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# Økonomi- og planleggingsaspekter av 5G-teknologi med risiko- og etterspørselsusikkerhet

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Innlevert: juli 2016
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## Abstract

For my master thesis I have evaluated business models for delivery of 5G technology with risk and demand uncertainty. I have described the key features of 5G and the various economical implications it brings. I have then discussed business models in light of portfolio theory with optimization under uncertainty. I have found that the models for network and content service provision I have studied prove well to capture the considerations that must be taken in the development of 5G mobile network technology. I have found that Quality of Experience is one of the most important aspects for a network or content provider, and that a reasonable risk measure for these providers are churn - customers leaving for other options.

## Sammendrag

I min masteroppgave har jeg evaluert forretningsmodeller for levering av 5G-teknologi, med risiko- og etterspørselsusikkerhet. Jeg har beskrevet de viktigste egenskapene ved 5G, og de forskjellige økonomiske implikasjonene det bringer. Jeg har så diskutert forretningsmodellene i lys av porteføljeteori med optimisering under usikkerhet. Jeg har funnet at modellene for nettverks- og innholdslevering som jeg har studert, fanger opp de betraktningene som må tas i utviklingen av 5G mobilnettverk på en god måte. Jeg har funnet at opplevelseskvalitet (Quality of Experience) er et av de viktigste aspektene for en nettverks- eller innholdsleverandør, og at et fornuftig risikomål for disse er kunder som forlater leverandøren for andre alternativer (”churn”).

# Acknowledgements

I would like to thank my supervisor Alexei A. Gaivoronski for the help and directions I have gotten for my project and master thesis.

## Terminology

Churn - customers leaving/quitting a subscription for alternative options.

Content provider - provides content to end users (consumers). Their services require the services of the network provider.

Network provider - provides bandwidth or network access (Internet).

Service provider - can be a content provider or a network provider.

QoE - Quality of Experience: the user's perceived quality of the service they are consuming.

QoS - Quality of Service: the actual quality of the service, measured by e.g. packet delay and jitter.

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# 1 Introduction

Ever since the advent of mobile telecommunications there has been a constant evolution of how we are able to communicate with each other. Once a mere tool to communicate via voice over great distances, the mobile phone has evolved into a small home entertainment system, and a device very few can manage without for the larger part of the day. All made possible by the technology that can transfer data packets from one end of the world to the other in a matter of seconds: the mobile network.

5G is the next generation of mobile network technology, and is expected to be globally available in 2020. 5G will not just be an upgrade of the current technology, 4G, it will need to satisfy demands that far surpasses what we see today, thereby presenting almost a paradigm shift for the telecommunication industry.

While there is extensive literature on the technical aspects of 5G technology, the economic side has not been given the same attention so far. I have therefore for my master thesis decided to investigate what economic implications comes with 5G, and what network providers, who give content providers access to their network, and content providers, who provide services and applications for the consumers, must consider when approaching the next generation mobile technology. The focus will be on the classical portfolio theory with risk and demand uncertainty.

The rest of this thesis is structured as follows:

In chapter 2 I will present some of the related work on this subject, namely business model evaluation and service portfolio selection under risk.

In chapter 3 I will give a thorough introduction to 5G, and try to describe what it is, what the visions are, and what the key features and requirements will be; and I will discuss some of the implications of the development of the 5G network.

In chapter 4 I will dive deeper into the various economic aspects of 5G. I will discuss some of the business opportunities and challenges the network and content providers face when they must adapt to the new reality.

In chapter 5 I will present and discuss the portfolio theory, made famous by Harry Markowitz. Given a set of assets, this theory will help to pick a portfolio of assets that satsify the demands of the actor, in terms of expected return and risk. I will discuss the mean-variance approach, and also mention two other risk measures: The Value-at-Risk and the Conditional Value-at-Risk.

In chapter 6 I will discuss what business models are favourable for actors in the telecommunication industry. I will present a multi-tiered price system, and I will elaborate on profit models and risk measures for network and content providers, and try to link these to the features of 5G.

In chapter 7 I will present my conclusions.

# 2 Related Work

There have been some papers evaluating how network or service providers can utilize modern portfolio theory to determine a proper trade-off between risk and return in delivering their services. Here are a few of them:

Gaivoronski et al. (2013) analyses the cloud brokering platform under uncertainty. They develop a set of models to investigate the economic and financial effects of various value configurations, and specifically the brokering of Software-as-a-Service offerings. They investigate how the cloud broker can choose the optimal trade-off between risk and return in cloud ecosystems, analyzing how Quality of Service (QoS) and churn affect the profits of the brokers. They measure risk as the share of demand that is not satisfied with the required QoS. The optimization problem that is evaluated is given by

$$\max_{x,u\geq 0}\Big\{(p-\alpha(p+c))\bar{d}-c_{0u}y_u-c_{1u}u-c_{0x}y_x-c_{1x}x\Big\}$$

subject to

$$\mathbb{E}\max\Big\{0,d-(1-z_u)u-(1-z_x)x\Big\}=\alpha\bar{d}$$

where p is the revenue, c is the cost, $\bar{d}$ is expected demand, (x, u) is the connectivity portfolio, z are random variables that takes values between 0 and 1, and $\alpha$ is some threshold the fraction of lost demand will not exceed. An efficient frontier of connectivity portfolios is then computed, and the actor can choose a portfolio with a given expected return according to the amount of risk he is willing to take.

The main findings include that the addition of a third connectivity alternative substantially improves the profit/risk balance by increasing the profit for a given level of risk; the combination of the connection alternatives improves QoS substantially, even when they individually provide poor QoS; for very high QoS there is still no substitute for carrier-grade connectivity; and the best connectivity portfolio depends on the interplay between costs and quality, and can't be found using empirical rules such as "use low-grade connections for low-grade QoS."

Gaivoronski et al. (2016) develop a model for ISPs to select a portfolio of end-to-end differentiated services to be offered to a non-homogeneous user population under conditions of uncertainty, considering pricing, QoS levels, the volume of service provision to different market segments, and investment in network expansion. Using portfolio theory from finance, they then find an appropriate trade-off between risk and profit, depending on the risk aversion of the actors. They compute efficient frontiers for ISPs with different levels of risk aversion for offering high quality service in the residential market, in the business market, and expanding the offer with a lower priced/quality service. They find that the introduction of End-to-End differentiated services is appropriate for ISPs with moderate risk aversion, and that it can bring substantial benefits to ISPs and demanding users, without degrading the quality of basic services.

Pisciella, Zoric & Gaivoronski (2009) analyze a business model in the case of provision of a bundle service consisting of IPTV, Video on Demand and User Generated Content. They analyze how many Mbps providers should supply to each service portfolio in order to get the highest return on costs for a given level of risk. The expected return on total costs of the i-th provider is given as

$$\bar{r}_i(x_i, \gamma_j) = \sum_{j=1}^{4} \mu_{ij} x_{ij} = \sum_{j=1}^{3} x_{ij} \Big( \gamma_{ij} E \frac{v_j}{c_i \lambda_{ij}} - 1 \Big) + x_{i4} \Big( E \frac{v_{i4}}{c_i} - 1 \Big)$$

where $x_{ij}$ is the portion of provision capability for service $i$ dedicated to participation in provision of service portfolio $j$, $\gamma$ is a vector of revenue shares, $c_i$ is the cost per unit of megabit of service $i$ sent per second, and $v_j$ is a random variable that represents the revenue per unit sold.

Risk is defined as the non predictability of the unit revenues in order to have a certain level of demand, which is simply the standard deviation of the return on costs:

$$R(x_i) = StDev(r_i(x_i)) = StDev\Big( \sum_{j=1}^{4} r_{ij} x_{ij} \Big)$$

Volatility, or standard deviation, is a very common measurement for risk, as we shall see in chapter 5 concerning portfolio theory.

# 3 5G Technology

5G, or 5th Generation mobile networks, is the next standard of mobile telecommunication, and is expected to emerge as the main standard by the year 2020 (Monserrat et al., 2016). From the analog beginnings of mobile communication in the 1980's (now dubbed "1G"), the evolution of telecommunication standards has seen an exponential growth in the technological possibilities, which in turn has spurred greater user demand, and thus setting even greater requirements for the next generation of mobile networks. With the emergence of the digital 2G networks in the early 1990's, it was now possible to send text messages between two cellular devices. The new millennium saw the advent of smartphones, which would let you communicate not only via voice or text messages, but also using video, and browsing the Internet, which was made possible by the next generation mobile network, 3G. With user demand ever increasing, the mobile network had to be able to cope with higher data rates to process services such as High Definition video streaming, which brings us to today's standard, 4G.

Now we are starting to look forward beyond 4G. In fact, the academic literature has debated the next generation of mobile network technology for many years now, and we are now seeing more and more consensus being reached as to what 5G should be like, what kind of requirements it needs to satisfy, how it will be deployed, and so on. The need for 5G comes mainly from two important aspects: the increase we will see in users of mobile communication devices, and the increase in user demands we will see in the same period. Laya, Ghanbari & Markendahl (2015) describe 5G as "the flipping point from a technology push to market pull", meaning that 5G will not just come as a natural consequence of the technological development; it is just as much the user demand that dictates what 5G should be like.

To give an indication as to exactly how big an increase we will see in users and user demands towards 5G, I will now present some of the estimates in the current literature. When some of the numbers seem to mismatch, it may be from the authors' distinctions between ”connected devices”, ”connected users”, ”mobile phones”, etc. Kou, Xiao & Wang (2015) states that an estimate of increase in global wireless data between 2013 and 2018 are “nearly 11-fold” from the 7 billion global mobile devices that existed in 2013. According to Gozalvez (2015), the number in 2014 was 7.4 billion, with the figures in 2020 expected to reach 10 billion, when 90% of the world population, excluding young children, are expected to have a mobile phone. According to Panwar, Sharma & Singh (2016), the amount of connected devices that will make use of cellular network services in 2020 are over 50 billion. Winzer & Massarczyk (2015) further gives an estimate of 50%-60% growth in data development per year, with the mobile data traffic in 2020 predicted to be 1 000 times larger than in 2010. In order for the increased number of users in a mobile radio cell not to tamper with the quality perceived by the user, 5G technology such as dynamic resource scaling needs to be implemented (Winzer & Massarczyk 2015).

The smartphone and tablet revolution has been a market driver for the switch from fixed broadband access demands, to mobile network demands. In Table 1 we see how smartphones and tablets will be more and more used for Internet browsing. With PCs constituting 86.4% of the Internet usage in 2013, it will only make up about half the Internet usage in 2020.

| Device | 2013 | 2020 |
|---|---|---|
| PC | 86.4% | 50.5% |
| Smartphone | 5.0% | 21.0% |
| Tablet | 3.1% | 18.0% |
| Other | 5.5% | 10.5% |

Table 1: Devices for Internet traffic usage, from Winzer & Massarczyk (2015)

In addition to the increase in Internet connected mobile devices, the user demand per mobile device is ever increasing as well. For every new generation of smartphones, their improved technical specifications let them perform even more and more demanding tasks, which in turn makes the service providers increase the quality of their services, all the time creating an upwards spiral of demand and supply of technological solutions. With the advent of more and more streaming services, real-time video applications, live broadcasting to smart devices and so on, we will need a mobile network infrastructure that can cope with these increased demands. Winzer & Massarczyk (2015) expects that the demand for bandwidth, with video consumption constituting more than 50% of the mobile traffic, will reach 100 Mbps in the near future; Nikolikj & Janevski (2014) estimates a moderate demand of mobile network in 2020 at 120 GB per user per month, while a high demand is estimated at 500 GB per user per month. This extraordinary growth in traffic volume as well as number of connected devices, "necessitates an evolution toward 5G" (Yazici, Kozat & Sunay, 2014). The 4G networks we see today simply cannot handle the upsurge in connected devices combined with the demands for e.g. low latency and spectral efficiency, which will be imperative in the future of communication and computation (Panwar, Sharma & Singh, 2016).

One phenomenon that has seen an explosive increase of attention, interest, research, development and demand in the latter years, and that is sure to continue its rapid development in the coming years, is the Internet of Things (IoT). With IoT, one should understand normal, everyday objects with the addition of Internet access, such as light switches you can control via your mobile phone, running shoes that can tell you how long, and where, you have been running, and even refrigerators that let you connect to social media. IoT has spurred massive debate, with people embracing it and repelling it almost at the same time. Proponents of IoT emphasize that in addition to making everyday life easier and more fun, one also has the advantage of improving health care systems, safety (such as self-driving cars), and so on. Opponents of IoT first and foremost criticize the security threats, with many IoT devices being vulnerable to even simple malicious attacks. Also, there is a resentment against making machines completely take over your life. One way or the other, IoT is here to stay, and will certainly not diminish in size over the next decade. Thus, the 5G network should support applications in relation to the IoT. Among such applications we find virtualized homes, smart societies, the Tactile Internet, health care systems and other industrial usages (Panwar, Sharma & Singh, 2016), smart energy networks, vehicular communication and intelligent transport systems (Simsek et al., 2016). Therefore the 5G architecture must combine high capacity and agile networks with low-cost solutions, so both the user's satisfaction is guaranteed, and the Mobile Service Providers can make a profit (Yazici, Kozat & Sunay, 2014).

There are debates over whether 5G should be considered an enhancement of 4G/LTE, or as a completely new paradigm. Panwar, Sharma & Singh (2016) states that 5G will "encompass a system architecture visualization, conceptualization, and re-designing at every communication layer", but at the same time integrate the current wireless technologies. According to Yazici, Kozat & Sunay (2014), a key differentiator between the two systems will lie in how the benefits of cloudification will be realized by taking advantage of the transport capacity with the countless infrastructure devices that will constitute the 5G system architecture.

## 3.1 Requirements for 5G

There have been numerous papers envisioning what 5G will be like, and what needs it must fulfill. This section will attempt to capture some of the recurring and most important visions for 5G, , and how they translate to actual requirements for the mobile network.

Amaral et al. (2016) envisions a cellular network system that will come closer to a broadband network, providing "fiber-like experience" for the users, and thus going far beyond what we have seen up to now in mobile telecommunication. To achieve this, they list seven key features that will define the next generation mobile network, and will thus be main drivers for 5G.

### 3.1.1 Massive System Capacity

As described in the previous section, the increase in connected devices (10 to 100 times than today's figures (Amaral et al. 2016)) will require a system capacity that can handle the higher data traffic demands (1000 times more data traffic than today (ibid.)) These devices are not merely mobile phones and tablets, but also devices related to IoT, such as machine type communication (MTC) devices (Lee et al., 2016).

### 3.1.2 Ubiquitous Data Rates

Panwar, Sharma & Singh (2016) list ubiquitous connectivity as one of the main features of 5G networks, realizing the user-centric view of 5G. This is achieved through higher data rates, specified by Amaral et al. (2016) as a minimum of 10 Mbps everywhere, 100 Mbps in urban areas, and all the way up to 10 Gbps for specific scenarios. The advent of Over-the-top (OTT) streaming services, such as YouTube and Netflix in Ultra High Definition and 3D are among the services that will require a high network rate (Feng-Hui, Wen-An & Yu, 2014).

### 3.1.3 Low Latency

5G should achieve latency as little as 1 ms or less for end-to-end latency-critical applications. This will fulfill the service-provider-centric view of Panwar, Sharma & Singh (2016). The Tactile Internet is relying on low latency for sensing objects far away via touch, sound and vision as precisely as possible.

### 3.1.4 Ultra-high Reliability and Availability

The 5G network should be reliable, and availability should be guaranteed for critical applications. Pandey, Gaurav & Kumar (2015) address the point of having great service in large, populated areas such as in the densely populated areas of India.

### 3.1.5 Low Cost and Energy Consumption

Future devices should be available at a very low cost and with a battery life of up to 10 years (Amaral et al., 2016) without recharging for IoT devices. Panwar, Sharma & Singh (2016). list energy efficiency (1/10 of today's energy consumption), scalability and cost efficiency as main drivers for the network-operator-centric view of 5G, which concerns the communication infrastructure. Pandey, Gaurav & Kumar (2015) suggest a saving of 90% energy compared to today's devices.

### 3.1.6 Virtualized Network Technology Support

To achieve cost and deployment flexibility, a virtualized network technology support and software-based implementations should be in place. Yazici, Kozat & Sunay (2014) envision "fully decoupled, independently scalable and programmable user and control planes".

### 3.1.7 Powerful Nodes at the Edge of the Network

To avoid congesting the network, and to cope with the multitude of sensors that will come with the advent of more and more IoT devices, offloading algorithms must be in place for nodes at the edge of the network. Rahman, Despins & Affes (2015) state that the vendor specific network nodes of today's mobile network is struggling to satisfy the requirements of the next generation network dynamics.

## 3.2 Quality of Experience

Another aspect that will be very important for the 5G network is the Quality of Experience (QoE). QoE is the overall satisfaction of the users to the service they experience (Feng-Hui, Wen-An & Yu, 2014). QoE should not be confused with Quality of Service (QoS), and is influenced by the content provider's requirements with respect to QoS, the actual QoS that is delivered by the network provider, and the end user's preferences and expectations about the service (Krämer, Wiewiorra & Weinhardt, 2013). A service may provide good or decent QoS, but if the expectations of the user is not met, for instance with regard to a different part of the service that is not directly linked to the QoS, then he may have a bad experience, and could choose a different service provider next time. Barbarossa, Sardellitti & Di Lorenzo (2014) state that shift of focus from QoS to QoE implies that the network aspects can't be separated from the application requirements, thus forcing network and service providers to look at the full network ecosystem, and not just their core product. This poses a challenge, however, with the QoE being difficult to measure from the network operator's point of view, who does not have full access to client applications and content server side networks (Nam et al., 2015).

QoE will differ between ordinary users and advanced users. An ordinary user will be satisfied with the best effort delivery service, while an advanced user will probably not be satisfied with this quality, and demand a higher bandwidth to have a better experience with the service. For bandwidth-demanding services, such as video streaming, the QoE can be low even though the QoS is good. For instance, some parameters to measure the QoS are initial buffering time, re-buffering time and frequency. Even if these parameters are kept low, the QoE of the user will degrade for each re-buffering, and the user will have a bad experience. Also, if the network condition is bad, the OTT service will experience problems, and the user will have a bad experience with the service, even though the underlying problem stems from the network provider. Thus, an evaluation of QoE based merely on service level parameters, may not catch the user's feeling of the experience properly. To improve a user's QoE, the provider must evaluate how they handle such things as traffic classification, bandwidth management, admission control and load balance.

## 3.3 Implications of 5G

So with 5G knocking on our doors, what will this technology development mean for the mobile network ecosystem? For one, mobile connections will to a greater extent substitute fixed broadband connections in the future. For the users' part, the flexibility in content, data transports, application and service will favour the mobile network, whereas for the Internet providers, mobile broadband technology has lower implementation costs than fixed broadband (Winzer & Massarczyk, 2015). Therefore, it is expected that mobile technologies will prevail as the leading technology in terms of number of subscribers and distribution (ibid.)

The implementation and deployment of the 5G mobile network as described so far poses serious challenges. Applications such as Voice over IP (VoIP), conferencing and messaging, that will be favoured by many users, will require a lot of resources (Carella et al., 2015). The costs seen from a mobile service provider's point of view should also not be ignored, even if the Long Term Evolution (LTE) technology has been successful in lowering their expenditures while at the same time increasing the end-user's QoE by providing higher data rates and lower latencies. Yazici, Kozat & Sunay (2014) argue that fresh thinking is needed with regards to the 5G mobile network architecture. A reduction of costs must take place in both the cloudification, i.e. the virtualization of network functions, and in programmability.

To conclude, we have seen some insight into what 5G probably will look like when it arrives around 2020, and what it must cope with of user traffic and demand. The natural way to go from here is to consider what the development of the next generation mobile network has to say economically, which is the subject of the next chapter.

# 4 Economic Considerations

The advent of 5G has indeed created much debate over what technical solutions should be implemented and how, and what will be possible to deliver over the 5G network. Another side of the story, which should be of equal or greater interest, are the economic considerations that comes with the development and deployment of 5G. In this chapter, I will look into some of the elements of the future mobile network, and the implications it brings, and view it from an economic perspective, both from the network provider's and the service provider's side.

## 4.1 The Introduction of a New Network Technology

A very relevant issue to the 5G network is how the market responds to the introduction of a new network technology. The network provider needs to address issues such as when to deploy the new technology, how it shall be implemented, to what extent it should be deployed, if they rather should upgrade the old network technology, to mention some of the questions that arises.

In this regard, Loumiotis et al. (2015) studied the transition from 3G to 4G mobile network, to see how the users reacted when facing a new technology. Timing is a crucial aspect for the mobile operator, as deploying the new technology too early can result in the customers not accepting it, thus leaving the mobile operator with a loss. Deploying the new technology too late, on the other hand, may see the customers choosing a different service provider, who can offer the new technology. Ultimately, it is the market demand that initiates the deployment of the new technology (a “market pull”). The mobile operator needs to be alert as to when the market is ready, in order to effectuate a rapid transition to the new technology at the right time.

When the mobile operator has deemed that the timing is right to deploy the new technology, Loumitis et al. (2015) found that the mobile operator should deploy an appropriate percentage of the new technology, depending on the market demand and the satisfaction with the legacy technology. If the subscribers' satisfaction with the new technology is heavily influenced by it, then there is a greater chance for a successful penetration of the new technology. Similarly, if the subscribers' satisfaction with the legacy technology is reduced, e.g. because it can not deliver satisfactory bandwidth to a new and traffic heavy application, then the introduction of the new technology can be facilitated. Penetration of the new technology can also be facilitated by lowering the price of the new technology or charging extra for the legacy technology.

Loumitis et al. (2015) found a threshold value for the price and satisfaction of the new technology, given as:

$$P_{HB}^{th} = S_{HB} + P_{LB} - S_{LB}$$

$$S_{HB}^{th} = S_{LB} - P_{LB} + P_{HB}$$

where $P_{HB}^{th}$ is the threshold price for the new technology, $S_{HB}$ is the satisfaction with the new technology, $P_{LB}$ is the price of the legacy technology, $S_{LB}$ is the satisfaction with the legacy technology, $S_{HB}^{th}$ is the threshold satisfaction with the new technology, $S_{LB}$ is the satisfaction with the legacy technology, $P_{LB}$ is the price of the legacy technology, and $P_{HB}$ is the price of the new technology.

The first equation tells us that the charging price of the new technology should not exceed the satisfaction minus the net payoff of the old technology, while the second equation tells us what satisfaction value threshold is the minimum before the subscribers are no longer appealed by the new technology.

### 4.1.1 Upgrade of Old Network Technology

Bourreau, Lupi & Manenti (2014) investigate the forces at play when there is a new generation network technology available, but the market is not yet mature enough for a full scale switch from the old technology to the new technology. They look at different scenarios, where the market leader is the one deploying the new technology, and where a new entrant is the proponent of the new technology. They find that in the case where the new entrant offers the new technology and the market leader decides to upgrade their old technology, social welfare is lower than when the market leader also pursues the new technology. In the case where the market leader offers the new technology and upgrade their old technology, the social welfare is less than when they don't upgrade their old technology. In this case it would be welfare enhancing if regulators were to forbid an upgrade of the old technology network. According to ElDelgawy & La (2015), there is no loss of efficiency when one provider is a market leader, and has a much stronger bargaining position, due to all of the providers seeking the maximum aggregate payoff - the price of stability is one.

When a network provider offers services from an old and a new technology, Baranes (2014) finds that the access price for the old technology should be set low enough to attract consumers, but not too low, to prevent the old technology from being too competitive towards the new technology. There is a trade-off here that is depending on how the old and new technology may serve as a substitute for one another, and how the consumers deem the value of the different technologies.

If the access price for the old technology network is set high, it will reduce consumer surplus, but at the same time, it stimulates migration to the new technology network, thus being beneficial for the competing firms. All in all this suggests an increase in social welfare. However, Bourreau, Lupi & Manenti (2014) suggest that for the migration from an old technology to an new technology to be effectuated, simply controlling the access price of the old network technology may not be efficient, so regulators should consider legal switch-offs, or simply forbidding upgrades of the old network technology.

## 4.2 Total Cost of Ownership

There are different ways for a project manager to analyse and evaluate different projects, to decide whether the project looks promising, and will generate a future profit for the company, or if the costs will surpass the revenue, thus making it an unprofitable project which the project manager should reject. One such project evaluation measurement is Total Cost of Ownership (TCO). A mobile network operator will have costs that span over the entire lifespan of its business, and thus TCO is a relevant cost estimate (Werda et al. 2016). TCO will look not only at the costs of manufacturing and installment, but also the running costs that a product or service will have over its lifespan. TCO consists of three parts, namely the capital expenditure (CAPEX), the implementation expenditure (IMPEX) and the operational expenditure (OPEX). For a mobile network operator, the CAPEX will typically be the initial investments in equipment and software; the IMPEX includes site acquisition, installation and planning costs; and OPEX regards the costs of running the mobile network, such as site operation, maintenance, administration and customer care (ibid.) If the network operator only considers the imminent costs visible at the time of planning, he might give too much attention to the CAPEX and the IMPEX, and too little to the OPEX, and could evaluate an unprofitable project erroneously.

## 4.3 Ultra-densification

When 5G is deployed, it will by the means of ultra-densification of the network infrastructure. Ultra-densification is the process of adding more and more low-power, small-sized base stations, using femtocell technology, to improve throughput, round-trip time, indoor coverage, handover between indoor and outdoor Internet access, security and more. Ultra-densification is a fairly new way of deploying Internet infrastructure, and will have different economic upsides and downsides than the traditional macrocell deployment. For network providers, such ultra-densification may bring benefits such as lower costs, network coverage expansion, higher network capacity from increased spectral reuse and lower power consumption in the macrocellular infrastructure. (Bouras et al., 2015)

Overlay macrocell-femtocell systems combines the standard macrocell system with femtocell base stations with low transmitting power indoor or in countryside environments (Wang & Wei, 2010). This will improve the stability of wireless services, lower signal loss rates to mobile stations nearby, improve signal qualities and extend system capacity, thus increasing the revenues of the service providers.

Werda et al. (2016) argue that mobile network operators need to propose new ways to improve their economic models to be able to meet the exploding demand in the coming years. Offloading strategies with small cell systems will in this regard prove a beneficial alternative to traditional macrocell system deployments. The main reason for this is the lower costs of small cell deployment.

When comparing the costs of small cell deployment to the Distributed Antenna System (DAS), we see why it is important to consider both the CAPEX and the OPEX of an investment project. When considering the CAPEX, the DAS deployment comes out as the less expensive one. The total costs does not depend much on the number of installed antennas, whereas for the small cell deployment, the CAPEX increases linearly with the number of installed antennas. For the OPEX, however, the DAS is much more expensive than the small cell system. Looking at the TCO, the small cell system is the economically more beneficial one. Werda et al. (2016) conclude these findings by stating that there is an absolute cost advantage for adopting small cell systems as offloading networks.

Wang & Wei (2010) compare a macrocell-only scenario with an overlay network scenario, with both fixed contracts and second-best contracts. Their findings is that the overlay network scenario outperforms the macrocell-only scenario, and second-best contracts extracts more revenue than fixed-price contracts in both scenarios. They conclude that adding a femtocell can enhance the spectrum utilization and increase the revenues of service providers.

## 4.4 Cloudification

Whereas we until now have mainly focused on the network providers and content providers as two separate entities in the Internet ecosystem, there are situations where actors can act as a network and content provider at the same time. A group of services that has evolved rapidly over the past years, and which is probably going to be more and more important in the years to come is cloudification. Cloudification is a way of computation offloading that enables users to utilize resources on demand, and can resolve many of the challenges future mobile network infrastructures face (Rahman, Despins & Affes, 2015). There are many ways to make use of cloudification for a service provider. Three important resources a cloud service provider can deliver are Infrastructure-as-a-Service (IaaS), where cloud providers can give the user access to physical or virtual servers; Platform-as-a-Service (PaaS), where users can develop, deploy and run applications on a platform specially provided for them; and Software-as-a-Service, where cloud providers deliver specific applications, such as Gmail and Dropbox (Anselmi et al., 2014).

Looking at the economic side of cloudification, there are two opposite forces in action. According to Anselmi et al. (2014), the profit of IaaS and PaaS providers is reduced when more competitors enter the playing field, slowly decreasing towards zero. SaaS providers, however, maintains their profit even with many competitors. In the long run, this gives SaaS providers market power over IaaS and PaaS providers, and the latter will eventually consist of just a handful actors per market. Therefore one needs to carefully evaluate the market or ecosystem when doing business in the cloud market, be it for companies that wish to penetrate the market, or companies that wish to deal with actors in the market.

## 4.5 Tactile Internet and the Internet of Things

We have already mention the Internet of Things, and a continuation of IoT is the Tactile Internet, where senses such as touch and smell can be incorporated with IoT devices, to make applications that will change the Internet from something you access on a machine, phone or tablet, to something you can find everywhere. Simsek et al. (2016) state that the Tactile Internet will open up for "massive business opportunities for the operators, vendors, over-the-top-content providers; and society at large." The Tactile Internet will have direct impact on both telecommunication operators and vendors. For operators, the emergence of Tactile Internet means that content providers will need high quality network for their over-the-top-content to be delivered with satisfying quality to the end-users, thus allowing the operators to charge the content providers accordingly, which in turn will generate more revenue for the operators. For the vendors, the Tactile Internet in its early phases will be more B2B-driven rather than consumer-driven, with the oil and gas- and transport industry as potential markets for Tactile Internet vendors. When the vendors have penetrated these markets, they will be able to negotiate better deals with the operators.

Palatella et al. (2016) state that there are clear financial returns in IoT technologies, and list three major Return on Investment (ROI) arguments to use IoT technologies. These are real-time instrumentation ROI, which would improve efficiency benefits from industrial IoT technologies; big data value ROI, which gives unique insights from cross-correlating data that are not obvious on their own; and wireless ROI, which will achieve substantial CAPEX and OPEX gains in replacing copper cable and human labour costs with electronics and sensors. So to summarize, one can say that there are many exciting opportunities for network and content providers related to the Tactile Internet and the Internet of Things.

## 4.6 Pricing of Services in the Telecommunication Industry

Finding the right pricing of the service or technology is imperative to extract the maximum revenue. If revenue management principles in resource allocation and pricing is applied properly, a telecommunications provider may improve its profit (Zachariadis & Barria, 2008).

Baranes (2014) showed that there is an interplay between the network provider, the service provider and the consumer. If the network provider makes a marginal network investment, it can increase both the provider surplus and the consumer surplus, i.e. the overall social welfare. In this regard, price discrimination and non-net neutrality, which will be dealt with in a subsequent section, could have positive effects. Whether content quality will have a positive impact on the network investments depends on how the consumers perceive the value they get from premium content compared to basic content, and whether these different content qualities can substitute each other. In this regard, high content quality may give the network provider a bigger incentive to invest in a new technology.

Zachariadis & Barria (2008) study the optimal dynamic policy for price and QoS of services in order to maximize the long-term expected revenue of the service provider. They look at policies where the prices and QoS are the same regardless of the state of the network, when they can be changed dynamically, and any combination of these. They find that the optimal policy is when prices and QoS can be dynamically changed according to the state of the network, however this comes at the cost of computational complexity. Under this policy, they find that under high demand, it is not necessarily true that prices increase and quality decreases.

In relation to the previous section about cloudification, we find the work of Di Valerio, Cardellini & Presti (2013) particularly interesting. They investigate the relationship between IaaS and SaaS providers in the cloud, and how IaaS should set the optimal price for their service - cloud facilities that SaaS providers need for their services. They find that, unless resources are scarce, the IaaS provider will maximize its revenue by lowering the spot prices from the maximum level in order for SaaS providers to buy more of their facilities, so the higher volumes of sold entities weigh up for the lower price.

## 4.7 The Effects of Vertical Separation/Integration

What business form a company should use, is a question that becomes more and more relevant as the business ecosystems become more and more complex, such as in the case of cloudification, where network providers can at the same time be content providers. An issue of importance for a company, is whether it should be vertically separated or integrated. Vertical separation is defined as selling services or products through an independent exclusive retailer, contrary to vertical integration where the firm is selling directly to the final consumers (Sloev, 2006).

In the telecommunication business, the question of vertical separation is no less of importance than elsewhere. According to Avenali, Matteucci & Reverberi (2014), vertical separation delivers bottleneck access on equivalent terms, thus increasing broadband competition and promoting quality improvements. Downstream firms may take advantage of the improved network quality and offer value-added services. When this is successful, it increases consumer surplus and social welfare. Vertical integration, on the other hand, makes for better coordination between upstream and downstream activities, and could improve end users' perceived quality of broadband services. Mizuno & Yoshino (2012) finds that a vertically integrated firm can utilize its superior position to obtain knowledge about a new telecommunications infrastructure to offer value-added services faster than the competitor when the infrastructure is deployed. The access charge is not always higher under vertical separation than under vertical integration. Vertical separation can have positive effects on competition, because of removing sabotage, and due to improvements in service quality. Consumer surplus is lower under vertical separation, either because of lower investment in network quality, or despite higher investment because of increase in retail prices.

## 4.8 Imposing Download Caps on Bandwidth

Download limits, or caps, is a tool a network provider can use to alleviate congestion in the network. However, as Economides & Hermalin (2015) shows, even without any motives for handling congestion, download caps could be used by the network provider to make a profit. The reasoning behind this is that download caps will put pressure on the content providers to charge less for their services, thus increasing consumer surplus which the network provider may seek to collect through higher access charge. The mechanisms that will make the content providers lower their prices are two-fold: If the caps are fixed, the consumers will perceive the digital services they get from different content providers as substitutes, which will increase the competition between content providers, and in turn reduce their prices. If the caps are permeable, a positive per-unit fee would act like an excise tax on trade between consumers and content providers, which will lead the content providers to cut their prices. If the content is free, the content providers would seek to protect their advertising revenue, and instead of cutting prices, improve their quality. A conclusion Economides & Hermalin (2015) reaches is that setting download caps on bandwidth actually creates an incentive for the network provider to expand its capacity.

## 4.9 Churn

A phenomenon that has a significant effect on network and service providers and their revenue is churn. Churn is when a provider loses customers, possibly to other competing providers.

D'Alessandro et al. (2014) find that when upgrading from an old technology network to a newer one (in their case from 3G to 4G), it is not necessary to provide access to the new and more expensive technology to all consumers to avoid churn; only a certain percentage of the customer base should be given access for churn not to be of great significance. Reasons for churn could be because of better service and coverage with the competitor, but good service, switching costs and simply habit were reasons for staying with their provider. Of these reasons, service is the one the providers can influence themselves for avoiding churn, and is the main reason for customer loss according to D'Alessandro et al. (2014). On the other hand, if a provider wants to attract customers from a competing company, they could offer to pay all or some of the switching costs.

Other aspects that could affect customer loyalty are the number of access points of the new technology, the capacity of the different network types, and the price of the old technology, which according to D'Alessandro et al. (2014) is more important than the price of the new technology.

There will always be churn, however, and a Nokia study revealed that almost 40% of all users are likely to churn within a year (Nokia Siemens Networks, 2013). Monserrat et al. (2016) state that service quality lately has become a key driver for loyalty, and a service provider that wishes to minimize churn should therefore pay close attention to how they handle customer service.

## 4.10 Net Neutrality

Net neutrality is defined as the policy that mandates ISPs to treat all data equally, regardless of source, destination or type of data (Lotfi, Kesidis & Sarkar, 2014). A violation of network neutrality is the same as user discrimination (Li et al., 2015). Krämer, Wiewiorra & Weinhardt (2012) defines net neutrality as a mean to keep ISPs from dictating the speed, or blocking Internet traffic, depending on its source, ownership or destination. Another definition from Hahn & Wallsten (2006) says that ISPs only charges consumers once for Internet access, and that they don't discriminate any content provider in any way. More specifically, the "Bright Line Rules" of the Federal Communications Commision (FCC) state that broadband providers should not block access to legal content, applications or services; they should not impair or degrade lawful Internet traffic; and they should not accept paid prioritization of Internet traffic from service providers (Li et al., 2015).

User tiering, or offering different QoS classes to users is, according to the strict definition, a violation of net neutrality. However, providing different bandwidth at different prices is generally accepted by proponents of net neutrality, as this is a capacity-based discrimination that do not consider the type of data traffic, thus no specific content is prioritized or degraded (Krämer, Wiewiorra & Weinhardt, 2012).

ISPs and end users are better off with non net neutrality. Users with low demands will get their desired content at a lower price, while users with high demands will opt for premium versions of their desired content, resulting in an increased welfare. ISPs, on their side, may collect more revenue stemming from the additional fees on the service provider side of the market.

ISPs may wish to block or throttle users with high bandwidth usage if the network infrastructure is poor. Violating net neutrality may also result in higher revenues for the ISPs by charging more to provide better service (Li et al., 2015)

When there are few ISPs with market power, one could find that too much capacity is dedicated to premium services, and we will see a welfare loss in the consumers who against their will must pay for these services. When there is competition between the ISPs, the ISPs will instead of increasing the QoS level, decrease the prices, as it is more cost effective to attract end users (Lee & Kim, 2014b)

One of the biggest concerns of non-net neutrality is the "dirty road fallacy". This suggests that an ISP making more money by selling priority access could be lead to degrading the quality of the standard traffic lane, forcing content providers to buy the priority lane.

To prevent such challenges, one could imagine invoking more transparency in the business of ISPs, in order for users to make an informed decision about what ISP to choose. Naturally, this requires that there is competition among ISPs, or else transparency will effectively be useless. Regulators could also implement a policy of minimum quality standard, that would act to prevent the dirty road fallacy, by ensuring a certain traffic speed to the standard class.

Some examples we have seen of violation of net neutrality, are European ISPs that have blocked, or charged extra fees for, OTT services; Google, who paid Orange for delivery of traffic, with the goal of maintaining the network so users could get faster access to Google; and also, the two largest ISPs in Great Britain have admitted to charge extra for giving content providers access to priority lanes (Li et al., 2015).

### 4.10.1 Proponents of Net Neutrality

The proponents of net neutrality are first and foremost governments, who desire a fair network, and content providers, who don't wish to be charged extra by the network providers (Li et al., 2015). According to ElDelgawy & La (2015), the proponents of net neutrality are afraid that resources would degrade the QoS for traffic other than the ones paid extra for by the content providers, and surely, speeding up some data traffic will have the consequence of slowing down some other traffic. Another concern is that ISPs may prioritize affiliated content, or even content providers who are vertically integrated with the ISP. ISPs would also be tempted to block or throttle traffic that does not generate revenue for them, such as P2P traffic, where the traffic is generated and consumed by the end users (Krämer, Wiewiorra & Weinhardt, 2012). Yet another concern, brought up by Lee & Kim (2014a) is that if ISPs impose a delay to the "standard" lane, all service providers will pay additionally to use the priority lane, resulting in everyone getting the same service as they had before, only at an additional price, resulting in reduced welfare.

### 4.10.2 Opponents of Net Neutrality

For the reasons regarding the same topics as mentioned in the above section, the ISPs are mainly the opponents of net neutrality, as they see non-net neutrality as a way to generate more revenue. They also claim that their investments in the network infrastructure are not compensated enough from more revenue. Instead, content providers will answer increased bandwidth by offering even more bandwidth demanding services, thus re-congesting the network, and forcing the ISPs to make further investments in infrastructure (Krämer, Wiewiorra & Weinhardt, 2012). In regard of infrastructure investment, ElDelgawy & La (2015) argue that permitting prioritized lanes could encourage additional investments to enhance Internet traffic speed, thus benefitting the society as a whole. Baranes (2014) claims that also content providers can profit from non-net neutrality, as price discrimination could see the content providers get significantly higher profit from premium content than from standard content.

### 4.10.3 Economic Implications of Net Neutrality

In general, it is expected that the cost of providing a certain level of QoS will diminish over time due to advances in technologies (ElDelgawy & La, 2015). Consumers' willingness to pay will increase with access to better technologies, and thus there is more profit to collect when there is no net neutrality.

Users who are less sensitive to price, are more reluctant to change their ISP. These users value ISPs closer to them more. If some ISPs follow net neutrality and some don't, the ones who don't will typically attract the users who are sensitive to price, leaving the users less price-sensitive to the neutral ISPs. According to Lotfi, Kesidis & Sarkar (2014), since only these users stay with the neutral ISP, content providers can charge these users more than users of other ISPs, thus compensating what they pay to the non-neutral ISPs.

ElDelgawy & La (2015) show how a content provider and a network provider can agree to a contract, that stipulates the QoS that the network provider is obliged to deliver to the content provider. This QoS is better than the minimum QoS, and the content provider must thus pay extra for access to this, a violation of net neutrality.

The revenue of the content provider and the network provider is given by

$$U_{CP,R}(Q) = \int_0^M N_{CP}(t;Q) f_{CP} e^{-\tau t} dt$$

$$U_{NP,R}(Q) = \int_0^M N_{NP}(t;Q) f_{NP} e^{-\tau t} dt$$

for the duration of the contract $(0, M)$, where $N$ are the number of subscribers to the content or the network provider at time $t$, when the content provider offers a QoS of $Q$, with $\tau$ denoting the discount rate, or the time value of money.

The investment cost for the network provider is

$$C_{NP}(Q) = c(Q,0) N_{CP}(0;Q) + \int_0^M c(Q,t) \frac{\partial}{\partial t} N_{CP}(t;Q) dt$$

where c(Q,t) is the additional investment necessary if a new content provider is served QoS Q at time t, and the partial derivative expression is the rate at which content providers subscribers increase at time t given QoS Q.

When a contract $\Gamma$ is signed between the content and network provider, that guarantees a QoS Q that is above the minimum QoS, the payment from the content provider to the network provider gives the following payoffs:

$$U_{CP,P}(\Gamma) = -\int_0^M p N_{CP}(t;Q) e^{-rt} dt$$

$$U_{NP,P}(\Gamma) = \int_0^M pN_{CP}(t;Q)e^{-rt}dt = -U_{CP,P}(\Gamma)$$

where $p$ is the price paid by the content provider to the network provider.

Finally, the aggregate payoff of the providers is equal to the sum of the two last equations:

$$U_{agg}(\Gamma) = U_{CP}(\Gamma) + U_{NP}(\Gamma) = U_{CP}(Q) + U_{NP}(Q) - C_{NP}(Q)$$

which only depends on the QoS Q, as the price p is cancelled out in the last equation.

# 5 Portfolio Theory

The portfolio theory suggests how to balance return and risk, in order to select the best portfolio of projects based on the risk attitude of the actor. How much is the actor willing to risk to collect the desired profit, or what is the least an actor is willing to get in return, and at what risk does this expected return come? With more risk comes more profit, up to a certain point, but by diversifying his portfolio, an investor can eliminate some of the risk he is taking, without sacrificing too much return. This is called the portfolio optimization problem, and has been one of the most important and well-researched areas of finance for the past decades. We will start off by describing the basic elements of this theory, and exploring some of the different risk measures that are popular, before discussing more in detail what is meant by return and risk in our case. To generalize the initial discussion, we will talk about an "investor", even though it for the telecommunication industry might as well be service or network provider.

We can describe the portfolio optimization problem like this: When selecting an optimal portfolio, we look at the trade off between risk and return. Consider a set of financial assets $i = 1, 2, ..., n$. These assets have returns

$$\xi = (\xi_1, \xi_2, ..., \xi_n)$$

which are the increases or decreases the assets have relatively during the time period which we are looking at. For these assets, an investor can then choose the positions which he want to place the investment in as the weights

$$x = (x_1, x_2, ..., x_n)$$

with budget constraint $\sum_{i=1}^{n} x_i = x^T\mathbf{1} = 1$ . We assume that short sales are not allowed, that is $x_i > 0$. While this does not have to be true in the real life case, it is a fair assumption to make.

The return on the portfolio can now be written as

$$W = x^T\xi = \sum_{i=1}^{n} x_i\xi_i$$

That is, the vector of portfolio weights transposed times the asset returns.

The expected return of a portfolio is what you expect to have left after taking the given positions in the different assets of the portfolio. The expected return is given by

$$\mathbf{E}(W) = \mathbf{E}(x^T\xi) = x^T\mathbf{E}(\xi)$$

What we see here is that the expected return of the portfolio weights times the asset returns is the same as multiplying the portfolio weights with the expected return of the individual assets.

This expected return is typically what the investor wishes to maximize. However, at some point there starts to become a trade off between getting more expected return and taking more risks on one side, and settling for a given expected return while not exceeding a certain level of risk. This risk can be measured in numerous ways. What we are interested in, is finding a risk measure $R$, such that the expected return exceeds or equals some given value when $R$ is minimized.

Mathematically, this is expressed as

$$\min_x R(x^T\xi)$$

when

$$x^T\mathbf{E}(\xi) \geq \mu$$

where $\mu$ is the mean or the expected value you at least wish to achieve.

## 5.1 The Mean-Variance Approach

Perhaps the most famous work that has been done in this field, is the seminal and groundbreaking work of Harry Markowitz, which lay the foundations for the modern portfolio theory. Markowitz published in 1952 an article called "Portfolio Selection", which is regarded as one of the most influencing papers in modern finance literature. He begins by stating:

> *"The process of selecting a portfolio may be divided into two stages. The first stage starts with observation and experience and ends with beliefs about the future performances of available securities. The second stage starts with the relevant beliefs about future performances and ends with the choice of portfolio."*
>
> *Harry Markowitz (1952)*

Then he goes on to explain the second stage through what is known as the Mean-Variance (MV) approach. In this approach, the variance $\sigma^2$ is used as the risk measure. The variance is defined as:

$$\sigma^2(W) = \mathbf{E}(W - \mathbf{E}(W))^T (W - \mathbf{E}(W))$$

Now when the investor seeks to select an optimal portfolio with the variance as the risk measure, the investor wishes to choose portfolio weights such that the total variance of the portfolio is minimized, while still reaching a predefined goal for the expected return.

Mathematically, this can be defined as

$$\min_{x \geq 0} x^T \left[ \frac{1}{N} \sum_{i=1}^{N} (\xi^i - e)(\xi^i - e)^T \right] x$$

where $e = \frac{1}{N} \sum_{i=1}^{N} \xi^i$ is the average return vector.

The constraints on the expected return and the budget are like before:

$$x^T e \geq \mu$$

$$x^T \mathbf{1} = 1$$

While this model lies at the bottom of much of the later work on portfolio theory, it has been subject to numerous attempts on improving the model.

One of the most appreciated views on portfolio selection, is that variance is not an optimal risk measure. Goh et al. (2012) state that there are two key assumptions in the traditional Markowitz approach, which are often violated. First, the MV optimization is appropriate to capture the trade off between risk and return only if the distribution of returns is elliptically symmetric. Empirical studies show evidence of asymmetries and large kurtosis in asset return distributions.

Second, the Markowitz approach assumes that people do not differentiate positive (upside risk) and negative (downside risk) deviations from the mean. However, it is shown that investors prefer positive skewness to negative skewness. Since volatility treats upside movement as equally bad as downside movement, this turns out unrealistic for the investor, who much rather will want their portfolio to move up, rather than down. In addition, investors would accept slightly lower mean returns in a trade off with positive skewness, which will protect against losses and enable the possibility of a large gain.

Further, there exists no permanent correlation between risk and return, and so a high volatility does not equal higher returns, and vice versa. Also, predicting volatility seems a quite wicked problem, and thus it is difficult to use that factor to rebalance the portfolio.

One of the biggest criticisms of Markowitz' model is according to du Plessis and Ward (2009) that the model does not produce portfolios that are adequately diversified, and that the portfolios thus turn out unrealistic when selected by the Mean-Variance model. They refer to a experiment by McLeod which came out with poor performance with regard to portfolio allocation. Moreover, it turned out to be difficult to estimate covariances because of the vast amount of data that the model required. Some other criticism they make is that the model has a "conceptually demanding nature", that it is too wicked for most investment companies, in that they are not structured enough to utilize the model, and finally that portfolio managers simply find the composition of optimized portfolios counter-intuitive (du Plessis and Ward, 2009).

Finally, the Mean-Variance approach has some fundamental assumptions, which are at best highly questionable. These assumptions include, but are not restricted to the following:

- All investors have the same information, and will act in a similar manner. Neither wishes take high risks.
- All assets can be bought and sold on the market.
- There are no transaction costs.
- Investors who are in it short term has the same interests as those who are in it for the long run.
- Politics have no effect on the stock market.

## 5.2 Efficient Frontier

After all the possible portfolios consisting of the possible assets are calculated, the investor needs to choose what or which portfolio(s) are of interest to him. These portfolios will lie along the efficient frontier, the blue line in Figure 1, where returns are given by the y-axis, and risk is given by the x-axis.

Portfolios that are below and to the right of the efficient frontier are feasible, but not desirable. This is intuitive to see, as moving upwards until you hit the blue line will increase the expected return while staying at the same level of risk, and likewise, moving to the left until you hit the blue line will decrease the amount of risk you will take, while staying at the same level of expected return. Thus, no investor would want to pick a portfolio that is below and/or to the right of the efficient frontier. Portfolios above

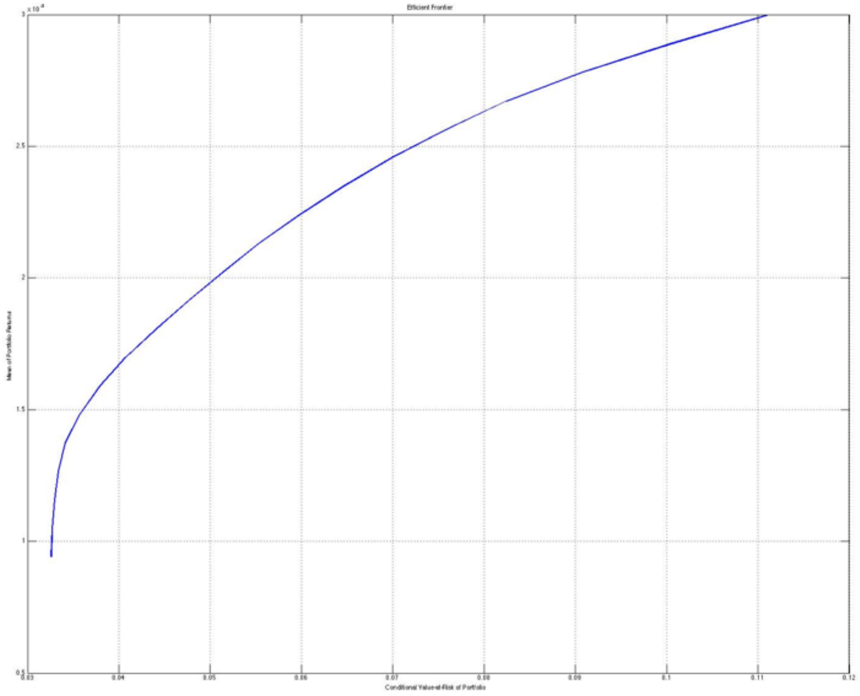

Figure 1: Efficient frontier

the efficient frontier are unfeasible portfolios, and thus not an option for the investor. This leaves only the set of portfolios that lie along the efficient frontier. No portfolios on the efficient frontier are superior to others (or else they would not be on the efficient frontier in the first place), and it all depends on the risk aversion of the investor. A risk seeking investor will typically find himself in the top right part of the efficient frontier, with possibilities of great returns, but at the cost of greater risk. A risk averse investor will on the other hand pick portfolios closer to the bottom left part of the efficient frontier, where he will receive a moderate return without risking too much.

So far we have understood risk as volatility, but as we will see, this need not be the case.

## 5.3 Different Risk Measures

The standard way of measuring risk is by the volatility, or the standard deviation, of the assets. There are however almost endless ways of determining risk, all with their pros and cons. There is a trade-off between modelling risk measure as accurate as possible, and the complexity of the model. I will now briefly discuss two of the most prominent risk measures: Value-at-Risk (VaR) and Conditional Value-at-Risk (CVaR).

### 5.3.1 Value-at-Risk

VaR remains a popular and standard tool in risk management. VaR is a loss that we are fairly sure will not be exceeded if the current portfolio is held over some time.

VaR is calculated as

$$VaR(W) = \mathbf{E}(W) - Q_\alpha(W)$$

where $Q_\alpha(W)$ is the $\alpha$-quantile of return:

$$Q_\alpha(W) = inf\{u : F(u) > \alpha\}$$

According to Cui et al. (2013), VaR is especially suitable for nonlinear portfolio selection where payoff structures are nonlinear and the skewed return distribution is a prominent feature, for example, portfolio selection problems involving derivative assets. In their work, the focus is on how to use parametric VaR in optimal nonlinear portfolio selection. Portfolio selection models using VaR risk measure estimated by historical simulation or Monte Carlo simulation are in general non-convex and non-smooth optimization problems and therefore computationally intractable.

### 5.3.2 Conditional Value-at-Risk

Instead of using VaR, the computationally much simpler CVaR can be used. Krokhmal et al. (2002) describe how optimization problems can be solved with CVaR constraints, and comparing it with mean-variance.

CVaR, or expected shortfall, is the conditional expected loss under the condition that it exceeds the VaR. While VaR only states that you will lose more than x amount a given percentage of the time, CVaR tells you what you on average will lose if you exceed the VaR. CVaR is a convex measure, as opposed to VaR.

CVaR is calculated as

$$CVaR(W) = \mathbf{E}(W) - C_\alpha(W)$$

where $C_\alpha(W)$ is the conditional expectation of return not exceeding the level $\alpha$ quantile:

$$C_\alpha(W) = \mathbf{E}(W|W \leq Q_\alpha(W))$$

The standard deviation is simply the square root of the variance.

The CVaR with confidence level associated with the weights $\mathbf{w}$ is

$$CVaR_\alpha(\mathbf{w}) = \frac{1}{1-\alpha}\int_{f(w,r)\leq VaR_\alpha(w)} f(\mathbf{w},\ \mathbf{r})p(\mathbf{r})d\mathbf{r}$$

with loss function

$$f(\mathbf{w}{,}\mathbf{r}) = -\mathbf{w}^T\mathbf{r}$$

The joint densities p($\mathbf{r}$) can be generated using Monte Carlo simulation.

Gaivoronski and Pflug (2005) show that mean-CVaR and mean-variance efficient portfolios provide a poor approximation for mean-VaR efficient portfolios in mean-VaR space. Therefore an investor who is concerned with VaR needs to consider VaR directly, and substituting VaR for the closely resembling CVaR is not necessarily gaining any advantage over the traditional variance. This is shown through historical and simulated data. To ease the computations, the VaR can be altered by smoothing the VaR line.

CVaR risk management constraints can be used in various applications to bound percentiles of loss distributions.

Aas and Low (2012) compare the CVaR optmization as a risk measure with the mean-variance approach of Markowitz. The CVaR strategy outperforms the mean-variance approach when there are no transaction costs. When there are (large) transaction costs, however, the advantage with this approach disappears. The reason for this is that the CVaR-pair-copula strategy involves large changes in weights, and hence large transaction costs. If this strategy is preferred, then different strategies for lowering the transaction costs should be considered.

*“ The possession of the best technological solution is not necessarily enough to assure the business success of an enterprise.”*
*- Gaivoronski & Zoric (2008)*

# 6 Business Models

A business model is a representation of how a firm intends to make money, and earn a stable profit over time (Stewart & Zhao in Laya, Ghanbari & Markendahl, 2015). A business model has to take into account the market a firm operates in, and describe how the firm will provide value for its customers in relation to other firms in the business ecosystem, in order to sustain a competitive advantage in the market. A business model will help the firm realize its potential, because having the best technological solution does not necessarily mean that the firm will succeed in its business (Gaivoronski & Zoric, 2008). If the technology is superior, but the business model is unsustainable, then the firm surely will fail, until they figure out how to convert the technological advantage into profit.

## 6.1 Multi-tiered Price Systems

One very prominent business model for telecommunication operators, is having multi-tiered price systems. In multi-tiered price systems, a business will set different price points for their product based on certain conditions; for Internet access such conditions are typically related to capacity or usage (Lv & Rouskas, 2009). Capacity-based price systems will set a different price based on the bandwidth offered to the user. Thus, in a multi-tiered price system, users will get different bandwidths, i.e. access speed, depending on what they are willing to pay, i.e. what tier they have subscribed to. Usage-based price systems will set the different tier prices according to the actual amount of traffic generated. ISPs typically measure their customers' traffic volume over five minute intervals to find how much traffic volume is within the 95th percentile of the user for a given time period, and charge accordingly. This is called the "95th percentile rule" (ibid.), and is analogous to the 95% Value at Risk measure in finance theory.

Lv & Rouskas (2009) argue that multi-tiered price systems, "if designed and applied appropriately, (...) have the potential to be a catalyst for Internet service innovation and penetration." The problem lies within the conflicting interests of the users and the providers of a service, where users want to pay as little as possible while achieving the highest possible QoS, whereas service providers wish to maximize their revenues while keeping the costs as low as possible. For multi-tiered price systems to be a driver for Internet service development, the prices between the service tiers must be set according to these conflicting interests. However, in current practice it is not clear how the ISPs set their tiered price structures, and if users' experience is even considered in the process (ibid.)

### 6.1.1 Economic Model for Tiered-Service Networks

In Lv & Rouskas (2009) an economic model for tiered-service networks is set up. They define three non-decreasing functions of service x: the utility function, U(x), which is the user's experienced utility, i.e. perceived value of the service provided, and describes what they are willing to pay for said service; the cost function, C(x), which is the service provider's cost of offering the service; and the price function, P(x), which is the price charged by the service provider for the service.

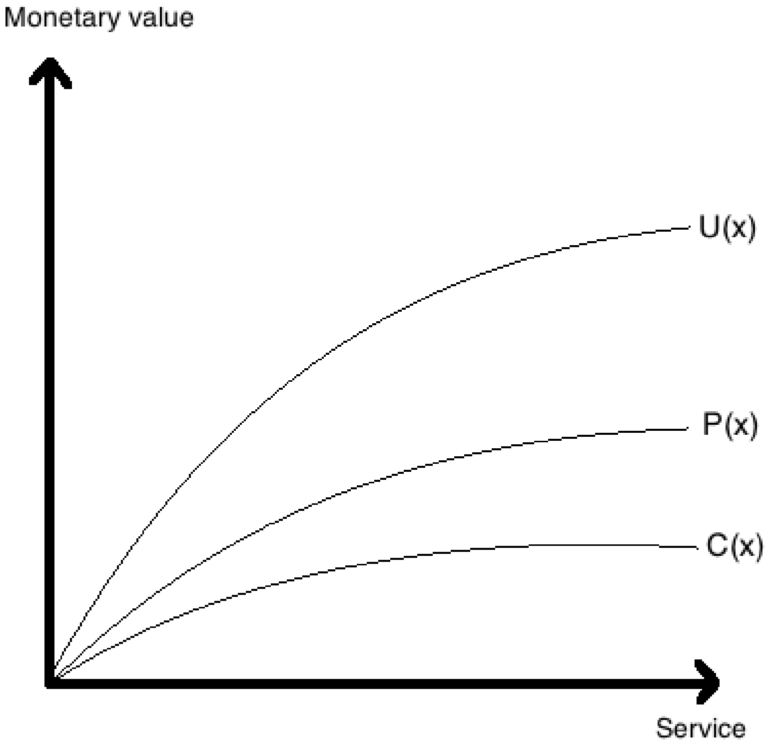

Figure 2: Utility, price and cost functions

The functions will relate to one another along the lines of Fig. 2. It is trivial to see why the curves lie where they lie. The user's utility curve must lie above the price curve, or else the user simply would not be willing to pay for the service. Analogous, the price curve must lie above the cost curve, or else the service provider would not provide the service. Thus we have the following relationship between the three functions:

$$U(x) \geq P(x) \geq C(x)$$

User surplus is defined as the difference between the utility function and the price function. Provider surplus is defined as the difference between the price function and the cost function. Users will seek to maximize the user surplus, service providers will seek to maximize the provider surplus, while network providers will seek to offset the cost of offering the service by charging a high fee, thus making a profit. The overall social welfare is defined as the sum of the user surplus and the provider surplus. The society as a whole will benefit from maximizing the overall social welfare. More formally, we have the following relations:

$$S_{user}(x) = U(x) - P(x)$$

$$S_{provider}(x) = P(x) - C(x)$$

$$S_{society}(x) = U(x) - C(x)$$

By choosing different sets of service tiers to be offered to the consumers, one will be able to maximize user surplus, provider surplus or overall social welfare. Lv & Rouskas (2009) find that the optimal tier prices $P^*(z_j)$ in a multiple tier case for tier $z_j$ is

$$P^*(z_j) = (1 - \beta)U(z_j) + \beta C(z_j)$$

where $\beta, 0 \leq \beta \leq 1$ is the bargaining power of the users.

The cost of providing a service will typically not change based on what service tiers are offered. Thus, it is in the interest of service providers to find the optimal solution to the service-tiering problem, or else they will lose out on potential revenue. This revenue will not come at the cost of the user's utility (at least not all of it), and therefore the optimal solution will increase the overall social welfare, compared to suboptimal solutions.

## 6.2 Profit Models

When evaluating business models, the most important thing to look at is the profit model. This tells us how much money the company will make by taking its revenues and subtracting the costs. The network providers and content providers will have different profit models, although they can feature a lot of the same components, as we shall see.

### 6.2.1 Network Provider

For network providers, we have seen that the revenues they get come from subscription fees and hookup fees for allowing content providers, or even end-users, to access their network. In the absence of net neutrality regulation, they can increase their revenues by offering tiered network access, charging more from the users with the highest willingness to pay, either directly, or through collecting the added revenues from content providers. The costs are provision costs, infrastructure investments costs, operation and maintenance costs, to name some.

In Nesse, Gaivoronski & Lønsethagen (2015), the profit function of the network provider is given by the expected revenue from charging price p, minus the variable provision costs provisioning the service portfolio. In this equation, they have included the quality q and a capacity expansion program W, which is the added capacity to their service. They let the demand function be dependent on price, quality and a random parameter, to account for the uncertainty of user demand, spurring from the user's subjective QoE, churn, and so on. More formally, the profitability equation is given as:

$$\begin{aligned} P(x,y,z,p,q,W,\omega) = \textstyle\sum_{i\in I}\sum_{j\in J}(p_i - c_i^v)\min\{x_{ij}, d_{ij}(p,q,\omega_j)\} - \sum_{i\in I} c_i^p z_i \\ - \textstyle\sum_{i\in I}\sum_{j\in J} c_{ij}^0 \max\{0, d_{ij}(p,q,\omega_j) - x_{ij} - c^f y - c^e W \\ - c^m(W_0 + W) - c^b \end{aligned}$$

In Gaivoronski et al. (2015) the profit model of the network provider is the fixed subscription fees from their customers, plus the revenue they collect from the content providers through paid peering. The profit model is given as:

$$P_{ISP} = C + px\mathbb{E}\min\{W_0 + W, D(p,\omega)\} - rW - q(W_0 + W)$$

### 6.2.2 Content Provider

Until now we have looked at profit models for the network providers, but there is also profit to be made for the content providers. They will typically get their revenues from the customers they are providing their content to, and their costs can be composed of provision costs, which is the amount they pay the network providers in order to deliver content on their network, and opportunity costs, which could come from churn. Gaivoronski et al. (2015) gives the profit model of the content provider as:

$$P_{CP} = (p(1-x)-c)\mathbb{E}_\omega \min\{W_0+W, D(p,\omega)\} - e\mathbb{E}_\omega \max\{0, D(p,\omega)-W_0-W\}$$

## 6.3 Risk Measures

The risk measure can be chosen from a variety of options, all depending on how "risk" and "uncertainty" is defined; what is the actor (most) uncertain about, or what uncertainty will have the biggest (negative) impact on him? One adequate way of defining risk, as we saw in Pisciella, Zoric & Gaivoronski (2009), is to define risk as the uncertainty of the unit revenues for a certain level of demand, or the standard deviation of the return on costs. The standard deviation, or volatility, is as discussed in the previous chapter, the most used risk measure in portfolio theory, and albeit with numerous shortcomings, it proves a pretty reasonable measurement of risk.

In Nesse, Gaivoronski & Lønsethagen (2015) and Gaivoronski et al. (2016), risk is defined related to churn, which was explained in a previous chapter. That is, the risk for the service provision of this network provider is measured by the portion of customers that are not satisfied with their provided QoS, and thus find other alternatives to satisfy their needs, i.e. leaves the network provider (probably for a competitor). They measure this risk as follows:

$$R(x,y,z,p,q,W) = \frac{\sum_{i\in I}\sum_{j\in J}\lambda_{ij}\mathbb{E}\max\{0, d_{ij}(p,q,\omega_j) - x_{ij}\}}{\sum_{i\in I}\sum j \in J\lambda_{ij}\mathbb{E}d_{ij}(p,q,\omega_j)}$$

which is the weighted sum of non-served demands divided by the weighted total demand. The weights are added to make it possible to manually set the relative importance of the different services, as one can imagine that some services are more important, and more revenue-generating, than others.

## 6.4 Profit Models and Risk Measures for 5G Technology

The profit models of network and content providers in the advent of 5G are highly uncertain, and will depend on many different aspects; some of which we have discussed in this paper, and some of which we have not. We have seen that it especially for network providers is important to include the costs of the total lifetime of their services in their profit models. Total Cost of Ownership is thus a good measurement, as it takes into consideration not only the initial investment expenditures, but also the running operational and maintenance costs. The introduction of a new technology, such as 5G, poses a series of challenges for the decision makers in the network operators. Whether you are the market leader or a new entrant, there are important decisions to make regarding when to offer the new technology and when to upgrade the old; if there should be a switch off of the old network technology, or if it should be priced out and slowly die in that manner. There could also come an unexpected force in terms of a regulator who considers the social welfare, and acts accordingly. With the coming of small cell deployment and hybrid versions, such as overlay macrocell-femtocell, the network providers are faced with yet more business opportunities, which it should take into careful consideration. With accessibility one of the key features of 5G, the traditional macrocell deployment simply will not be good enough on its own for the next generation of mobile network technology.

The shift in what we are using the Internet for, and how we are using it, will be a very important issue for both network and content providers to consider in the future. The imminent full scale advent of Internet of Things will see the rise of user demands that until recently only have been considered fiction. Also, cloudification has partly erased some of the distinctions between a network provider and a content provider, which is something the providers must understand and adapt to. Net neutrality, or the violation of it, will also have an impact on the telecommunications ecosystem. If network providers are allowed to price discriminate on the basis of content type, many new opportunities and challenges are opened up. The main assumption is that non-net neutrality is for the good of network providers and end-users, while content providers are worse off under such discrimination. There is however raised some questions as to whether content providers can be at advantage under net neutrality violation. If, for instance, one content provider is so huge and popular that the network providers will benefit them for choosing their network service, then we will see some of the profit models presented earlier change.

The risk measures considered for 5G technology can be vast. If we revisit the key features of 5G, we can pinpoint some features that can directly translate to risks for the network or content providers:

- Capacity
- Data rates
- Latency
- Reliability

- QoE

Risks could be related to not being able to handle the massive data traffic that 5G will bring (capacity and data rates), or providing inadequate real-time services (latency), or not delivering with the consistency that is expected (reliability). All these points will lead to a decrease in the user's QoE, which could harm both the network provider and the content provider. Therefore, a good measurement for QoE is churn, which we saw being used as a risk measurement by Nesse, Gaivoronski & Lønsethagen (2015), Gaivoronski et al. (2015) and Gaivoronski et al. (2016).

## 6.5 Service Portfolios

After deciding the appropriate profit models and risk measures, one can use the portfolio model as described in chapter 5 to decide what types of services to offer different customers, by the means of the multi-tiered service approach. The profit function $P(x, y, z, p, q, W, \omega)$ was described in chapter 6.2.1, and is used by Nesse, Gaivoronski & Lønsethagen (2015) and Gaivoronski et al. (2016), and is a good measure for service portfolios in 5G risk-profit space, as it incorporates important variables such as (additional) network capacity $W$, price of service $p$ and QoS $q$. Furthermore, the risk measure of chapter 6.3 also serves as a good risk measure here, for reasons already explained.

The goal of the service provider is to maximize its expected profit subject to its desired risk level. This translates to the following optimization problem:

$$P^* = \max \mathbb{E}P$$

subject to

$$R \leq \sigma$$

The resulting solution constructs the efficient frontier of this service provider. Given a predefined risk measure $R \leq \sigma$, the service provider will find the combination of assets (price, capacity, QoS) that yields the highest expected return. Alternatively, the service provider could decide on a desired expected return, and then find the combination of said assets that satisfy this expected return.

# 7 Conclusion

In this master thesis I have looked at the economic aspects of the 5G mobile network, which is due to come full scale in 2020. I have found that the increased user demands and requirements for the 5G network will force both network providers and content providers to look at new opportunities that the new technologies create, and take advantage of the ever changing environment in the telecommunications ecosystem.

Using portfolio theory to find the optimal delivery of services proves a good option for the telecommunication industry. I have presented some profit models and risk measures that have been used to estimate service portfolios, and find that these are well fitting to be adapted to questions concerning 5G technology.

My general finding is that Quality of Experience (QoE) will, due to the increased user demands, and thereby increased promised delivery of service, be one of the most important aspects of future mobile networks. The pressure on network and content providers to deliver flawless services will be bigger than ever, and failing to deliver as promised can prove disastrous for the provider. In this regard, a good risk measure for network and content providers in the future will be churn, or customers giving up their subscription for other alternatives who can deliver what they expect.

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