FACULTY OF ENGINEERING
AND ARCHITECTURE

Defining and comparing business models for providing inflight connectivity using an integrated satellite - 5G network

Jens Vandenberghe
Student number: 01402260

Supervisors: Prof. dr. ir. Sofie Verbrugge, Prof. dr. ir. Didier Colle
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Master's dissertation submitted in order to obtain the academic degree of
Master of Science in Industrial Engineering and Operations Research

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I am now ready to take the next step in my career, with the confidence that I have had a first-rate education. I will do my utmost to honour my education and I will keep Ghent University and more specifically the Faculty of Engineering and Architecture forever in my heart.

Jens Vandenberghe, June 2019

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Abstract

There are two ways that allow airplanes to have on-board Internet access: via air-to-ground and via satellite. Satellite Internet has greater coverage and can provide connectivity over the ocean. The complementary characteristics of new developments in 5G terrestrial networks and innovations in satellite systems create a large opportunity for inflight connectivity, although it remains unclear which business models are sustainable and if they are economically viable. The aim of this research is to define and compare different types of business models for providing connectivity to airplanes via an internal 5G cell connected to the Internet via a satellite backhaul link. By developing a techno-economic model including both a cost and revenue model for each of the identified business models, the average cost per user can be derived. This modelling approach makes it possible to draw a conclusion about the economic viability of the use case for the main stakeholders: the mobile network operator, end user, satellite network operator and airline. Freemium models are expected to have higher prices per MB and the price per MB in long-haul flights is significantly lower compared to short-haul and medium-haul flights. Simulations on different scenarios learn that economic viability is assured in every business model and a freemium retail model has the lowest total cost of ownership. The key input parameters of the models are the cost of a VSAT and the number of paying users. If costs should be cut, it is suggested to lower the bitrate per user, while keeping the caching rate at a maximum.

Keywords*:* inflight connectivity, Wi-Fi, satellite, 5G, MNO, airline, techno-economics

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***Keywords* — inflight connectivity, Wi-Fi, satellite, 5G, MNO, airline, techno-economics**

I. Introduction

Because of the complementary characteristics of new developments in 5G terrestrial networks and innovations in satellite systems, a large opportunity is created for inflight connectivity. This paper investigates feasible business models in the use case of providing Internet to airplanes via an internal 5G cell connected to the Internet via a satellite backhaul link.

Starting from 1G to 5G, a lot of improvements have been made in data speeds, channel capacities, services, roaming, switching, security, latency and spectrum efficiency thanks to advances in technology. 5G will allow data speeds over 1Gbps with a latency smaller than 10ms and a lot of added flexibility, which will in turn open doors for many new use cases.

ESA explains the new mobile generation 5G as follows: “The future communications system referred to as 5G represents far more than just the next generation of mobile services. It will drive a convergence of fixed and mobile services, introduce a new set of technologies and standards, create a network of networks and facilitate communications between everyone and everything, whilst focusing on some key vertical markets” [1].

This convergence is not only between fixed and mobile networks but can also include satellite resources. Telecom satellites offer wide coverage and high aggregated throughputs, making them well suitable for communication in difficult-to-reach areas, such as on-board airplanes.

Integrating a 5G cell with geostationary satellites has the opportunity to provide wide area coverage to rural networks or a network in the air. A Next Generation Node B (gNB) is the hardware that is connected to the mobile network that communicates directly with user equipment over a wireless link. Small cells and short-range links enhance the connectivity for indoor services and extend the coverage of the macro cells.

Satcom systems are often the only economic solution to address the enhanced Mobile Broadband use cases in underserved and unserved areas. High throughput satellites make it possible to lower the costs and provide a reliable and secure solution with increased capacity. Challenges are found in bandwidth management, taking connectivity worldwide and aligning supply and demand. Section II will expand on the suggested network architecture and the relevant stakeholders.

The goal of this paper is defining and comparing different types of business models, as well as to draw conclusions about the most feasible business model for providing inflight connectivity using an integrated satellite-5G network. Business models will be identified and compared in a qualitative way in section III.

In section IV, a techno-economic analysis will be performed, including not only detailed cost models for each identified business model, but also revenue models. These models will make it possible to draw a conclusion about the economic viability of the use case for the main stakeholders: the mobile network operator (MNO), satellite network operator (SNO), end user and airline. Section V allows the reader to discover the key inputs that explain the variance in the outcomes of the cost and revenue models. Simulations will be performed to analyse the robustness of the models. From combining these results, one can derive strategic recommendations for airlines in order to make well-considered decisions about which business model to adopt.

II. An integrated satellite-5G network architecture is offered by two main stakeholders

The use case of providing onboard Internet access via satellite-5G can be summarized as providing backhaul connectivity to airplanes with the ability to multicast the same content and provide efficient broadband access. To offer the service, each aircraft is equipped with a satellite terminal and is connected via satellite to a central facility that controls the satellite network. This central facility then makes interconnections with the Internet, similar to enterprise networks. This scenario proposes a bi-directional broadband access for each passenger for private use which is transparent to the moving platform. Hence the network requests are individual and proper to each passenger's activities. The end users connect via Wi-Fi and can use their own device(s) and the whole applications installed as they do on the ground.

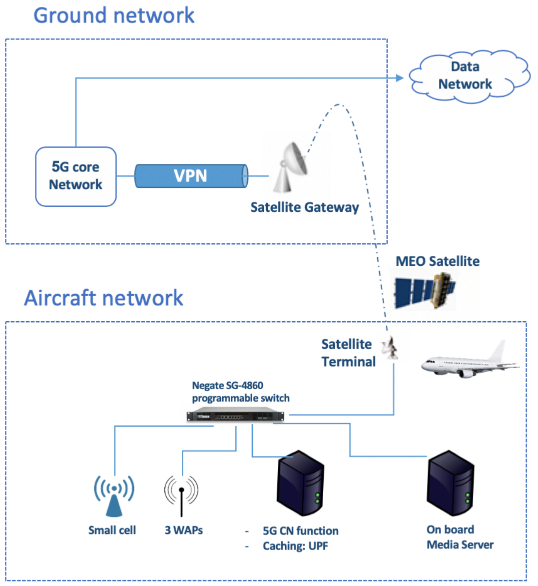

Figure 1: Network architecture for providing inflight connectivity via an integrated satellite-5G network [2]

A general satellite network architecture has three elements: a ground segment, a user segment, both linked by a space segment. The ground segment is composed of an antenna and gateways. The ground segment is often the property of a terrestrial network operator, who leases capacity from a satellite operator. The space segment holds the satellite constellation and the uplink and downlink satellite links. The user segment consists of a radio

receiver and the required hardware to convert the received radio signal into a usable Internet signal.

It is assumed that an MNO will install a 5G gNB in the aircraft and provides an Internet connection to the passengers. Besides, it is assumed that the MNO itself has the rights for the content and caches the popular content on the aircraft. Other stakeholders in the value network are the satellite operator, satellite manufacturer, airline, end user, content distributor, content provider, equipment vendor and regulator.

III. Identification and Qualitative Comparison of Business Models

This section will define six feasible business models and compare them via a customized framework. This allows to obtain a clear overview of the value streams and (dis)advantages per business model.

The value network intelligence framework, developed by Allee, is used as a starting point for comparing identified business models [3]. It is slightly adapted by removing non-relevant links, but the main structure is conserved. The added subtopics: 'Technology', 'Differentiation opportunities', 'Branding potential', 'Specialist knowledge' and 'Financial risk' are case-specific and are identified by common sense.

This framework is applied on six identified business models, see Table 1.

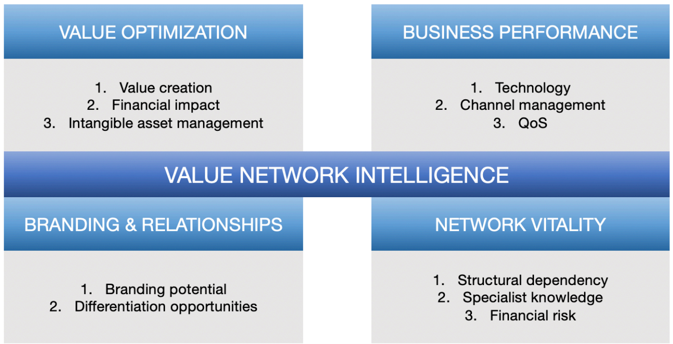

Figure 2: Qualitative analysis framework, based on the Value Network Intelligence framework developed by Allee

Currently, 4 out of 5 airline operators prefer the scenario of the wholesale model over the retail model, although some airlines offer the service for free [4]. The inflight connectivity market is expected to become a \$30 billion market by 2035, compared to a 1\$ billion market in 2018 [5]. The fact that this market will become large implies that, if the conversion rate is sufficiently high, a freemium business model should certainly be considered in the rest of the analysis.

From evaluating Table 1, it was possible to draw some conclusions. In scenarios where the airline operator wants full control over pricing, the wholesale model is suggested. The retail model is beneficial for airline companies, who are more risk-averse and do not want to drift away from their core business. The customer will also benefit from the retail model, as the value chain is shorter and the quality is assured. The sponsorship model is suggested when the need or interest of the company in marketing is rather low. This could be because tickets already sell out fast, or that a low-cost structure is the main marketing strategy. The freemium wholesale and retail models should certainly be considered, because they bear many branding opportunities and customers are often attracted by free services. Combining this with a qualitative service and the option to generate extra connectivity-dependent revenues, make up a very viable business model. Key to making the freemium business model work is having a conversion rate from free to premium that is high enough. The complementary service model will be preferred for premium airline companies, as customers from these companies prefer to pay for the full premium service, in which connectivity is already included.

IV. Techno-Economic Analysis of the Identified Business Models

After identifying and describing the business models, their economic viability should be evaluated. A high-level cost model will be created, which will serve as the input for the revenue models. Combining cost and revenue models will allow to calculate the average cost per user (or for a possible sponsorship partner). Using cost-based pricing, a cost per MB data will be calculated starting from the equivalent annual cost of the project with an added profit margin based on the business model [6].

Table 1: Summary of applying the Value Network Intelligence framework on six identified business models.

Model	**Short description**	**Value optimization**	**Business performance**	**Branding and relationships**	**Network vitality**
Wholesale	The airline buys the project from an MNO and sells the service to end users.	Value for end user: connectivity Value for airline: increased ticket sales and revenues for connectivity service. Threat of hidden costs for airline.	Business performance might encounter delays in case of problems due to an indirect link between end user and MNO. Available bandwidth is split between paid users.	Airline can brand itself as an on-board internet provider and grow its name. Opportunity to serve as a platform for other connectivity-dependent revenues: sales – promotions.	Quality requirements and delivery times MNO may not be aligned with airline needs. Airline takes the financial risk.
Retail	The MNO installs the project on the platform provided by the airline and sells the service directly to end users.	Value for end user: connectivity. Value for airline: increased ticket sales and a share in revenues of the MNO.	Business performance efficiently handled due to a direct link between end user and MNO. Available bandwidth is split between paid users.	Less branding potential for airline, although still significant.	Quality requirements from end user are directly linked to MNO. MNO's business is dependent on airline. MNO takes the financial risk.
Sponsorship	The airline buys the project from an MNO and generates revenues by selling sponsorship projects. End users are offered the service for free.	Value for end user: connectivity with frictionless service (no worries about payment). Value for airline: increased ticket sales. Value for sponsorship partner: end user credentials, data and the opportunity to advertise and promote.	Business performance might encounter significant delays in case of problems due to an indirect link between end user and MNO. Available bandwidth is split between all users.	High branding potential for sponsors via log-in page, advertisements, sales. Opportunity to differentiate from other airline companies providing paid connectivity. Threat of premium users preferring no advertisements.	Quality requirements and delivery times MNO may not be aligned with airline and sponsor needs. Airline takes the financial risk of finding adequate sponsors.
Freemium wholesale	The airline buys the project from an MNO and sells the service to premium end users. Limited service is offered to free users.	Value for free user: connectivity with a frictionless service (no worries about payment). Value for premium user: fast connectivity. Value for airline: increased ticket sales, end user data and advertising opportunities.	Business performance might encounter delays in case of problems due to an indirect link between end user and MNO. Free users' speed can be limited so that free users cannot use the bandwidth of the premium users.	Opportunity to differentiate from other airline companies. Opportunity to serve as a platform for other connectivity-dependent revenues: holiday sales, promotions, food/drink order, taxi service.	Quality requirements and delivery times MNO may not be aligned with airline needs for both free and premium end users. Airline takes the financial risk (conversion rate needs to be sufficiently high).
Freemium retail	The MNO installs the project on the platform provided by the airline and sells the service directly to premium end users. Limited service is offered to free users.	Value for free user: connectivity with a frictionless service (no worries about payment). Value for premium user: fast connectivity. Value for airline: increased ticket sales.	Business performance efficiently handled due to a direct link between end user and MNO. Free users' speed can be limited, so that free users cannot use the bandwidth of the premium users.	Less branding potential for airline, although still significant. Airline can brand itself as an on-board internet provider and grow its name.	Quality requirements from end user are directly linked to MNO MNO's business is dependent on airline. MNO takes the financial risk (conversion rate needs to be sufficiently high).
Complementary service	The airline buys the project from an MNO and offers the service for free to all end users.	Value for end user: connectivity with a frictionless service (no worries about payment). Value for airline: end user credentials, data and the opportunity to advertise and promote.	Business performance efficiently handled due to a direct link between end user and MNO. Risk of passengers consuming large amounts of data, reducing performance for other passengers.	Airline can brand itself as a free on-board internet provider and grow its name. Opportunity to differentiate from other airline companies and to serve as a platform for other connectivity-dependent revenues.	Quality requirements and delivery times MNO may not be aligned with airline needs. Airline takes the financial risk.

The cost will then be translated into ticket price increases, subscription prices, sponsorship deals, prepaid data price, freemium conversion rates, etc., depending on the business model and their linked possible pricing models. The structure of the modelling approach is shown in Figure 3.

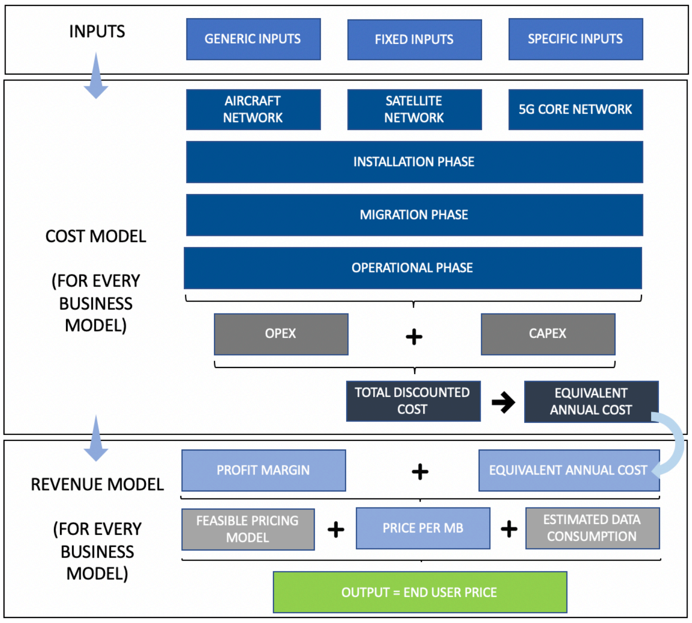

Figure 3: Modelling structure used for the techno-economic analysis

A. Calculating the total cost of ownership for the use case per aircraft

To incorporate all costs involved in the project, a project lifecycle approach is suggested, consisting of a planning, deployment, migration, operations and teardown phase. As Internet on airplanes is considered a necessity in the future and as such the technology will be updated, the teardown phase is not considered. This approach makes it possible to calculate the total cost of the use case over its entire lifetime, also referred to as the Total Cost of Ownership (TCO). It is chosen to classify the network equipment in what is needed for the core network, satellite network and edge network (on-board).

An important characteristic of the cost model is that it should be time-variant, as the costs for satellite capacity are forecasted to drop significantly between 2020-2025 [7]. Reliable cost inputs are essential for the outputs of the model. It is chosen to use cost inputs from academic papers, equipment vendor websites, technology magazines and – if no other option – from Internet websites. An overview of the most important input parameters and assumptions can be found in Table 2. Please note that some inputs such as 'MNO to airline' profit margin and 'freemium conversion rate' are only used in specific business models and are often the drivers of the differences in cost outcomes between the business models.

The Total Discounted Cost (TDC) in the 'average' case (using the averages of ranges from the input data) is estimated close to 1.4 million € for a (freemium) wholesale, sponsorship and complementary service model. The similarity is explained by the fact that the involved costs are similar. OpEx is slightly smaller in the freemium models due to lower bandwidth requirement for the free users and the TDC in a sponsorship model is higher due to extra overhead. A big difference can be noted between the already mentioned models and the (freemium) retail model. This is mostly explained by the fact that channel management is very efficient in these latter models. This means that linking the service provider directly to the end users saves project costs. The results will be visualized in section V.

Table 2: Overview of important input parameters

Input	**Quantity**	**Unit**	**Reference**
WAP	5000 - 10000	€	[2]
gNB	50 000 - 100 000	€	[2]
VSAT	200 000 - 500 000	$	[2]
VPN	12 000	€	[2]
Satellite capacity	75 -> 35 between 2020-2025	$ / Mbps / user	[2]
Installation % (of CapEx)	15%	/	[8]
Maintenance % (of CapEx)	10%	/	[8]
Overhead % (of TCO)	23%	/	[9]
Average number of passengers per flight	175	/	[10]
Fraction of passengers that connect	81%	/	[11]
Fraction of flight duration with effective internet use	36%	/	[12]
Bit rate per user	2	Mbps	Assumption
Caching rate	40%	/	Assumption
Average number of airplane cycles (Boeing 747)	35 000	/	[13]
Average lifetime airplane	27	years	[13]
MNO to airline / end user margin	11%	/	[14]
Airline to end user / sponsorship partner margin	5%	/	[15]
Freemium conversion rate	8%	/	[16]
Average flight duration	1,5-4,5-7,5	hours	[17]

B. Generating revenues from providing inflight connectivity

It is important to note that in the techno-economic model of inflight connectivity a positive ROI is not absolutely required, as many side benefits are linked to making this investment. Nonetheless, it is a very interesting exercise to verify what would be the required pricing and sales to make this project profitable on its own. Table 3 indicates what are the feasible revenue models per business model.

Table 3: Feasible pricing models per business model

Business model	**Feasible considered pricing models**
Wholesale	Data-based, subscription-based, tiered-bandwidth, per-flight, time-based pricing
Retail	Data-based, subscription-based, tiered-bandwidth, per-flight, time-based pricing
Sponsorship	Average sponsorship deal size per month
Freemium wholesale	Subscription-based, per-flight pricing
Freemium retail	Subscription-based, per-flight pricing
Complementary service	Indirect increase in ticket price

An estimation of the data consumed has to be made in order to calculate a price per MB via the following formula: Data consumed per year = Number of passengers per year * fraction of connected users * fraction of duration with effective internet use * average flight duration * bitrate per user. The price per MB is then calculated by adding a profit margin to the equivalent annual cost and dividing by the estimated data consumed per year.

This outcome can be compared per business model with the given assumptions. The break-up is made for short-haul (flight duration under 3 hours), medium-haul (flight duration between 3 and 6 hours) and long-haul flights (flight duration over 6 hours) [18]. The results for the 'average' case can be seen in Figure 4.

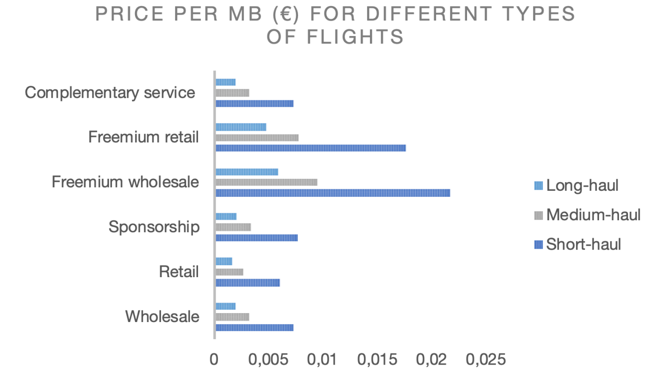

Figure 4: Price per MB for each identified business model and type of flight

The first conclusion that can be made from Figure 4 is that freemium models have a much higher price per MB because a small fraction of the passengers has to pay for the data consumption of the free users. Secondly, it becomes clear that the price per MB on long-haul flights is significantly lower. This is explained by the fact that the need to have Internet in long-haul flights is higher and there is more time per flight to consume data, which in turn increases the revenue potential and allows the investments costs to be divided by a larger data volume. This explains why the inflight connectivity market first took off in the United States [19], where the average flight duration is longer.

V. Defining the Key Inputs in the Techno-Economic Model to Reduce Uncertainty

In the previous model uncertainties and risks were not considered. Some input data such as network architecture costs, the number of paying customers or the occupancy rate of the airplane remain questionable. Sensitivity analysis makes it possible to discover the boundaries in which the business case is considered safe and to calculate the probabilities of experiencing a positive business case. In a global sensitivity analysis, the key or uncertain parameters are varied according to their probability density functions [6]. Monte Carlo simulation is used to retrieve this outcome. This simulation method randomly creates samples of all the distributions of the inputs in each step and generates the outcomes. It is common to repeat the simulation 10 000 times.

The sensitivity analysis is performed for medium-haul flights and the results are found below. First, the TDC is simulated for every identified business model. The 90% certainty intervals (blue) and median (grey) of the outcomes are shown in Figure 5. One can conclude that freemium retail and retail are the business models that allow the project to be the most cost-effective. The sponsorship model has the highest total discounted cost and there is a large variance in the discounted cost for every business model.

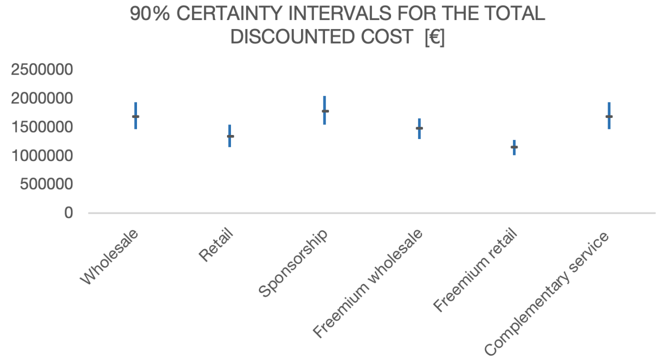

Figure 5: 90% certainty intervals (blue) and median (grey) for the Total Discounted Cost

Next, it is analysed how this variance can be explained. A sensitivity chart indicates what the key inputs of the sensitivity analysis are. The percentages shown on the graph are defined as the percentages of forecast variance due to each assumption. Positive coefficients indicate that an increase in the assumption is associated with an increase in the forecast, while negative coefficients imply that an increase in the assumption leads to a decrease in the forecast. One can conclude from Figure 6 that the uncertainty in VSAT cost, the bitrate per user and the caching rate are the most important factors to explain the variance in cost outcomes. If cost should be cut, it is suggested to lower the bitrate per user, while keeping the caching rate at a maximum.

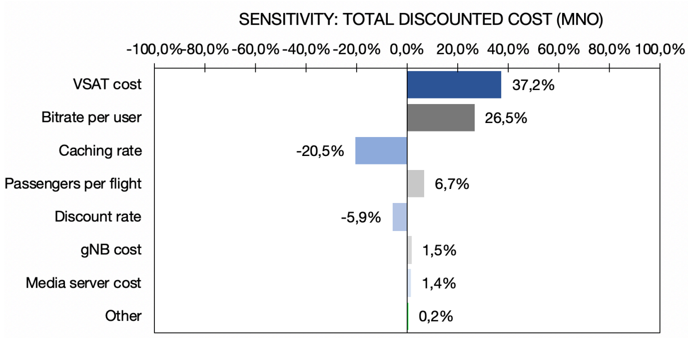

Figure 6: Sensitivity chart for the total discounted cost in the retail business model

Secondly, the price per MB is simulated for every identified business model assuming medium-haul flights.

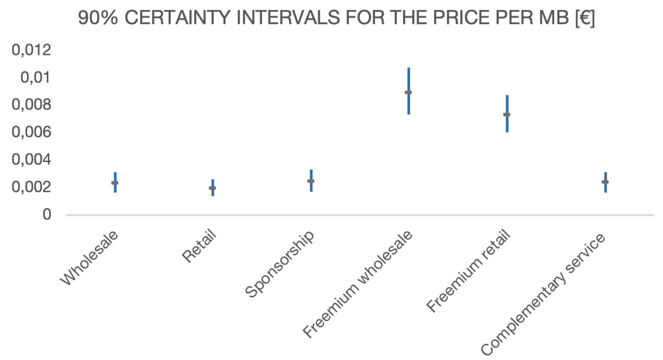

Figure 7: 90% certainty intervals (blue) and median (grey) for the price per MB

The variance in this price per MB can also be explained with a sensitivity chart. From Figure 8, it can be concluded that the key parameters to explain the variance are the conversion rate (only applicable in freemium models), the VSAT cost and the passengers per flight. A higher conversion rate implies more users, which then makes it possible to offer lower prices per MB. The VSAT cost is again a large uncertainty in the input model because it depends on a lot of factors (type of airplane, type of antenna, router etc.). Having more passengers also implies having more premium users, which makes it again possible to offer lower prices per MB.

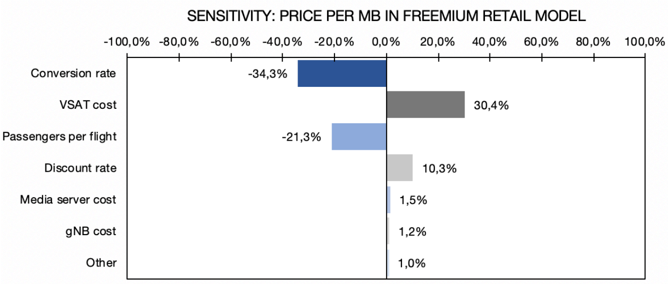

Figure 8: Sensitivity chart for the price per MB in the freemium retail business model

VI. CONCLUSION AND FUTURE WORK

Combining satellite and 5G introduces new business opportunities for providing Internet to difficult-to-reach platforms such as airplanes. This paper closes the gap between the technology and the economic viability of providing inflight connectivity via an integrated 5G-satellite solution. A network architecture was proposed and stakeholders were identified. Business models were defined and compared via a customized framework. The economic viability of these business models was then verified with a techno-economic model, which was simulated multiple times to deal with uncertainties in the input data.

An overview of each identified business model was created in terms of value optimization, branding and relationships, vitality of the network and business performance. This included the strengths and weaknesses per business model allowing decision-makers to adopt the business model that fits their corporate strategy the most.

The techno-economic analysis made it possible to conclude that prices per MB are certainly affordable for the end user in every business model, also when data volumes rise in the future.

Future work on this research topic could be investigating the impact of competition on the proposed business models. It is not clear what will happen to the feasibility of the identified business models if a fraction of the competitors adopts a complementary service model. Furthermore, in this paper, assumptions were made on the number of passengers, the average lifetime of an aircraft, the number of 5G cells required, the number of media servers required, the VSAT cost etc. These are parameters that solely depend on the aircraft that is used. An interesting next step would be to repeat the analysis for multiple types of aircrafts. This will certainly lower the variance of the outcomes in the simulations. A last and interesting exercise would be to quantify the opportunity of indirect revenue creation by providing inflight connectivity such as holiday sales, promotions, food or drink orders and taxi services.

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Table of contents

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List of acronyms

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3GPP	Third Generation Partnership Project

A

API	Application Programming Interface
ATG	Air-to-ground

B

BMC	Business Model Canvas

C

CapEx	Capital expenditures
CN	Core Network
CP	Content Provider

D

DNS	Domain Name System

E

EAC	Equivalent annual cost
EDGE	Enhanced Data Rates for GSM Evolution
eMBB	Enhanced Mobile Broadband
eNB	Evolved Node B

F

FSS	Fixed Satellite Service

G

GEO	Geostationary Orbit
gNB	Next Generation Node B
GPRS	General Packet Radio Service
GSM	Global System for Mobile communications
GW	Gateway

H

HDTV	High Definition Television
HTS	High Throughput Satellites

I

IFC	Inflight connectivity
IoT	Internet of Things
IP	Internet Protocol

J

K

L

LEO	Low Earth Orbit
LTE	Long Term Evolution

M

MB	Megabyte
Mbps	Megabit per second
MEC	Multi Edge Computing
MEO	Medium Earth Orbit
mMTC	micro Machine-type Communications

MNO	Mobile Network Operator
MTC	Machine-type Communications
MVNO	Mobile Virtual Network Operator

N

NAT	Network Address Translation
NCC	Network Control Centre
NFV	Network Function Virtualization
NPV	Net Present Value

O

OpEx	Operational expenditures

P

POV	Point of view

Q

QoS	Quality of Service

R

RAN	Radio Access Network
RF	Radio Frequency

S

SAT-5G	Combining satellite Internet with 5G technology
SDN	Software-defined Network
SNO	Satellite Network Operator
SWOT	Strengths – Weaknesses – Opportunities – Threats

T

TCO	Total Cost of Ownership
TDC	Total Discounted Cost

U

UE	User Equipment
UMTS	Universal Mobile Telecommunications System
URLLC	Ultra-Reliable Low Latency Communications

V

VPN	Virtual Private Network
VSAT	Very Small Aperture Terminal

W

WAP	Wi-Fi Access Point

X

Y

Z

1 Introduction and motivation

Combining satellite Internet and 5G allow research, development and validation of satcom capabilities in order to improve the 5G ecosystem. New business models can be identified, and the economic viability of these models can be analysed for the stakeholders. Satellite can provide ubiquitous geographic coverage and mobility to complement and extend terrestrial cells, complement connectivity for mobile nodes, offload temporarily congested networks, provide backhauling services to fixed or moving base stations and provide emergency response communications.

The integration of satellite into 5G networks allows the identification of several new use cases. One of these use cases is providing inflight connectivity to passengers via an integrated satellite-5G network. Though technically possible, it remains unclear which business models are sustainable and if implementing this technology is economically viable in these business models. Hence this thesis closes the gap between the technically possible proposed solution and the economic viability of providing inflight connectivity via an integrated 5G-satellite solution. The aim of this research is to define and compare different types of business models for the use case of providing connectivity on airplanes via an internal 5G cell connected to the Internet via a satellite backhaul link.

To get a sense of feasible business models, a clear understanding of the desired network architecture and relevant stakeholders in the value network is required. On the network architecture side, there are two ways that allow airplanes to have on-board Internet access: via air-to-ground and via satellite. Satellite Internet has greater coverage and can provide connectivity over the ocean. The complementary characteristics of new developments in 5G terrestrial networks and innovations in satellite systems, that lead to the current state of technology will be explained in detail in chapter 2.

On the stakeholder side, it needs to be clarified why the stakeholders are interested in this use case. By developing a value network (chapter 3), it will become clear who benefits and what value exchanges happen between the different stakeholders and which costs are allocated to whom. Does everyone benefit similarly and why (not)?

By making swaps in the focus of the value network (mobile network operator, end user and airline), feasible business models can be identified. A qualitative comparison will be performed in chapter 4 by evaluating the differences of the business models via a custom-made framework, made from building blocks of other existing business model analysis frameworks, and via an in-depth comparison of the dissimilarities in their business model structure.

A techno-economic model for this use case including not only cost models for each identified business model, but also a revenue models to find the Average Revenue Per User (ARPU), will be created in chapter 5. These models will make it possible to draw a conclusion about the economic viability of the use case for the main stakeholders in the value network. The techno-economic analysis will be performed by calculating the equivalent annual cost for the project based on a high-level cost model per identified business model including all costs involved on the operational and investment side. The cost model will serve as input for revenue models for the identified business models. Different revenue models will be proposed to estimate the end user price of being connected on board. The key inputs for the models will be extracted in chapter 6 via a sensitivity analysis, as well as the certainty intervals for the outcomes.

Combining the results of the qualitative comparison and techno-economic model will allow us to derive strategic recommendations for airlines on which business model to adopt and conclude about the economic viability of integrating satellite into 5G networks for inflight connectivity.

2 Some background on terrestrial and satellite systems and how they can be combined

Thanks to 5G, inflight connectivity via satellite will see a large cost reduction, hopefully leading to a reliable and fast Wi-Fi-connection as a standard on a plane. It is important to understand the technology that lies behind inflight connectivity before diving into the economics of such a project, as this will allow us to make better estimations and to come up with more detailed and reliable business models, cost models and revenue models. In the first part of this literature study, it will be investigated how mobile technologies have improved, which new technologies are introduced in 5G and what are the challenges and benefits related to 5G. Secondly, a short review of satellite types and technologies is performed. In the last part of the literature study, it will be researched which new use cases are introduced by combining satellite Internet and 5G. These new use cases have many advantages, but they also introduce many new challenges.

2.1 Introduction to 5G concepts

ESA explains the new mobile generation 5G as follows: "The future communications system referred to as 5G represents far more than just the next generation of mobile services. It will drive a convergence of fixed and mobile services, introduce a new set of technologies and standards, create a network of networks and facilitate communications between everyone and everything, whilst focusing on some key vertical markets" [1]. This section will explain what the technology is actually about, after guiding the reader through the evolution of mobile technologies.

2.1.1 The evolution of mobile technologies

Mobile communication networks have significantly changed in the last few decades. A change in a mobile wireless generation (G) generally refers to a change or improvement in one or more of the following factors [2]:

- Nature of the system
- Speed
- Technology
- Frequency

- Data capacity
- Latency

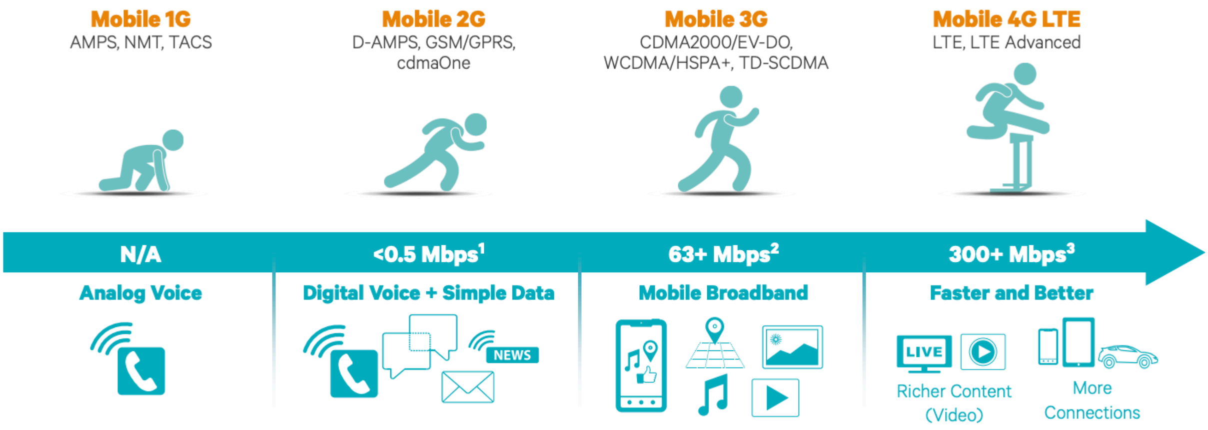

Figure 1: The key changes for every new mobile generation [3]

Each generation is different from the last one by providing a change in standards, capacities, techniques and features. A summary of the comparison between the generations is provided in Table 1. The first generation (1G) mobile communication network was introduced in 1982 and was an analogue network, only used for voice services. A technology called Advanced Mobile Phone System was the main driver for 1G. Together with the introduction of 1G, a cleared spectrum for exclusive use by mobile technologies was introduced. Reusing frequencies without interference could be executed through geographical separation. The key differentiator for 1G was the opportunity to add mobility. The main weakness of 1G was its poor spectral efficiency and security issues.

The second generation of mobile communication networks (2G) is a digital technology that allowed text and picture messaging. It was launched on the Global System for Mobile communications (GSM) standard, which is the standard that describes the protocols for digital cellular networks used by mobile devices. The main focus was put on digital signals and messaging at low speeds. In 2G, the mass adoption of mobile networks started. Security had already improved, although weaknesses could be found in the limited data rates and difficulties to support Internet and e-mail demand. In between 2G and 3G we can find 2.5G, which uses both packet-switched and circuit-switched domains to provide a speed up to 144 kbps. 2.5G allows e-mail messages and Internet browsing. Enhanced Data Rates for GSM Evolution (EDGE) is known as a pre-3G technology. It makes use of existing GSM networks and is an extension of General Packet Radio Service (GPRS).

The third generation (3G) mobile technology was launched in 2000 and provided a higher data transmission rate. Capacity was increased and multimedia support was improved. 3G networks gradually overlaid but did not replace the existing 2G networks. Data services, access to television and global roaming services were added, so the key adaptation in this particular generation was a better Internet experience. The 3G mobile system was called the Universal Mobile Telecommunication System (UMTS).

The fourth generation (4G) integrated 4G with fixed Internet to support wireless mobile Internet. Other factors include the increases in bandwidth and the reduced cost of resources. 4G offers generally spoken the same features as 3G with additional services. The technology that is used, is called Long Term Evolution (LTE). It was developed to meet the requirements of applications like wireless broadband access, video chat and HDTV.

The fifth generation of mobile networks (5G) is planned to launch in some major cities in 2019. The technology has high data speed capabilities and the ability to offer low latencies. It opens many new opportunities for a “connected” world. 5G will be able to connect billions of devices with different capacity and bandwidth needs. Many new services will be enabled and these will be elaborated on in section 2.1.5.

A comparative summary of the evolution of mobile technologies can be found in Table 1.

Table 1: A comparative summary of mobile generations

	1G	**2G**	**3G**	**4G**	**5G**
Data speed	2.4 kbps	64 kbps	2 Mbps	10 – 500 Mbps	>1 Gbps
Channel capacity	30 kHz	Up to 200 kHz	1.5 – 10 MHz	5 – 20 MHz	3.5 GHz

Technology	Analog cellular technology	Digital cellular technology	Broad bandwidth CDMA, IP Technology	Single unified standard	Network Function Virtualization, Software-defined Networks, Network Slicing
Services	Voice calling	Digital voice, short messages, multimedia messages	High-quality audio and data streaming	Dynamic information access, wearable devices, high-quality video streaming and other multimedia services	Internet of things applications, control of remote devices, smart vehicles and infrastructure, global broadband coverage
Roaming	Limited to one country	Limited to one country	Global	Global	Global
Switching	Circuit	Circuit, Packet	Packet	Packet	Packet
Security	Poor	Intermediate	Intermediate	High	High
Latency	/	300 - 1000 ms	100 - 500 ms	< 100 ms	< 10 ms
Spectrum efficiency	+- 0.0015 bits/(s.Hz)	+- 0.45 bits/(s.Hz)	+- 1.3 bits/(s.Hz)	+- 30 bits/(s.Hz)	Up to 140 bits/(s.Hz)
Key differentiator	Mobility	Mass adoption	Better Internet experience	Faster broadband Internet,	Low latency and increased capacity

				lower latency	create new use cases

2.1.2 New network functions and technologies in 5G

A natural question that arises now is: “What technology concepts will drive this change?”. This subsection will provide an answer to that question by providing an overview of technologies that will disrupt the current mobile networks.

2.1.2.1 Introducing the data plane, control plane and management plane

First of all, three abstract logical concepts will be introduced. Routers and switches use a conceptual model called “planes”. These planes describe how packets travel to, from, and through a device [4]. The control plane is anything that is required to make routing work on a device. It determines how the packets should be forwarded. The functions of the control plane include the system configuration and routing information transfer. The data plane moves packets from input to output to the destination network following the control plane logic. Data plane packets go “through” the router, compared to “to” the router. These concepts are often used to explain the transition from a physical to a virtualized network, which has major implications on the cost of the network.

Since the introduction of digital communications, networks have seen an exponential increase in capacity and growth. The growing capacity and complexity of networks activated the industry to develop technologies that would lead to a simplification in deploying, managing and monitoring these networks. One of these technologies is called Network Function Virtualization (NFV). Innovation is stimulated by enabling diverse network elements to work together on a shared physical infrastructure [3]. Software-defined networking (SDN) makes the control plane, which makes decisions about where traffic is sent, programmable and NFV does the same thing for the data plane, which forwards the traffic. The network complexity is simplified as custom hardware for each network function is no longer required. This implies that the network-related CapEx and OpEx can be reduced by using network resources more flexibly and efficiently.

2.1.2.2 Network Function Virtualization

NFV is a network architecture concept that virtualizes entire classes of network node functions such as network address translation (NAT), firewalling, intrusion detection, domain name service (DNS) and caching into building blocks that are able to connect, chain together or create communication services [5].

A virtualized network function is composed of virtual execution environments running software, on top of standard high-volume servers, cloud computing infrastructure, switches and storage devices [6]. It is able to deliver the components to support a virtual environment with servers, storage and even other networks. Figure 2 gives a structured overview of the functions that can be deployed with NFV.

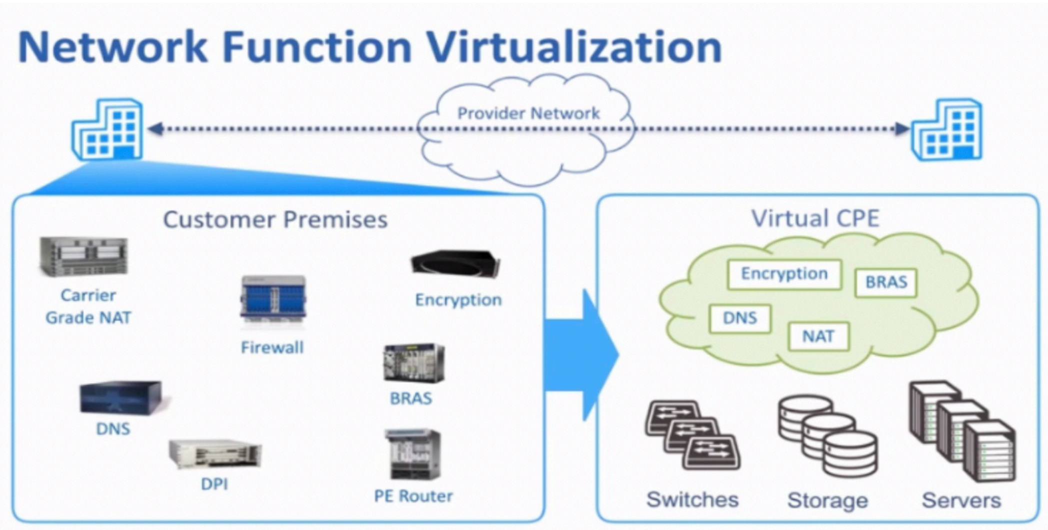

Figure 2: Overview Network Function Virtualization [7]

2.1.2.3 Software-defined Networks

As mentioned before, SDN makes the control plane programmable. The original intention of SDN is to design, build and manage networks that separate the networks' control planes and forwarding planes. It could in fact enable the network control to become programmable implying that the underlying infrastructure is no longer attached to applications and network services. Enabling network providers to adapt and respond quickly to changing business requirements is the main goal of SDN. This is done by separating the control logic to off-device computer resources. SDN makes the network more flexible to support the virtualized servers that were explained in section 2.1.2.2.

The three components that all SDNs have is an SDN controller, southbound Application Programming Interfaces (API) and northbound API's. The overall framework can be found in figure [8].

- **Controllers** offer a centralized view over the network. They enable administrators to tell switches and routers how the data plane network traffic should be handled.
- **Southbound APIs** send information to switches and routers "below". The first and standard protocol used is called OpenFlow.
- **Northbound APIs** communicate with the business logic "above". Network administrators are enabled to deploy services and shape traffic thanks to these API's.

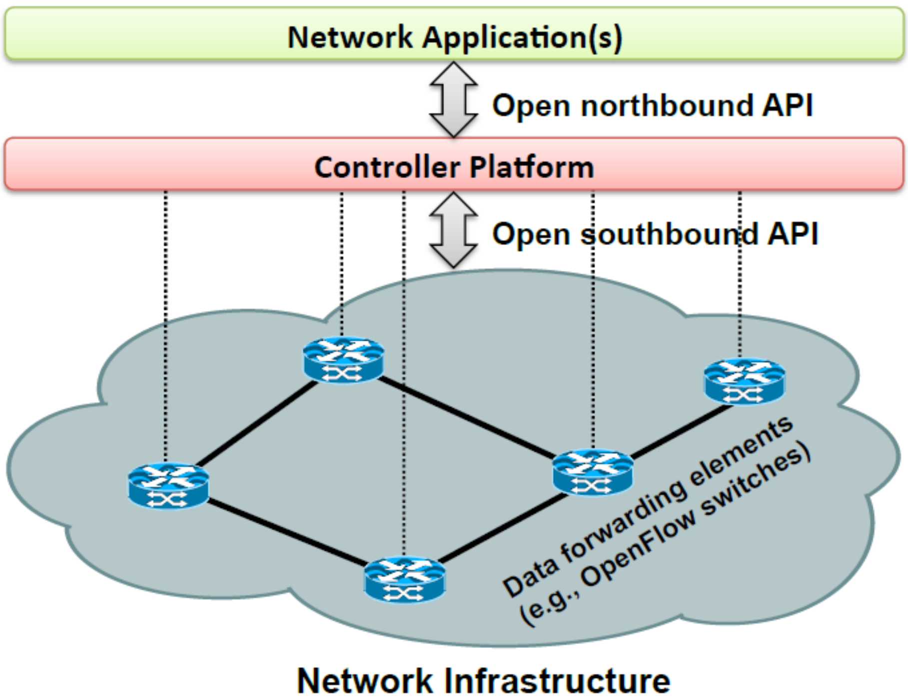

Figure 3: Software-defined Network framework [9]

The advantages of SDN are that the network policy is directly programmable because of the decoupling of data plane and control plane functions. This enables the network to be configured by automation tools. The centralized controller software has an overview of the network, which is seen as a single switch by applications.

2.1.2.4 Benefits of NFV / SDN

Direct benefits of SDN and NFV are the reduced CapEx by limiting the need to buy purpose-built networking hardware, and the fact that SDN supports pay-as-you-grow models. OpEx are reduced as well because network elements such as switches and routers could be controlled by an algorithm. This simplifies the design, deployment, management and scaling of networks, which implies lower requirements for space, cooling and power. Service availability and reliability can be improved by automating transfers and composition. In general, this will make the risk of human errors and management time decrease. Another important factor is that agility and flexibility are improved. These benefits allow network providers to easily try and adapt services in order to understand customer needs better. The increase in flexibility allows network providers to scale services up or down in case of varying demands. Innovative services can be provided via software on industry-standard server hardware. By doing that, the network can become more valuable and create more revenues.

2.1.2.5 Network Slicing

A mobile network is often used sub-optimally due to diverse and sometimes conflicting needs of businesses. Some will prefer ultra-high-bandwidth solutions, while others will need low latency or a very reliable connection. A possible answer to these needs is found in building a dedicated network to serve one type of business customer. This network then allows the implementation of specific functionalities and operations linked to the needs of the business, compared to a one-size-fits-all approach [10].

An even better solution is found in the concept of network slicing. It is classified as a virtual networking architecture linked to SDN and NFV. It stands for running multiple networks as virtually independent operations on a common physical infrastructure in an efficient way that also lowers CapEx and OpEx. Network slicing uses NFV to ensure that the exact resources in the network structure are used for a particular business need. The network slices are split as individual frameworks that are very adaptable and can be independently controlled. Slicing networks also provides insights in the network resource utilization, which ensures that the usage of the network can be billed according to the specific use case [11].

2.1.2.6 Multicasting for content

Multicasting is an effective and clever solution to simultaneously transfer data to a large group of mobile users by allowing a source to send a single copy of data to a single multicast address, which is then distributed to an entire group of recipients. This increases the capacity and the spectrum efficiency of mobile communication systems [12].

Researched 5G solutions incorporated:

- Short-range enhanced communication: boosting of data rates by providing cellular links, which results in better channel conditions by devices that are located close to each other. Latency will be reduced, although short-range links introduce delays.
- Macro / small cell cooperation: The idea is to multicast the data stream in the macro-cell region [13]. Other users that request the same stream within a certain time will immediately join the multicast group and the missing fraction of the stream will be served through small cells. This will reduce latency.
- Network coding: Throughput and robustness of data can be improved in the process where the receiver decodes the packet and obtains the packet as a combination of different information with different characteristics.
- Beamforming: technique in which directive antennas achieve spatial diversity and improved throughput by improving the data rate of the users with the lowest channel gain [14].

2.1.3 Advantages of 5G for mobile networks

The benefits of rolling out a 5G mobile network will be listed below. These are the benefits that will lead to new use cases such as driverless cars, MTC and providing Internet to moving platforms. Some of the benefits that are discussed below have already been mentioned in previous sections and will therefore only be touched upon shortly.

Table 2: Benefits of 5G and a short explanation

Benefit	Description
Faster speed	As introduced in section 2.1.1, 5G will be able to offer theoretical speeds of more than 10 Gbps leading to practical speeds of more than 1 Gbps (20-100 times the speed of 4G networks). A complete HD movie could be downloaded in under 10 seconds, compared to 10 minutes on 4G.
Reduced latency	Due to the virtualization functions discussed in section 2.1.2.2, less delay or lag will be noted when using mobile devices. A latency of 1 ms is proposed, which is undetectable for mobile users and 50 times lower than the latency of the current 4G network.
Greater capacity	5G will allow mobile networks to handle multiple high-demand applications at once. Private networks and other high-end heterogeneous services can be supported.
Flexibility	Technologies such as network slicing allow the operator to adapt to different requirements for different use cases, which will finally lower costs. The fact that a big part of the network becomes programmable means that improvements will be continuously integrated in such a way that 5G might mark the end of generational improvements.
Global coverage	5G should be able to solve the unavailability of network connectivity in rural populated areas. A high-speed fiber-based network is not economically viable, so satellite Internet combined with small 5G cells to serve rural areas is another interesting use case.
Reliability	Critical use cases such as digital healthcare and connected cars will benefit from the increased reliability that 5G networks can provide. This means that the connection will be consistent and uninterrupted.

2.1.4 Challenges related to 5G technologies

The challenges related to 5G are described in Table 3.

Table 3: Challenges related to 5G

Challenge	Description

Significant investment	A report from Deloitte written in 2016 [15] notes that China has taken $400 billion into account in its five-year economic plan for 5G-related investments. This shows that investment costs are gigantic but also carriers incur heavy expenses for upgrading existing infrastructure to accommodate new devices and antennas that are required by 5G systems.
Uncertainty about radio frequencies and coverage	Data transmission in 5G will be in the range of two different radio frequency bands: the band from 600 MHz to 6GHz and the band between 25 GHz to 52 GHz [16]. This radio frequency range is used by many other signals as well. With numerous types of signals operating in this radio frequency range, there is a chance that overcrowding is going to cause problems. Linked to these radio frequencies is the fact that the 5G network cells will offer lower coverage than those of 4G due to the higher frequency. More cell towers will be required to have similar coverage.
Data or signal losses	Reliability is improved, but mmWave losses can be caused by different reasons such as penetration problems, foliage losses, rain attenuation. These problems can be critical in some use cases such as driverless cars.
Security	Both 3G and 4G have been exposed to different forms of data hacks. To make 5G viable and safe, carriers will need a robust endpoint security standard to identify and remove malware. Firewalls, identity management systems, monitoring of DNS activities and data integrity assurance will be required, along with sandboxing solutions.
Safety	Concerns are raised about radiation. At the moment of writing, there is still no conclusive evidence of the influence of high radio frequencies on humans [17].

2.1.5 Newly identified use cases thanks to 5G

The advantages above allowed the 3rd Generation Partnership Project (3GPP), a collaboration between groups of telecommunications standards associations, to classify the 5G use cases into three areas as shortly touched in the evolution of mobile communication networks [18]:

- **Enhanced Mobile Broadband (eMBB):** data-driven use cases requiring high data rates across a wide coverage area.
- **Ultra-Reliable Low Latency Communications (URLLC):** strict requirements on latency and reliability for mission-critical communications, such as remote surgery, autonomous vehicles or military applications.
- **Massive Machine Type Communications (mMTC):** A large number of devices in a small area need to be supported, which may only send data sporadically, such as Internet of Things (IoT) use cases

2.2 Introduction to satellite communication

Telecom satellites offer wide coverage and high aggregated throughputs, making them well suitable for communication in difficult-to-reach areas. Satellite communication is typically done with parabolic antennas in order to increase the signal-to-noise ratio and to compensate for propagation losses [19]. Satellites can be classified based on the orbit that they are positioned in. Each of these types has different characteristics and (dis)advantages.

Telecom satellites cover broadcast satellites (unidirectional satellite for television use), broadband satellites (bidirectional satellites for Internet access) and mobile satellites (bidirectional satellites for wideband voice and data communication with handhelds). The next parts will mainly focus on broadband satellites as these are the most relevant in this thesis book.

A general satellite network architecture has three elements: a ground segment, a user segment, both linked by a space segment. The ground segment is composed of an antenna and gateways. The ground segment is often the property of a terrestrial network operator, who leases capacity from a satellite operator. The space segment holds the satellite constellation and the uplink and downlink satellite links. The user segment consists of a radio receiver and the required hardware to convert the received radio signal into a usable Internet signal.

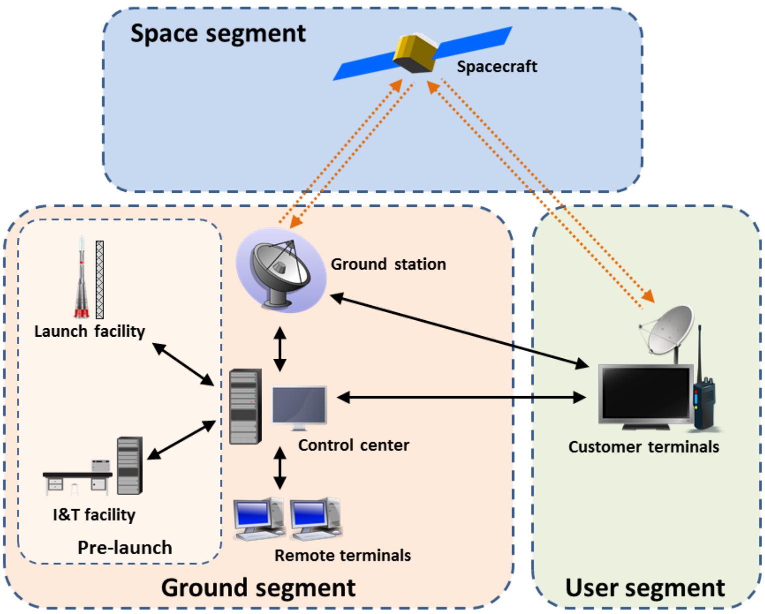

Figure 4: General satellite network architecture. Dotted orange arrows stand for radio links while solid black arrows stand for ground network links [20].

In the underlying sections, different approaches in classifying satellite systems will be introduced, as well as technological innovations that led to higher capacities and faster speeds, introducing many new use cases.

2.2.1 Classic single-beam FSS satellites

The first Fixed-Satellite Service (FSS) satellites were based on a single shaped beam that covers a target area. Services included television broadcast, military and other telecom services.

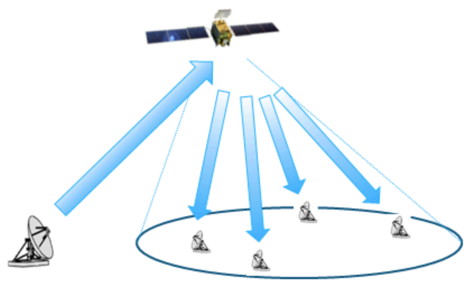

Figure 5: Working of single-beam FSS Satellites [19]

2.2.2 Multi-beam satellites

Multi-beam satellites or high throughput satellites (HTS) surpass the limits of single-beam FSS satellites. The evolution was made possible by introducing multi-beam and frequency reuse concepts. The first generation of HTS became operational in 2004 and was able to provide tenths of gigabits per second. A higher frequency reuse factor was achieved by narrow satellite beams, higher spectral efficiency modulation and coding schemes. This allowed professional systems to reach data rates of 100 Mbps and above. This type of satellite allows increased capacity, which leads to cheaper data rates by reusing the allocated frequencies multiple times. This finally leads to data rates of up to 100 Gbps for one satellite.

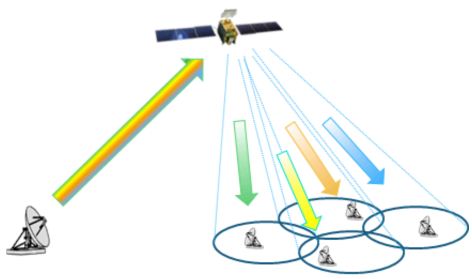

Figure 6: Working of multi-beam FSS Satellite [19]

2.2.3 Classification in terms of altitude

As explained in section 2.2, satellites can also be classified based on the altitude where they are positioned. All types have different advantages and disadvantages, as described in Table 4: Comparison of satellite systems LEO - MEO – GEO

Table 4: Comparison of satellite systems LEO - MEO – GEO [19]

	LEO	MEO	GEO
Distance	500-1500 km	5000-12000 km	35800 km
Orbital period	10-40 min	2-8h	24h
Number of satellites per operator	40-80	8-20	3
Life	Short (3-7y)	Long (10-15y)	Long (10-15y)
Space segment cost	High	Low	Medium
Gateway cost	Very expensive	Expensive	Cheap
Propagation loss	Least	High	Highest
Coverage	Global	Not northern & southern region of the world (plane equator)	Not northern & southern region of the world (plane equator)
Latency	60 ms	200 ms	600 ms

The most important factors for the inflight connectivity via satellite-5G use case can be found in terms of coverage, costs and latency. For inflight connectivity to be feasible a low-cost solution should be preferred. Coverage is actually linked to that, because one needs less GEO satellites to have the same coverage as a LEO satellite. In order to have a frictionless experience inflight, latency should be kept at a minimum. This allows end users to perform activities such as gaming or video calling inflight. The lower latency can only be linked to LEO / MEO satellite systems. Another benefit of LEO / MEO is that they can handle greater bandwidth, because they are positioned closer to the earth.

2.2.4 Classification in terms of usage of the electromagnetic spectrum

Please note that the spot beam size depends upon the specific ranges of frequency within a portion of the electromagnetic spectrum in which the satellite constellation operates and on the altitude of the satellite. This relationship is summarized in Table 5.Table 5: Illustration of the relationship between frequency and cover area diameter of beams

Table 5: Illustration of the relationship between frequency and cover area diameter of beams

	Frequency range	**Cover area diameter**
Ka-band	26.5 – 40 GHz	322 km
Ku-band	12 – 18 GHz	965 km
C-band	4 – 8 GHz	1609 km
L-band	1 – 2 GHz	1720 km

Satellite Internet works by transmitting data to and from satellites over designated frequency bands that are offered by different satellite operators. Which band an Internet service provider uses can have an impact on the quality of the satellite connection.

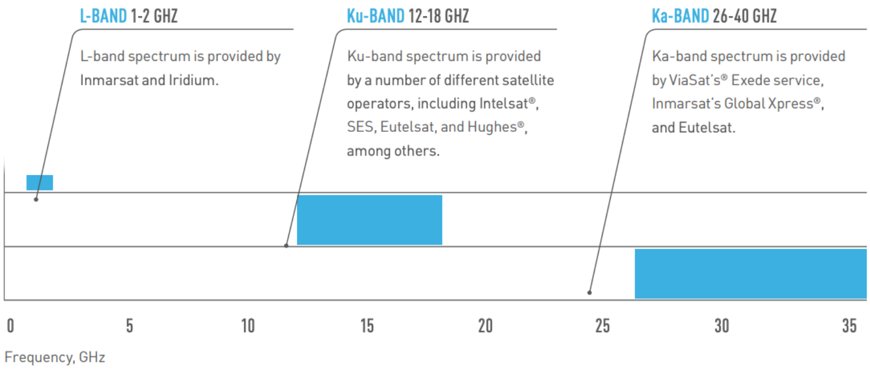

Figure 7: Spectrum bands of and most prominent satellite operators in L-band, Ku-band and Ka-band [21]

The differences can be found in the following characteristics.

- Throughput: Indicates the data transmission rate.
- Antenna size: Indicates how large the antenna is. A smaller antenna has a lower cost.

- Susceptibility to rain fade: Indicates if signal losses can occur due to bad weather conditions. Note that HTS systems overcome weather issues better, compared to traditional wide beam systems. Spot beams are ‘hotter’, which allows them to cut through weather more easily.
- Capacity: Indicates if the satellite network has sufficient capacity to serve the passengers now and in the upcoming years.
- Coverage: Indicates if there are enough satellites covering all flight routes.
- Availability: Indicates if passengers can stay connected, even if one connection drops.

Table 6: Comparison of Ku- and Ka-band [22]

	Ku	**Ka**
Throughput	Greater with similar size	Greater for equally sized installations
Antenna size	1.8 m antenna has a transmit gain of 46.8 dBi	1.8 m antenna has a transmit gain of 52.5 dBi (4 times larger)
Susceptibility to rain fade	Influenced by the weather, but less than Ka-band	More complex technologies required to mitigate the effects of weather
Coverage	Currently more satellites operating (due to historical reasons)	More satellites expected in the future
Capacity	Similar for one geographic region if amplifiers are equally sized	Similar for one geographic region if amplifiers are equally sized
Availability	Thanks to overlap, demand is insatiable and in some geographical regions the available capacity has become exhausted for particular application requirements	Currently no global availability, as more and more satellites are launched, availability will be on a worldwide scale

2.3 Combining satellite and 5G technologies

Integrating a 5G network with geostationary satellites gives the opportunity to provide wide area coverage to rural networks or networks in the air. A Next Generation Node

B (gNB) or base station is the hardware that is connected to the mobile network that communicates directly and wirelessly with user equipment (UE) [23]. Small cells and short-range links enhance the connectivity for indoor services and extend the coverage of the macro-cells.

Satcom systems are often the only economic solution to address the eMBB use cases such as coverage and network dimensioning in underserved and unserved areas. It is often the case that these areas are unserved because they offer low Average Revenue Per User (ARPU), are located in emerging markets or are based on a moving platform. Satcom can be seamlessly integrated into 5G architecture via technological collaborations. Backhauling and traffic offloading solutions can be discovered. When satcom and 5G are combined, the collaboration of satellite and terrestrial stakeholders can lead to the identification of new economically viable business models.

2.3.1 Newly identified use case for satellite-5G

The following use cases can be identified for integrated satellite-5G networks [24].

- Edge delivery and offload of multimedia content through multicasting and caching allows the network infrastructure optimization
- Serve as a fixed backhaul, to provide 5G in rural areas, where it is difficult or not economically viable to provide 5G service
- 5G to premises provides 5G services into offices or homes in underserved areas via hybrid networks, using both a terrestrial network and a satellite network
- 5G moving platform backhaul, supporting 5G service on board of moving platforms. Examples include vessels, trains and aircrafts.

This thesis will investigate the use case of providing broadband Internet on airplanes via an integrated satellite-5G network.

2.3.2 Benefits of integrating satellite and 5G

The following table indicates the benefits of using an integrated satellite-5G cell compared to existing satellite Internet technology and air-to-ground broadband technology.

Table 7; Overview of the benefits of an integrated satellite - 5G cell

Benefit	Explanation
Security	The satellite network will be more secure than terrestrial networks, as the radio signals travel exclusively from the satellite to the ground, compared to going through fiber- or tower-based relays. The traffic consists of digital pieces that can only be rearranged by the satellite. With a satellite connection at an unknown spot in the sky, it is difficult for hackers to intercept this beam [25].
Cost reduction	Due to technologies such as NFV and multicasting for content the cost of backhaul GEO HTS is expected to drop by 60% in the period 2016-2019 [26]. The drop is driven by various factors: • Lagging demand from customer groups like militaries • Increased spectral efficiency • Capacity dumps by distressed operators This cost reduction will be quantified in section 5.1.3.
Reliability	Technologies such as SDN and NFV allow automated orchestration of the network, which leads to a more reliable network.
Capacity	As mentioned in section 2.2.2, HTS can provide up to 150 Gbps and the expected demand for mobility services by 2014 is 57 Gbps [27].

2.3.3 Challenges of integrating satellite and 5G

2.3.3.1 Bandwidth management

One of the main differences between a satellite communication service and a terrestrial network is that the available bandwidth of the former is inherently more limited. The amount of available bandwidth must be shared across among multiple devices. It is preferable that the experience is more or less the same for every end user that is connected to the network. The networks can have capacity lags and the latency is always higher than terrestrial networks due to the large distance that the signal has to cover between the satellites and the connected base station.

2.3.3.2 Taking connectivity worldwide

When a network is globalized, there is a regulatory complexity that has to be resolved. Regulatory policies and compliance frameworks vary in different regions and countries, so service providers have to secure the appropriate approvals and licensing per country.

2.3.3.3 Supply and demand

Networks need to be managed in order to maintain a satisfying user experience. Demand mostly exceeds supply in a satellite network service environment, which means that the available bandwidth must be managed in order to assure a good user experience. As data demand for personal electronic devices is and for online video streaming is rising, this will stay the case in the upcoming years.

3 Defining the stakeholders and the required network architecture

The use case can be summarized as providing backhaul connectivity to airplanes with the ability to multicast the same content (e.g. video, HDTV, as well as other non-video data) across a large coverage area (e.g. for local storage and consumption) and provide efficient broadband access. Both satellite stand-alone backhauling and hybrid multiplay, i.e. the satellite link acting as a complement of existing terrestrial infrastructure, can be envisaged depending on the scenario and the type of targeted platform. For the use case of providing efficient broadband access connectivity from and towards commercial aircrafts, a stand-alone satellite backhaul is envisaged.

To offer the service, each aircraft is equipped with a satellite terminal and is connected via satellite to a central facility that controls the satellite network. This central facility then makes interconnections with the Internet, like in the case of enterprise networks. This scenario proposes bi-directional broadband access for each passenger for private use which is transparent to the moving platform. The network requests are therefore individual and proper to each passenger's activities. The end user connects via Wi-Fi and would use their own device(s) and all the applications installed as they do on the ground. In addition, they could use the seat screens to access only the local content (i.e. from the entertainment catalogue), but in the future this is expected to become obsolete.

3.1 Who are the stakeholders and how do they relate to each other?

In this section, definitions related to value networks will be given. Roles, actors and their configurations in the use case will be elaborated on and explained. Different business models will be analysed in terms of how value can be exchanged between the stakeholders.

3.1.1 Definitions

Allee defines a value network as "a web of relationships generating tangible or intangible value by dynamic exchanges between two or more individuals, groups, or organizations." [28]. A mapping method is described in order to visualize and gather better insights. The mapping is supported by the following three pillars:

- **Roles** are filled in by participators in the network, contributing and fulfilling particular functions.
- **Transactions** start at a particular participant and end at another participant. An arc represents the directional link and shows the movement and direction between the different roles. Solid lines are used for contractual exchanges such as products and revenues. A dashed line shows intangible exchanges such as information and benefits.
- **Deliverables** are the things that move from one role to another. They can be physical (e.g. a document) or non-physical (an oral message).

Allee indicates that it is important to focus on the importance of these roles and not confuse them with the persons or business units that fulfil these roles.

3.1.2 Identified roles in the value network

The roles in the network are composed of stakeholders. The following stakeholders were identified based on [19]:

- **Satellite Operator (SO):** The SO owns and operates the spacecraft and the satellite control centre (the unit that controls the satellite bus). The business of the SO involves launching and operating satellites and selling their capacity to a Satellite Network Operator.
- **Satellite Manufacturer:** The entity that manufactures the satellite.
- **Satellite Network Operator (SNO):** The SNO manages the running of the network consisting of satellite gateways, satellite terminals and a backbone to interconnect the satellite communication system to the terrestrial network as well as a network controller centre (NCC), network management centre (NMC) and satellite network control (SNC).
- **Mobile Network Operator (MNO):** The MNO provides service to the airline or immediately to the end user, depending on the business model. It does not own or operate a gateway but uses the infrastructure of any SNO. It may or may not own satellite terminals. It does operate a Network Control Centre (NCC) and a backbone. An MNO owns and operates the core network on the ground. If an MNO leases the terrestrial network of a terrestrial network operator, it is called a Mobile Virtual Network Operator (MVNO).

- **Airline**: The airline is the company that provides flights to end users via an aircraft. The specific tasks for this actor in the use case clearly depends on the business model. In some business models, the airline will buy or lease services from an MNO, and in other business models an airline only provides the platform for the inflight connectivity service. An airline can own multiple terminals that use resources of MNOs. Services or content are bought from a service provider or content provider.
- **End user:** The entity that makes use of the services via a device. Several devices and hence several users can share the same satellite terminal. The end user connects to applications provided by service providers.
- **Content distributor:** The entity that distributes content to the content provider.
- **Content provider (CP):** provides content to the end user.
- **Equipment vendor:** sells networking equipment to the MNO and SNO, in order to be able to install and manage the network.
- **Regulator:** regulators offer licenses for the satellite spectrum license for SNOs, but also for operating the core ground network to terrestrial network operators.

3.1.3 Structure of the value network

Following the definitions from section 3.1.1, the following generic value network is constructed. It is called generic, as it provides a general overview, but it is not fixed and can be different when stakeholders act in multiple roles and make different transactions to the identified stakeholders. Relationships between the different actors are shown in Figure 8. The focus of the business model analysis will be on the interactions between the stakeholders coloured in orange, while the stakeholders coloured in blue help to create a clear overview of the complete value network.

The Mobile Network Operator is placed centrally in the network because the operator has many out- and ingoing arcs and is the main end provider of the service. It offers the service, equipment and insights for the service in exchange for a fee paid by the subscriber, which is the airline in this case. In order to provide these values, the MNO has to buy equipment from an equipment vendor and capacity from a satellite network operator. It is assumed that the MNO owns and operates the core network on the ground. Intangible arcs include product suggestions, expertise and trends.

From a satellite network operator point of view, regulation is very important. Spectrum licenses for satellite capacity are sold via a regulator but are also to be used in different countries with different law systems. This is relevant for both terrestrial network operators and satellite network operators. The complexity of regulation is not included in the scope of this thesis but is important and should thus be mentioned.

A satellite manufacturer builds satellites in order to sell them to a satellite operator. The high throughput satellites are one of the main factors that make this use case feasible. A mission operator manages the satellite payload and sells or leases capacity to satellite network operators. Note that a mission operator and a satellite network operator can be the same entity.

Without the airline in the value network, there is no use case available. The airline links the end user, content provider and mobile network operator by providing the moving platform. As the end user demands ungrouped and grouped content in exchange for a fee (tangible value such as via payment or intangible value such as loyalty), the content provider plays an important role in finding which content should be cached. A content distributor provides the content to the content provider, as well as industry expertise in exchange for a fee, feedback and trends. It becomes clear that this use case involves many actors, leading to many possible value network configurations. The next section will dive deeper into these different configurations, mainly the stakeholders that are marked in orange in Figure 8.

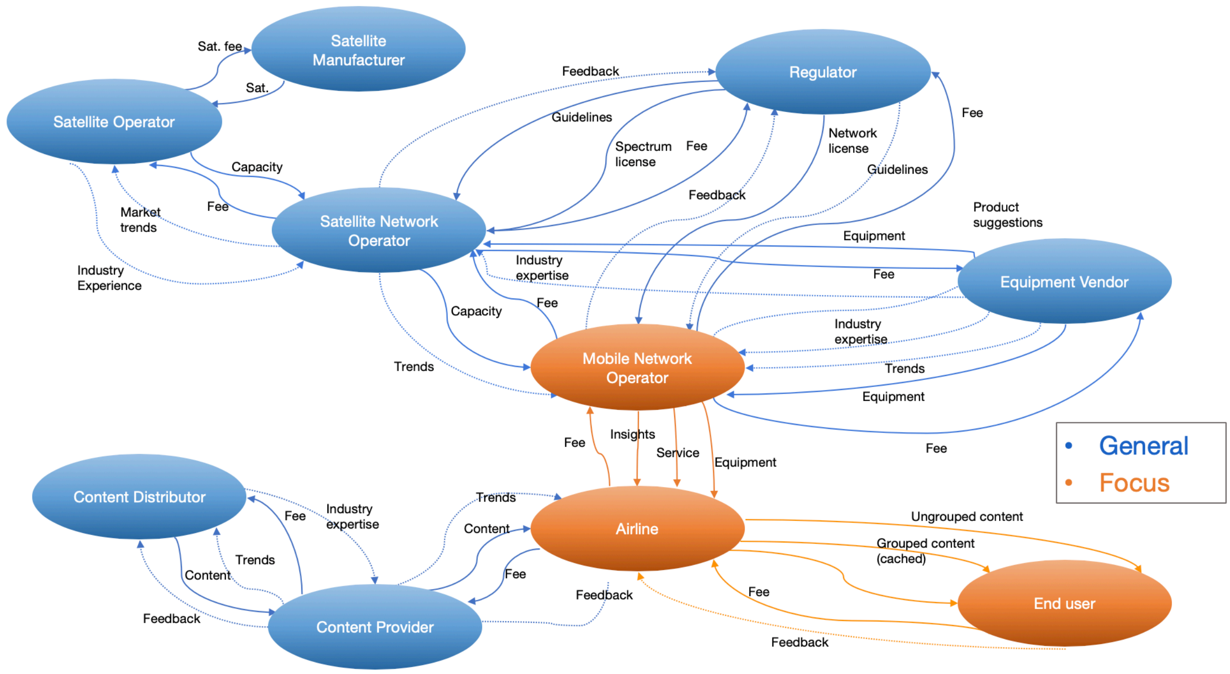

Figure 8: Value network inflight connectivity case using the Verna-Allee approach

3.2 What are the required components of the network architecture?

3.2.1 Precise description of parts and working of the suggested satellite-5G solution

The general idea of the use case is to ‘embark’ a gNB on-board the plane.

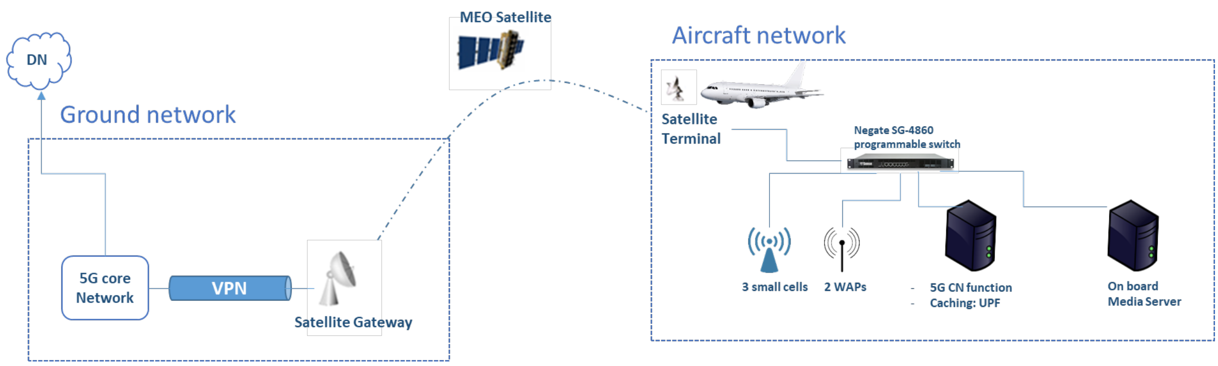

Figure 9: Network architecture for providing inflight connectivity via an integrated satellite-5G network [29]

As can be seen in Figure 9, the components of the network architecture can be divided in the ground network, aircraft network and space segment.

The ground network consists of the following parts:

- **5G core network:** A core network is a telecommunication network's core part, which offers numerous services to the customers who are interconnected by the access network [30].

- **Satellite gateway**: A ground station that transmits data to and from the satellite. It consists of the antennas and equipment that convert a Radio Frequency signal to an Internet Protocol and vice versa.

The space segment consists of one part:

- **Satellite:** An artificial object that relays and amplifies radio telecommunications signals via a transponder, orbiting the earth in this case.

The aircraft network consists of the following parts:

- **VSAT**: A satellite terminal required to acquire the radio signal.
- **gNB:** A telecommunications node in mobile networks that provide the connection between UE and the wider network (in this case via a router + WAP). It follows the UMTS standard.
- **Router**: A device that connects WAPs and gNBs.
- **Wi-Fi Access Point (WAP)**: This device is the source of Internet for end users.
- **UE**: Any direct device used by the end user in order to communicate.
- **Media server**: A media server is a device that stores and shares media. Both the hardware and the software aspects of successful storing and retrieval are managed, as well as the sharing of media files and data [31]. This server stores previously and often requested information from the Internet locally and temporarily. Bandwidth is saved and browsing speeds for already cached websites become faster because they are now accessible locally. Media servers accumulate information found in video, audio, photos and books.

It is assumed that the Mobile Network Operator (MNO) will install a 5G gNB in the aircraft and provide Internet connection to the passengers. It is also assumed that the MNO itself has the rights for the content and caches the popular content on a Mobile Edge Computing (MEC) infrastructure on the aircraft. In addition, the airline should have the capability to cache some ‘popular’ content. Satellite handovers are pure satellite procedures and they do not affect the service in any way. A combination of small cells and Wi-Fi access points (WAPs) is used. WAPs are mainly used for the local content, but they can carry traffic to the 5G core network.

In a single-beam configuration, the UE is attached to the 5G relay node, which is connected to a donor-gNB through the satellite gateway station. The aircraft is moving from one beam to another and the connection remains through the Radio Access Network (RAN) that is connected to the satellite GW. This means that a change of position from the moving platform donor node does not imply a change for the UE, from a terrestrial point of view.

When someone tries to reach a UE on the moving platform, the donor gNB will relay the message to the satellite GW it is attached to. The gateway forwards the message to the satellite and the satellite will guide the message to the right beam, i.e. where the airplane is. If the user leaves the moving platform, a better terrestrial signal can be found and the source gNB will initiate a handover procedure.

A multi-beam configuration allows the moving platform to pass from a beam connected to a satellite gateway to another beam that is connected to another gateway, as explained in section 2.2.2. In this case, the IAB node will change to another donor gNB each time it connects to another ground gateway station by performing a handover procedure.

3.2.1.1 Comparison of LEO – GEO – MEO

Based on a comparison the factors mentioned in section 2.2.3 it can be concluded that the best trade-off can be found in a MEO satellite network. It is assumed that the airplane always flies within the coverage of MEO satellites. Therefore, the use of a MEO network within the O3B constellation will be assumed for the rest of the thesis book. O3B Networks is a subsidiary of the company SES. It claims an end-to-end latency of 140 ms for data services and connectivity speeds up to 500 Mbps. It is assumed that the MEO network covers the whole flight trajectory and that the satellite link can support 150 Mbps downlink and 75 Mbps uplink.

3.2.1.2 Ku- band versus Ka-band

The factors mentioned in section 2.2.4 learn that currently there are more Ku satellites positioned around the globe, which makes it better in terms of capacity and coverage. In the future, more Ka satellites are expected, which results in a trade-off between current and future capacity and coverage of satellites, keeping in mind bandwidth, consistency and reliability. As mentioned before, a MEO satellite network by O3B is assumed, implying the usage of the Ka-band spectrum.

4 Identification and qualitative comparison of feasible business models

Today, there are several options to provide inflight connectivity, although they are not adapted to current user needs. ATG and current satellite Internet solutions are often slow and unreliable, so a new solution integrating satellite and 5G is. This implies the need to define one or more new business models. The current business model landscape for inflight connectivity is very diverse, and an ideal sustainable business model is yet to be defined for providing onboard Internet access via satellite-5G.

In this section, swaps will be made in the focus of the value network (orange colour in Figure 8). First, feasible business models will be identified and after that, they will be analysed more in-depth with a custom framework constructed by building blocks from Value Network Intelligence analysis framework, SWOT analysis framework and common sense. The business model canvas will be shortly explained and applied on the identified models to allow the reader to evaluate and ratify business models in a more structured way. Differences in the canvas will be highlighted in order to have a clear overview of the working and vitality of the network.

4.1 Framework for structured analysis of inflight connectivity business models

To evaluate the inflight connectivity use case, multiple business model frameworks were checked for their fit to the business models. It was then decided to extend an existing framework to analyse the case. The value network intelligence framework, developed by Allee, is used as a starting point [32]. Non-relevant links are removed, but it was decided to keep the main structure. The added subtopics: ‘Technology’, ‘Differentiation opportunities’, ‘Branding potential’, ‘Specialist knowledge’ and ‘Financial risk’ are case-specific and are identified by common sense. These subtopics are added because they allow us to evaluate differences between the business models. Every subtopic of the framework will be answered from a SWOT (Strengths, Weaknesses, Opportunities and Threats) perspective [33], which is often used to make business decisions related to strategy, position or direction of a company but too generic to use as a standalone tool due to the complexity of this use case. The framework can be found in Figure 10 and will be explained after.

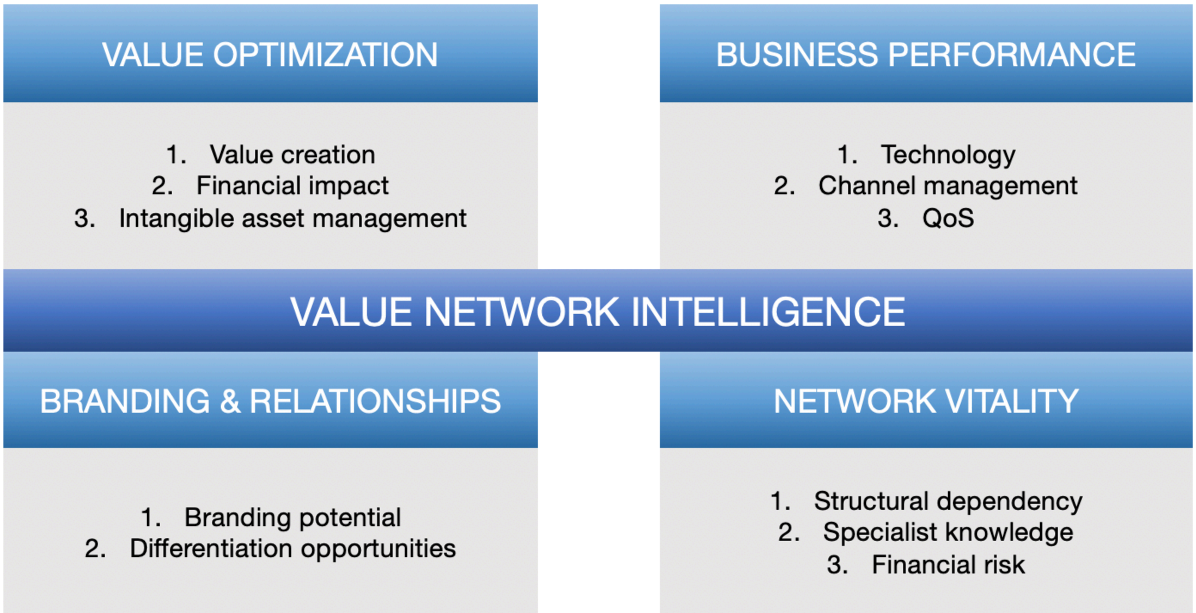

Figure 10: Qualitative analysis structure based on the Value Network Intelligence framework by Allee [32]

In Table 8 the subtopics are explained via questions that have to be answered for every business model. The business model framework consists of the following parts:

Table 8: A suggested business model framework

TOPIC	DESCRIPTION
Value optimization	
Value creation	How is the value created in the network, by whom and for whom?
Financial impact	What is the financial impact for the stakeholders? Who makes revenues and are there any missed opportunities?
Intangible asset management	What are the intangible assets involved in the value network?
Business performance	
Technology	What technology is required to meet the customer requirements?
Channel management	Which channels are used to bring the service to the end user and how efficient is the channel structure?
QoS	What is the required Quality of Service (QoS) for the end users and are there implications on the performance of the proposed solution?

Branding & relationships	
Branding potential	Who can gain a better perception and what are the advantages that are linked to that?
Differentiation opportunities	Which additional opportunities are identified in the business case that stakeholders can benefit from in terms of relationships and branding?
Network vitality	
Structural dependency	Who depends on whom and are there threats in the structural dependency of the stakeholders?
Specialist knowledge	Which stakeholders require specialist knowledge of the inflight connectivity?
Financial risk	Who takes the highest financial risk in the investment? Linked to this is of course also the revenue potential. A trade-off has to be made.

4.2 Introducing the Business Model Canvas framework

The Business Model Canvas (BMC) was presented in the book ‘Business model generation’ written by Piqueur and Osterwalder as a visual framework for devising, developing and testing an organization’s business model(s) [34]. A business model describes the way an organization creates, delivers and captures value [35].

The BMC summarizes all influential and value creating factors in nine building blocks. They are summarized shortly underneath: [36]

1. **Value proposition** describes the value of your product or service for a particular customer segment. It indicates why customers will choose your product or service over another.
2. **Customer segments** describe who the customers are that you are targeting and also which properties they have.
3. **Channels** indicate how your company gets in touch with customers. Marketing and distribution strategies are described here.
4. **Customer relationships** describe how you will communicate with customers and what relationship you will build with them.

5. **Key activities** give an overview of the action and processes that will make the business model work.
6. **Key resources** are the entirety of people and means required to service the customers. These resources allow you to create the value proposition.
7. **Key partners** are the main strategic partners and suppliers that are influencing your business model.
8. **Revenue streams** indicate how money will be made with the business model. Where do the revenues come from?
9. **Cost structure** gives an overview of all costs required to get the business running including both operational and investment costs.

The reason why the BMC is used in this analysis is threefold. First of all, it allows the reader to understand how different aspects of providing on-board broadband relate to each other. It makes the reader think in a more systematic way about the structure of business modelling, leading to a better understanding of the overall picture. Secondly, the BMC allows flexibility in determining the key inputs to each building block. These can change over time and can then be adapted if required. Last, the BMC is intuitive, making it a great starting point to build, ratify and evaluate the IFC business case [37].

As can be noticed from the explanation above, the BMC is always filled in from one stakeholder's perspective. It is chosen to do this from the airline's point of view, because that shows the most interesting differences and makes comparing the business models more intuitive.

4.3 Identification of feasible business models and application of a comparison framework

One can identify different business models of the use case based on the swaps in the value network, company whitepapers and specialized technology news providers. This will be done and the differences will be made clear by evaluating the business models with the framework introduced in Section 4.1.

4.3.1 Wholesale model with connectivity for paying users

In a wholesale model, a mobile network operator sets a fixed rate per aircraft for providing connectivity and sells a number of connections [38]. The MNO also covers the installation and migration of the project. The airline charges this cost to the passengers that are willing to pay for bandwidth. The airline collects 100% of the revenues. Many airlines want to control everything inside the plane. They want to have the flexibility to support programs such as having one price on Monday and another one in the weekend [39]. The tools to manage their own retail experience is provided by the MNO. Airlines want to buy the wholesale capacity and determine themselves how the capacity is shared and what is charged for it. An example of an MNO that works via this business model is Panasonic Aviation [38].

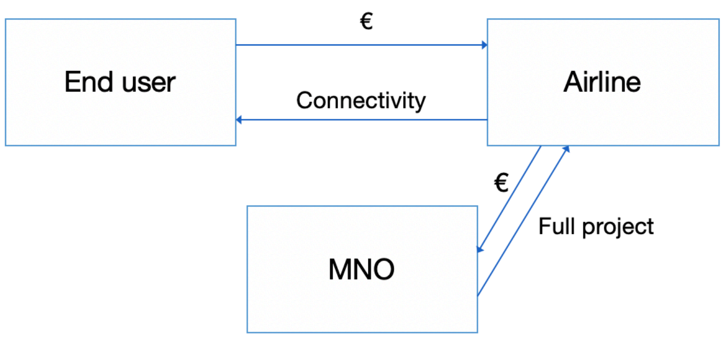

Figure 11: Visualization of the wholesale model

Table 9: The business model framework applied to the wholesale model

Value optimization	
Value creation	Value for end user: connectivity Value for airline: increased ticket sales and revenues for connectivity service
Financial impact MNO	The MNO makes profits by selling the project, but can miss out on revenues by not selling directly to the end users
Financial impact airline	Increased revenues for airline Threat of hidden costs for airline
Financial impact end user	End user pays a price – different pricing options available

Intangible asset management	End user feedback can be incorporated in service
Business performance	
Technology	Sat-5G integration required to reach high performance
Channel management	Business performance might encounter delays in case of problems due to the indirect link end user – MNO
QoS	Available bandwidth is split between paid users
Branding & relationships	
Branding potential	Increased perception of airline that can lead to higher loyalty
Differentiation opportunities	Airline can brand itself as an on-board Internet provider and grow its name Opportunity to serve as platform for other connectivity-dependent revenues: sales - promotions
Network vitality	
Structural dependency	Quality requirements and delivery times MNO may not be aligned with airline needs
Specialist knowledge	Airline needs internal experts / managers
Financial risk	Airline takes the financial risk

4.3.2 Retail model with connectivity for paying users

In a retail model, the MNO installs, migrates and operates the full inflight connectivity project on-board, using the aircraft platform from the airline. This implies that the airline is not directly involved in the revenue stream from the end users. The MNO installs its own equipment for a small fee and sets the prices that it will charge to the end users [38]. This allows the MNO to manage the customer experience and optimize the pricing model.

The airline serves as the platform in exchange for a share in revenues. This share is agreed upon in a deal between the MNO and the airline. The share in revenue is required because the airline is also facing additional challenges such as occupied space by the equipment and installing the equipment (during maintenance of the aircraft). Another factor is that fuel efficiency will be less due to the added weight of the network infrastructure, as well as aerodynamic losses due to the antenna. An airline will often not be inclined to overcome these challenges, without a remuneration apart from the added service for the passengers. The end users pay the MNO via mobile payment methods or their credit cards. They often have the possibility to buy a subscription for all airlines served by a particular MNO.

An example of an MNO that works via this business model is Gogo. Examples of airlines working together with Gogo are Alaska Airlines, American Airlines, Vietnam Airlines, Virgin America, etc. [40].

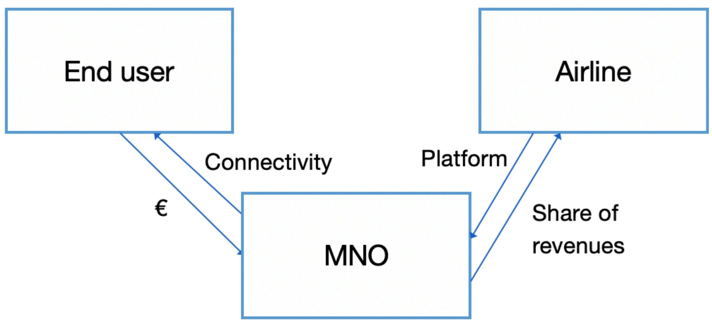

Figure 12: Visualization of the retail model

Table 10: The business model framework applied to the retail model

Value optimization	
Value creation	Value for end user: connectivity Value for airline: increased ticket sales
Financial impact MNO	MNO has higher revenue potential by selling directly to end users
Financial impact airline	Overhead costs / Share in revenues possible

Financial impact end user	End users pays a price – different pricing options available
Intangible asset management	End user feedback can be incorporated in service
Business performance	
Technology	Sat-5G required to reach high performance MNO has the opportunity to use multicasting to its advantage
Channel management	Business performance efficiently handled thanks to direct link between end user and MNO
QoS	Available bandwidth is split between paid users, depending on the pricing model
Branding & relationships	
Branding potential	Less branding potential for airline, although still significant
Differentiation opportunities	Airline can brand itself as an on-board Internet company and grow its name
Network vitality	
Structural dependency	Quality requirements from end user are directly linked to MNO MNO's business is dependent on airline
Specialist knowledge	Airline does not need internal experts / managers
Financial risk	MNO takes the financial risk

4.3.3 Sponsorship model with free connectivity for all passengers

In a sponsorship model, the airline buys the inflight connectivity project as a whole from an MNO and sells sponsorship deals to sponsors to offset the costs of the project partly or completely. off In a sponsorship model, third parties have the opportunity to reach a captive audience and generate ancillary revenues [41]. Sponsorship partners are willing to pay the airline for free inflight connectivity for the end user in exchange for the opportunity to spread a promotional message or improve their company brand.

It is important to note here that the sponsorship partner will evaluate the project based on the potential increase of leads or sales. This implies that the partner will put a value on the deal. This valuation combined with the demand from other potential partners will lead to a particular value of the contracts.

An interesting case study is the partnership between Delta Airlines and LinkedIn at the end of 2018, in which passengers were offered free Internet. In addition to that, they were also offered free online courses on topics such as ‘Leadership’ and ‘Story telling’ on the platform LinkedIn Learning [42].

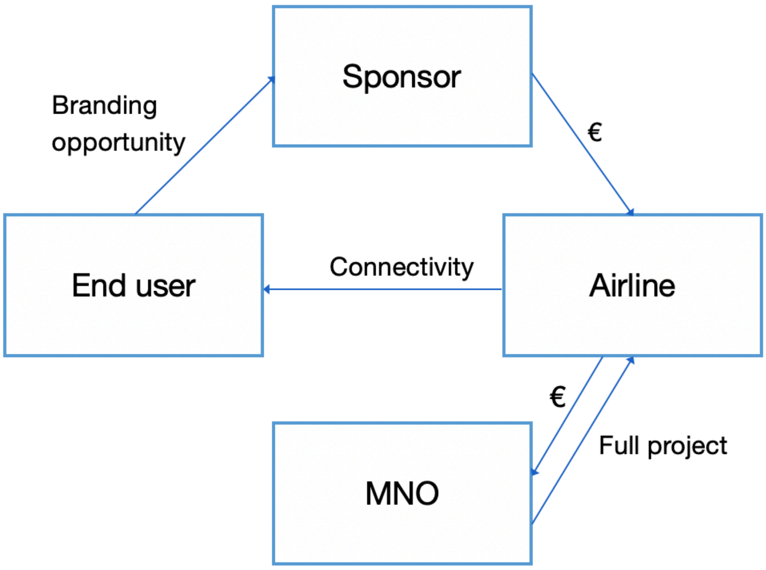

Figure 13: Visualization of the sponsorship model

Table 11: The business model framework applied to the sponsorship model

Value optimization	
Value creation	Value for end user: connectivity Value for end user: frictionless service (passengers do not have to worry about payment on-board or in advance) Value for airline: increased ticket sales Value for sponsorship partner: end user credentials, data and the opportunity to advertise and promote
Financial impact MNO	MNO makes profits by selling the project to the airline
Financial impact airline	Airline has an opportunity to create extra revenues if sponsorship demand is high, resulting in a higher revenue potential Threat of hidden costs for airline
Financial impact end user	Service is free
Intangible asset management	End user feedback can be incorporated in service
Business performance	
Technology	Sat-5G required to reach high performance, although air-to-ground can also be used depending on end user needs and sponsor needs
Channel management	Business performance might encounter significant delays in case of problems due to the indirect link end user - MNO
QoS	Available bandwidth is split between all users
Branding & relationships	
Branding potential	High branding potential for sponsor via log-in page, promotions, advertisements, sales Less branding potential for the airline, although still significant
Differentiation opportunities	Opportunity to differentiate from other airline companies providing paid connectivity

Network vitality	
Structural dependency	Quality requirements and delivery times MNO may not be aligned with airline and sponsor needs
Specialist knowledge	Airline needs internal experts / managers / sales Sponsor needs internal managers
Financial risk	Airline takes the financial risk of finding adequate sponsors

4.3.4 Freemium wholesale model

A freemium wholesale model is based on the wholesale model explained in section 4.3, with a major difference in customer segments and revenue streams. This difference is based on the fact that customers can be divided into two segments: the free users and the premium users. The free users will have access to broadband Internet until a certain limit is reached (e.g. 50 Mb) or at a much slower speed than premium users [43]. The premium users will be able to upgrade and have unlimited access to broadband. They often form a smaller percentage of the customers, although they are the only customer segment generating direct revenue streams for the airline. The goal is to have a high conversion rate from free to premium users, and this depends on many factors. Questions a business has to ask when interested in a freemium model are the following [44].

- Is the service of high quality? Service quality is the most crucial and particularly challenging task for a freemium company. An ideal freemium service will market itself, acquire new free and paying on-board users and automate customer service, with little or no human intervention and minimal expense.
- How complex is the service? Passengers need to be able to understand and use the service product quickly.
- Are customers attracted by free? It is important that the service makes sense to be provided for free.
- Can value be made from free customers, either by converting them into paying users, by attracting more paying users, or via indirect revenue

streams? An airline wants its service to be used, but if these users do not lead to revenues, they become an expensive weight.

- Is the market big enough? Most freemium companies have customer conversion rates between 1% and 10%, implying that a large customer base is required to make the model work.

This model is sustainable for this use case because the technology required is the same for free and premium users. Satellite-5G makes the quality of service high and connectivity is not difficult to explain to customers. It is crucial that connecting is as intuitive as possible. Customers are very much attracted by free, although there is a rising awareness for privacy issues with free models. Value can be made from free users by converting them into paying users, attracting more paying users, or via indirect revenues such as connectivity-dependent sales.

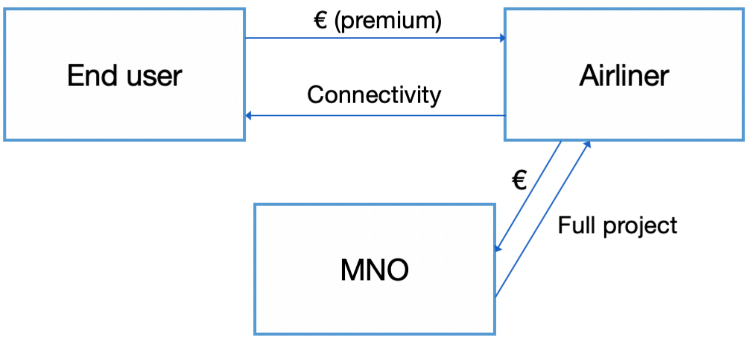

Figure 14: Visualization of the freemium wholesale model

Table 12: The business model framework applied to the freemium wholesale model

Value optimization	
Value creation	Value for free user: connectivity Value for free user: frictionless service (passengers do not have to worry about payment on-board or in advance) Value for premium user: fast connectivity Value for airline: increased ticket sales and revenues Value for airline: end user credentials, data and the opportunity to advertise and promote

Financial impact MNO	MNO makes profits by selling the project to the airline
Financial impact airline	Airline has an opportunity to create extra revenues if the conversion rate is high, resulting in a higher revenue potential Threat of hidden costs for airline
Financial impact end user	Service is free for free users Service is paid for premium users
Intangible asset management	End user feedback can be incorporated in service
Business performance	
Technology	Sat-5G required to reach high performance for premium users, lower performance needs for free users
Channel management	Business performance might encounter delays in case of problems due to link end user - airline - MNO
QoS	Free users' speed can be limited, so that free users cannot use the bandwidth of the premium users
Branding & relationships	
Branding potential	Increased perception of airline that can lead to higher loyalty
Differentiation opportunities	Opportunity to differentiate from other airline companies Opportunity to serve as platform for other connectivity-dependent revenues: holiday sales - promotions – food/drink order – taxi service
Network vitality	
Structural dependency	Quality requirements and delivery times MNO may not be aligned with airline needs for both free and premium end users
Specialist knowledge	Airline needs internal experts / managers / sales
Financial risk	Airline takes the financial risk (the conversion rate needs to be high enough)

4.3.5 Freemium retail model

A freemium retail model is based on the retail model explained in section 4.3.2. This implies that only the premium end user pays for the connectivity to the MNO and the airline provides the platform in exchange for a share of the revenues. The explanation, goals and sustainability of 'freemium' are the same as in section 4.3.4, and will not be repeated here.

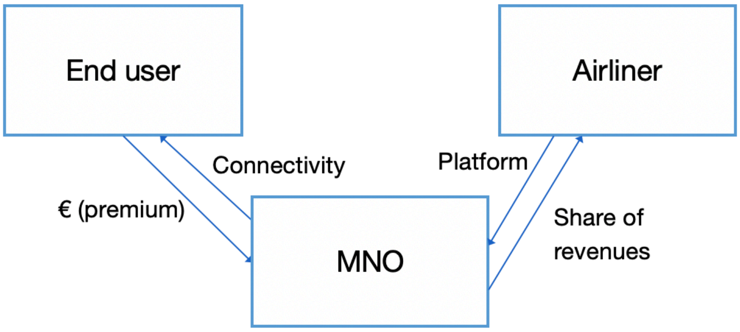

Figure 15: Visualization of the freemium retail model

Table 13: The business model framework applied to the freemium retail model

Value optimization	
Value creation	Value for free user: connectivity Value for free user: frictionless service (passengers do not have to worry about payment on-board or in advance) Value for premium user: fast connectivity
Financial impact MNO	MNO has an opportunity to create extra revenues if the conversion rate is high, resulting in a higher revenue potential
Financial impact airline	Overhead costs / Share in revenues possible
Financial impact end user	Service is free for free users Service is paid for premium users
Intangible asset management	End user feedback can be incorporated in service

Business performance	
Technology	Sat-5G required to reach high performance for premium users, lower performance needs for free users MNO has the opportunity to use multicasting to its advantage
Channel management	Business performance efficiently handled thanks to the direct link between end user and MNO
QoS	Free users' speed can be limited so that free users cannot use the bandwidth of the premium users
Branding & relationships	
Branding potential	Increased perception of airline that can lead to higher loyalty Airline can brand itself as an on-board Internet provider (including Internet for business needs) and grow its name
Differentiation opportunities	Opportunity to differentiate from other airline companies
Network vitality	
Structural dependency	Quality requirements from end user are directly linked to MNO MNO's business is dependent on airline
Specialist knowledge	Airline does not need internal experts / managers / sales
Financial risk	MNO takes the financial risk (the conversion rate needs to be high enough)

4.3.6 Complementary service model with free connectivity for all passengers

In the complementary service model, a mobile network operator sets a fixed rate per aircraft for providing connectivity and sells a number of connections to the airline, which offers them for free to its passengers. Free inflight Wi-Fi can be a key differentiator for airlines that want to obtain a higher market share. A Wi-Fi connection without charge can drive preference and serve as a platform for connectivity-dependent revenues such as taxi service, other flights, promotions, food or drink orders [41]. Loyalty and perception by the current customers can be improved and new customers can be attracted by introducing a frictionless service. The price of inflight connectivity can be reflected in the ticket price for premium customers and be part of their amenity package or broadband could be traded for loyalty program points. The latter could be very effective as frequent travellers are often travelling for business – but not always in business class, which will make them value a stable Internet connection more than other rewards .

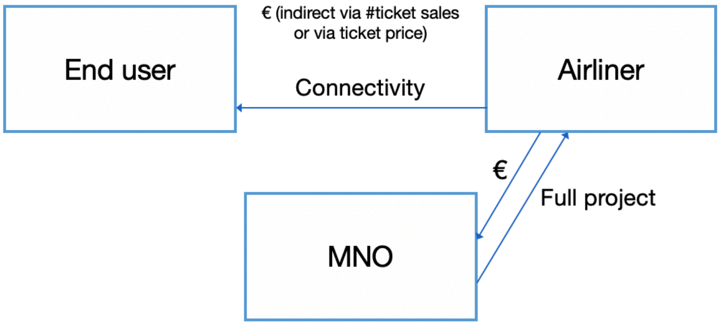

Figure 16: Visualization of the complementary service model

Table 14: The business model framework applied to the complementary service model

Value optimization	
Value creation	Value for end user: connectivity Value for end user: frictionless service (passengers do not have to worry about payment on-board or in advance) Value for airline: end user credentials, data and the opportunity to advertise and promote
Financial impact MNO	MNO makes profits by selling the project to the airline
Financial impact airline	Airline has an opportunity to create extra revenues if ticket demand rises, resulting in a higher revenue potential Threat of hidden costs for airline
Financial impact end user	Service is free

Intangible asset management	End user feedback can be incorporated in service
Business performance	
Technology	Sat-5G required to reach high performance for premium users
Channel management	Business performance efficiently handled thanks to the direct link between end user and MNO
QoS	Risk of passengers consuming large amounts of data, reducing performance for other passengers
Branding & relationships	
Branding potential	Increased perception of airline that can lead to higher loyalty
Differentiation opportunities	Airline can brand itself as a free on-board Internet provider (including Internet for business needs) and grow its name Opportunity to differentiate from other airline companies Opportunity to serve as a platform for other connectivity-dependent revenues: sales - promotions
Network vitality	
Structural dependency	Quality requirements and delivery times MNO may not be aligned with airline needs
Specialist knowledge	Airline needs internal experts / managers / sales
Financial risk	Airline takes the financial risk (incorporating connectivity service in ticket price may lead to lower ticket demand)

4.3.7 Summary of identified business models

Six business models were identified, each of them including different relationships between the actors 'end user', 'airline' and 'MNO'. A very short summary of the identified business models can be found in Table 15.

Table 15: Summary of identified business models

Business models	
MODEL	**SHORT DESCRIPTION**
Wholesale model	The airline buys the project from an MNO and sells the service to end users.
Retail model	The MNO installs the project on the platform provided by the airline and sells the service directly to end users.
Sponsorship model	The airline buys the project from an MNO and generates revenues by selling sponsorship projects. End users are offered the service for free.
Freemium wholesale model	The airline buys the project from an MNO and sells the service to premium end users. Limited service is offered to free users.
Freemium retail model	The MNO installs the project on the platform provided by the airline and sells the service directly to premium end users. Limited service is offered to free users.
Complementary service model	The airline buys the project from an MNO and offers the service for free to all passengers.

Currently, four out of five airline operators prefer the scenario of the wholesale model over the retail model, although some airlines offer the service for free. In a paid model, the passengers pay for the broadband service depending on the usage. There are many different pricing strategies possible and many of them are used in practice. These strategies will be discussed in section 5.2.1.

The inflight connectivity market is expected to become a $30 billion market by 2035, compared to a $1 billion market in 2018 [45]. The fact that this market will become large implies that, if the conversion rate is high enough, a freemium business model should certainly be considered in the rest of the analysis. Revenues will be generated from broadband access, e-commerce, advertising and premium content. The identified business models will co-exist, as they have many different advantages and disadvantages.

4.4 Application of the BMC to the inflight connectivity use case

The BMC applied to the generic inflight connectivity use case leads to Figure 17. It shows that the value proposition is valuable and can be communicated clearly to the end user. Special attention is required for different and rising needs of users. Loyalty is important because inflight connectivity is an added service to the flight itself.

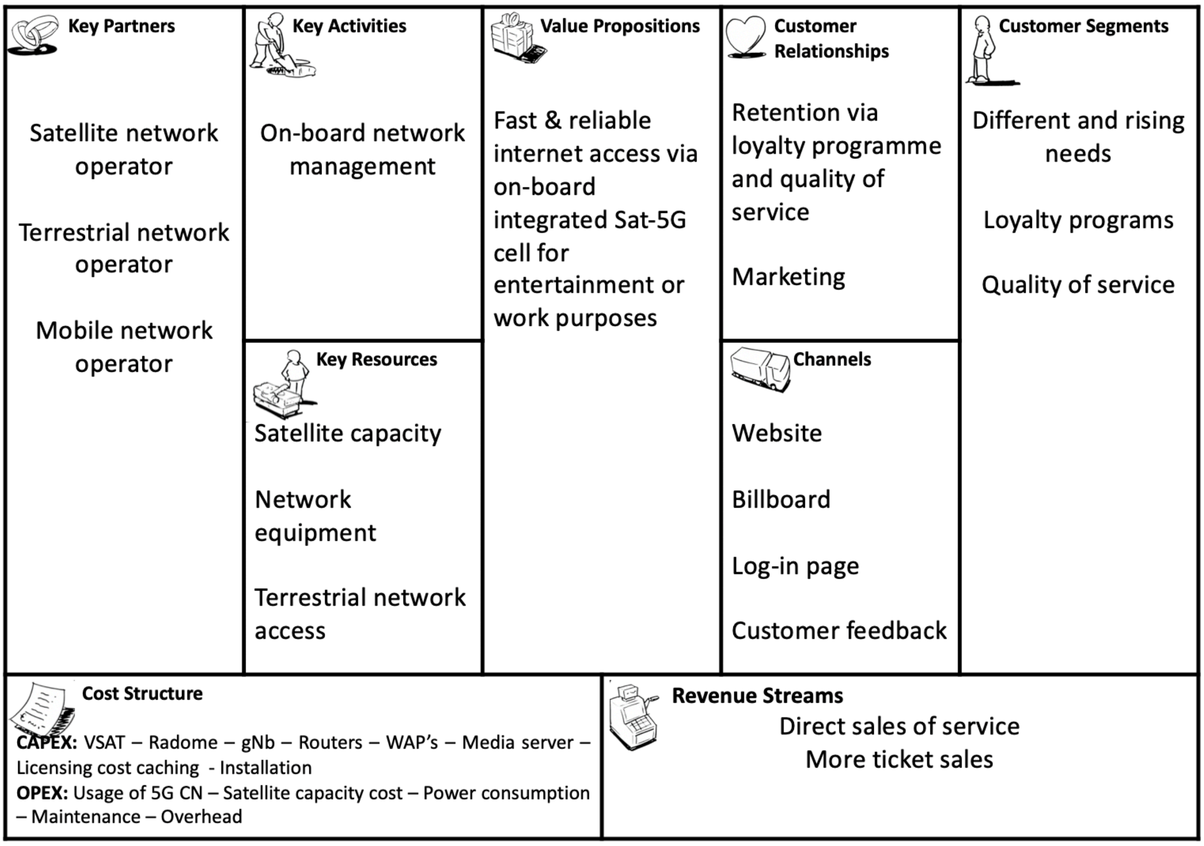

Figure 17: Business Model Canvas applied to inflight connectivity via SAT-5G from an airline's POV

4.4.1 Qualitative comparison based on differences in the BMC

This BMC introduced in section 0 holds for all business models, although there are significant and interesting differences between some of the business models regarding some subtopics of the BMC. These differences are explained in Table 16.

Table 16: Differences with the generic BMC per business model

Wholesale model
• Additional revenue streams via connectivity-dependent sales
Retail model

• Fewer channels possible as the MNO owns the service completely including feedback and log-in page • Direct sales of service are no longer applicable as a revenue stream for the airline, so the only remaining revenue stream remains an increase in ticket sales • Loyalty programs are only possible with contractual agreements between MNO and airline, making this harder to incorporate for the airline
Sponsorship model
• There is now an additional customer segment: the sponsors, who can have different needs • The sponsor is offered value in terms of brand impression and the opportunity to send a promotional message to end users • The revenue streams from the airline now come from sponsorship deals
Freemium wholesale model
• There are now two classifications in the end users: one group of premium customers that are expecting value propositions in terms of fast, reliable and capable Internet access via an on-board integrated Sat-5G cell and free users with lower expectations in terms of speed and reliability • Direct sales of service as a revenue stream is now only applicable to premium users, although the connectivity-dependent sales revenue stream is applicable to both of the customer segments
Freemium retail model
• There are now two classifications in the end users: one group of premium customers that are expecting value propositions in terms of fast, reliable and capable Internet access via an on-board integrated Sat-5G cell and free users with lower expectations in terms of speed and reliability • Fewer channels possible as the MNO owns the service completely including feedback and log-in page • Loyalty programs are only possible with contractual agreements between MNO and airline, making this harder to incorporate for the airline • Direct sales of service are no longer applicable as a revenue stream for the airline, so the only remaining revenue stream remains an increase in ticket sales
Complementary service model

- Offering the full high service for free can result in a differentiation opportunity to improve customer relations
- Revenue streams can only come from an increase in ticket sales or a higher ticket price

The key take-aways from Table 16 will allow the reader to differentiate between the business models in a more structured way:

- The main differences between the business models are situated in Customer relationships, Customer segments, Channels and Revenue streams, while the other segments are similar.
- The retail and freemium retail model differ in cost structure, because the MNO earns the revenues directly in these models. In the other models, the MNO will take a profit margin on the equipment and service.
- In the retail model and freemium retail model it is harder to increase loyalty as the airline is not directly involved in the service.
- There are additional revenue streams possible: direct sales of service, connectivity-dependent sales and an increase in ticket sales (or higher priced tickets). In the sponsorship model and the complementary service model the direct sales are not possible, although the customer relationship and channel management section are much stronger, because of the higher number of branding and retention opportunities.
- An important note on the sponsorship model and complementary service model: Although the service is free for everyone, the needs are different for end users. Some end users have low capacity requirements to chat and check their e-mails, while some end users may require higher capacity. As the service is the same for everyone, the end users with higher requirements who are willing to pay for it, can be unsatisfied. This problem is solved in the best way by the freemium model, as the value proposition is better aligned with the customer needs.
- The highest differentiation opportunity is in the complementary service model. This can be an important factor in a competitive environment such as the airline industry.

4.5 Conclusion of the comparative analysis

By linking the topics of section 4.3 and 4.4 to business characteristics, one can come up with a comparison table. An airline can indicate which values/subtopics are the most important to them in the table and the airline can then find the business model that is related closely to its wishes. A '+' (respectively '-') in the left column of Table 17 indicates that the business model has a significant (dis)advantage on that particular characteristic.

Table 17: Business models versus airline characteristics

BUSINESS MODEL - CHARACTERISTIC (Airline)	Wholesale model	Retail model	Sponsorship model	Freemium wholesale model	Freemium retail model	Complementary service model
Technology	+	++	+	+	++	+
Channel management	-	+	--	-	+	-
QoS	+	+	-	+	+	-
Structural dependency	-	+	-	-	+	-
Branding	+	-	-	+	-	+
Customer attraction	-	-	++	+	+	++
Risk aversity	-	+	-	-	+	-

Direct revenue potential	+	-	+	+	-	-
Specialist personnel	-	+	-	-	+	+

It can be derived from Table 17 that in scenarios where the airline operator wants full control over pricing, the wholesale model is suggested. The retail model is beneficial for airline companies who are more risk-averse and do not want to drift away from their core business. The customer will also benefit from the retail model, as the value chain is shorter and the quality is assured. The sponsorship model is suggested when the need or interest for marketing of the company is rather low. This could be because tickets already sell out fast or a low-cost structure is the main marketing strategy.

The freemium wholesale and retail model should certainly be considered in the rest of the analysis because they bear many branding opportunities, and customers are attracted by free services. Combining this with a qualitative service and the option to generate extra connectivity-dependent revenues, make up a very viable business model. Key to making the freemium business model work is having a conversion rate from free to premium that is high enough. The complementary service model will be preferred by premium airline companies, as no revenues will be generated by the service directly. Customers from these companies prefer to pay for the full premium service, in which connectivity is already included.

5 Techno-economic analysis of the identified business models

After identifying and describing the business models, one could ask how these business models can be quantified and if they are feasible from an economic point of view. To answer that question, a techno-economic analysis is proposed. First, a high-level cost model will be created, in order to calculate the cost of the project for each of the identified business models. This cost model will serve as the input for the revenue models. The revenue models will calculate the final cost for the end user (or for a possible sponsorship partner). Starting from the equivalent annual cost of the project with an added profit margin based on the business model, a cost per MB data will be calculated. This is called cost-based pricing. The cost will then be translated into ticket price increases, subscription prices, sponsorship deals, prepaid data prices, freemium conversion rates… depending on the business model and its linked possible pricing models. The structure of the modelling approach is shown in Figure 18.

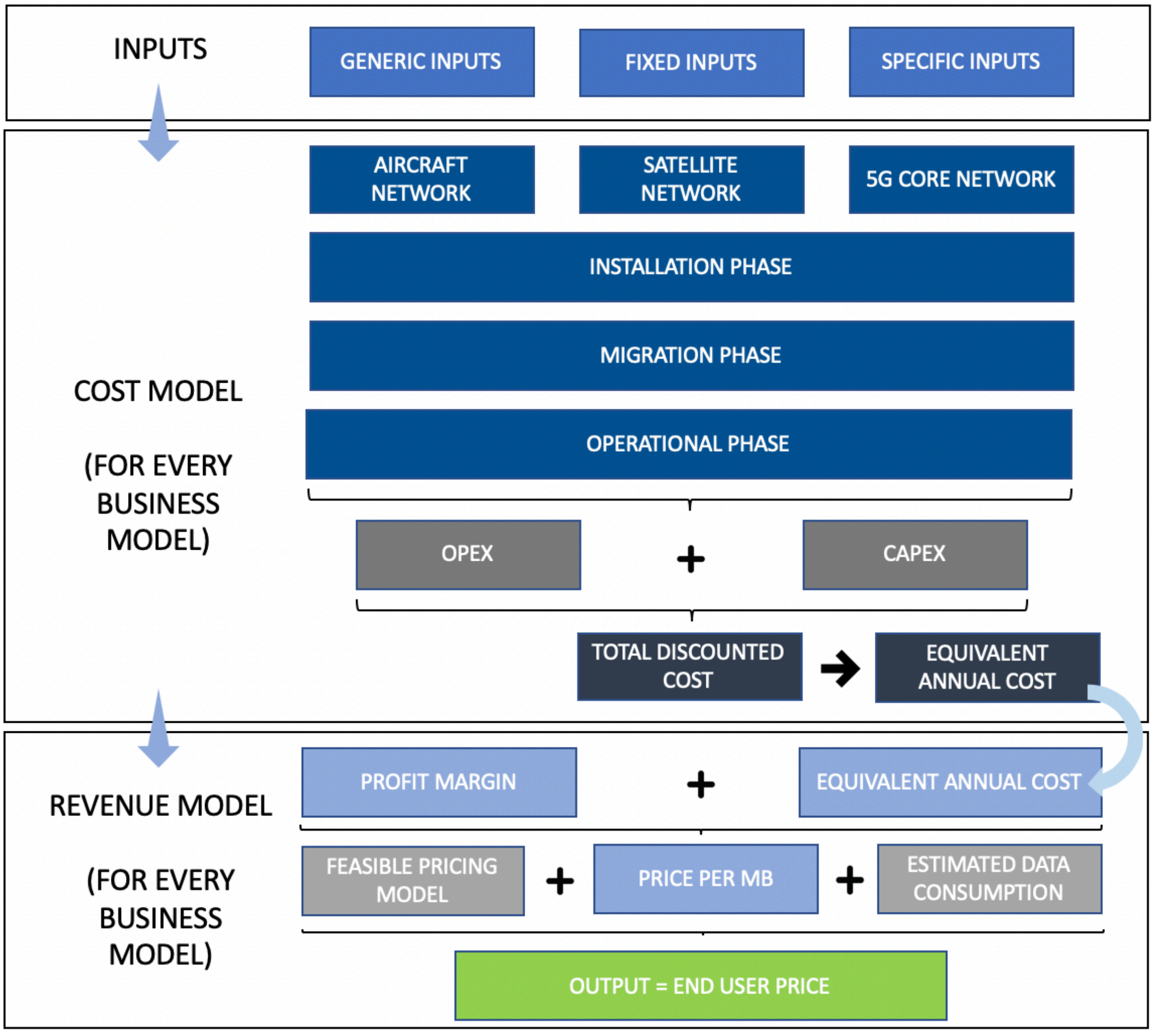

Figure 18: Modelling structure used for the techno-economic analysis

5.1 Building a cost model for every identified business model

It is chosen to develop a cost model to evaluate the total lifecycle cost of an integrated satellite-5G cell in an airplane. This cost model will serve as input for revenue models, which will allow us to discover which business models and pricing models are feasible.

5.1.1 Cost modelling approach

As a business case is being evaluated, a distinction is made between capital and operational expenses, referred to as CapEx and OpEx. CapEx are defined as “funds used by a company to acquire, upgrade, and maintain physical assets such as property, buildings, an industrial plant, technology, or equipment” [46]. CapEx are depreciated over time, allowing optimization of taxes by following a depreciation scheme. OpEx are defined as “expenses a business incurs through its normal business operations” [47] and are not depreciated over time.

To incorporate all costs involved in the project, a project lifecycle approach is suggested, consisting of a planning, deployment, migration, operations and teardown phase. As the teardown phase is less relevant in this use case – Internet on airplanes is considered a necessity in the future and as such the technology will be updated – this teardown phase is not considered. This approach makes it possible to calculate the total cost of the use case over its entire lifetime, also referred to as the Total Cost of Ownership (TCO) [48]. To structure the cost model, it is chosen to classify the network equipment in what is needed for the core network, satellite network and edge network (on-board). Combining these two approaches, a cost model structure matrix is found as can be seen in Figure 19.

		Lifecycle approach			
		Installation phase	Migration phase	Operational Phase	Teardown phase
Network break-up	Core network	√	√	√	
	Satellite network	√	√	√	
	Edge network	√	√	√	

Figure 19: Cost structure matrix

A bottom-up cost model is suggested, as the costs are calculated for a new network architecture [49]. The cost model can start from the demand for the service. The 5G-cell is dimensioned so that it can cover the demand of the users, thereby respecting the proposed quality of service (QoS). Current costs are linked to the required network equipment and are combined with service costs. This allows us to finally find a cost of the total project per airplane and derived from that a cost per service.

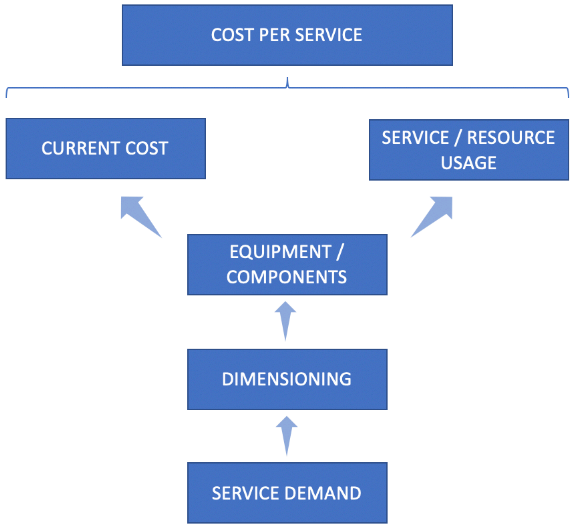

Figure 20: Bottom-up cost modelling schema [49]

An important characteristic of the cost model is that it should be time-variant, as the costs for satellite capacity are forecasted to drop significantly between 2020-2025 [26]. Reliable cost inputs are essential for the outputs of the model. It is chosen to use cost inputs from academic papers, equipment vendor websites, technology magazines and – if no other option – from Internet websites.

The model is created in Excel and consists of one input page and generates cost models automatically for the identified business models. The main cost from an MNO point of view is linked to the retail and freemium retail models and the outcome of these models is used for calculating the cost model for the other business models, in which the airline buys the project from an MNO. The airline cost model consists of the project investment, overhead and a yearly or monthly fee to the MNO.

5.1.2 Input data and assumptions

The input data is divided into three categories: ‘Generic inputs’, ‘Specific inputs’ and ‘Fixed inputs’.

5.1.2.1 Generic inputs

This category stands for the inputs that are used in every business model. It includes general inputs, network architecture inputs and flight-focused inputs. For the use case, a project lifetime of five years is suggested, with a discount rate of 10% [50].

The network architecture holds the following CapEx costs:

Table 18: CapEx of network architecture

Aircraft Network	Price	Unit	Reference
Wi-Fi AP: Aero-adapted	5 000 – 10 000	€	Input from SaT5G project
5G Small Cell: Aero-adapted gNB HW: Ettus B210 SDR, Intel Nuc Server with 4 cores CPU, 16 GB RAM and 500 GB Disk SW: OAI 4G CN srsLTE	50 000 – 100 000	€	Input from SaT5G project
Number of gNBs	1		[Assumption]
Media Server HW: COTS SW: Open Source / Proprietary	30 000 – 50 000	€	Input from SaT5G project
Number of media servers	> 2		Input from SaT5G project
Caching license	12 000	€	Input from SaT5G project
5G Satellite network	Price	Unit	
VSAT SES AvL antenna + radome	200 000 – 500 000	$	Input from SaT5G project

The following network architecture OpEx inputs are considered:

Table 19: OpEx of network architecture

5G Core Network	Quantity	Unit	Reference
Data Centre	66	€ / user / year	Input from SaT5G project
Power usage: 5G	14 907	kWh / year	Data sheet
Aircraft Network	Quantity	Unit	
Power usage: Servers	298	kWh / year	Data sheet
Power usage: gNB	0,7	kWh / year	Data sheet
5G Satellite network	Quantity	Unit	
Power usage: VSAT	447	kWh / year	Data sheet
Satellite capacity	75 -> 35 between 2020-2025	$ / Mbps / user	Input from SaT5G project
General	Quantity	Unit	
VPN: BT	12 247	€	Input from SaT5G project
Installation % (of CapEx)	15%	/	[51]
Maintenance % (of CapEx)	10%	/	[51]
Overhead % (of TCO)	23%	/	[52]

Three important notes should be made on Table 19. First, the use of the 5G Core Network, including a data centre is CapEx for an MNO but is paid in the yearly fee as OpEx for an airline. Secondly, the number of gNBs is dependent on the number of users. It is assumed to utilize 1 gNB and increase the range via WAPs, as the gNBs are ten times more expensive than the WAPs and because gNBs are not required for locally stored data. The WAPs are connected via an internal network. This has implications for SMS and voice calling but is not further considered in this book. Thirdly, multicasting is not included in the model because it is mainly used for live streaming events to large distributed audiences.

The following flight-focused inputs are considered for the cost model:

Table 20: Flight-focused inputs

Flight	Quantity	Unit	Reference
Number of passengers	175	/	[53]
Fraction of passengers that connect	81%	/	[54]
Fraction of flight duration with effective Internet use	36%	/	[55]
Bit rate per user	2	Mbps	[Assumption]
Caching rate	40%	/	[Assumption]
Number of users per WAP	50	/	[56]
Average number of airplane cycles (every landing or take-off is considered as a cycle) (Boeing 747)	35 000	/	[57]
Average lifetime airplane (Boeing 747)	27	years	[57]

5.1.2.2 Specific inputs

There are also some inputs that only matter in a particular business model and/or pricing method:

Table 21: Specific business models inputs

Specific inputs	**Quantity**	**Unit**	**Business model**	**Reference**
MNO to airline / end user margin	11%	/	(Freemium) retail model	[50]

Airline to end user / sponsorship partner margin	5%	/	(Freemium) wholesale model / Sponsorship model / Complementary service model	[58]
Number of flights per subscriber per month	3	/	(Freemium) retail, (Freemium) wholesale model	[Assumption]
Extra overhead: sponsorship	5%	/	Sponsorship model	[Assumption]
Conversion rate	8%	/	Freemium retail, Freemium wholesale	[59]
Bitrate free user	0,5	Mbps	Freemium retail, Freemium wholesale	[Assumption]
Bitrate paid user	2	Mbps	Freemium retail, Freemium wholesale	[Assumption]

5.1.2.3 *Fixed inputs*

The fixed inputs include electricity prices, exchange rates and conversion numbers such as the number of seconds per hour.

5.1.3 Calculations included in the cost model

Given the real, specific and fixed inputs, some quantities that will be useful for the cost calculation can already be calculated. Calculating the number of required WAPs allows us to calculate the total price for the WAPs. The total gNB cost price is calculated as well. The 5G CN usage cost is classified as CapEx for MNO's and OpEx for airline, because the MNO makes the data centre investment. That clarifies why the formula to convert an annuity into a net present value is used. The installation cost is calculated as a percentage of CapEx.

The number of passengers per year and the satellite capacity cost slope are required to calculate the satellite capacity cost per year. Maintenance costs are calculated as a percentage of CapEx. An overhead cost is added as a percentage of the TCO.

The Total Discounted Cost is calculated by discounting all cash flows to year 0 and adding them up. It is then possible to calculate the Equivalent Annual Cost (EAC) from the Total Discounted Cost.

Table 22 gives an overview of the abbreviations used in the calculations.

Table 22: Nomenclature for the cost calculations

Abbreviation	**Description**	**Abbreviation**	**Description**
Br_u	Bit rate per user [Mbps]	f_o	Overhead % added
Br_{u_f}	Bit rate for free users in freemium models [Mbps]	f_p	Fraction of passengers that connect
B_{ru_fr}	Average bit rate in freemium models [Mbps]	i	Discount rate
C_{CN}	Cost of using the 5G core network per user per year	Lt_a	Average airplane lifetime
C_{CN_C}	5G CN CapEx cost	Lt_p	Project lifetime
C_{ins}	Installation cost	N_c	Average number of cycles per airplane
C_m	Maintenance %	N_{pf}	Number of passengers per flight
C_o	Overhead cost	N_{py}	Number of passengers per year
C_{sy}	Satellite capacity cost per Mbps in year y	N_u	Number of users per WAP
C_{sy_T}	Total cost of satellite capacity in year y	N_{WAP}	Number of WAPs required
C_{WAP}	Price of 1 WAP	r_c	Caching rate
C_{WAP_T}	Total WAP cost	r_{co}	Conversion rate in freemium models

f_d	Fraction of flight duration with effective Internet use	S_{sl}	Satellite capacity cost slope
f_{ins}	Installation %	S_y	Satellite capacity cost in year y
f_m	Maintenance %	y	current year in range from 1 to Lt_p

5.1.3.1 CapEx calculations

The number of WAPs that need to be installed is calculated with the following formula:

$$N_{WAP} = \lceil \frac{N_{pf} * f_p}{N_u} \rceil$$

The total cost of the WAPs is calculated with the following formula:

$$C_{WAP\_T} = N_{WAP} * C_{WAP}$$

The core network cost is a CapEx cost for the MNO, but an OpEx cost for the airline:

$$C_{CN\_C} = C_{CN} * N_u * \frac{\left(1 - \frac{1}{1+i}\right)^{Lt_p}}{i}$$

The installation cost is a fraction of the CapEx:

$$C_{ins} = f_{ins} * CapEx$$

5.1.3.2 OpEx calculations

The number of passengers per year is calculated as follows:

$$N_{py} = \frac{N_c}{LT_a * 2} * N_{pf}$$

The satellite capacity cost slope is required for incorporating the time dependency of the satellite capacity cost:

$$S_{sl} = \frac{S_{2025} - S_{2020}}{Lt_p - 1}$$

The satellite capacity cost per Mbps in year y is calculated with the following formula:

$$C_{sy} = (S_{2025} - S_{Sl}) * y$$

The total satellite capacity cost per year is calculated as follows:

$$C_{sy\_T} = C_{sy} * N_{pf} * f_p * f_d * Br_u * (1 - r_c) * 12$$

The maintenance cost is a fraction of CapEx costs:

$$C_m = f_m * CapEx$$

5.1.3.3 Other calculations

Overhead is added as a percentage on the total cost of ownership:

$$C_o = (1 + f_o) * TCO$$

The total discounted cost is converted into an annual cost with the following formula:

$$EAC = TDC * \frac{i}{1 - (1 + i)^{-Lt_p}}$$

5.1.3.4 Differences per business model in calculations

The current cost model was made from an MNO perspective. When an airline buys the project from an MNO, there are additional considerations that should be made. First of all, the MNO will sell the project with a profit margin. Secondly, there is additional overhead for the airline operator. Last, there are differences in power consumption costs, but these will be ignored because they are not significant in the NPV. For the sponsorship model there is an added overhead cost for the extra relationships with potential sponsorship partners.

Another important factor is the required satellite capacity. In freemium models, the total required capacity is much lower due to the fact that the speed for free users is limited. Therefore the required speed needs to be recalculated. Due to the fact that this bit rate is lower, the operational costs will be smaller.

$$Br_{u\_fr} = r_{co} * Br_u + (1 - r_{co}) * Br_{u\_f}$$

5.1.4 Outcomes of the cost model: the total discounted cost per business model

After putting all the mentioned cost inputs into a discounted cash flow model, the following results are obtained. The results are split into a ‘worst case’, ‘average case’ and ‘best case’ scenario. The average of the boundaries of range inputs was used to come up with an ‘average case’. These uncertainties will be improved in the sensitivity analysis performed in chapter 6. The Total Discounted Cost of the project with a lifetime of five years and a discount rate of 10% is as follows:

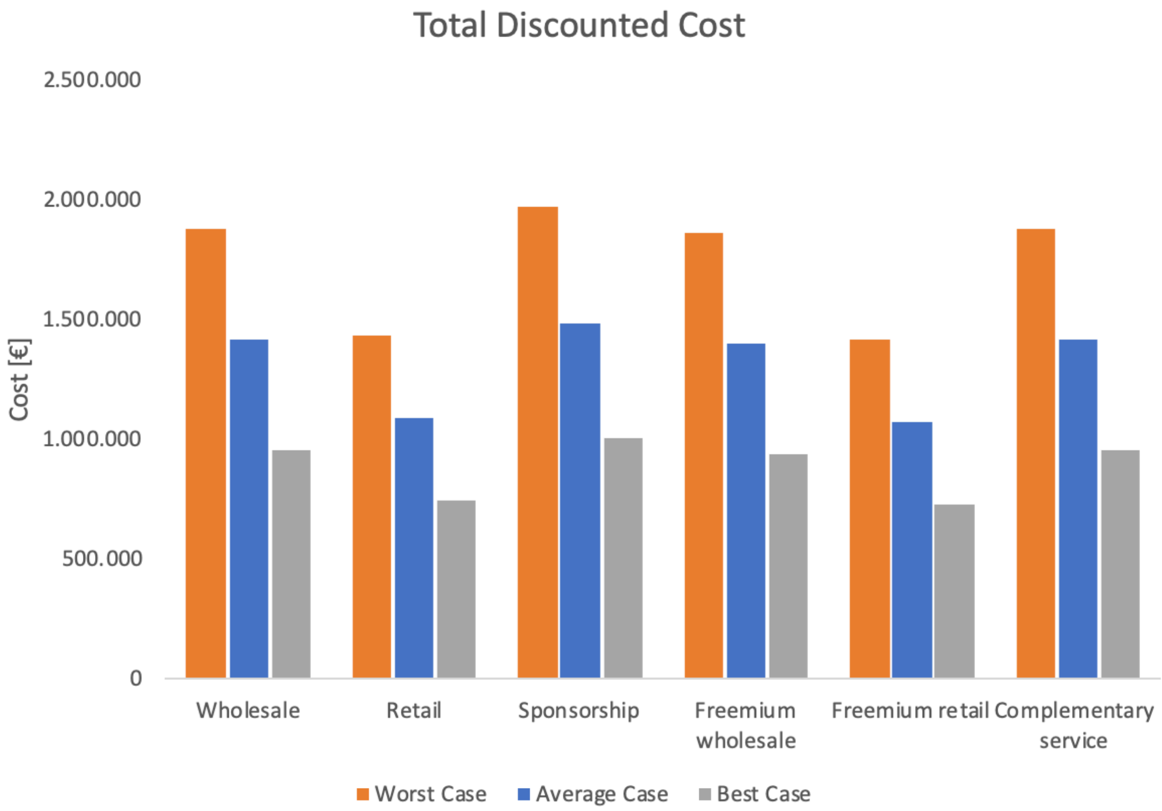

Figure 21: Outcomes for Total Discounted Cost

The TDC in the average case is estimated close to €1.4 million for the (freemium) wholesale, sponsorship and complementary service model. This is expected, as the involved costs are similar, although OpEx is slightly smaller in the freemium models and sponsorship models introduce extra overhead. A big difference can be noted between the already mentioned models and the (freemium) retail model. This is mostly explained by the fact that the channel management is very efficient in these latter models. This means that linking the service provider directly to the end users saves project costs.

One could also examine the costs based on the project timeline. It can be noted in Figure 22 that CapEx are the main drivers of the TCO. The negative CapEx is explained by the fact that there is a compensation for equipment that lasts longer than the project lifetime such as the VSAT. The rest value is then evaluated as a negative cost in year five. OpEx are slightly dropping over time due to a reduced satellite capacity cost.

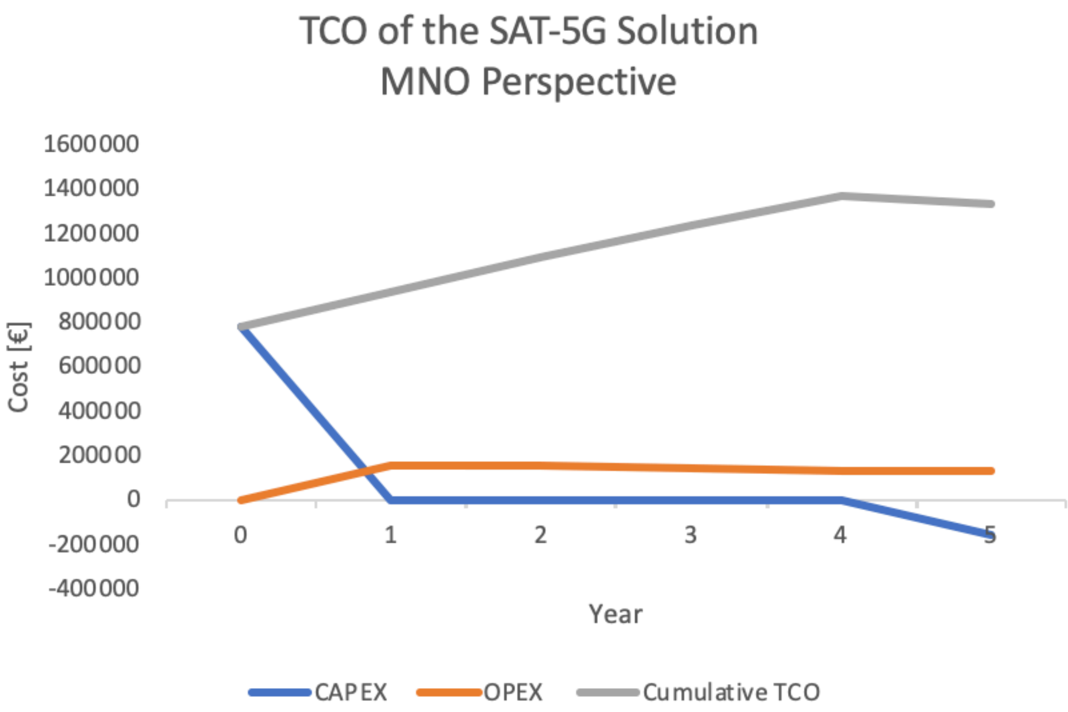

Figure 22: Overview of costs per year

5.2 Building a revenue model to evaluate the prices for end users

The cost model is used as an input for the revenue model. After that, a margin is added that is based on the profit margins of airline or telecom companies. It is important to note that in the techno-economic model of inflight connectivity a positive ROI is not absolutely required, as many advantages are linked to making this investment such as more ticket sales, higher ticket prices, differentiation, branding, marketing, on-board sales and so on. There is an opportunity to offset the costs of the investment, but inflight connectivity will be viewed as a necessary amenity in the future. Nonetheless, it is a very interesting exercise to verify what would be the required pricing and sales to make this project profitable on its own.

5.2.1 Via which pricing model are revenues going to be earned?

Bandwidth can be sold in many different ways. This subsection will elaborate on the possibilities for selling inflight connectivity. Not every revenue model is feasible for every business model. Retail and wholesale models allow data-based pricing, tiered-bandwidth pricing, per-flight pricing, subscription-based pricing and time-based pricing. These terms will all be explained in detail in this subsection. Tiered-bandwidth pricing is the only pricing method that is no longer relevant in the freemium wholesale and retail models, compared to their non-freemium counterparts. These pricing models are not feasible for both the sponsorship and the complementary model, precisely because the service is offered for free to the end user. In the sponsorship model, it is possible to expose revenues in the required average sponsorship deal size per month and in the complementary service model the 'pricing' can be seen as an indirect increase in the ticket price.

Table 23: Feasible pricing models per business model

Business model	Feasible considered pricing models
Wholesale	Data-based, subscription-based, tiered-bandwidth, per-flight, time-based pricing
Retail	Data-based, subscription-based, tiered-bandwidth, per-flight, time-based pricing
Sponsorship	Average sponsorship deal size per month
Freemium wholesale	Subscription-based, per-flight pricing
Freemium retail	Subscription-based, per-flight pricing
Complementary service	Indirect increase in ticket price

Apart from pricing, airlines should also think about creating an intuitive and simple way of earning the revenues. Payment points for inflight connectivity should be made possible throughout the whole passenger journey from purchase with ticket, to online or in-app to airport as well as inflight [43]. Passengers should be able to pay by credit card but more innovative approaches such as one-touch payments from mobile push notifications could convince passengers to pay as they go.

5.2.1.1 Data-based pricing

This pricing model is based on packages that provide a certain number of megabits per flight. This is comparable to data tariffs on the ground, where a user pays for packages of e.g. 100 MB, 500 MB, 1 GB.

5.2.1.2 Tiered-bandwidth pricing

Many end users may be satisfied with the moderate bandwidth available to check their e-mails and pay a visit to social media. However, some business travellers or passengers who enjoy video entertainment have much higher bandwidth needs. Business travellers may want to send large file attachments, connect to a VPN, or perform a video call. These applications require significant bandwidth, but this bandwidth can often not be offered to all end users due to capacity limits. A pricing model that varies on the required bandwidth can meet the need of the different customer segments. Lufthansa offers three different packages, that allow passengers to choose a tier depending on the only activity that they want to perform (streaming, calling, regular browsing). Additionally, passengers are offered a ten-minute, up to 10MB trial service.

5.2.1.3 Subscription-based pricing

Frequent travellers may prefer a subscription pricing method in which they pay a fee every month and always have Internet access when they are flying with the same airline or with an MNO in the retail model, working together with multiple airlines.

5.2.1.4 Per-flight pricing

This is a very user-friendly pricing option in which inflight connectivity is sold for the whole flight and can thus easily be sold together with the flight ticket. One should mention that flat rates are not always the most lucrative for airlines, which is perhaps why few have adopted this model [43]. A trade-off has to be made between triggering impulse buys for e.g. less than €10 per session and selling fewer sessions for higher prices. Examples of airlines following the impulse buy strategy are Icelandair, Southwest and SAS, while Air Berlin and Garuda Indonesia charge more.

5.2.1.5 Time-based pricing

In this pricing model, connectivity can be bought for e.g. 30 minutes, 60 minutes or 2 hours. Air Canada, American Airlines, Air Berlin, Delta and Virgin America offer time-based plans ranging from 30 minutes to multiple hours [43].

5.2.1.6 Hybrid pricing

In reality, the pricing models explained above are often combined. Subscriptions are often combined with the other models to meet frequent traveller needs. Another option is that there is a possibility to buy connectivity for a limited time period, but also for the whole flight.

5.2.2 Revenue modelling approach

It is chosen to assume a cost-based pricing model, which means that the Equivalent Annual Cost of the different business models will be used as input for the revenue models, with a profit margin added to it. This will result in an annual revenue per year incorporating the time value of money of the cost model. An indication of the MB effectively consumed is required to estimate prices for passengers.

The models are created in Excel. One input sheet is required to evaluate the outcomes of the revenue models for the identified business models. Every business model is linked to the pricing models explained in section 5.2.1, if possible. Every pricing model starts from a certain price per MB. Outcomes depend per business model but include the price an end user will pay for the service in the (freemium) wholesale and (freemium) retail model. Other outcomes are for example which conversion rate to premium users is required at a certain price in the freemium models for the project to be economically viable or how much ticket prices are expected to rise if the service is included in the complementary service model. Last, in the sponsorship model, one can calculate which size is required for the average sponsorship deal for the project to be profitable.

5.2.3 Input data and assumptions

The assumptions mentioned in section 5.1, are still used in the revenue models. To calculate the number of MB that is required per business model, additional assumptions and references are needed.

Table 24: Additional revenue inputs

Additional revenue inputs	Quantity	Unit	Reference
Average flight duration	4,6	hours	[60]
Fraction passenger activity: Internet browsing / E-mails	38%	/	[55]
Fraction passenger activity: Social networks	40%	/	[55]
Fraction passenger activity: Video streaming	22%	/	[55]
Bit rate requirement activity: Internet browsing / E-mails	0,1	Mbps	[61]
Bit rate requirement activity: Social networks	1	Mbps	[62]
Bit rate requirement activity: Video streaming	4	Mbps	[61]

5.2.4 Calculations included in the revenue model

To calculate the total number of MB required per year, the bit rate per user is required. This rate is assumed to be 2 Mbps as in the cost model. To verify if this assumption makes sense it is first advised to calculate the average required bandwidth from the inputs above. This is expected to be slightly lower than the capacity assumption that was already made. The reason for that is that a buffer is required to cover peak periods in capacity requirements. This calculation results in an average required bit rate of 1,32 Mbps, which is less than 2. After validating this, the total required data volume per year and per flight can be calculated.

Table 25 gives an overview of the abbreviations used in the calculations.

Table 25: Nomenclature for the revenue calculations

Abbreviation	Description	Abbreviation	Description
Δ_{ti}	Ticket price increase to recover investment indirectly	f_{tbw}	Fraction of paying customers with high requirements
Br_i	Bit rate required for Internet browsing [Mbps]	f_v	Fraction of active users streaming videos
Br_{sn}	Bit rate required for employing social networks [Mbps]	Lt_a	Average airplane lifetime
Br_u	Bit rate per user	m_s	Average profit margin of the seller to end user (airline – MNO)
Br_{u_r}	Required average bit rate per user	N_c	Average number of cycles per airplane
Br_v	Bit rate required for streaming videos [Mbps]	N_f	Flights per subscription per month
D_{c_f}	Data consumed per flight [MB]	N_p	Number of passengers per year
D_{c_y}	Data consumed per year [MB]	N_t	Number of t-hour tickets that have to be sold per month at price p_t
Du_f	Flight duration	p_{co}	Price per flight-ticket to convert from free user to premium user
EAC	Equivalent Annual Cost from the cost model	P_{GB}	Price per GB
f_{co}	Conversion rate from free to premium user	p_i	Per-flight ticket price

f_d	Fraction of flight duration with effective Internet use	P_{MB}	Price per MB [€]
f_f	Required % of passengers buying a per-flight ticket at price p_i	p_s	Subscription price per month
f_i	Fraction of active users browsing the Internet	P_{sp}	Required price of the average sponsorship deal per month
f_p	Fraction of passengers that connect	p_t	Per-time ticket price (e.g. 1 hour)
f_{ptbw}	Required % of paying passengers	p_{tbw}	Weighted average price in tiered-bandwidth pricing
f_s	Required % of passengers subscribing at price p_s	p_{tbw_1}	Price for passengers with high requirements in tiered-bandwidth pricing
f_{sn}	Fraction of active users employing social networks	p_{tbw_2}	Price for passengers with low requirements in tiered-bandwidth pricing

The average required bitrate can be calculated as follows:

$$Br_{u\_r} = f_i * Br_i + f_{sn} * Br_{sn} + f_v * Br_v$$

The amount of data consumed per year is calculated with the following formula:

$$D_{c\_y} = N_p * f_p * f_d * Du_f * Br_u * 3600 \frac{s}{hour} * \frac{1MB}{8Mb}$$

The amount of data consumed per flight is then calculated as follows:

$$D_{c\_f} = \frac{D_{c\_y} * Lt_a * 2}{N_c}$$

The outcome of the last calculation is slightly different for the freemium wholesale and freemium retail model, as free users experience different speeds than premium users in those models. The formula used is the same but the average required Mbps is lower, because it was already assumed that free users only receive 0,5 Mbps, and premium users are expected to use 2 Mbps. With a conversion rate of 8% this leads to a required average bandwidth rate per user of 0,62 Mbps. Implementing this in the formula leads to a factor 3 less required data than in the other models.

To evaluate the revenues per business model, assuming industry average profit margins [63], the price per MB is calculated for every business model as follows:

$$P_{MB} = \frac{EAC * (1 + m_s)}{D_{c\_y}}$$

From this calculation, many outcomes can be produced based on the pricing methods introduced in section 5.2.1 with the following formulas.

The price per GB is calculated as follows:

$$P_{GB} = 1024 * P_{MB}$$

The required fraction of passengers subscribing at price p_s is calculated as:

$$f_s = \frac{P_{MB} * D_{c\_y} * N_f}{N_p * p_S}$$

The required fraction of passengers buying a per-flight ticket at price p_i is calculated as follows:

$$f_f = \frac{P_{MB} * D_{c\_y}}{N_p * p_i}$$

Number of t-hour tickets that have to be sold per month at price p_t is calculated as:

$$N_t = \frac{P_{MB} * D_{c\_y}}{p_t}$$

The weighted average price in tiered-bandwidth pricing is calculated with the following formula:

$$p_{tbw} = p_{tbw\_1} * f_{tbw} + p_{tbw_2} * (1 - f_{tbw})$$

The fraction of paying passenger in tiered-bandwidth pricing is calculated as:

$$f_{ptbw} = \frac{P_{MB} * D_{c\_y}}{p_{tbw}}$$

The required value of the average sponsorship deal per month is calculated with the following formula:

$$p_{sp} = \frac{P_{MB} * D_{c\_y}}{12}$$

Price per flight-ticket to convert from free user to premium user in freemium models with a given conversion rate is calculated as:

$$p_{co} = \frac{P_{MB} * D_{c_y} * 12}{N_p * f_{co}}$$

The increase in the ticket price to incorporate the inflight connectivity service is calculated as:

$$\Delta_{\text{ti}} = \frac{P_{MB} * D_{c_y} * 12}{N_p}$$

5.2.5 Outcomes of revenue models: price per MB per business model and end user connectivity prices

The price per MB can be compared per business model with the given assumptions. The division between ‘best case’, ‘average case’ and ‘worst case’ scenarios is made again. This division can be made for short-haul (flight duration shorter than 3 hours), medium-haul (flight duration between 3 and 6 hours) and long-haul flights (flight duration longer than 6 hours) [64]. All graphs are created on the same scale and can be found in Figure 23, Figure 24 and Figure 25.

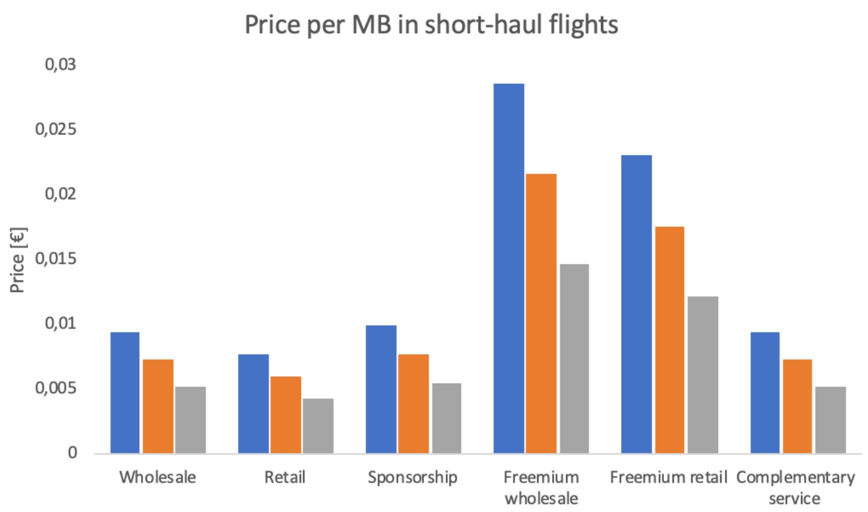

Figure 23: Price per MB in short-haul flights

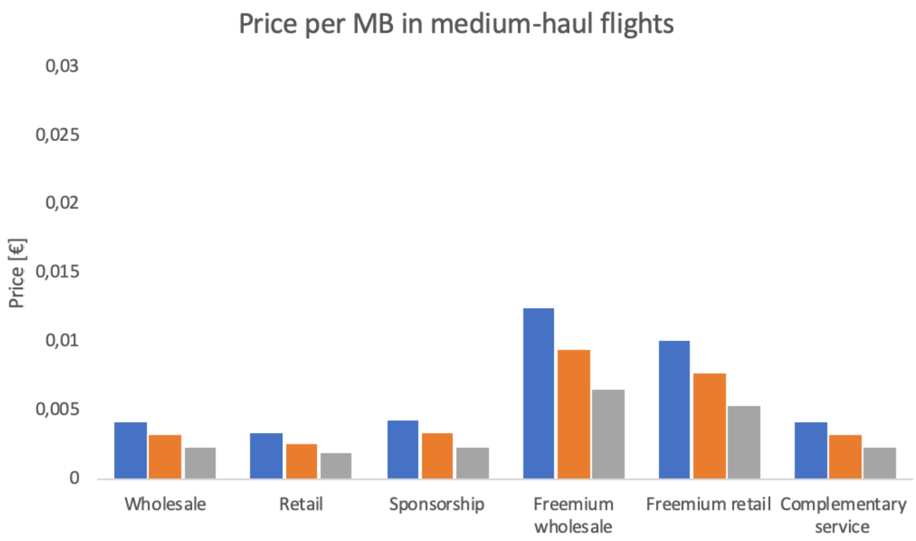

Figure 24: Price per MB in medium-haul flights

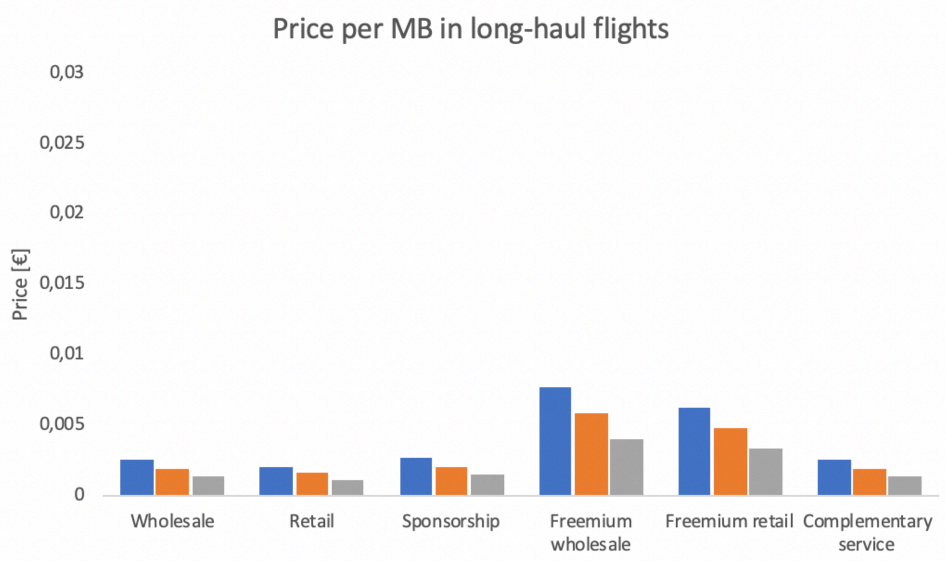

Figure 25: Price per MB in long-haul flights

It becomes immediately clear that the price per MB in long-haul flights is significantly lower. This is explained by the fact that the duration of the flights also impacts the amount of data that is consumed, making long-haul flights profit from economies of scale. This also explains the fact that the inflight connectivity market first took off in the United States [65]. In the United States the average flights are much longer than in Europe, implying that the revenue potential is higher if pricing is equal to short-haul flights. Freemium models are more expensive because a small fraction of the passengers is assumed to pay for the data consumption of the free users.

To convert these results into tangible results, functional for benchmarking and for a feasibility check, Table 26 is prepared for the 'average case', in which the values given are assuming that the industry average profit margin is achieved.

Table 26: Results per business model - pricing model for the 'average case' scenario

PRICING MODEL	DESCRIPTION	VALUE
Wholesale model		
Data-based	1 GB Prepaid	€3,26
Subscription-based	Fraction of passengers subscribing required paying €100 / month	11,5%
Per-flight	Fraction of passengers paying €20 per per-flight ticket required	19,2%
Time-based	Number of 1h flight connections that have to be sold per month at a price of €20	1816
Tiered-bandwidth	Fraction of passengers paying €10 if they have low requirements and paying €50 if they have high requirements	23,0%
Retail model		
Data-based	1 GB Prepaid	€2,69

Subscription-based	Fraction of passengers subscribing required paying €100 / month	9,5%
Per-flight	Fraction of passengers paying €20 per per-flight ticket required	15,9%
Time-based	Number of 1h flight connections that have to be sold per month at a price of €20	1498
Tiered-bandwidth	Fraction of passengers paying €10 if they have low requirements and paying €50 if they have high requirements	19,0%
Sponsorship model		
Sponsorship deal	Required average sponsorship deal size per month	€38 126
Freemium wholesale		
Subscription-based	Price per month for subscriptions to offset costs with given conversion rate	€133,1
Subscription-based	Required conversion rate with subscription prices of €50 / month	21,3%
Per-flight	Price for per-flight ticket to offset costs with a given conversion rate	€44,36
Per-flight	Required conversion rate with per-flight prices of €20 / month	17,7%
Freemium retail		
Subscription-based	Price per month for subscriptions to offset costs with given conversion rate	€108,5
Subscription-based	Required conversion rate with subscription prices of €50 / month	17,4%
Per-flight	Price for per-flight ticket to offset costs with a given conversion rate	€36,15
Per-flight	Required conversion rate with per-flight prices of €20 / month	28,9%

Complementary service model		
Indirect	Ticket price increase for all passengers	€3,84

5.2.6 Benchmarking to current pricing of inflight connectivity

It is interesting to evaluate how the results of our techno-economic analysis compare to current ATG or satellite inflight connectivity and which business models are used in these cases. In order to do this, it is chosen to convert the prices of these existing case examples as a 'price per MB', using the same assumptions and calculations for data consumption as in the techno-economic model. If the business model is known, one can directly compare the current prices to prices with future prices using an integrated satellite-5G network. This helps the reader to evaluate if the business case is economically viable and what the benefits of the proposed network infrastructure for the end user from a quantitative perspective. It is important to note that this comparison is not completely correct, because the technology and thus capabilities are significantly different from the satellite-5G use case. The benchmarking is performed on 10 companies and can be found in Table 27.

Table 27: Benchmarking to current pricing of inflight Wi-Fi

Airline	Provider	Business model(s)	Price	Pricing model(s)	Average price per MB	Reference
Air Lingus	Panasonic Avionics, Aeromobile, Deutsche Telekom	Retail, Complementary service	Economy class: €6,95 / 50 MB €13,95 / 120 MB €29,95 / 270 MB Business class: free	Data-based pricing	€ 0,122	[66]
Air Canada	Gogo	Retail	$49,95 / 1 month $5 / 1 hour $14 / 24 hours	Subscription-based pricing,	€ 0,017	[67]

				time-based pricing		
Air France	Panasonic Avionics	Unclear	€5 / 20 MB €10 / 50 MB €30 / 200 MB	Data-based pricing	€ 0,200	[68]
All Nippon Airways	AeroMobile	Retail	$2 / 10 MB $6 / 50 MB $9 / 90 MB $20 / 200 MB	Data-based pricing	€ 0,116	[69]
British Airways	.air	Wholesale	£8 / 1 hour £18 / 4 hour £24 / flight First hour sponsored by VISA	Time-based pricing, Tiered-bandwidth pricing Sponsorship deal	€ 0,486	[70]
Emirates	OnAir	Freemium wholesale	20 MB free – After: $9,99 / 150 MB $15,99 / 500 MB	Data-based pricing	€ 0,044	[71]
Finnair	Nordic Sky Wi-Fi	Wholesale, Complementary service	Economy class: $6 / 1 hour $18 / flight Business class: free	Time-based pricing, Per-flight pricing	€ 0,020	[72]
Hong Kong Airlines	OnAir	Complementary service	Free	Indirect pricing	Unclear	[40]
Lufthansa	Flynet	Unclear	€9 / 1 hour €14 / 4 hours	Time-based pricing	€ 0,021	[73]

Turkish airlines	TTnet	Unclear	Economy class: $9.99 / 1 hour Business class: free	Time-based pricing	€ 0,033	[74]

It can be noted from Table 27 is that there is currently a large difference in price per MB for inflight connectivity. This can be explained by the fact that the assumptions for a satellite-5G solution were used in the calculations as before. In current cases satellite capacity is much lower, resulting in lower data consumption per time unit, which would increase the 'real' price per MB. It should be mentioned that we assumed the price per MB as fixed, while in reality the price per MB drops for higher volumes. Though it can be noted from comparing these results, the price per MB can be reduced by a factor ranging from 5 (Emirates) to 150 (British Airways). The total end user price will stay similar, but this proves that an integrated satellite-5G network will be able to offer a much higher capacity than current solutions at an affordable price.

6 Sensitivity analysis

In the previous model uncertainties and risks were not considered. Some input data such as network architecture costs, the number of paying customers or the occupancy rate of the airplane remain questionable. A sensitivity analysis makes it possible to discover the boundaries in which the business case is considered safe and to calculate the probabilities of experiencing a positive business case.

6.1 Approach used to include uncertainties in the model

In a global sensitivity analysis, the key or uncertain parameters are varied according to their probability density functions [49]. The input parameters often follow a normal, triangular or uniform distribution. The distribution and the range in which these distributions are defined will be essential influences for the outcome of the analysis. The outcome gives a distribution itself of the possible outcomes. It is also possible to define the key parameters, which are the parameters that leverage the outcome the most.

The Monte Carlo simulation is used to retrieve this outcome. This simulation method randomly creates samples of all the distributions of the inputs in each step and generates the outcomes. It is common to repeat the simulation 10 000 times. The Monte Carlo simulation is executed via the Oracle Crystal Ball extension in Excel [75].

6.2 Defining the input distributions

The inputs for the sensitivity analysis can be found in Table 28. Percentages were always assumed as uniformly distributed and costs as normally distributed. The assumption of the bitrate per user being triangularly distributed between 2 and 5 Mbps is based on [62].

Table 28: Sensitivity analysis inputs

Input	Distribution	Parameters
Discount rate	Uniform	Range: 5% -12%
Media server cost [€]	Normal	μ = 40 000 σ = 3500

VSAT cost [$]	Normal	μ = 350 000 σ = 3500
WAP cost [€]	Normal	μ = 7500 σ = 750
gNB cost	Normal	μ = 75000 σ = 7500
Number of passengers per flight	Normal	μ = 175 σ = 12
Bit rate per user	Triangular	Range: 2 Mbps - 5 Mbps Likeliest = 2 Mbps
Caching rate	Uniform	Range: 20% - 80%
Freemium conversion rate	Uniform	Range: 5% - 15%

6.3 Results of the simulations and sensitivity charts

The sensitivity analysis is run for medium-haul (4,5h) flights. First, the total discounted cost for an MNO is simulated (retail business model). This serves as an example because the uncertainty is very similar in the other identified business models. It can be seen that there is much uncertainty in the outcome. The entire range of outcomes of 10 000 simulations is from €956 000 to €1 918 603. The histogram is shown in Figure 26. The 90% certainty interval of the outcome is indicated in blue.

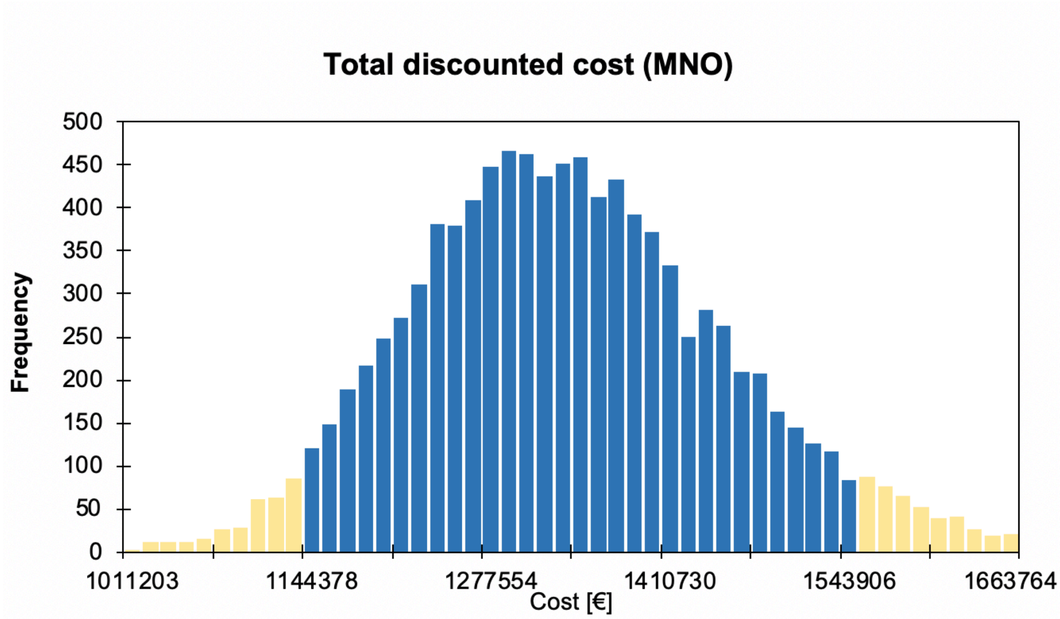

Figure 26: Histogram of 10 000 simulations for the total discounted cost in the retail business model

Next, it is analysed how this variance can be explained. A sensitivity chart indicates what are the key inputs of the sensitivity analysis. The percentages shown on the graph are defined as the percentages of forecast variance due to each assumption. Positive coefficients indicate that an increase in the assumption is associated with an increase in the forecast, while negative coefficients associate an increase in the assumption to a decrease in the forecast. One can conclude from Figure 27 that the uncertainty in VSAT cost, the bitrate per user and the caching rate are the most important factors to explain the variance in cost outcomes in the simulation. If costs should be cut, it is suggested to lower the bitrate per user, while keeping the caching rate at a maximum. It is logical that more passengers imply a higher total discounted cost.

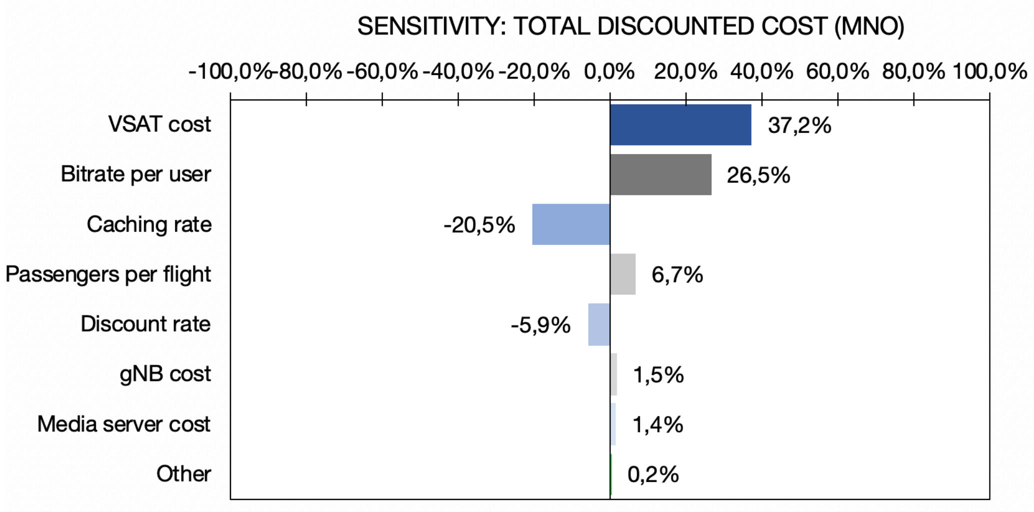

Figure 27: Sensitivity chart for the total discounted cost in the retail business model

Secondly, the price per MB is simulated for a freemium retail model for medium-haul flights. This also serves as an example because the uncertainty is very similar in the other identified business models, except for the freemium conversion rate. The entire range of outcomes of 10 000 simulations is from €0,00495 to €0,01104. The histogram is shown in Figure 28. The 90% certainty interval of the outcome is indicated in blue.

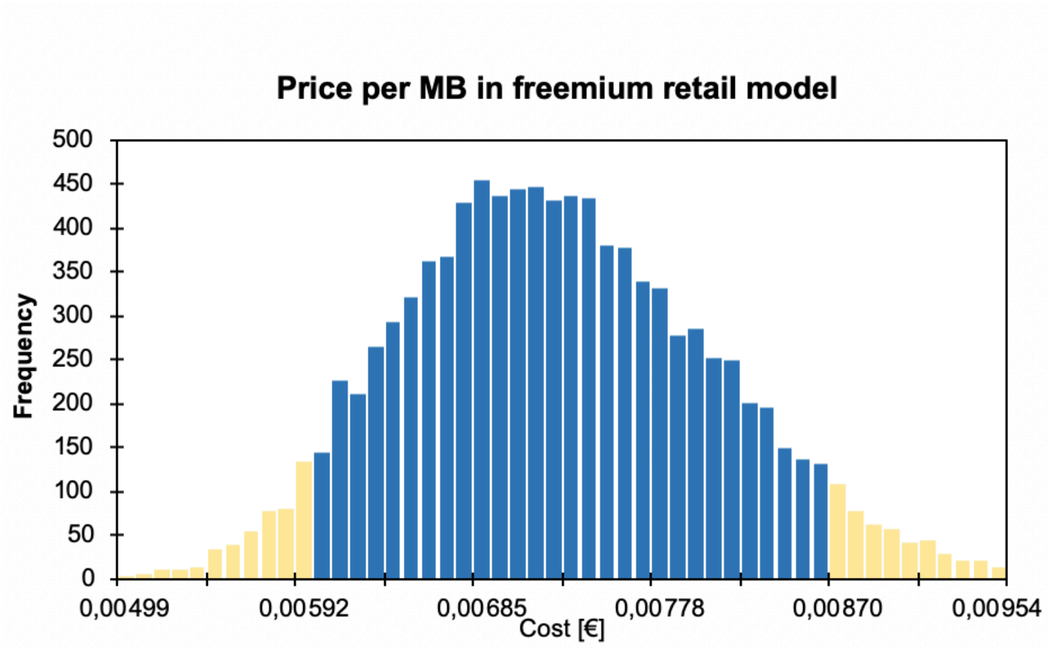

Figure 28: Histogram of 10 000 simulations for the price per MB in the freemium retail business model

The variance in this price per MB can also be explained thanks to a sensitivity chart. From Figure 29, it can be concluded that the key parameters to explain the variance are the conversion rate, the VSAT cost and the passengers per flight. A higher conversion rate implies more users, which then makes it possible to offer lower prices per MB. The VSAT cost is again a large uncertainty in the input model, because it depends on many factors (type of airplane, type of antenna, router etc.). More passengers also mean more premium users, which makes it again possible to offer lower prices per MB.

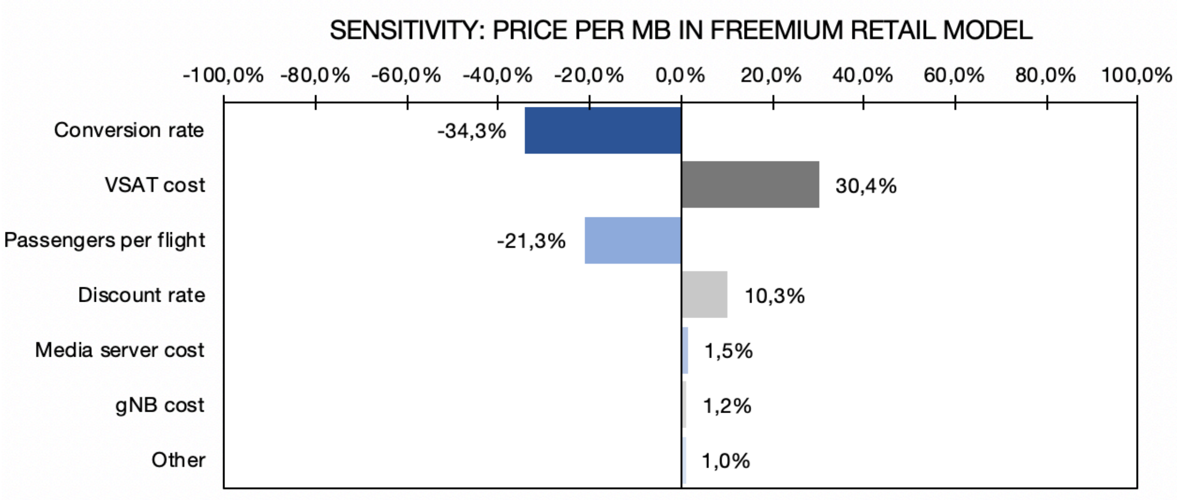

Figure 29: Sensitivity chart for the price per MB in the freemium retail business model

A summary of the 90% certainty intervals of the total discounted cost and the price per MB is found in Figure 30 and Figure 31. One can conclude similarly to section 5.1.4 that freemium retail and retail are the business models that allow the project to be the most cost-effective. The sponsorship model has the highest total discounted cost. End user pricing is similar in all business models except for the freemium models, because there paid users also pay for the free users, although there are important advantages to freemium models as mentioned in chapter 4.

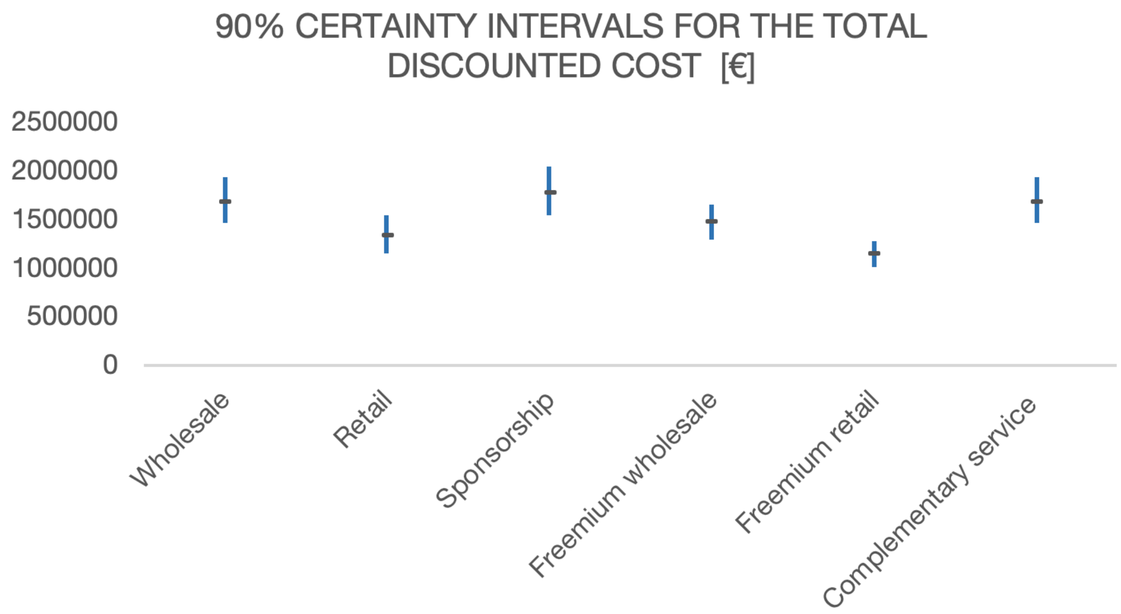

Figure 30: 90% certainty intervals (blue) and median (grey) for the total discounted cost

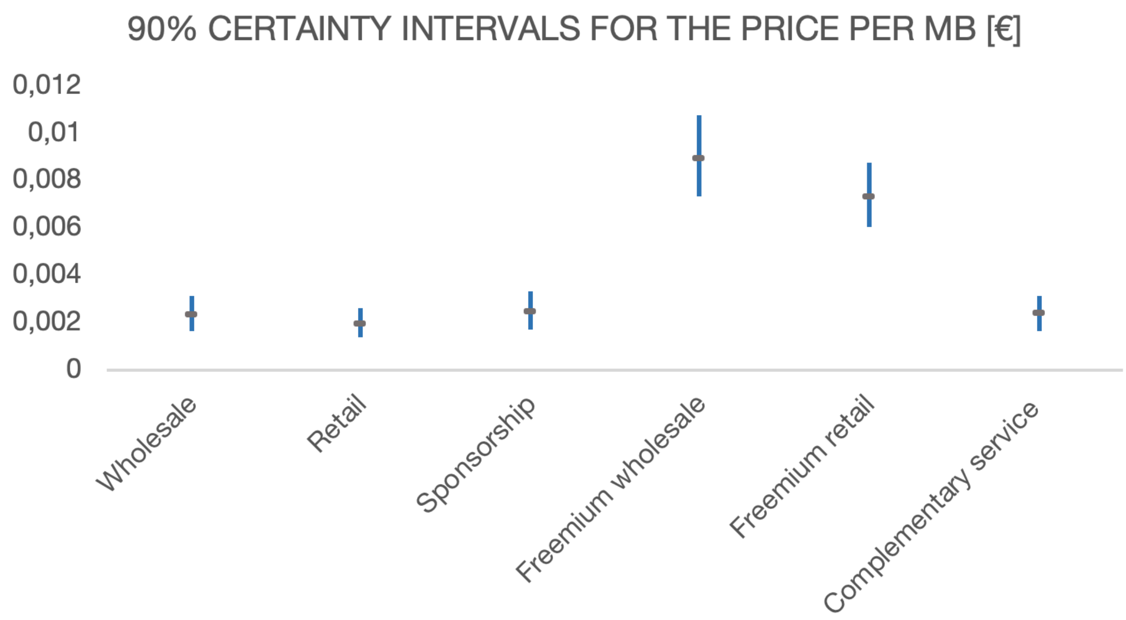

Figure 31: 90% certainty intervals (blue) and median (green) for the price per MB

Last, an evaluation of the project OpEx over its lifetime should be made. In Figure 32 it can be noted that the OpEx clearly decrease over time, but also the uncertainty intervals become smaller.

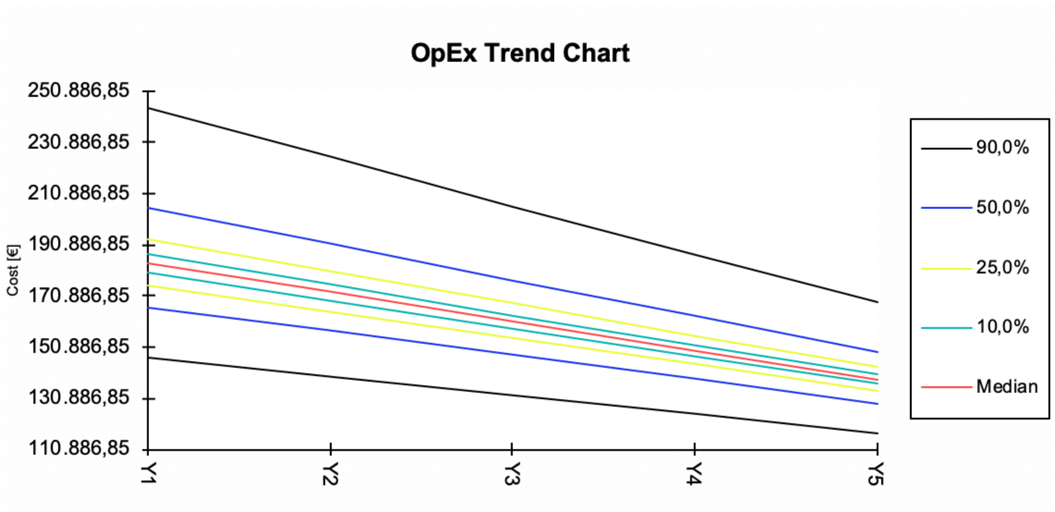

Figure 32: OpEx trend chart including respectively 90%, 50%, 25% and 10% certainty intervals

7 Conclusion and perspectives

The integration of satellite into 5G networks allows the identification of several new use cases. One of these use cases is providing inflight connectivity to passengers via an integrated satellite-5G network. Though technically possible, it was unclear which business models are sustainable and if implementing this technology is economically viable in these business models. Hence this thesis closes the gap between the technically possible proposed solution and the economic viability of providing inflight connectivity via an integrated 5G-satellite solution.

The use case of providing onboard Internet access via satellite-5G can be summarized as providing backhaul connectivity to airplanes with the ability to cache content and provide efficient broadband access. To offer the service, each aircraft is equipped with a satellite terminal and is connected via satellite to a central facility that controls the satellite network. This central facility then makes interconnections with the Internet, similar to enterprise networks. This scenario proposes bi-directional broadband access for each passenger for private use which is transparent to the moving platform. Relevant stakeholders and their interactions in the value network were identified, but it was decided to focus on the main stakeholders: the mobile network operator, end user and airline.

Different types of business models are explained and analysed via a combination of a customized value network intelligence framework and the business model canvas. From applying the framework, an overview was created summarizing the advantages and disadvantages per identified business model, allowing decision-makers in airlines to adopt the business model that fits their strategy the most. These airlines typically have different preferences for implementing the service in terms of use of technology, channel management, QoS, structural dependency, branding and risk averseness. The following business models were analysed:

- Wholesale model with connectivity for paying users
- Retail model with connectivity for paying users
- Sponsorship model with free connectivity for all passengers
- Freemium wholesale model
- Freemium retail model

- Complementary service model with free connectivity for all passengers

It was concluded that in scenarios where the airline operator wants full control over pricing, the wholesale model is suggested. The retail model is beneficial for airline companies who are more risk-averse and do not want to drift away from their core business. The customer will also benefit from the retail model, as the value chain is shorter and the quality is assured. The sponsorship model is suggested when the need for or interest of the company in marketing is rather low. This could be because tickets already sell out fast or a low-cost structure is the main marketing strategy. The freemium wholesale and retail model should certainly be considered because they bear many branding opportunities, and customers are often attracted by free services. Combining this with a qualitative service and the option to generate extra connectivity-dependent revenues, make up a very viable business model. Key to making the freemium business model work is having a conversion rate from free to premium that is sufficiently high. The complementary service model will be preferred by premium airline companies, as no revenues will be generated by the service directly. Customers from these companies prefer to pay for the full premium service, in which connectivity is already included.

A techno-economic model was developed for this use case, including not only detailed cost models for each identified business model, but also revenue models. These models made it possible to draw a conclusion about the economic viability of the use case for the main stakeholders. After putting all generic, fixed and specific inputs into a discounted cash flow model, the following results were obtained for a project lifetime of 5 years and a discount rate of 10%. The results are split into a 'worst case', 'average case' and 'best case' scenario. The average of the boundaries of range inputs was used to come up with an 'average case'. The Total Discounted Cost (TDC) in the 'average' case, which means using the averages of ranges from the input data is estimated close to € 1.4 million per aircraft for a (freemium) wholesale, sponsorship and complementary service model. The similarity between these models is explained by the fact that the involved costs are similar. OpEx are slightly smaller in the freemium models due to the lower bandwidth requirement for the free users and the TDC in a sponsorship model is higher due to extra overhead from the extra stakeholder in the value network. A big difference can be noted between the already mentioned models and the (freemium) retail model. This is mostly explained by the fact that channel management is very efficient in these latter models. This means that linking the service provider directly to the end users saves project costs. It could also be concluded that CapEx are the main drivers of the TCO.

A cost-based pricing model was assumed, which means that the Equivalent Annual Cost of the different business models will be used as input for the revenue models, with a profit margin added to it. This results in an annual revenue per year incorporating the time value of money of the cost model. An indication of the MB that are effectively consumed was required to estimate prices for passengers. The price per MB was then finally converted in a per-hour price, per-flight price, etc. depending on the pricing models that were feasible for the chosen business model. Benchmarking to current pricing indicated that prices per MB will drop with a factor ranging from 5 to 150, which indicates that the higher capacities that come with integrating satellite into 5G networks will be affordable for end users. It became clear that the price per MB in long-haul flights is significantly lower, compared to short-haul flights. This is explained by the fact that the duration of the flights also impacts the amount of data that is consumed per flight, making long-haul flights profit from economies of scale. Freemium models are more expensive because a small fraction of the passengers has to pay for the data consumption of the free users.

Simulations were performed to analyse the robustness of the models. Uncertainty in VSAT cost, the bitrate per user and the caching rate are the most important factors to explain the variance in cost outcomes in the total discounted cost. If costs should be cut, it is suggested to lower the bitrate per user, while keeping the caching rate at a maximum. More passengers imply a higher total discounted cost, because they consume more data in total. The key parameters that explain the variance in the estimated price per MB are the conversion rate (only applies to freemium models), the VSAT cost and the passengers per flight. A higher conversion rate implies more users, which then makes it possible to offer lower prices per MB. The VSAT cost is again a large uncertainty in the input model, because it depends on many factors (type of airplane, type of antenna, router etc.). More passengers also mean more premium users, which makes it possible to offer lower prices per MB.

A final conclusion is that in order to select a business model, the feasible models should all be aligned to the airline's strategy and preferences. End user prices will certainly be affordable in every business model if there is a sufficiently large fraction of customers willing to pay, also when data volumes rise in the future.

Future work on this research topic is the impact of network slicing, NFV and SDN on inflight connectivity technologies and business models, as these were introduced but not quantified exactly in this thesis. Another impact that should be analysed more closely, is the impact of competition on the proposed business models. The airline industry has a very competitive landscape. This implies that if competitors provide free high-quality Wi-Fi on-board, there is a possible threat that the data volumes sold drop significantly, or that fewer tickets are sold in total. It is not clear what will happen to the feasibility of the identified business models, if a fraction of the competitors adopts a complementary service model.

In this book, assumptions were made on the number of passengers, average lifetime of an aircraft, number of 5G cells required, number of media servers required, VSAT cost etc. These are parameters that solely depend on the aircraft that is used. An interesting next step would be to repeat the analysis for multiple aircrafts. This will certainly lower the variance of the outcomes in the simulations. Linked to that more details could be added to the model, e.g. the influence of multicasting or quantifying installation, maintenance and overhead costs instead of using percentages of CapEx and TCO.

A last and interesting exercise would be to quantify the opportunity of indirect revenue creation by providing inflight connectivity such as holiday sales, promotions, food or drink order and taxi services, as this was not included in this revenue model proposed by the author. To summarize, the assumptions made in the thesis book can be revisited to expand the model and thus to have a more complete overview of the revenue potential of the use case.

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