Who will capture the new value in the 5G Future X network era?

Quantifying winning strategies for new value creation & capture

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1 Introduction

Imagine a world where the laws of business survival are being redefined and new competitive market models re-assembled with the advent of 4^{th} industrial revolution. We will see the rise of machines and the ushering in of a new era of control and automation, resulting in new breed of digital Enterprise and Consumer services that optimize how we live and work. The ICT industry is embracing 5G as the foundational enabler that will allow network operators[1] to address these emerging needs. However, for network operators to fully capitalize on the new opportunities, there needs to be a fundamental shift in their business models and a transformation from a communication service provider (CSP) to a new digital value provider.

Bell Labs Consulting has built techno-economic models to quantify the potential outcomes and impact of automation and the 5G end-to-end technology transformation. Our models predict that while network traffic will continue to grow at a brisk pace, CSPs can reduce their overall TCO and significantly improve their time to market by adopting a pre-integrated and end to end automated network solution. Our models also indicate that CSPs can increase their overall profitability by providing digital value services on top of their traditional connectivity services.

The architecture choices, business model strategies, and pace of transformation will determine the future of CSPs and their market success. In this paper, we discuss the challenges, opportunities and cost implications of strategic decisions. Using ‘economic game theory’ formulations, we compare the relative market position of a CSPs with differing levels of aggressiveness in deploying an end-to-end pre-integrated automated network and offering digital value services and model possibilities for future profit shaping in a competitive market.

2 Reassessing strategic business Value

CSPs urgently need to make strategic decisions as the conventional modes of operation are challenged by digital transformation, 5G and automation. The changes and choices ahead need to

[1] A Communications Service Provider is defined as a network operator who own their own network and provides communication and connectivity services to their customers

be assessed considering current challenges and two core imperatives that will serve as the base to predict market competitive models and future winners.

CSP Challenge: Exploding traffic, declining profitability, value shift to digital services

CSP Imperative 1: Plan for foundational shifts in network architectures

CSP Imperative 2: Maximize digital value through business model changes

2.1 CSP Challenge: Exploding traffic, declining profitability

Traffic carried by CSPs has increased massively over the past decade. Mobile data traffic grew from 4PB/month in 2006 to 7,201 PB/month in 2016 - a 1800x increase. Global IP Traffic grew 24x to 1.1 ZB during the same period. Traffic will continue to grow with increased use of smart devices, content rich immersive applications and high-resolution video streaming on the consumer side. On the enterprise side, in addition to increased use of immersive applications, massive scale adoption of IoT and industrial automation will enable new services and spur new data demand as these connected things communicate with cloud-based applications and systems for the purposes of monitoring, storage, data analysis and control. Bell Labs Consulting projects that there will be a 25x to 82x increase in wireless data demand by 2025 and 7x to 15x increase global IP traffic (Figure 1). Yet operators have not been able to fully monetize this growth, as shown in Figure 2, with declining voice ARPU not offset by a concomitant increase in data ARPU. Revenue growth, where it has occurred, has been primarily due to increased adoption of mobile phones and smart phones.

Figure 1: Global IP Traffic growth and wireless data demand 2016-2025[2]

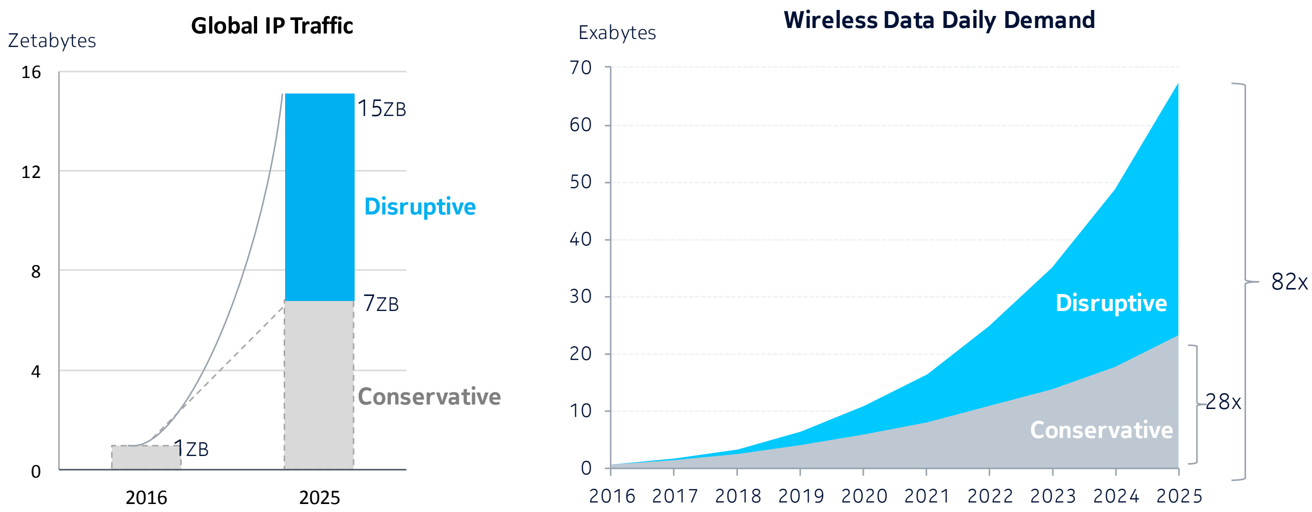
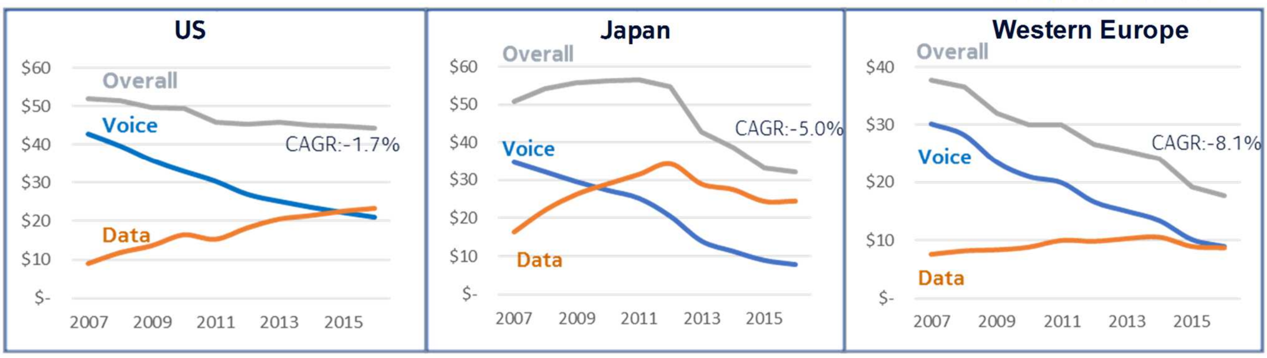


Figure 2: Mobile Voice and Data ARPU trends in major markets



The other challenge CSPs face is the value shift over the last decade from connectivity services to content. Platform Companies[3] have emerged as a formidable force offering a variety of content-rich applications and value-added services. As a result, the traditional CSP connectivity-centric

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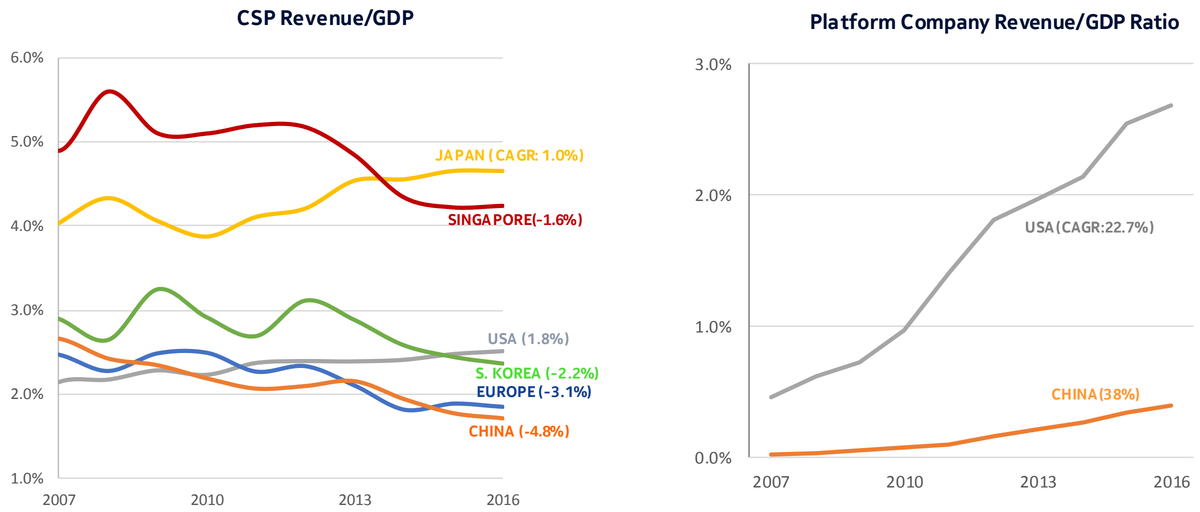
[2] *Future of Network Traffic: Anticipating disruptive shifts in traffic evolution that will reshape communications industry*, Internal whitepaper, Nokia Bell Labs 2018

[3] Platform Companies is the term used in the paper by Accenture – *Platform-Technology-Vision-Trend 2016*. These are technology companies that they consider "born digital" organizations that heavily leverage their platforms.

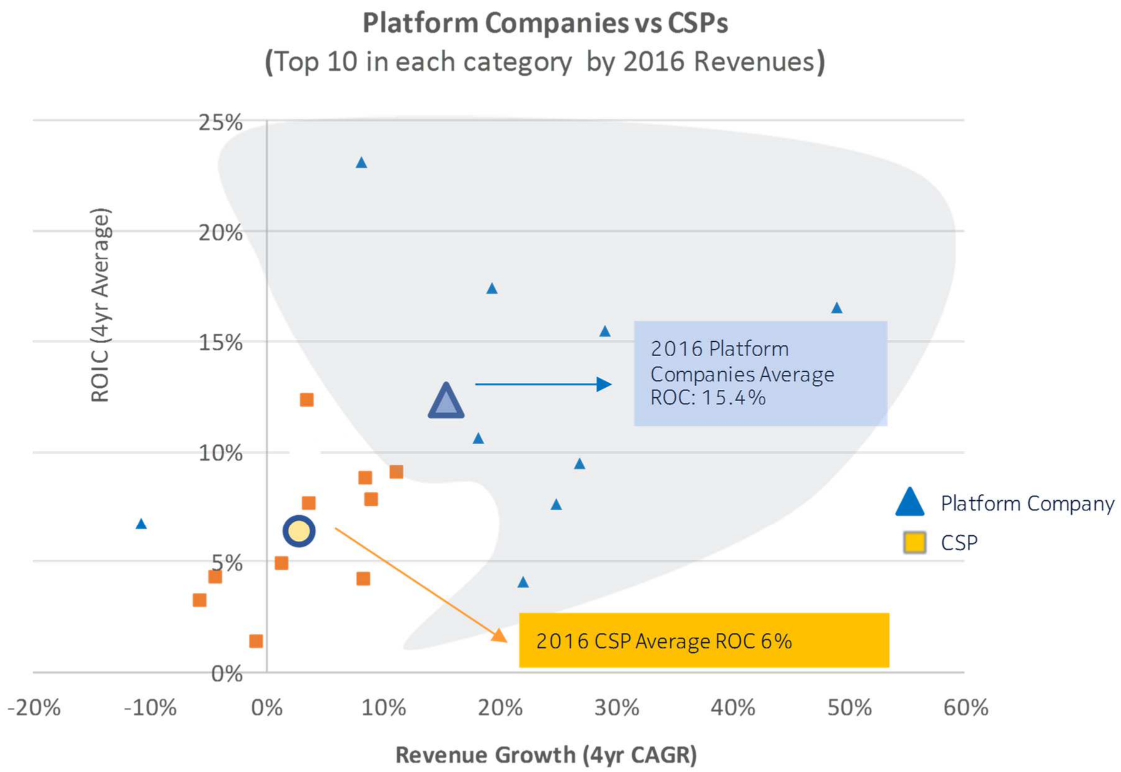
business model has seen diminishing value capture, reflected in the flat or declining CSP share of the GDP (Figure 3).

Figure 3: CSP and Platform company revenues share of GDP



The fact that CSPs need to continuously invest in connectivity capacity without the accompanying topline revenue growth results in low Return on Capital (ROC). A Bell Labs Consulting analysis indicates that the ROC of the top 10 Platform Companies on an average is 2x times the ROC of the top 10 CSPs in the 2012-2016 time-frame (Figure 4).

Figure 4: CSP[4] and Platform Company[5] ROC* comparison



*CAGR and ROC calculated over the 2012-2016 period. Data Source: Capital IQ, Bell Labs Consulting Analysis

But CSPs can only invest in new capacity and service offers if there is an adequate return on investment, so the vicious cycle of increased investment demand and declining profit will continue unless operating models are refreshed. A fundamental shift in the underlying network and operations infrastructure as well as business models is required that will put them on a path to sustained profitability in an evolving dynamic market.

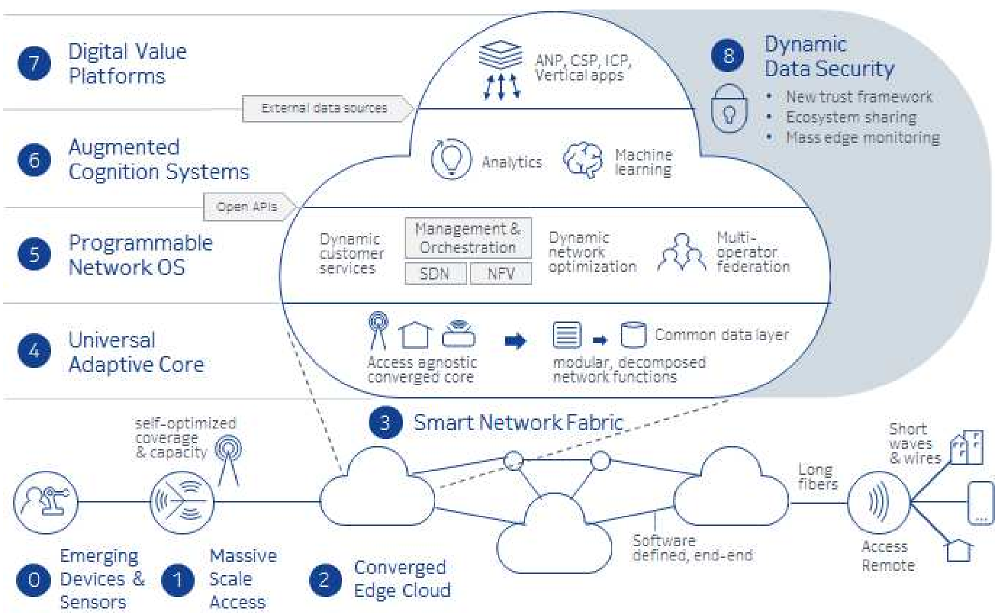
[4] Top 10 CSPs by 2016 revenues: AT&T, Verizon, China Mobile, DTAG, Softbank, Vodafone, America Móvil, China Telecom, Telefonica

[5] Top 10 Platform Companies by 2016 revenues: Apple, Amazon, Google, Facebook, Tencent, Alibaba, Priceline, Baidu, eBay, Netflix

2.2 CSP Imperative 1: Plan for foundational shifts in network architectures

In the web era, CSPs have with increasingly served applications that are capacity intensive. However, in the future, different types of demands will be placed on their network. The nature of applications will range from simple low power sensors to mission critical applications with very stringent latency and reliability requirements. 5G network standards are targeted towards addressing the need to support enhanced Mobile Broadband (eMBB), ultra-Reliable Low Latency Connectivity (URLLC) and massive Machine Type Connectivity (mMTC). Nokia Bell Labs vision of Future X Network[6] for the 5G era is depicted in figure 5 and provides the essential value framework for the future, driven by networks, systems and platforms that support the required dynamic scale, flexibility, bandwidth and latency performance, as well as automation, programmability, security and operational efficiency.

Figure 5: The Future X Network Architecture for future value creation



It is comprised of nine domains that work together to enable the 'automation of everything', in the new digital economy. Specifically, for CSPs, it supports the following 'network' requirements:

1. *Seemingly infinite* capacity – the capability to offer very low single-digit milli-second level latency services, and the ability to *scale up* easily to handle millions of devices

[6] *The Future X Network Architecture: A vision for the 5G Era*, Nokia Bell Labs Whitepaper, 2018

2. Combining local delivery with global reach thereby enabling *global-local value chains*
3. *Human cognitive operations* that intelligently predicts, automates and augments human decisions, tasks, and operations, translating these into network action and actuation
4. Ability to provide context-dependent *personalized protection* at scale

A critical aspect of the Future X network is the ability to create customized “network slices”, where instances of virtual network resources and applications can be tailored to specific customer needs on demand. This enables CSPs to generate new revenues through customized industrial automation and enterprise services while maximizing the utilization of their network resources.

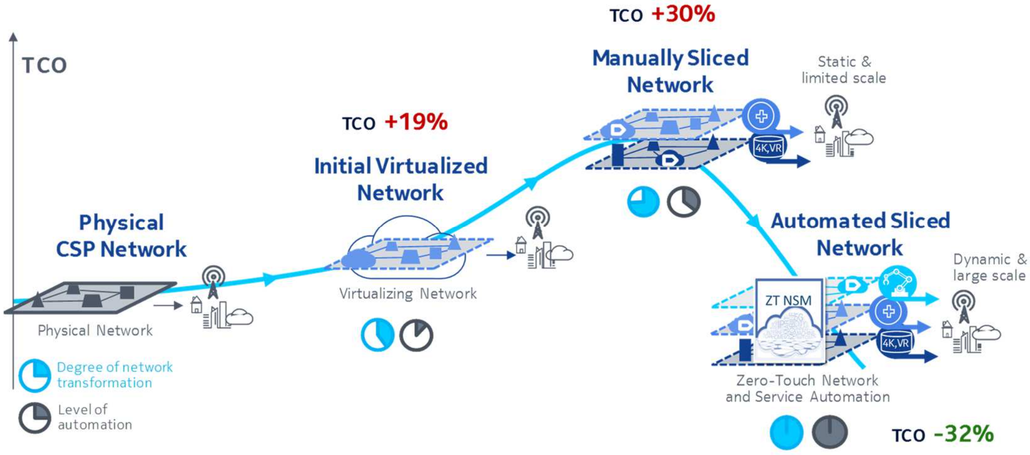
The transformation to the Future X architecture requires investments in not only network and automated operations infrastructure but also new skills to run and manage the highly automated environment. There is a need for CSPs to understand the overall cost implications of this transformation and to explore strategies that can lower their costs. Bell Labs Consulting has developed a series of models to understand the Total Cost of Ownership (TCO) implications of transforming from today’s static, manually provisioned and operated network environment to a highly automated intelligent network that enables dynamic network slicing. In addition, we have evaluated the implications of different vendor strategies’ impact on the ability to achieve the optimal TCO.

2.2.1 Future X Network: Cost implications of automation

The typical network transformation journey from a physical, static, and monolithic network to one that is virtual, dynamic, and optimally sliced is illustrated in Figure 6. CSPs are gradually starting to deploy virtual network functions and the required NFV infrastructure and management platforms. During this phase, the overall TCO will increase due to the transformation cost and the need to have two parallel platforms running in the network (Initial Virtualized Network). As more of the network gets virtualized, CSPs will then be able to start providing some level of customized network slices at a premium to customers (Manually Sliced Network). However, since the full end-to-end network transformation is not complete, these slices are static with relatively manual or limited dynamic orchestration, resulting in increased TCO, that may, in part, be offset by higher revenues. In the end state, the increasing the level of automation will lead to greater TCO savings through Automated Sliced Network (ASNM) Management, the last step of the transformation.

While the TCO behavior follows this general curve, the actual TCO values are dependent on the specific virtualization and slicing strategies adopted by the CSP. An aggressive SDN/NFV migration plan, for example, will increase the amplitude of the cost curve by increasing the cost penalties incurred at the intermediate stages; however, it will also lead to a faster realization of ASNM and its associated TCO benefits.

Figure 6: TCO journey through virtualization, automation and network slicing[7]



2.2.2 Future X network: need for pre-integrated end-to-end solution

To optimize the TCO, there is a paradigm shift required when moving from network elements with tightly coupled and integrated hardware and software to a virtualized architecture comprised of multiple disaggregated and orchestrated elements. Importantly, although the different network functions and applications can be procured from different providers, the operational cost and complexity of integrating the myriad potential elements to work seamlessly together and to manage the different lifecycles on an ongoing basis can be a monumental task.

In fact, a recent Bell Labs Consulting analysis indicates the initial Capex and recurring operations and lifecycle management costs can be significantly higher for field-integrated solutions involving products from multiple suppliers. A pre-integrated solution that is tuned and optimized for performance will result in lower deployment and lifecycle costs, and higher asset utilization. Moreover, with a pre-integrated solution the overall fulfillment, service assurance, and vendor management costs will be lower. As such, CSPs will also gain significant time to market advantage because of decreased vendor selection time, lower design customization time, and lower deployment time.

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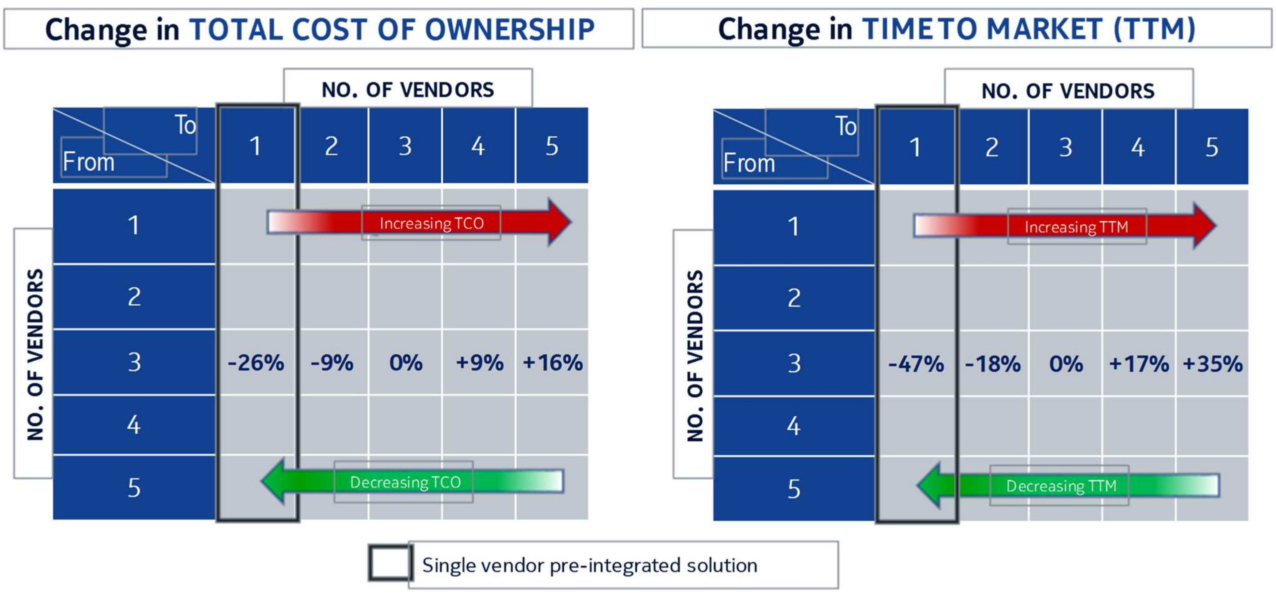
[7] *Future X Cost Economics: A network operator's TCO journey through virtualization, automation and network slicing*, Bell Labs Consulting Whitepaper, 2018

Figure 7 shows how the TCO and time to market (TTM) change with the number of vendors in the Future X network deployment by a converged CSP service in a representative mid-sized metropolitan region of 16 million population. The network modeled assumes that the CSP has both 4G and 5G to provide adequate wireless coverage and capacity. In addition, the operator has a GPON network providing FTTH connectivity to 2million households. The CSP is assumed to have a cloud-RAN architecture with distributed edge clouds optimally placed for efficient processing of user plane functions with a centralized core cloud to provide management and control plane processing together with end-to-end service orchestration, cloud orchestration, and SDN control functions.

Figure 7: Single vendor pre-integrated solution vs CSP integrated Multi-vendor solution



As the number of vendors in each domain decrease, there is a reduction in TCO and TTM. As an example, the TCO of a network with a single vendor pre-integrated solution is 26% lower and the TTM is 30% lower than those of baseline network with 3 vendor field integrated solution.

The increased complexity of multi-vendor solutions not only results in greater integration effort and higher TCO during the intermediate stages, but also results in a longer time required to realize the efficient ASN network and diminishes its gains.

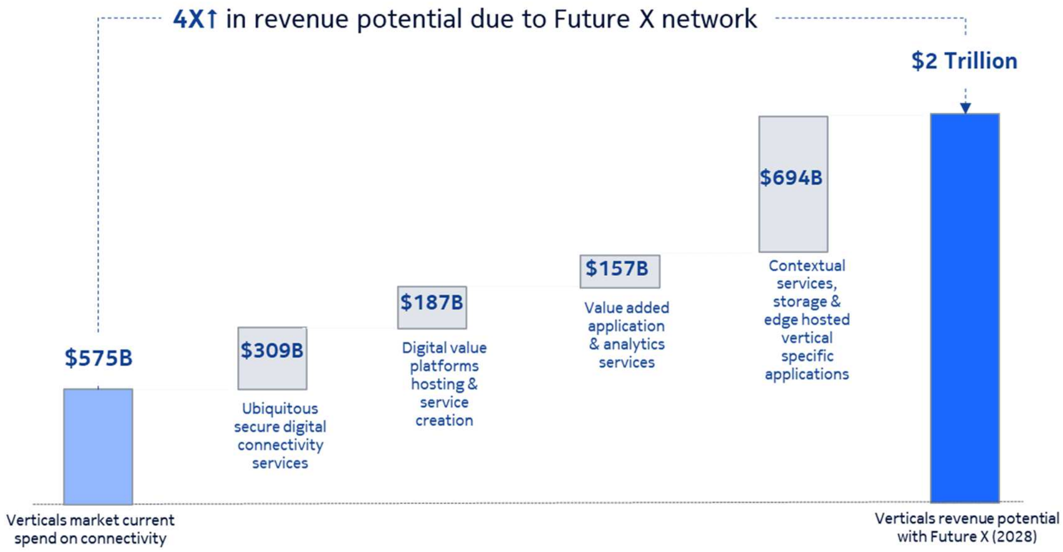
2.3 CSP Imperative 2: Maximize digital value through business model changes

With the emergence of cloud-based digital services and the flattening or decline in connectivity service revenues, CSPs must move from their traditional consumer and connectivity-centric focus to a digital value focus targeting both consumers and enterprises. The consumer of the future will demand contextualized video, smart home services, highly interactive gaming applications and high resolution immersive content all delivered from cloud. With the Future X network, network operators will be able to deploy enabling platforms in edge clouds to offer these new services on demand. On the enterprise and industrial front, we know industries are at varying stages of their digital journey but all ‘physical’ industry sectors will be massively transformed by the ability to become automated and to exist independent of physical space and infrastructure — essentially become virtualized. But the critical requirements of mission-critical operations technologies (OT) will put unprecedented demands on latency, performance, reliability, and security.

The Future X network will allow CSPs to tap into this new value opportunity and to deliver a new breed of cross-sector services with superior performance on-demand. The “hyper-scale distributed cloud architecture” with functions and applications placed in edge cloud nodes, will enable networks to provide high bandwidth and/or ultra-low latency (~1ms) for highly interactive and time-critical applications, using dedicated secure slices with on-demand instantiation of multi-component application services to any customer, whether consumer or enterprise/industrial.

As industries transform, the conventional operations and OT must change. This means modification of current business models, shifting investments, diversion of capital to furnish new requirements and in some cases complete abandonment of legacy to enhance sector productivity and economic output. As a result, industries have two choices: (1) use a traditional ‘in house’ approach based on proprietary solutions or (2) use a trusted partner to drive their transformation and automation needs. The latter represents a significant potential opportunity for CSPs, who can leverage the connectivity services to offer additional value-added services and provide enabling (network-derived) analytics and security platforms and applications to enterprises. Bell Labs Consulting analysis estimates that enterprise/industrial market opportunity will expand from ~$500B today to $2T by 2028 if CSPs become full Digital Service Providers (DSP). 75% of this new value will be due to enabling digital platforms, platform hosting, and value-added applications and 25% of the increase will be due to growth in traditional as well as secure connectivity services. (Figure 8).

Figure 8: New value creation of the Future X network



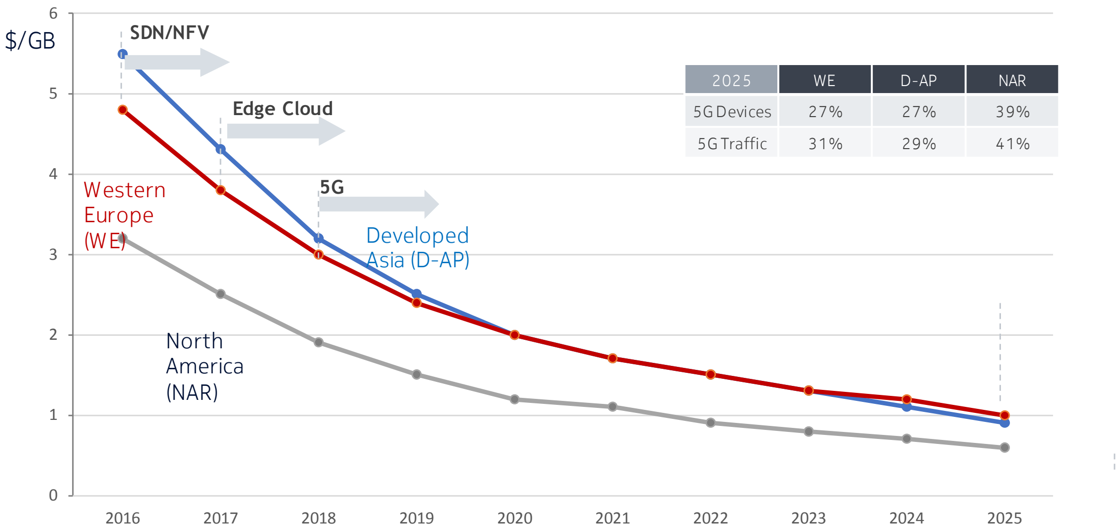
The critical issue for CSPs is to optimize the TCO outlay to realize this new value creation. In the next section, we analyze the strategies CSPs can employ to maximize success in a dynamic competitive market.

3 Predicting market winners using a game theoretic approach

Market evolution is hard to predict when existing paradigms are changing, and new business models are emerging. The emergence of virtualization and cloud technologies, unlicensed and shared spectrum, and new 5G network architectures have lowered the barriers to entry and provide an opportunity for Platform Players or Digital Value Players to potentially compete with CSPs and provide edge cloud infrastructure and services, and even the required connectivity services. Conversely, CSPs can leverage the same suite of technologies and architectural options to access new value pools.

CSPs aiming to thrive in this emerging market environment need to select investments that not only lower costs but also provide the capability to support emerging service needs. As CSPs embrace the Future X architecture and migrate more customers (and traffic) onto these networks, the Network Cash Cost/GB[8,9] of traffic is expected to come down significantly. Figure 9 shows the results of a Bell Labs Consulting study of the projected network cash cost/GB evolution for CSPs in three developed markets.

Figure 9: CSP network cash cost trajectory in the developed economies



2025	WE	D-AP	NAR
5G Devices	27%	27%	39%
5G Traffic	31%	29%	41%

Source: Bell Labs Consulting

The cost decline for individual CSPs depends on 3 factors:

(1) how fast they adopt newer architectures
(2) how quickly they migrate their customers to the newer networks and;
(3) the end-to-end network build-out strategy (single integrated vs multi-vendor field integrated)

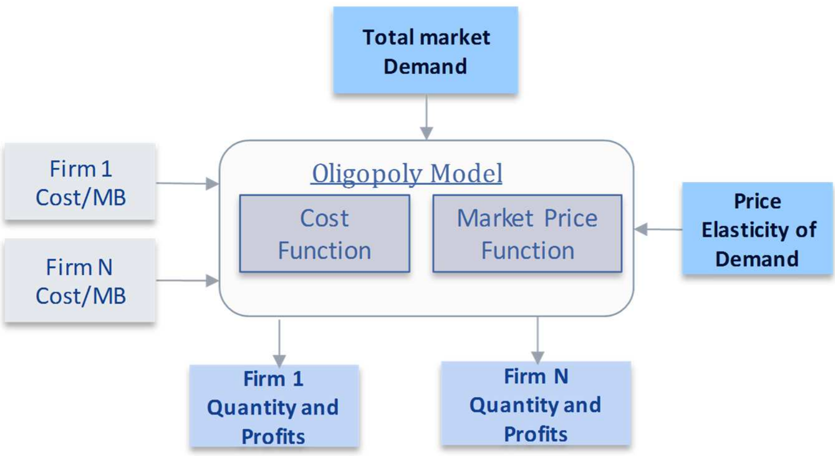
With the Future X network, CSPs can build on strong relationships with their customers as a trusted connectivity provider and to provide new value platform and services as described above, but they will also need to partner with, or acquire, industry and application-specific solution providers. The additional value that can be extracted by CSPs will depend on how aggressively they pursue this strategy and the nature of acquisitions and/or partnerships they are able to establish.

[8] Network Cash Cost/GB = (Amortized Incremental Capex/Incremental Traffic) + (Total Opex/Total Traffic)
[9] Based on network evolution plans, projected growth in traffic, and mix of traffic in different generations of networks, we expect the overall network cash cost/GB to drop by around 80% in 8 years

To better understand the potential dynamics in this nascent market, Bell Labs Consulting has applied a game theoretic approach using 3-player Cournot-Nash model. In most global markets, the nature of competition can be regarded as an oligopoly with typically 3-4 dominant service providers. With the emerging new business models offering digital services, such an oligopoly model is likely to persist; however, it is likely that new partnerships will emerge between the traditional CSPs and the industry and application-specific service providers.

The oligopolistic approach assumes that none of the CSPs are in a market-dominating position, hence the attempts by each operator to maximize profits will be sub-optimal. In such a scenario, the market can reach an equilibrium where the profitability of each CSP is determined by the equilibrium market price and the cost efficiency of the respective CSPs. The modeling framework for the oligopolistic game theory is shown in Figure 10 and the approach is described in more detail in the Appendix.

Figure 10: Modeling framework for the oligopolistic game theory



The analysis compares plausible strategies that may be considered by the primary CSPs in a given market:

1. <u>Speed of adoption of Future X Network</u>: Faster migration to a more automated platform allows significant service differentiation with respect to service reliability, latency, throughput, and compliance with the requirements of emerging digital services
2. <u>Deployment of single pre-integrated solution</u>: End-to-end automation efficiency of 5G and cloud-based networks is significantly enhanced with a pre-integrated platform supported by an intelligent, automated DevOps methodology, resulting in lower TCO and time to market.

3. Digital Value Platform strategy: Aggressive pursuit of a digital value platform strategy through integration of industrial and application platforms with own and/or partner assets enabling new value services, and higher digital value capture.

In a hypothetical market competition scenario, the game-theoretic approach identifies the winning strategy based on the derived equilibrium market shares, price and profits in each period for each player.

Specifically, the 3-player game considers two scenarios:

1. Three incumbent CSPs with different strategies toward Future X network and digital services and platforms,
2. Two incumbent CSPs facing a new digital value player with considerable digital assets (stakes in parallel digital businesses) entering the market with a Future X network solution in a mature market.

We analyze these scenarios in the following sections.

3.1 Scenario 1: Three incumbent CSPs with different 5G/Future X network strategies

We assume the incumbent CSPs currently have both 3G and 4G networks and have started deploying a 5G Future X network. Moreover, since they are primarily in the connectivity business, they must enter into partnerships with other ecosystem players for access new value. However, the strategies can vary depending on their ability to embrace change and take measured risks. For this analysis we consider the three types of CSPs, typically found in many markets:

1. **Dominant Conservative**: CSP currently has a leadership position and is confident in their market position and therefore slow to embrace change.
2. **Cautious Follower:** CSP currently in second position in the market and is willing to take moderate risks to attempt to achieve leadership position, but they will typically adopt new technologies and business models only when they become 'standard'.
3. **Aggressive Challenger**: CSP currently last position in the market and needs to take market share to increase return on investment and is therefore willing to adopt new technologies and business models, as a 'first mover'.

The main drivers of the gaming model are the cost/GB and price-demand elasticity. Faster Future X deployment will lead to greater cost/GB declines and CSPs will see even larger declines in cost/GB if they deploy an end-to-end pre-integrated solution. The profit associated with the new digital value services is captured as a cost offset for modeling purposes and will result in lower "effective

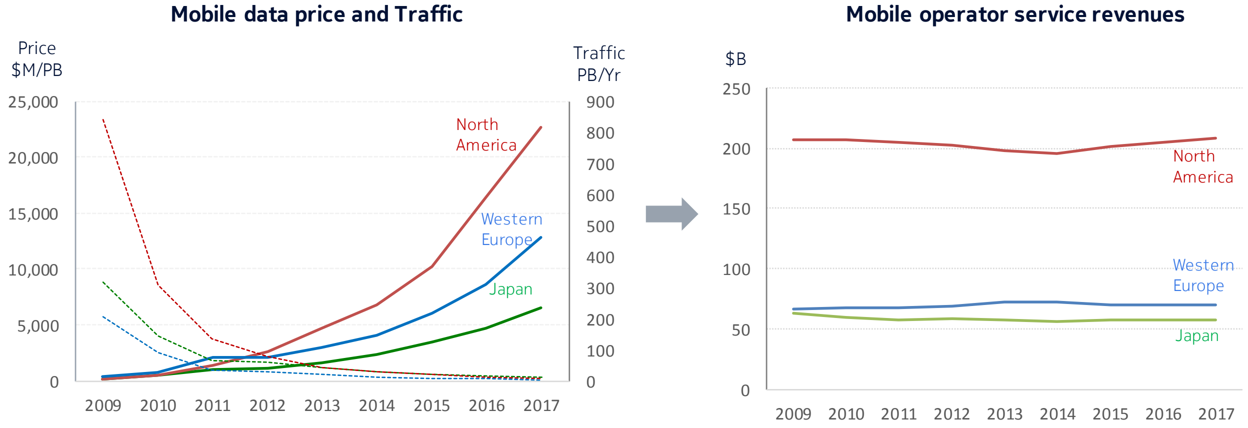
Cost/GB" for those operators. The table shows summarizes the different operator strategies and the forecast cost evolution.

Table 1: Competitive attributes of CSP's in scenario 1

CSP (NETWORKOPERATOR)	INITIAL MARKET SHARE	FUTURE X NETWORK DEPLOYMENT	FUTURE X BUILD	DSP STRATEGY	EFFECTIVE COST/GB
DOMINANT CONSERVATIVE	46%	Slow (2025: 22% on 5G)	field-integrated	Limited digital value services No revenue uplift	\$2.35(2019)→ \$0.56(2028)
CAUTIOUS FOLLOWER	31%	Moderate (2025: 27% on 5G)	field-integrated	Moderate digital value services Max revenue Uplift: ~7%	\$2.19(2019)→ \$0.52(2028)
AGGRESSIVE CHALLENGER	23%	Aggressive (2025:70% on 5G)	pre-integrated	Substantial digital value services Max revenue Uplift: ~14%	\$2.37(2019)→ \$0.37(2028)

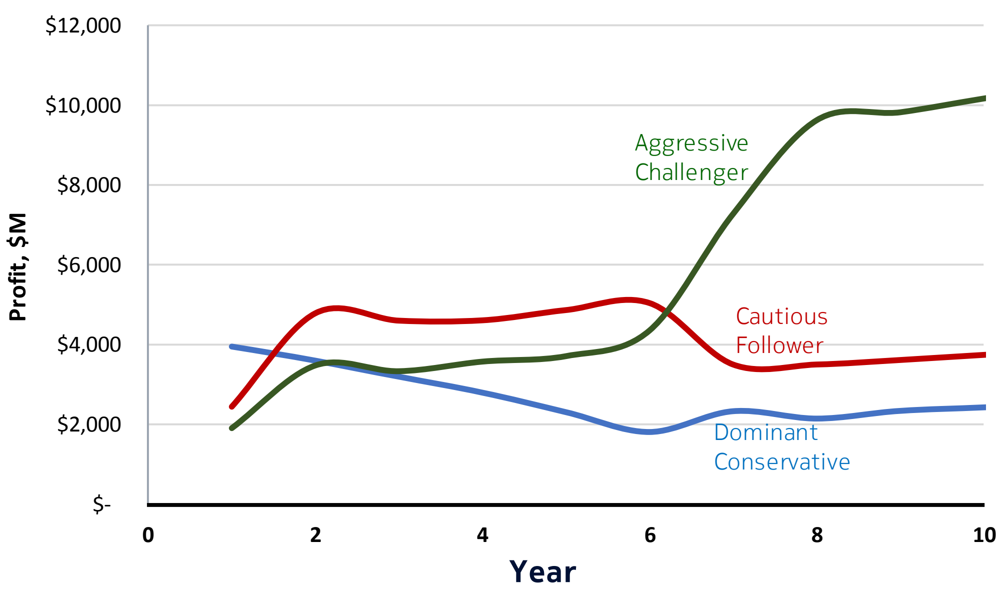
The second major driver for the gaming model is the price-demand elasticity. As markets become saturated they become inelastic and further reduction in price/GB results in higher traffic but not enough to increase the total revenues. This phenomenon explains the flattening of the CSP revenues from mobile services. Figure 11 shows the price decline and traffic increase over a 9-year interval, for North American, Western European and Japan markets.

Figure 11: Mobile data traffic growth, price and revenue trends in major economies, 2009-2017



Source: BLC analysis of GSMA data

Figure 12: Profit evolution in 3-player market



Putting this all together, Figure 12 shows that:

- The Aggressive Challenger who deploys 5G early with pre-integrated build approach can provide the necessary platform capabilities to launch digital services faster and increase % margin, leading to higher share and profitability and overtake the other two CSPs by year 7.

- The Dominant Conservative very rapidly loses share due to a conservative strategy.
- The gains achieved by the Dominant Conservative and Cautious Follower CSP are due to better unit margins, which is indicative of the differential impact of more advanced and cost-effective infrastructure technology that enables offering services with higher margins, as they migrate legacy services to the newer connectivity platform.

Scenario 2: Two incumbents and a new entrant with different 5G adoption strategies

In this scenario, two incumbent CSPs with different Future X network rollout and digital value play strategies are facing a new entrant who is already an established digital value player. One of the incumbents takes a moderate strategy and the other an aggressive strategy with respect to Future X network rollout and digital value play. The new entrant is not saddled with a legacy network and adopts the Future X network from the start – i.e. they start with a very efficient, agile and scalable network that is optimized for performance. The new entrant's network cost/GB after the initial startup cost will be much lower than the incumbents who must deal with multi-generational networks, parallel platforms and the problems/issues with transformation.

Table 2: Competitive attributes of CSPs in scenario 2

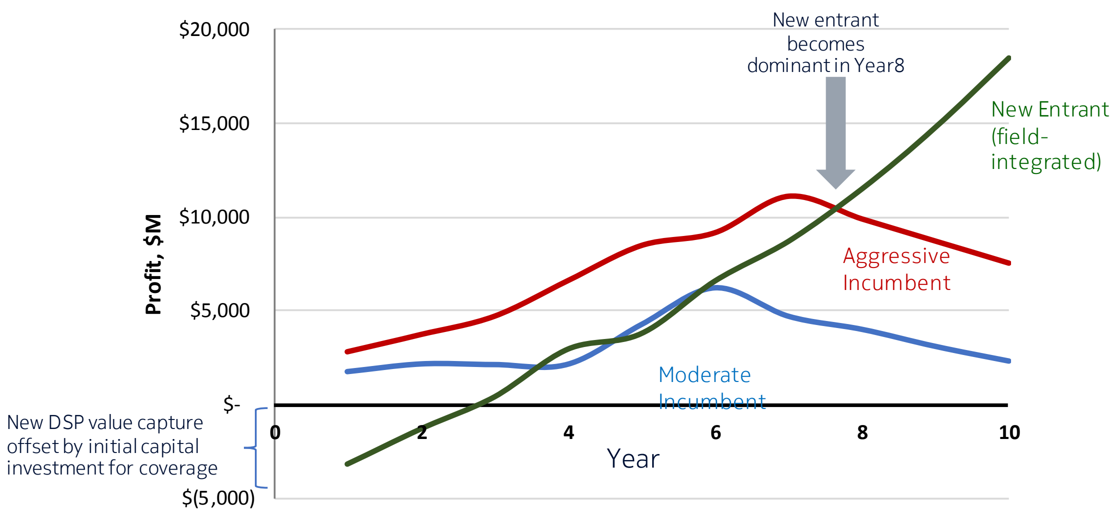
CSP	INITIAL MARKET SHARE	FUTURE X NETWORK DEPLOYMENT	FUTURE X BUILD	DSP STRATEGY	EFFECTIVE COST/GB
MODERATE INCUMBENT	46%	Moderate (2025: 27% on 5G)	field-integrated	Limited digital value services Max revenue uplift: ~7%	\$2.33(2019)→ \$0.53(2028)
AGGRESSIVE INCUMBENT	51%	Moderate (2025: 70% on 5G)	field-integrated	Moderate digital value services Max revenue uplift: ~14%	\$2.13(2019)→ \$0.43(2028)
NEW ENTRANT	23%	Aggressive (100% 5G from Y1)	field-integrated/ pre-integrated	Substantial digital value services Max revenue uplift: ~22%	\$1.51(2019)→ \$0.32(2028)/ \$1.19(2019)→ \$0.25(2028)

The new entrant will have to initially invest in new infrastructure but will eventually begin to dominate. The two incumbents will see their overall network cost/GB drop as they start migrating customers from the less efficient 3G and 4G networks to the 5G Future X network, but the new entrant will always operate at a much lower overall cost point. Moreover, the digital value player enters the market with a strong digital value proposition and uses that to capture associated connectivity business. Therefore, the new entrant can get more value out of the digital value play from the start when compared to incumbent CSP's, who must establish the right partnerships and establish themselves as a digital service provider.

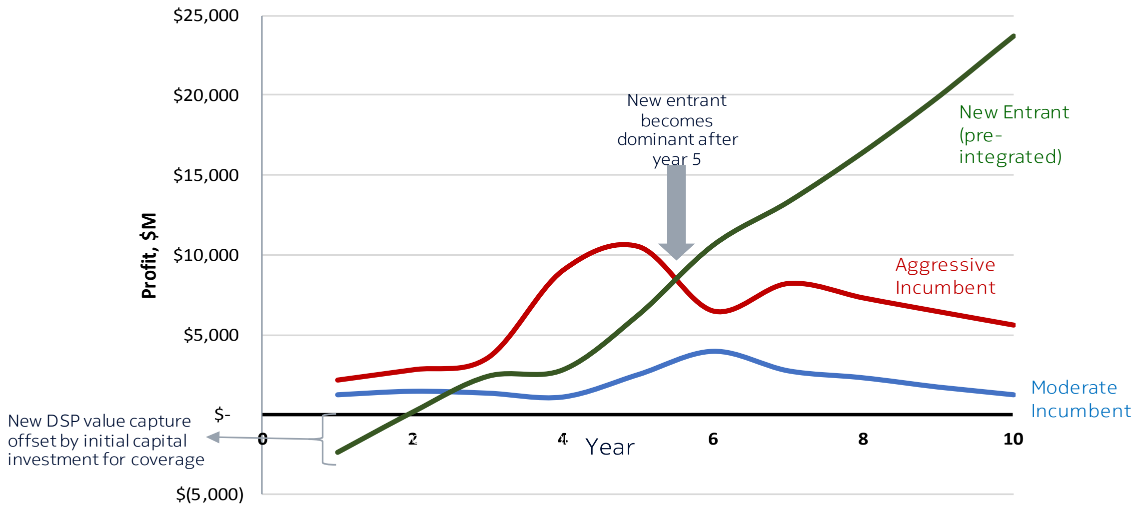
Figure 13 shows two possible strategies for the new entrant and the implications. Figure 13a shows that with a multi-vendor field integrated strategy the new entrant achieves the dominant position in year 8. But by employing a pre-integrated solution with the additional cost savings and deployment efficiencies, the digital value player can assume market profitability leadership two and half years earlier (Figure 13b).

Figure 13: Profit evolution in a 2-player market with a new entrant

(a) **New entrant with multi-vendor field integrated solution**



(b) New entrant with single pre-integrated end-to-end solution



4 Conclusions

In this paper we examine the potential new value creation for CSPs, as they look to become DSPs. To maximize the new value creation, they must carefully define their market strategy, in terms of network platform evolution, business models and partnerships and/or acquisitions, relative to the competition. The speed and efficiency with which CSPs evolve to a Future X network architecture, with high levels of pre-integration, virtualization and distributed cloud infrastructure, and dynamic end-to-end automation, together with a willingness to embrace new business models, will directly determine the ultimate market position and the long term financial outcomes.

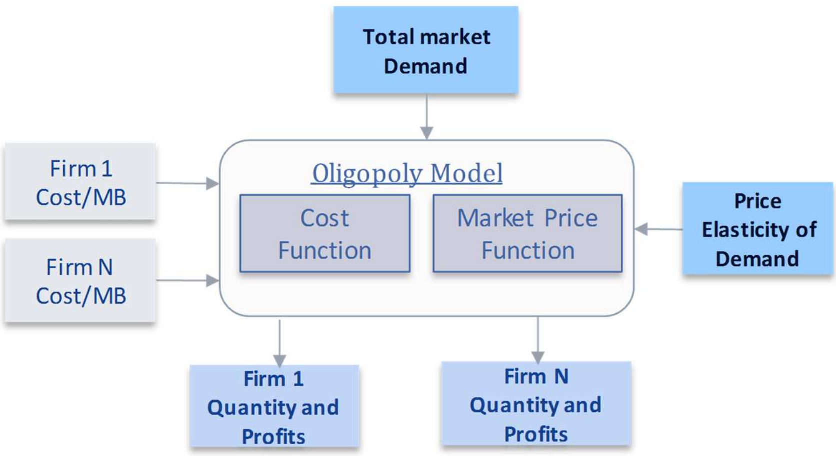
Acknowledgements

Thanks to Chris Jones for his valuable comments and insights that help shape the paper. This paper also leverages multiple studies by the Bell Labs Consulting team.

Appendix

A.1 Cournot-Nash model details

The Cournot-Nash model is based on economic game-theoretic formulation in a quantity-supplied competition where each firm attempts to optimize their respective profits. In such a formulation, each firm has its own cost model while price is determined by the market, based on the total quantity supplied. The cost function for each player is a function of quantity provided, and a market price is a function of the total quantity offered by all players in the market.



The output from the model is the equilibrium quantity of traffic that can be supplied by each service provider. From these quantities one can compute the market price and the profits for each market player. In this analysis, we have used linear cost functions and an elastic supply curve as the representation between quantity and price.

A.2 Cost model

This is a function representing the cost for a player to supply a given quantity of goods. We assume linear cost functions to represent the service provider costs to deliver a fixed quantity of data. The cost function for firm $\mathbf{i}$ is as follows,

$$C_i(q_i) = b_{0,i} + b_{1,i}q_i \tag{1}$$

$b_{0,i}$ represents the deployment cost associated with the rollout of a given technology, e.g., 4G for service provider i. $b_{1,i}$ represents the incremental cost of supplying a unit of data traffic, e.g., petabytes, and it is derived from the amortized capex and traffic-driven OpEx associated with supplying the unit traffic. The cost model reflects the differentiation between service providers

A.3 Derivation of cost coefficients

The cost coefficients in equation 1 are derived using a benchmarking method developed by Bell Labs Consulting. The coefficient $b_{1,I}$ is termed network cash cost and is based on the sum of amortized network capacity investment (i.e., CapEx) and the annual traffic-driven of network operation expense (i.e., network OpEx). The coefficient $b_{0,i}$ represents the investment related to the addition of network radio sites.

A.4 Price model

The price function is based on an elastic supply curve and function of total traffic supplied by all Network Operators in the market, as follows,

$$P(Q) = (\frac{Q}{Q_0})^{(-\frac{1}{\varepsilon})} \tag{2}$$

Where, $Q=\Sigma q_i$, and ε is the market price elasticity of demand for mobile data, and Q_0 is a calibration coefficient.

A.5 Service provider profit at market equilibrium

The market price that is established by the total traffic supplied, and each service provider will attempt to maximize their profit by adjusting their supplies. This will lead to a zero-sum game where equilibrium quantities will be established, and an equilibrium market price is calculated. The profit of each service provider at market equilibrium is,

$$\pi_i^*(Q^*) = q_i P(Q^*) - C_i(q_i^*) \tag{3}$$

Derivation methods for the equilibrium values are provided by Bell Labs research[10].

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[10] Theoretical and Numerical Analysis of the Stackelberg and Nash Games, Milan Bradonjic and Marty Reiman, Bell Labs Research, Nokia, January 16, 2015

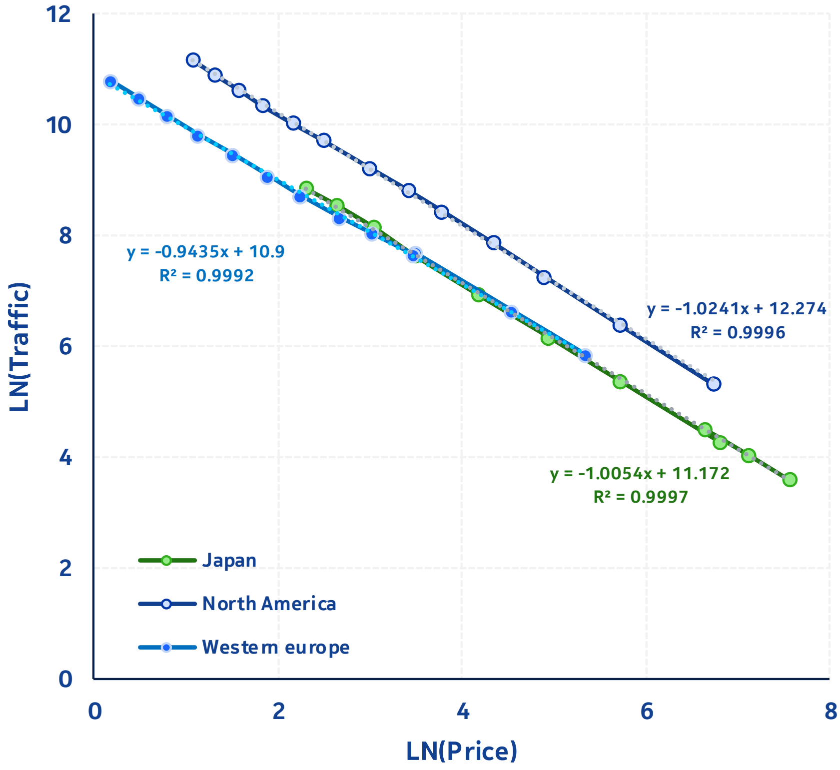
A.6 Price elasticity of demand in the developed markets

Using empirical market data, the price elasticity of demand can be derived as shown in figure 14. By taking the natural logarithms of traffic and market price in (2), the price elasticity of demand will be the negative of the slope,

$$\ln(Q) = -\varepsilon \ln(P) + \ln(Q_0) \tag{4}$$

Figure A1 is based on the mobile market data from Japan, North America, Western Europe. The price elasticities for these markets are 1.005, 1.0241, and 0.9435, respectively. The results demonstrate that the mobile data markets are relatively inelastic. For the competitive analysis in this paper, the Japanese market data have been used.

Figure A1: Price elasticity of demand for CSP mobile services in advanced economies



Source: GSMA intelligence, BLC analysis, Cisco VNI

About the authors

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