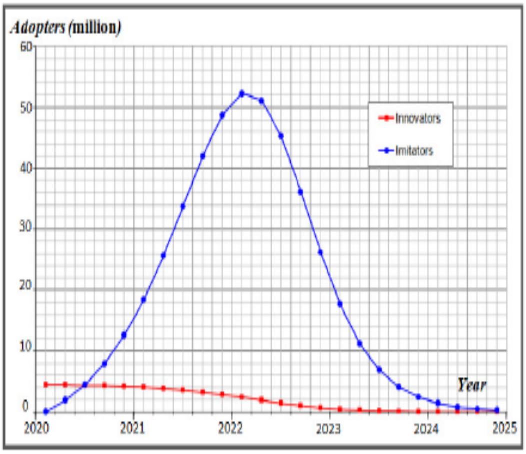

Figure 3. Sales prediction

Pricing Model

The exponential growth in data traffic anticipated with the advent of The Next Generation of Mobile Network (5G) raises a critical concern regarding pricing strategy, especially if this surge is not accompanied by a corresponding increase in revenues. Paradoxically, the rapid expansion of mobile broadband could lead operators into a profitability dilemma. Intense price competition, often exacerbated by flat-rate offers and customers' diminishing willingness to pay based on data usage, perpetuates this challenge. Moreover, when factoring in the typical network costs associated with serving customers, an increasing number of mobile broadband subscribers become financially unsustainable for operators. According to [16], a significant 89% of mobile broadband operators employ volume-charging models, sometimes supplemented with capped pricing plans. However, these models are generally advantageous only for lower data consumption levels typical of 4G Mobile Networks (e.g., 1GB, 3GB, or 10 GB per month), and may prove inadequate for the demands of 5G Mobile Networks. As illustrated in Figure 4, the profitability of data usage under such models could become increasingly precarious.

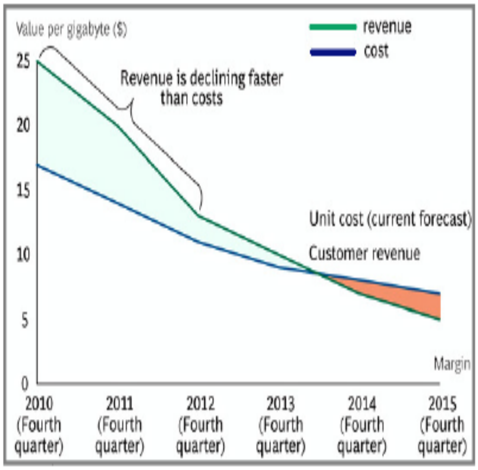

Figure.4. Mobile data could be unprofitable

To effectively navigate and capitalize on the vast revenue potential within the rapidly expanding mobile broadband market, it's imperative to prioritize three key areas: smart network management, smart costing strategies, and smart pricing tactics. In our paper, we introduce innovative and adaptable pricing models designed to enable Operator Mobile Networks (OMNs) to capitalize on the surge in data traffic, thus fostering sustainability and growth in this fiercely competitive landscape. Research underscores that users are increasingly reliant on broadband services, with heavy users willing to invest more in enhanced broadband options. Conversely, emphasizes price as the primary lever for driving profitability, suggesting that OMNs explore value-based pricing strategies. Additionally, proposes leveraging customer value management techniques to gauge the value of market offerings and maximize returns. As our contribution, we advocate for a new pricing policy grounded in three distinct approaches:

Looking on the transparency and simplicity rather than network settings:

To streamline complexity and enhance user experience, it's essential to periodically notify users of their data consumption. The combination of volume-based and value-based pricing emerges as a critical decision for Operator Mobile Networks (OMNs) striving for profitability. As outlined in economic policy, prioritizing value-based strategies before volume-based ones aids in targeting the right consumers. Consequently, our approach integrates value pricing parameters such as speed, time, and data as the primary pricing strategy. Additionally, we incorporate volume-based criteria, leveraging user context factors like time of use, location, and content, for the secondary pricing model. For instance, if video content is monetized based on time (e.g., per minute or hour), users can easily track their consumption levels. In this scenario, time becomes a parameter for volume-based pricing, while the content being consumed serves as a criterion for value-based pricing. This framework is summarized in Table 1.

Table1. New Pricing Policy Using Users Context.

Value-Based criteria	Volume-based criteria	Proposed model
Time of use	Data	Data flow is depending on the time of use (limited at day, unlimited at night and in weekend)
	Speed	Speed is depending on the time of use (high speed offered at certain times and low in others)
	Time	Time is depending on the time of use (2 hours/day,4 hours/night, 6 hours/weekend)
Content	Data	Data flow ceiling for certain applications (unlimited "youtube" at night)
	Speed	Speed is dependent on the application used
	Time	Time is dependent on certain apps (2 hours of video/day, 4 hours of video/night)
Location	Data	Data flow is depending on the location of usage (home network plans)
	Speed	Speed is depending on the location (high speed offered at certain locations and low in others)
	Time	Time period of connection is depending on location

Using Price Elasticity of Volume and Volume Elasticity of Revenue

To bolster profits and expand their share of the mobile market, Operator Mobile Networks (OMNs) must ascertain the optimal pricing of their services and forecast sales volume. To achieve this, they can leverage two key economic concepts:

Price Elasticity of Volume EV (P):

Similar to the concept of Price Elasticity of Demand (PED), which measures the percentage change in realized volume V per percentage change in unit price P, the Price Elasticity of Volume (PEV) represents a measure of the sensitivity of realized volume to variations in unit price.

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

$$= E_V(P).\frac{\Delta V}{P}$$

When Price Elasticity of Demand (PED) is less than one (< 1) in absolute value, it indicates an inelastic response. This suggests that changes in price exert only a minor impact on the quantity demanded of the service. Conversely, when PED exceeds one (>1), signifying elasticity, variations in price lead to substantial changes in the quantity demanded.

Volume elasticity of revenue $E_R(V)$:

Defined as the percentage change in revenue R (charge) per percentage change in realized volume V, the Revenue Elasticity of Volume (REV) serves as a measure of the sensitivity of revenue to fluctuations in realized volume.

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

The Operator Mobile Network (OMN) operates under the assumption that the Revenue Elasticity of Volume ($E_R(V)$) is greater than 1, indicating that an increase in realized volume corresponds to an increase in revenue. Conversely, users expect that the Price Elasticity of Volume ($E_V(P)$) is less than 1, meaning that changes in realized volume lead to a decrease in unit price, and vice versa. By leveraging these two concepts, OMN can collect data on how users respond to changes in price, thus mitigating risk and uncertainty. As illustrated in Figure 5, a decrease in the price of services (such as voice calls or data) typically results in an increase in the quantity demanded by users due to heightened demand, and conversely.

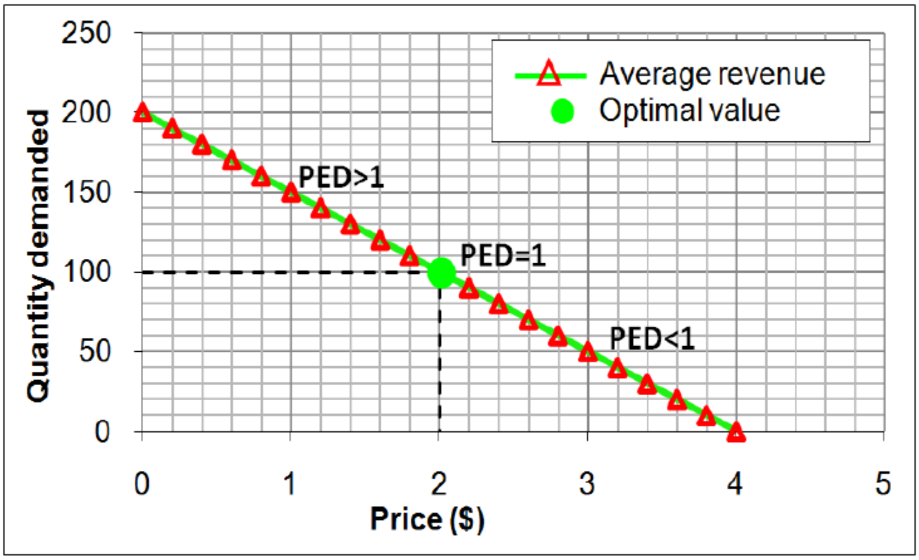

Figure. 5. Predicted price and volume of 5G MBB using $E_V(P)$ and $E_R(V)$.

Table 2 illustrates how selling prices affect profitability using equations (2) and (3), considering demanded volume ranging from 50 to 150 GB. We categorize 50 GB as low demand, 100 GB as moderate demand, and 150 GB as excessive demand levels for the year 2020. Based on data from, network costs are estimated at €0.91 per GB, inclusive of site acquisition and build. In our scenario, we assume that 5G technology incurs lower costs than 4G, with an average cost of $0.75 per GB.

In this context, it becomes evident that the profit from selling 100 GB is substantially higher than that from selling 150 GB ($125 versus $37.5). However, if we compare the profitability of 5G with that of 4G LTE, assuming that both offer 10 GB per user per month at the same price per GB, we find that the profit margin of 10 GB of 4G LTE equals that of 100 GB of 5G mobile network ($125/200 = $12.5/20). This underscores the significant benefits of 5G technology over 4G, not only due to its lower costs but also owing to the increased average data consumption.

Moreover, it's imperative to implement flexible data tariffs catering to different categories of users, as this approach has the potential to attract more users and generate higher revenues.

Table 2. Effect of price and volume on profitability for 5G MBB.

Data sold (GB/User/Month)	150	140	130	120	110	100	90	80	70	60	50
Price per GB ($)	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3
Cost per GB($)	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Revenue ($)	150	168	182	192	198	200	198	192	182	168	150
Total cost ($)	112.5	105	97.5	90	82.5	75	67.5	60	52.5	45	37.5
Profit ($)	37.5	63	84.5	102	115.5	125	130.5	132	129.5	123	112.5
Profit margin	25%	37.5%	46.4%	53.1	58.3	62.5%	65.5%	68.7%	71.1%	73.2%	75%

Additionally, we define the profit of 5G Mobile Broadband (MBB) as the difference between total revenue and total network costs for 1 GB of package. As depicted in Figure 6, revenue peaks at around $200 when the price per GB is set to $2. Furthermore, we observe that the quantity demanded decreases as price rises; however, revenue is maximized when the price is set so that the Price Elasticity of Demand is precisely one, as illustrated in Figure 7.

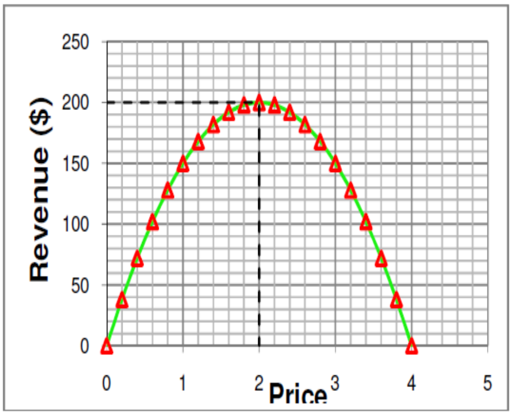

Figure 6. Pricing strategy for maximizing of revenue.

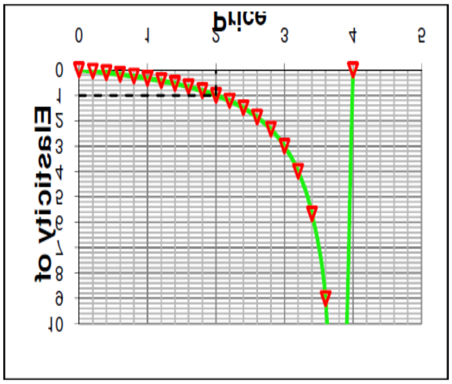

Figure. 7. Price and elasticity of demand.

Extending the monthly package for 5G MBB

To address the challenge posed by 5G technology, which offers high-speed wireless broadband connections and large monthly data allowances per user, we propose the implementation of an "Extended Package" policy. This policy aims to attract more users and foster competition among operators. Under this policy, if a user opts for a moderate package, such as 100 GB per month, but fails to consume the entire allowance by the end of the month, the unused portion of the package is carried over to the following month. However, to incentivize users to consume more data, we stipulate that any remaining data from the previous month must be used before the end of the subsequent month, after which it expires. This approach prevents unlimited extensions of packages and adds practicality to our proposal. Figure 8 provides a visual representation of our contribution regarding the extended package policy.

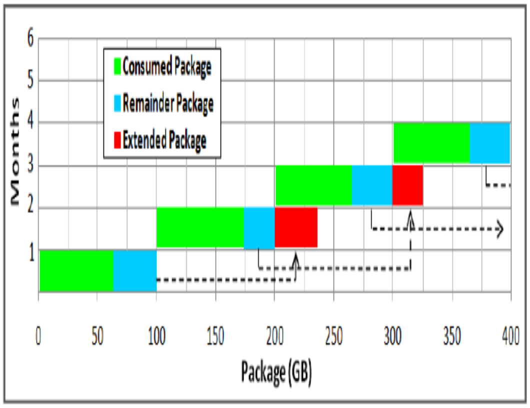

Figure. 8. Extended package.

Cost predicting and analysis

The CAPEX consists of the fixed investment costs associated with migrating network elements, while OPEX encompasses the ongoing costs related to the management and maintenance of the 5G network post-deployment. To conduct a techno-economic analysis and comparison, we consider two deployment scenarios:

Scenario 1: Involves the replacement of previous equipment at base stations with the deployment of new Radio Access Technology (RAT), including new antenna systems and radio equipment, at regular sites. The CAPEX for fiber backhaul is not included in this scenario, assuming it is already installed.

Scenario 2: Encompasses the enhancement of previous base stations by adding new carriers and radio equipment to the existing RAT, along with the deployment of additional base stations supporting the previous RAT. In this scenario, a software upgrade is required to augment backhaul transmission capacity in the hot spot layer. Our analysis revolves around comparing the total costs for each deployment scenario, with the total expenditures (C_i) for a base station class i being discounted as:

$$C_i = \Sigma_{k=0}^{k-1} \frac{(\alpha)k,i}{(1+\beta)^k} \quad (4)$$

In this paper, we considered a timeframe of k = 6 years and a discount rate (β) of 10%, with all base stations (BSs) installed during the first year. According to [9], we assume the cost for deploying a new Macro Base Station (MaBS) site in the urban area to be $110,000, with an additional $10,000 for radio equipment supporting 3 sectors and 5-20 MHz, resulting in a total cost of $120,000. Additionally, we assume a cost of $20,000 for a single carrier in the MaBS, with an added $5,000 per sector per carrier for additional transceivers. For the annual OPEX of the new MaBS deployment, we estimate it to be $30,000.

For the reuse of existing MaBS, we assume a cost of $30,000 related to site upgrades. The associated costs for Micro Base Stations (MiBS) and Pico Base Stations (PBS) are assumed to be 50% and 15%, respectively, of a single-carrier MaBS equipment cost, with an additional $2,000 per PBS for transmission. It is estimated that MiBS and PBS require $10,000 and $2,000, respectively, for site deployment.

For Femto Base Stations (FBS), we consider a CAPEX of $1.1k and an OPEX of $0.5k, while for WI-FI Access Points (AP) IEEE 802.1ac, we assume a CAPEX of $1.05k and an OPEX of $0.14k based on [22]. Additionally, European industry efforts have aimed at reducing OPEX by at least 20% [23], and a 30% reduction in CAPEX associated with fully standards-based solutions to smart city deployments is anticipated over the period 2017-2025 [24]. Consequently, we estimate that the OPEX and CAPEX for 5G millimeter Wave (mmW) sites are 30% lower compared to those for 4G LTE-A RAT.

To analyze the most beneficial approach for maximizing benefits and minimizing expenditures, we consider only the case of a monopoly market to determine the optimal upgrade strategy. Our simulation of the CAPEX and OPEX for different base stations (BSs) in scenarios 1 and 2 is presented in Figures 10 and 11, respectively.

Furthermore, we illustrate the total discounted costs in Table 3 according to equation (4).

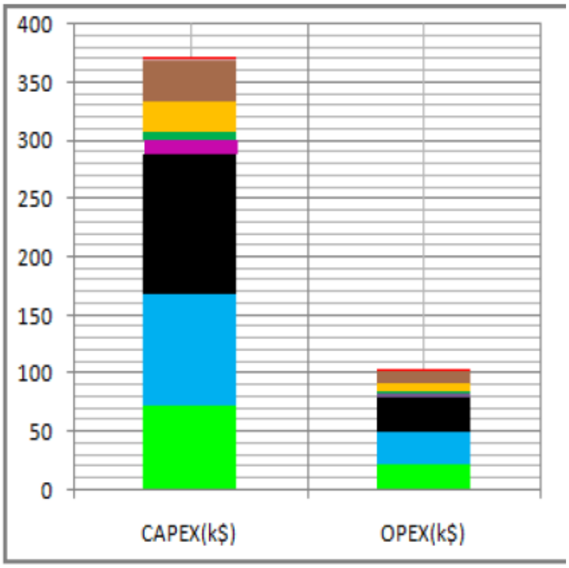

Figure.9.Predicted values of CAPEX & OPEX for BS/AP of different RATs related to new site (scenario 1).

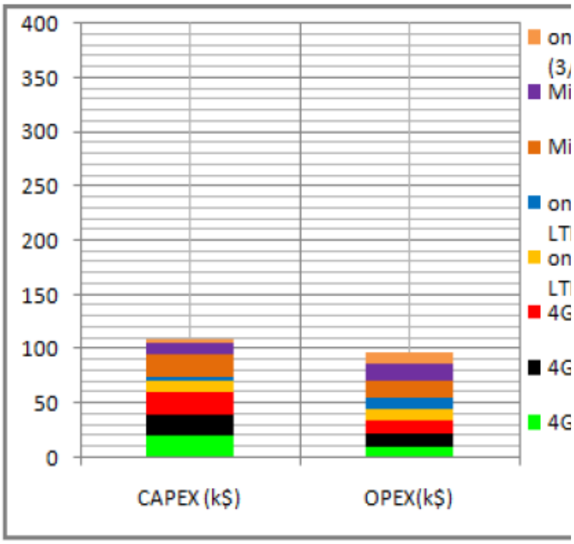

Figure. 10. Predicted values of CAPEX & OPEX for site reuse (scenario 2).

From Figures 9 and 10, when comparing the two scenarios, it becomes evident that site reuse results in significantly lower CAPEX, making it more financially advantageous for the Operator Mobile Network (OMN). However, the two OPEX values appear to be very close, indicating that the operational costs for both scenarios are similar.

Table 3. Estimates of the total discounted cost in present value for new bss deployment using lTE-A, 5G mmW and IEEE 802.11ac [k$].

Cell Type/RAT	CAPEX	OPEX	Total discounted cost for 6 years
MaBS(3 carrier)	120	30	233.4
MaBS(2 carrier)	96.2	26.7	194.1
MaBS(1 carrier)	72.9	23.2	159.7
LTE-A MIBS	36.4	10.4	75.6
LTE-A PBS	11.4	3.4	24.1
5G mmW MIBS	25.4	7.4	54.1
5G mmW PBS	7.9	2.3	16.4
FBS	1.0	0.5	2.7
IEEE 802.11ac	1.05	0.14	1.5

Traffic Demand and Network Investment

Estimation of generated traffic demand

As the data volume per subscriber remains independent of the deployment scenario, the generated network traffic is directly proportional to the population density (ρ). Therefore, we adopt the traffic model outlined in [25] to estimate the traffic demand for 1 km^2 in Shanghai, which is as follows:

$$G(t) = \rho . \frac{8}{N_{dh} \cdot N_{md}} . \varphi(t) D_k \qquad (5)$$

In the presented traffic model, Ndh represents the number of busy hours during a day when traffic is at its peak, while Nmd denotes the number of days in the month. The function (t) signifies the percentage of active users at a given time t, with (t)=100% used to calculate the peak area traffic demand during busy hours in terms of Gbps/km^2. Additionally, D_k represents the average data demand per month.

For our analysis, we set N_{dh}=9 over a span of 30 days. Considering the results from Figure 2 regarding the number of users, we focus on an area with a particularly high population density, ρ=7,708 citizens/km^2 (twice the average density). To ensure the network remains future-proof beyond 2025, we dimension the network based on the case study with our contributions from Table 2, considering three levels of demanded volume (low, moderate, and excessive). Moreover, we only consider downlink traffic.

Table 4 provides a summary of our estimated throughput for active users during busy hours in Shanghai, assuming subscribers are uniformly distributed within a cell.

Table 4. Predicted area traffic demand (Gbps/km2).

Monthly demand (GB)	**Percentage of active users during the busy hour**	**Area capacity [Gbps/km 2]**	**User data rate [Mbps]**
50 (low)	100%	11	1.29
	60%	6.6	0.77
	30%	3.3	0.38
100 (moderate)	100%	20	2.59
	60%	12	1.55
	30%	6	0.77
150 (excessive)	100%	31	3.89
	60%	18.6	2.33
	30%	9.3	1.16

The presumed demand levels correspond to an average user data rate of approximately 1.59, 2.59, and 3.89 Mbps, respectively, during the 8 busy working hours in the case of 100% active users during peak hours. However, we found that the total data demand for 7,708 users in a 1 km^2 area amounts to 11, 20, and 31 Gbps of throughput for low, moderate, and excessive monthly demands, respectively, with consideration of 80% radio resource utilization.

Network investment modeling

In our case study, we will explore various indoor deployment scenarios utilizing different Base Station (BS) classes and spectrum sizes to meet the throughput requirements of 11, 20, and 31 Gbps in 1 km^2. However, a significant challenge in these scenarios is the issue of wall penetration losses. According to [9], two compensation options are feasible: building a denser network at 2.6 GHz or deploying 10 MHz within the 0.8 GHz band to maximize indoor coverage. To address this issue and compensate for losses, a denser network with 12 dB of attenuation, equivalent to a 5 times denser network, should be constructed at the 2.6 GHz band.

Alternatively, when utilizing only a 10 MHz spectrum in the 0.8 GHz band, the number of sites needs to be doubled due to capacity limitations. Subsequently, we will analyze deployment options with Macro Base Stations (MaBS) incorporating carrier aggregation and wall loss compensation. Additionally, we will develop one deployment scenario based on the number of Femto Base Stations (FBS) per floor and the number of users per FBS in the case study. Moreover, we will utilize an indoor average spectral efficiency of 6.6 bps/Hz and allocate 20 MHz of spectrum for FBS.

Based on coverage and capacity elaborations from, we consider 1.02 km^2 with a capacity of 228 Mbps for MaBS LTE-A and 0.001 km^2 with a capacity of 4245 Mbps for 5G mmW PBS. Additionally, we allocate 0.008 km^2 with a capacity of 132 Mbps for FBS and 0.003 km^2 with a capacity of 1300 Mbps for Wi-Fi IEEE 802.11ac. The respective cost and capacity for different strategies of FBS/Wi-Fi, PBS, and MaBS satisfying the throughput requirements are summarized in Tables 5 and 6.

Table 5. CAPEX and capacity for macro sites with carrier aggregation and wall losses compensation deployment.

BS deployment scenario	Level	Number of sites	Total CAPEX(MS)	Capacity (Gbps)
New 5G mmW PBS	Low	3	0.057	12.04
	Mod.	5	0.095	20.07
	Exc.	8	0.152	32.11
Reuse MaBS LTE-A (0.8 & 2.6 GHz) carrier aggregation	Low	33	1	20.10
	Mod.	59	1.77	31
	Exc.	91	2.73	11.24
New MaBS LTE-A (0.8 & 2.6 GHz) carrier aggregation	Low	33	3.96	20.10
	Mod.	59	7.08	31
	Exc.	91	10.92	11.05
Reuse MaBS LTE-A (0.8 GHz wall loss compensation)	Low	96	1.92	20.15
	Mod.	175	3.5	31.08
	Exc.	270	5.4	11.05
New MaBS LTE-A (0.8GHz wall loss compensation)	Low	96	9.6	20.09
	Mod.	175	17.5	31
	Exc.	270	27	11.12
Reuse MaBS LTE-A (5x2.6 GHz wall loss compensation)	Low	49	0.96	20.21
	Mod.	89	1.76	31.10
	Exc.	137	2.7	11.17
New MaBS LTE-A (5x2.6 GHz wall loss compensation)	Low	49	4.9	20.29
	Mod.	89	8.8	31.23
	Exc.	137	13.6	12.04

Table 6. CAPEX and capacity for FBS and Wi-Fi IEEE 802.11ac.

FBS/Wi-Fi Deployment	Number of sites		CAPEX(MS)		Capacity (Gbps)	
	FBS	Wi-Fi	FBS	Wi-Fi	FBS	Wi-Fi
7 BS/floor	350	350	0.35	0.36	46.2	455
5 BS/floor	250	250	0.25	0.26	333	325
3 BS/floor	152	152	0.15	0.16	20.06	195
4 user/BS	2500	2500	2.50	2.62	330	3250
8 user/BS	1250	1250	1.25	1.31	165	1625
16 user/FBS	625	625	0.63	0.65	82.5	812.5
32 user/FBS	313	313	0.32	0.33	41.3	406.9
64 user/FBS	156	156	0.16	0.16	20.58	203.5

From Tables 5 and 6, it's evident that deploying a large number of new sites incurs significant costs (e.g., $17.5M for 175 sites), while reusing existing sites leads to less expensive deployments even when equipping many sites with new RAT (e.g., $3.5M for 175 sites). Additionally, the results highlight that 5G mmW PBS offers the lowest cost for our study case, but it poses a critical constraint related to coverage when dimensioning the network.

Furthermore, considering a13.6 dB wall attenuation for denser indoor deployment with 5G mmW PBS, as described in we would need to deploy 797 mmW sites inside buildings to cover a 1 km^2 area. This would result in a total CAPEX of $75.71M (0.095 x 797). These findings underscore the significant cost implications associated with denser indoor deployments using 5G mmW PBS.

However, for a relatively modest investment of around $2.73M to upgrade existing

sites using MaBS
LTE-A (0.8 & 2.6 GHz) carrier aggregation, we can ensure the capacity to meet excessive user demands. Additionally, in comparing different MaBS deployment strategies, utilizing carrier aggregation functionality of LTE-A RAT emerges as the most cost-efficient approach, requiring relatively small base station densities (only 33, 59, and 91 sites per km^2) to meet low, moderate, and excessive demand levels, respectively.

The option of deploying new sites with carrier aggregation proves to be more cost-efficient compared to all other deployment scenarios for moderate cases, with costs of $7.08 million versus $8.8 million, $17.5 million, and $75.71 million, respectively. Leveraging existing sites (scenario 2) for 0.8 GHz frequency carrier and 10 MHz proves to be the most cost-efficient option for OMN due to high coverage performance, costing only $1 million, $1.77 million, and $2.73 million to satisfy demands of 11, 20, and 31 Gbps/km^2 for low, moderate, and excessive levels, respectively.

Moreover, reusing MaBS sites (0.8 & 2.6 GHz) with carrier aggregation is comparable to reusing MaBS (5x2.6 GHz) with wall losses compensation, costing $1.77 million versus $1.76 million, respectively. However, FBS and Wi-Fi IEEE 802.11ac deployment becomes significantly cost-efficient when FBS deployment can support a large number of users (64 users/FBS) or (3 FBS/floor), allowing satisfaction of the moderate level (20 Gbps) with the same cost for each scenario. These deployment options, although range-limited, offer nearly unlimited capacity and similar costs.

The impact of reusing existing sites is notable, even with denser MaBS deployments to compensate for wall attenuation. However, for the deployment of new sites, unless utilizing carrier aggregation functionality of LTA-A RAT, the situation differs. Therefore, the main challenge of the next-generation network lies in balancing limited coverage with small cell solutions like femtocells, picocells deployed with 5G mmW systems, and Wi-Fi, along with capacity limitations imposed by macro sites. Investigating cooperative layouts of macro sites with femtocells, 5G mmW PBS, or Wi-Fi presents a promising solution to achieve trade-offs and synergies between cost, capacity, and coverage.

Conclusion and Future Work

Limited studies have explored the deployment of 5G technology through cost-benefit modeling and analysis techniques. This research focuses on deploying 5G technology atop existing 4G mobile networks within a monopoly setting, utilizing real datasets from Shanghai, China. Over a six-year period, a cost-benefit modeling approach was employed, comparing prices, costs, coverage, and capacity across various scenarios employing different classes of base stations and access points. Additionally, a new pricing model was developed to align with the evolution of Mobile Broadband (MBB), considering both value and volume-based parameters.

The study endeavors to assess the benefits and cost-effectiveness of transitioning from 4G to 5G mobile technology. Simulations have indicated that a thorough analysis of Price Elasticity of Volume (PED) yields significant benefits. Furthermore, it was found that all analyzed technologies can support mobile broadband demand across various scenarios, with macrocells enhanced by carrier aggregation emerging as the most cost-effective solution. Additionally, the study underscores the substantial impact of utilizing existing sites, even with denser MaBS deployments to counter wall attenuation.

However, deploying new sites proves costly unless leveraging the carrier aggregation functionality of LTA-A RAT. Moreover, the study highlights the limitations of next-generation networks, particularly in terms of coverage with small cell solutions like femtocells, picocells deployed with 5G mmW systems, and Wi-Fi. Conversely, capacity limitations are associated with macro sites. To address these challenges, it is imperative for OMNs to explore cooperative layouts of macro sites with femtocells, 5G mmW PBS, or advanced Wi-Fi APs like IEEE 802.11ac to achieve optimal trade-offs and synergies between cost, capacity, and coverage. Finally, the study suggests examining the impact of the proposed pricing model on OMNs' revenue and comparing it with traditional pricing strategies as a potential avenue for future research.

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