

*Marja Matinmikko-Blue*

# STAKEHOLDER ANALYSIS FOR THE DEVELOPMENT OF SHARING-BASED SPECTRUM GOVERNANCE MODELS FOR MOBILE COMMUNICATIONS

UNIVERSITY OF OULU GRADUATE SCHOOL;  
UNIVERSITY OF OULU,  
FACULTY OF TECHNOLOGY





ACTA UNIVERSITATIS OULUENSIS  
C Technica 678

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**STAKEHOLDER ANALYSIS FOR THE  
DEVELOPMENT OF SHARING-BASED  
SPECTRUM GOVERNANCE MODELS  
FOR MOBILE COMMUNICATIONS**

Academic dissertation to be presented, with the assent of the Doctoral Training Committee of Technology and Natural Sciences of the University of Oulu, for public defence in the Wetteri auditorium (IT115), Linnanmaa, on 12 October 2018, at 12 noon

UNIVERSITY OF OULU, OULU 2018

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Acta Univ. Oul. C 678, 2018

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ISBN 978-952-62-2050-5 (Paperback)  
ISBN 978-952-62-2051-2 (PDF)

ISSN 0355-3213 (Printed)  
ISSN 1796-2226 (Online)

Cover Design  
Raimo Ahonen

JUVENES PRINT  
TAMPERE 2018

# **Matinmikko-Blue, Marja, Stakeholder analysis for the development of sharing-based spectrum governance models for mobile communications.**

University of Oulu Graduate School; University of Oulu, Faculty of Technology

*Acta Univ. Oul. C 678, 2018*

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## ***Abstract***

Radio spectrum is a scarce natural resource whose efficient management has been the source of contentious debate for over a century. The mobile communication ecosystem has created a tremendous business that is reliant on the availability of spectrum for wireless networks. The growth of mobile communications has increased the rivalry between the different wireless ecosystems that compete over gaining access rights to radio spectrum. Due to the scarcity of unallocated spectrum bands without incumbent users, sharing-based governance models for spectrum management have gained increasing attention in regulation, industry and academia. Spectrum sharing allows two or more wireless systems to operate in the same spectrum band. These systems often come from different wireless ecosystems that have conflicting goals. Spectrum sharing, and specifically the development of new sharing-based governance models for more efficient management of the scarce resource, is a strategic management topic that calls for the development of rules and conditions by regulators that are agreeable to all involved stakeholders.

This thesis presents a novel framework for the development of upcoming sharing-based spectrum governance models that bring together stakeholders from different wireless business ecosystems with conflicting goals. The framework is built upon the theoretical basis of governance models, stakeholder analysis, and business ecosystems. Spectrum management is here seen as governance of common pool resources, and the tool of stakeholder analysis from strategic management is formally introduced into the development of new sharing-based spectrum governance models where different business ecosystems collide. The developed three-step stakeholder analysis is applied to two case studies for mobile communications including the future use of the ultra-high frequency (UHF) band, and the licensed shared access (LSA) concept. For the UHF band case study, the thesis identifies the stakeholders, analyses their relations and saliences to reach long-term compromises between broadcasting and mobile communication ecosystems. For the LSA case study, the thesis identifies the stakeholders and their relations, and develops management actions through a work flow for the main phases and stakeholders' tasks. It then presents the world's first live field trial with mobile communication systems, where the conflicting requirements of all stakeholders were considered. The developed stakeholder analysis model formally introduces the strategic management of stakeholders into the spectrum management domain, and it provides regulators, industry and academia a new tool for reaching long-term compromises in spectrum management through sharing.

***Keywords:*** business ecosystem, governance, mobile communications, regulation, spectrum sharing, stakeholder analysis, strategic management



# **Matinmikko-Blue, Marja, Sidosryhmäanalyysi taajuuksien yhteiskäyttömenetelmien kehittämiseen matkaviestinjärjestelmille.**

Oulun yliopiston tutkijakoulu; Oulun yliopisto, Teknillinen tiedekunta

*Acta Univ. Oul. C 678, 2018*

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## ***Tiivistelmä***

Radiotaajuudet muodostavat rajallisen luonnonvaran, jonka tehokas hallinta on ollut vuosikymmenten ajan kiistanalainen keskustelunaihe. Matkaviestinnän ekosysteemi on luonut suurta liiketoimintaa saamalla käyttöönsä radiotaajuuksia, joilla matkaviestinverkot voivat toimia. Matkaviestinnän kasvu on lisännyt eri langattomien järjestelmien ekosysteemien välistä kilpailua radiotaajuuksien saatavuudesta. Taajuuksien yhteiskäyttöön perustuvat hallintamallit ovat herättäneet kasvavaa kiinnostusta taajuushallinnoissa, teollisuudessa ja tutkimusmaailmassa, koska lähes kaikki radiotaajuudet on jo annettu erilaisten langattomien järjestelmien käyttöön. Taajuuksien yhteiskäyttö mahdollistaa kahden tai useamman radiojärjestelmän toiminnan samalla taajuusalueella. Usein nämä järjestelmät edustavat erilaisia langattomia ekosysteemejä, joilla on ristiriitaiset tavoitteet. Taajuuksien yhteiskäyttö ja siihen liittyvien hallintamallien kehittäminen rajallisen luonnonvaran tehokkaamman käytön mahdollistamiseksi on strategisen johtamisen aihealue, joka edellyttää, että taajuushallinnot kehittävät säännöt ja ehdot, jotka ovat hyväksyttävissä sidosryhmille.

Tämä väitöskirja esittelee uuden viitekehityksen taajuuksien yhteiskäyttöön perustuvien taajuuksien hallintamallien kehittämiseksi tuomalla yhteen eri sidosryhmät, jotka edustavat erilaisia langattomia liiketoimintaekosysteemejä, joilla on ristiriitaiset tavoitteet. Kehitetyn viitekehityksen teoriapohja koostuu hallintomalleista, sidosryhmäanalyysistä sekä liiketoiminnan ekosysteemeistä. Tässä työssä taajuuksien hallinta nähdään yhteisresurssien (common pool resource, CPR) hallintana, ja strategisen johtamisen työkaluista sidosryhmäanalyysi on valittu taajuuksien yhteiskäyttömallien kehittämiseen erilaisten liiketoiminta-ekosysteemien kohtauspisteessä. Työssä kehitettyä kolmiaskelistaa sidosryhmäanalyysiä sovelletaan kahteen matkaviestinnän tapaustutkimukseen sisältäen UHF-taajuuden tulevaisuuden käytön sekä taajuuksien lisensoidun yhteiskäytön (licensed shared access, LSA). UHF-taajuuden tapaustutkimuksessa väitöskirjassa tunnistetaan sidosryhmät ja analysoidaan niiden riippuvuuksia ja painoarvoja pitkän tähtäimen kompromissin löytämiseksi yleisradioliikenteen ja matkaviestinnän ekosysteemien välille. LSA-tapaustutkimukselle väitöskirjassa tunnistetaan sidosryhmät ja niiden riippuvuudet sekä kehitetään johtamismalleja työnkulkukaavion avulla. Lisäksi työssä esitellään maailman ensimmäinen todellisella matkaviestinjärjestelmällä tehty kokeilu, joka ottaa huomioon eri sidosryhmien ristiriitaiset vaatimukset. Työssä kehitetty malli on ensimmäinen strategisen johtamisen sidosryhmäanalyysin sovellus taajuuksien hallintaan ja tuo taajuushallinnoille, teollisuudelle ja tutkimusmaailmalle uuden työkalun pitkän tähtäimen kompromissien löytämiseen taajuuksien hallinnalle yhteiskäytön avulla.

*Asiasanat:* hallintamalli, liiketoiminnan ekosysteemi, matkaviestintä, regulaatio, sidosryhmäanalyysi, strateginen johtaminen, taajuuksien yhteiskäyttö





## Preface

While finalizing my first doctoral dissertation in telecommunications engineering on cognitive radio techniques in 2012, I felt that the story was just beginning. To understand the complexity of spectrum management, and particularly spectrum sharing, I urgently needed tools beyond the technical ones that were available. Prof. Harri Haapasalo, the supervisor of this thesis from University of Oulu, encouraged me to pursue a PhD degree in industrial engineering and management, and introduced the concept of stakeholder analysis into my research. It was a game changer, an unexplored area that provided the theoretical basis from management sciences that could articulate what I knew was happening in real world. I am truly grateful for the guidance he has given me, not just the continuous support during my PhD thesis research, but all the way back to my master's studies two decades ago. Another fundamental influencer was COST Action IC0905 TERRA on technoeconomic and regulatory framework for cognitive radio in 2010-2014. That activity brought together researchers with versatile educational backgrounds. Those interactions broadened my research scope and made it truly interdisciplinary. I am grateful to especially Dr. Peter Anker, Dr. Vania Gonçalves, Dr. Oliver Holland, Dr. Arturas Medeisis, Prof. Leo Fulvio Minervini, and Prof. Fernando Velez.

I would like to thank the pre-examiners of this thesis, Professor Erik Bohlin from Chalmers University of Technology, and Professor Martin B.H. Weiss from University of Pittsburgh for their highly encouraging comments. I would also like to thank my opponents, Professor Erik Bohlin and Associate Professor Jan Markendahl from KTH Royal Institute of Technology. My UniOGS follow-up group including Assist. Prof. Kirsi Aaltonen and Dr. Hanna Kropsu-Vehkaperä, deserves a sincere thank you.

The data collection for the case studies of the thesis was done in CORE+ (Cognitive Radio Trial Environment), CORE++, and FUHF (The Future Use of UHF) projects in 2013-2015 funded by Business Finland (formerly Tekes) while I was working at VTT Technical Research Centre of Finland, Ltd. The writing of the thesis was done at Centre of Wireless Communications (CWC), University of Oulu, in 2016-2018 where the work was supported in part by the Academy of Finland 6Genesis Flagship (grant no. 318927). The CORE project continuum that I coordinated was a unique combination of business, regulation, technical, and trialling activities that developed the new Licensed Shared Access (LSA) spectrum sharing concept in close collaboration with industry, regulation and research. It led to world's first live trials of the concept, contributions to regulation and

standardization, and a number of pioneering scientific publications. Some of those publications are reported in this thesis and have already been cited more than 200 times. I am deeply grateful to my collaborators from different organizations for bringing their know-how together and creating such an enjoyable and productive working atmosphere. In particular, I want to express my deepest gratitude to Dr. Miia Mustonen, Mr. Marko Palola, Mr. Teemu Rautio, Dr. Seppo Yrjölä, Dr. Petri Ahokangas, Mrs. Marjo Heikkilä and Mrs. Hanna Okkonen, who formed the core project team for this thesis research. I would also like to thank all other co-authors and colleagues who contributed to the research over the years. Financial support from Taunö Tönning Foundation is also acknowledged.

During the thesis research, I took a position at the University of Oulu, my daughter Milla has continued to grow into a lovely young woman and I met my missing half, Scott, who widened my personal and professional perspectives beyond my own little bubble and married me. The time with you at home or traveling is the best thing in life. Finally, my friends and family deserve a special thanks for the continuous support and for not letting me give up on the goal of completing the thesis before turning 40; a bet that was made at my first doctoral thesis defence.

31.08.2018

Marja Matinmikko-Blue

## Abbreviations

2G	Second Generation
3G	Third Generation
3GPP	3 <sup>rd</sup> Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
BC	Broadcast
B2B	Business to Business
B2C	Business to Consumer
BNO	Broadcast Network Operator
CBRS	Citizens Broadband Radio Service
CEPT	Conference of European Postal and Telecommunication Administrations
CPR	Common-Pool Resource
CRS	Cognitive Radio System
CUS	Collective Use of Spectrum
EC	European Commission
ECC	European Communications Committee
eMBMS	Evolved Multimedia Broadcast Multicast Service
ETNO	European Telecommunications Network Operators' Association
ETSI	European Telecommunications Standards Institute
GSM	Global System for Mobile Communications
GSMA	GSM Association
HD	High Definition
ISM	Industrial, Scientific and Medical
ITU-R	International Telecommunication Union Radiocommunication Sector
LSA	Licensed Shared Access
LTE	Long-Term Evolution
MNO	Mobile Network Operator
NRA	National Regulatory Authority
OAM	Operations and Maintenance
OTT	Over the Top
QoE	Quality of Experience
QoS	Quality of Service
SD	Standard Definition

SDL	Supplemental Downlink
UHF	Ultra-High Frequency
WLAN	Wireless Local Area Network
WRC	World Radiocommunication Conference

## List of original publications

This thesis is based on the following publications, which are referred throughout the text by their Roman numerals:

- I Matinmikko, M., Mustonen, M., Roberson, D., Paavola, J., Höyhty, M., Yrjölä, S. & Rönning, J. (2014). Overview and comparison of recent spectrum sharing approaches in regulation and research: From opportunistic unlicensed access towards licensed shared access. *Proceedings of IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN)*, 92-102.
- II Matinmikko, M., & Mustonen, M. (in press). Spectrum sharing policy at global level. In W. Zhang (Ed.), *Handbook of cognitive radio*. Singapore: Springer. 21 p.
- III Matinmikko, M., Mustonen, M., & Haapasalo, H. (2017). Stakeholder analysis for future use of the ultra-high frequency (UHF) band. *International Journal of Technology, Policy and Management*, 17, 159-183.
- IV Matinmikko, M., Okkonen, H., Palola, M., Yrjölä, S., Ahokangas, P., & Mustonen, M. (2014). Spectrum sharing using Licensed Shared Access: The concept and its workflow for LTE-Advanced networks. *IEEE Wireless Communications*, 21, 72-79.
- V Matinmikko, M., Okkonen, H., Yrjölä, S., Ahokangas, P., Mustonen, M., Palola, M., Gonçalves, V., Kivimäki, A., Luttinen, E., & Kemppainen, J. (2015). Business benefits of Licensed Shared Access (LSA) for key stakeholders. In O. Holland, H. Bogucka, & A. Medeisis (Eds.), *Opportunistic spectrum sharing and white space access: The practical reality* (pp. 407-424). New Jersey: John Wiley & Sons.
- VI Matinmikko, M., Palola, M., Saarnisaari, H., Heikkilä, M., Prokkola, J., Kippola, T., Hänninen, T., Jokinen, M. & Yrjölä, S. (2013). Cognitive radio trial environment: First live authorized shared access-based spectrum-sharing demonstration. *IEEE Vehicular Technology Magazine*, 8, 30-37.

The author has had the main responsibility in being the primary author of all the publications. She has formulated the research problems and planned the contents of all publications. Co-authors have provided valuable inputs and comments to all papers. In Paper VI the role of co-authors was significant including the development of the trial environments and conducting and reporting all trials and measurements.



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# 1 Introduction

## 1.1 Background and research environment

Future competitiveness of both public services and private enterprises is increasingly seen to require cost-effective access to high capacity wireless networks to create new applications and business models for production, distribution, and selling of products and services (EC 2016). High-speed mobile broadband access to the Internet ranks high on the political agendas around the world and significant attempts are made to allow affordable mobile broadband access for all (EC 2016). All wireless systems rely on the availability of the radio spectrum whose efficient management is a key societal priority. The demand for spectrum as the basic natural resource continues to change over time, which is increasing the conflict between the different wireless business ecosystems that compete over spectrum access, such as mobile communications, broadcasting, satellite, and various governmental usages (Hazlett 2008; Keiser 1977; Levin 1966; Melody 1980; Soroos 1982).

Spectrum management is about coordinating the use of the scarce radio spectrum resources between the different wireless systems, which is a complicated problem of governance of public goods (Anker 2017; Weiss et al., 2015; Bazelon & McHenry 2013). A national regulatory authority (NRA) typically has the power to decide on the spectrum governance models that define which stakeholders are allowed to operate wireless systems under which rules and conditions, thus effectively shaping the business ecosystem around the wireless services in a country. The traditional governance models for the NRA to give spectrum access rights have been based on individual access rights (exclusive licensing) or general authorization (license-exempt operations) (CEPT 2009; Anker 2017). For decades, spectrum decisions have acquired significant political and economic significance (Melody 1980). Spectrum management decisions traditionally require long time spans between the identification of a band for new usage and when it becomes available requiring actions at various governance levels (Soroos 1982; Anker 2017; Faulhaber 2006). The development of efficient spectrum governance models to meet the changing spectrum demands of the various wireless systems is therefore an important goal in order to reach long-term balance between the conflicting needs of the stakeholders.

Cellular mobile communication networks, such as 2G, 3G, and 4G, are typically deployed by a small number of mobile network operators (MNOs) on the basis of individual access rights via wide-area long-term exclusive spectrum licenses acquired through auctions (Cramton 2013; Olla & Patel 2002; Feasey 2015). This guarantees operational certainty and high quality as the mobile communication networks are protected from harmful interference from other wireless systems. The traditional spectrum governance model for cellular mobile communication has ultimately restricted the number of potential stakeholders to operate the cellular networks due to the limited availability of spectrum licenses and high license costs (Feasey 2015; Peitz & Valletti 2015; Sabat 2002). License-exempt bands on the other hand have allowed the deployment of various short-range devices on a shared spectrum access basis where the most notable example is wireless local area networks (WLAN). License-exempt spectrum bands have been a significant arena for scientific and business innovations due to their openness for any stakeholder to develop and deploy the new wireless systems in accordance with the rules defined by the NRAs for operations (Holland et al. 2012). This sharing-based approach has proven its success by carrying the majority of indoor mobile traffic today.

Due to the challenges of clearing spectrum bands from incumbent usage, sharing-based spectrum governance models have become increasingly appealing for NRAs to allow new entrants to use otherwise underutilized spectrum bands in a timely manner (Anker 2017; Beltran 2017). This had led to the development of mechanisms for spectrum sharing where two or more wireless systems could operate in the same spectrum band (ITU-R 2014; RSPG 2011; RSPG 2013). However, despite extensive research on the techniques for spectrum sharing in the research literature (Akyildiz, et al. 2008, Chapin & Lehr 2007; Holland et al. 2012; Matinmikko 2012; Minervini 2012), the real world deployment of sharing-based spectrum management models beyond license-exempt bands has remained limited to date (Mustonen et al. 2017).

Spectrum governance models for future fifth generation (5G) mobile communication networks are increasingly seen to be based on spectrum sharing (RSPG 2018; EC 2016; EC 2017). To find new spectrum for 5G networks, there is a need to protect the incumbents in the bands from harmful interference from the entrant 5G networks. This presents a complex setup where the NRA needs to define feasible rules and conditions for sharing-based operations between stakeholders with conflicting goals. These stakeholders represent different business ecosystems, the incumbents currently using the spectrum band, existing services wishing to expand into a new band for growth, and totally new services that could form around

spectrum sharing. Spectrum management becomes a strategic management problem where the different stakeholders have conflicting views on the long-term spectrum use of specific frequency bands. The NRA is in the central position to develop spectrum governance models to maintain the full potential of the spectrum resources. This calls for management actions that identify the key stakeholders and their requirements, and reach long-term compromises between the stakeholders for ensuring efficient use of the scarce natural resource.

## 1.2 Objectives and scope

Motivated by the challenges of the long time-cycles in spectrum management decisions, growing mobile data demand, emergence of new spectrum sharing concepts and the conflicting views of different stakeholders on future spectrum use, the overall objective of this research is *to develop sharing-based spectrum governance models for mobile communications*. To narrow the focus, the specific objectives of this research are to answer the following questions and sub-questions:

1. How is the radio spectrum managed?
  - A) What are the existing spectrum governance models?
  - B) What are the upcoming sharing-based spectrum governance models?
2. How to develop sharing-based spectrum governance models?
  - A) How to take into account different stakeholder views?
  - B) What management actions need to be taken?

Research question 1) is answered by Papers I and II that review the existing spectrum regulatory framework including the different forums, currently used spectrum governance models and latest sharing-based governance model developments for mobile communications.

Research question 2) is answered by Papers III, IV, V, and VI by introducing stakeholder analysis into spectrum management and particularly for mobile communications in order to understand the relevant stakeholders' requirements for the development of spectrum governance models using two case studies. Paper III formally introduces stakeholder analysis into wireless communications domain by using it for the future use of the ultra-high frequency (UHF) band (Case 1). Papers IV, V, and VI apply selected parts of stakeholder analysis into the development of the new Licensed Shared Access (Case 2) concept. To further respond to research

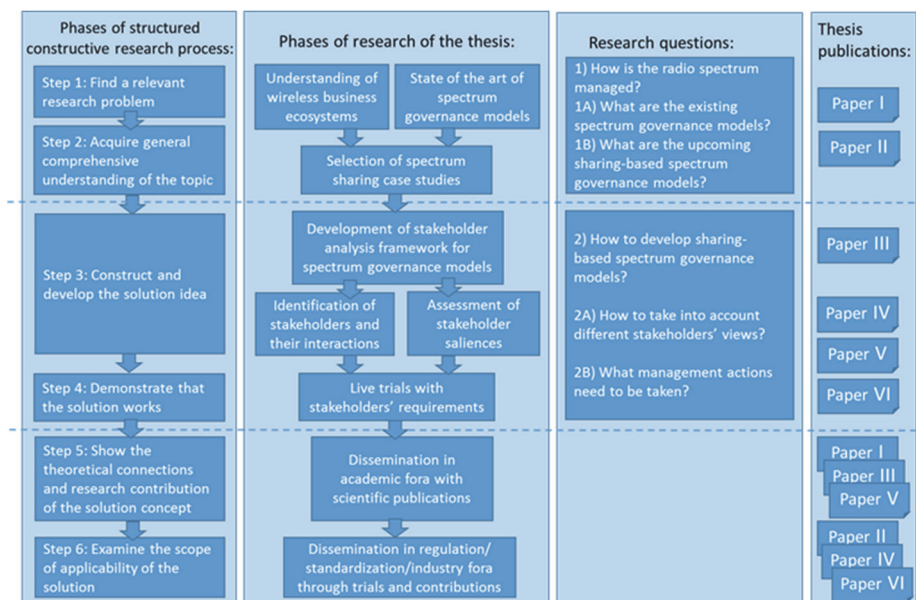
question 2) Papers III, IV, V, and VI present details of the stakeholder analysis in the two case studies. Paper III develops a three-step stakeholder analysis framework for Case 1. Paper IV identifies the key stakeholders and their management actions in the form of a work flow and Paper V by deriving their interactions and business benefits for Case 2. Moreover, Paper VI presents the world's first live trial implementation of the LSA concept (Case 2) with real world mobile communication networks capturing the different stakeholders' requirements into specific management actions.

### **1.3 Research methodology**

The selected research approach addresses spectrum management from governance viewpoint and presents stakeholder analysis as a tool to aid in the development of new sharing-based governance models using two case studies. Spectrum management has recently been addressed using governance theory by considering it as governance of common pool resources (Ostrom et al., 1999; Dietz et al. 2003) in (Weiss et al. 2015; Anker 2017) which indicate the applicability to use of governance as a tool to understand spectrum management. Spectrum sharing in turn involves multiple stakeholders operating in the same spectrum band whose interests can be highly conflicting, which calls for the tool of stakeholder analysis (Freeman 1984; Mitchell et al., 1997). Finally, as spectrum management decisions impact entire wireless business ecosystems competing over access to the spectrum bands, new spectrum sharing concepts bring together these ecosystems, which is why the development of new sharing-based spectrum governance models need to be addressed at the business ecosystem level.

This research is qualitative in nature and focuses on the development of specific sharing-based spectrum governance models that are applicable to mobile communications with two different case studies. The research process is carried out based on the structured constructive research process of Kasanen et al. (1993) where the phases are the following:

1. find a relevant research problem;
2. acquire general comprehensive understanding of the topic;
3. construct and develop the solution idea;
4. demonstrate that the solution works;
5. show the theoretical connections and the research contribution of the solution;
6. examine the scope of applicability of the solution.



**Fig. 1. Phases of the thesis research process.**

The corresponding phases of the research process in this thesis are depicted according to the structured constructive research process in Figure 1. In the first step, the research problem is identified by considering the key challenge that future mobile communication face, i.e., need for new spectrum bands to meet the growing mobile data demand. In second phase, understanding of the topic is gained by getting familiar with the mobile communication business ecosystem and spectrum governance models. After obtaining understanding on how regulators make spectrum management decisions and how these decisions influence the mobile communication business ecosystem, in the third step, the solution idea of using stakeholder analysis in the development of sharing-based spectrum governance models is developed. In the fourth step, the feasibility of the developed solution is evaluated and demonstrated with two case studies for which detailed stakeholder analyses are presented.

The fifth step includes deriving the theoretical connections and research contributions that included the introduction of theoretical concepts from management sciences (governance, stakeholder analysis, and business ecosystems) into the mobile communications context resulting in the development of a stakeholder analysis framework for the development of sharing-based spectrum governance models. Finally, the applicability of the proposed solution for the

development of sharing-based governance models was examined through dissemination of research results in academic, regulatory, and industry forums in the form of scientific publications, contributions to groups responsible for preparing regulatory documents, and trial demonstrations.

Data collection techniques in this research have included reviews of scientific literature, arrangement of expert workshops, interviews with stakeholders, participation and discussions at regulation, standardization, and scientific meetings and conferences, and reading and preparation of regulatory and standardization documents. More specifically, the scientific literature on spectrum sharing concepts and mobile communication business ecosystem was reviewed. Literature reviews of the theories of governance, stakeholders, and business ecosystems and their applications were also done. Two full-day workshops were arranged with 10-20 experts from industry, academia, and regulation for Case 1 in 2015. Several tens of smaller workshops with 5 to 10 participants were arranged for Case 2 in 2013-2015. Additionally, a large number of one-to-one conversations were held to collect different stakeholders' views in both case studies. Related activities in regulation and standardization on the case studies were reviewed through meeting documents and reports of several groups of the relevant forums including International Telecommunication Union Radiocommunication sector (ITU-R), Conference of European Postal and Telecommunication Administrations (CEPT), European Telecommunications Standards Institute (ETSI), and European Commission (EC). For Case 2, participation in specific regulatory and standardization activities in CEPT and ETSI were done, as well as the presentation of trial demonstrations at regulatory, standardization and scientific events to collect stakeholders' feedback.

#### **1.4 Outline of the thesis**

This thesis consists of six original publications. Summary of data collection methods and outputs of the papers is presented in Table 1. Paper I presents an overview of the spectrum regulatory framework and identifies the key spectrum regulatory forums at national, regional, and international levels. The paper reviews recent activities related to the development of sharing-based spectrum governance models in these forums. Paper II focuses on the global level of spectrum governance and reviews the activities related to the development of sharing-based spectrum governance models at the different groups of the ITU-R.

The theory of stakeholder analysis is introduced into the context of wireless communications Paper in III where a case study of the future use of the ultra-high

frequency (UHF) band is presented (Case 1). The paper presents a three-step flow for stakeholder analysis for the hybrid use of broadcasting and mobile communication systems in the UHF band and identifies key stakeholders, their dynamics and relations, and saliences. Paper IV applies stakeholder analysis to the development of the LSA concept (Case 2) including the identification of key stakeholders, and development of key technical building blocks and a work flow with the main phases and the tasks of the key stakeholders. Paper V dwells deeper into the business ecosystem around the LSA concept, identifies the interactions between the stakeholders and derives the needs, benefits, and constraints of the key stakeholders. Finally, Paper VI presents the world's first live demonstration of the LSA concept for mobile communication networks to share the 2.3 GHz band with wireless cameras. The paper highlights, how the different requirements of the stakeholders need to be considered in the development of the new spectrum sharing concept to reach compromises between conflicting needs.

The rest of this thesis is organized as follows. Chapter 2 presents the theoretical framework that consists of governance models, stakeholder analysis, and business ecosystems. Original contributions are presented in Chapter 3 including the resulting stakeholder analysis framework for the development of sharing-based spectrum governance models. Finally, discussion is presented in Chapter 4 including theoretical, managerial, and practical implications as well as analysis of reliability, validity, and recommendations for future research.

**Table 1. Summary of publications.**

Papers	Data collection method	Output
I	Review of scientific literature and regulatory and standardization documents	Overview of spectrum management framework and spectrum sharing concepts
II	Review of regulation documents and attendance to ITU-R meetings	Overview of spectrum sharing activities in international level
III	Review of scientific literature, two expert workshops	Development of stakeholder analysis framework and its application to Case 1
IV	Review of regulatory and standardization documents, project workshops	Stakeholder analysis for Case 2 including stakeholder identification and management actions
V	Review of regulatory and standardization documents, project workshops	Stakeholder analysis for Case 2 including stakeholder interactions and relations
VI	Review of regulatory and standardization documents, experts' views	World's first live trial of Case 2 showcasing fulfillment of stakeholders' requirements



## **2 Literature review**

The literature review consists of the research context of spectrum management, and the theoretical framework that was selected for the thesis topic.

### **2.1 Spectrum management**

Spectrum management is at the heart of wireless communication systems whose deployment is fully dependent on the availability of the radio spectrum. Spectrum management decisions made by the regulators aim to be effective by allocating spectrum to the right use, and efficient by assigning it to those who value it the most (Beltran 2017). Spectrum allocation decisions have acquired enormous political and economic significance over several decades as discussed in (Melody 1980). Overall, spectrum management is about maximizing the value of spectrum, its efficient utilization, and its benefits to society (Beltran 2017). Regulators aim at maximizing the value of spectrum in their allocation and authorization decisions, which in turn have a significant impact on the structure of the market.

Spectrum allocation methods have evolved from administrative allocation towards market-based mechanisms (Beltran 2017; Melody 1980; Hazlett 2008) and commons approach that aim to make more efficient use of the scarce spectrum. The main goal of the regulators in administrative allocation has been to create rules that minimize harmful interference without considering the economic values that the wireless systems can provide (Hazlett 2008). Administrative allocation defines which services can be offered, resulting in a situation where regulators' decisions define the market structures. To gain access rights under administrative allocation, competitive entrants must prove that they will advance the public interest while the incumbent spectrum users enjoy financial incentives to oppose these petitions (Hazlett 2008). This results in lower competition. Administrative allocation considers harmful interference as engineering parameters without considering the trade-offs between the cost of harmful interference for one application and the benefits of additional activities of another application which would reflect the economic values (Hazlett 2008).

Market-based mechanisms have replaced administrative allocation for spectrum allocations decisions in many countries in the provisioning of commercial wireless services. In market-based mechanisms the regulators take into account the value of spectrum and replace case-by-case administrative rules by defining

spectrum property rights that incentivize more efficient spectrum use (Hazlett 2008).

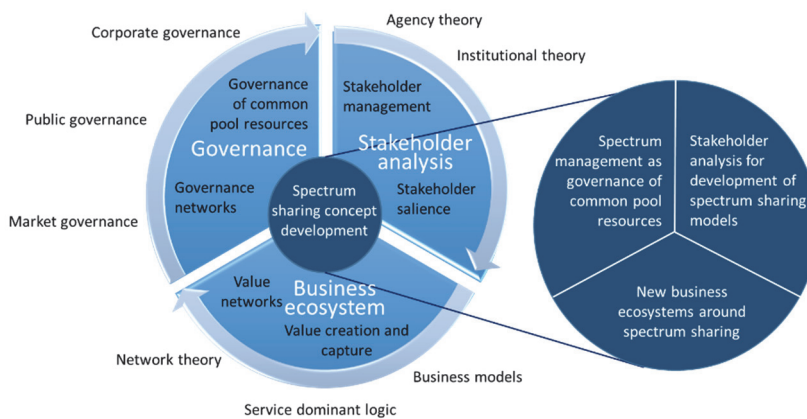
The most common market-based mechanism for spectrum allocation and assignment is the use of spectrum auctions (Cramton 2013; Beltran 2017; Cave & Nicholls 2017). Auctions are widely used today when granting rights to deploy cellular mobile communication networks. While the first spectrum auctions generally assigned a chosen number of licenses to highest bidders, modern auctions allow for a wider set of outcomes through design features that consider efficiency and equity objectives (Cave & Nicholls 2017). According to (Klemperer 2002) the overall goal of auction design should be to attract the potential bidders and discourage collusive, entry-detering and predatory behaviour. A thorough analysis of spectrum auction design is presented in (Cramton 2013) including the strengths and weaknesses of different spectrum auction designs approaches and practical examples. Traditionally, auction revenues have been seen as an indicator of the success of spectrum auctions but more recently the impact on other social aspects has also been taken into account (Hazlett and Munoz 2009). Auction rules that alter market structure or operator performance produce welfare effects, which have not been systematically incorporated in policy analysis (Hazlett and Munoz 2009).

While the market-based mechanisms have focused on defining spectrum property rights through exclusive licenses, an alternative approach, the commons approach, puts the spectrum access in the hands of many by allowing license-exempt (unlicensed) devices to operate under regulator defined rules and conditions (Bazon 2009; Carter 2006). The value of unlicensed spectrum under the commons approach arises from making spectrum access possible for a number of different usages which have resulted in new profits as well as from its capability to promote of innovation and competition. Allocations of unlicensed bands are considered to be highly irreversible as once allocated to unlicensed use, it is very difficult to take the spectrum away (Bazon 2009). The most notable example has been the use of wireless local area networks (WLAN) in unlicensed bands to mobile data delivery especially in indoors (Bazon 2009; Carter 2006).

## **2.2 Theoretical framework**

This thesis builds upon a theoretical framework that consists of governance models, stakeholder analysis, and business ecosystems in order to understand spectrum management and particularly spectrum sharing as depicted in Figure 2. This theoretical framework forms the ground for the development of new sharing-based

spectrum governance models. Governance describes the structures and models for the efficient management of natural resources such as spectrum (Ostrom et al. 1999; Dietz et al. 2003; Ostrom 2010). From the field of strategic management, stakeholder analysis (Freeman & Reed 1983; Freeman 1984; Mitchell et al. 1997) provides tools for identification of the relevant players within a specific topic. Business ecosystems (Moore 2003; Moore 1998; Gossain & Kandlah 1998; Iansiti & Levien 2004; Letaifa 2014) further provide insight into the relations between stakeholders in order to create and capture value. Theories outside the circle in Figure 2 were left outside of the scope of this thesis.



**Fig. 2. Theoretical framework for research.**

### **2.2.1 Governance models**

Governance models provide tools for policy analysis and present the management structures and systems including the roles of who can do what. Governance refers to self-organizing, inter-organizational networks that are charged with policy-making (Rhodes 1996; Stoker 1998). Governance is ultimately concerned with creating the conditions for ordered rule and collective action, and a government is characterized by its ability to make decisions and its capacity to enforce them. As defined in (Chhotray & Stoker 2009), governance is about the rules of collective decision making in settings where there are a plurality of organisations and where no formal control system can dictate the terms of the relationship between these actors and organisations. Governance literature argues that networks are at the heart

of policy-making. Any setting with multiple actors and no formal control system that can dictate the relationships between the actors is a governance network (Chhotray & Stoker 2009). Policy making involves multiple organizations from both within and outside the public sector.

Setting policy goals, defining solutions, and implementation all require resources that are not held by any single organization, resulting in interdependence of the organizations (Toikka 2011). Social network analysis is a tool to identify actors and their ties (Wasserman & Faust 1994). The nodes are the actors – usually individuals or organizations. A tie is a relation between a pair of nodes. A network is the measurement of a tie between all possible pairs of nodes in the network. The social network methods take this set of nodes and the ties between them, and then maps and analyses the structures of the network and the positions of the actors in it.

Governance has been applied to a range of disciplines and to the management of natural resources (see e.g. Toikka 2011). A specific governance model in this domain uses common pool resources (CPR). In terms of CPR, Hardin (1968) has argued that the users of a commons are caught in an inevitable process that leads to the destruction of the resource in question. This is a result from the rational users who make demands on the resource until the expected benefits equal the expected costs. While users ignore the costs from others the result is a tragic overuse of the resource which is denoted as the tragedy of the commons. The two proposed solutions to the problem of the tragedy of the commons were either socialism or the privatism of free enterprise.

Ostrom et al. (1999) challenged Hardin's (1968) view on commons and provided new insight into CPR indicating that such tragedy of the commons can be avoided with proper management of the resources. Ostrom et al. (1999) considered CPRs in a generic way as resource systems regardless of the property rights involved. CPRs are natural and human-constructed resources where exclusion of beneficiaries is especially costly (i.e. difficulty of exclusion), and exploitation of the resource by one user reduces the resource availability for others (i.e. subtractability). Users following their short-term interest cause outcomes that are not in anyone's long-term interest.

According to Ostrom et al. (1999) "solving of CPR problems involves two distinct elements: restricting access and creating incentives (usually by assigning individual rights to, or shares of, the resource) for users to invest in the resource instead of overexploiting it". Ostrom et al. (1999) note that "given the substantial differences among CPRs, it is difficult to find effective rules that both match the

complex interactions and dynamics of a resource and are perceived by users a legitimate, fair, and effective.”

According to Dietz et al. (2003) successful governance of the commons requires that the rules evolve. Strategies for efficient governance of commons include dialogue among interested parties, complex, redundant, and layered institutions and designs that facilitate experimentation, learning, and change. Effective commons governance is easier to achieve when 1) the resources and their use can be monitored, 2) rates of change are moderate, 3) communities maintain frequent face to face contacts to increase the potential for trust, 4) outsiders can be excluded at relatively low cost from using the resource, and 5) users support effective monitoring and rule enforcement.

Spectrum management falls under the governance of natural resources. Spectrum exists even when it is not used and its use must be constrained to assure safe, reliable, and effective occupancy (Levin 1966). Spectrum demand has increased over the decades, which has increased the problems of congestion and interference (Melody 1980). The specific characteristic of radio spectrum as a natural resource is the high interdependency between its users since spectrum rights are probabilistic in nature depending on band’s characteristics and use of spectrum by others (Melody 1980). Holders of spectrum usage rights have lacked the incentives to economize their use (Levin 1970).

Most recently, spectrum management has been seen in the CPR framework in (Weiss et al. 2015) and (Anker 2017). Weiss et al. (2015) introduce the CPR framework to design and manage spectrum rights bundles to best maximize social and economic benefits from sharing the spectrum resource. Anker (2017) proposes a new spectrum governance process where the role of the government shifts from the traditional controlling of spectrum management to become a facilitator of decentralized coordination in a multi-actor governance process. There, a coordination platform can bring interested stakeholders together, assess the requirements, and build trust among them to allow spectrum sharing.

### **2.2.2 Stakeholder analysis**

Stakeholder analysis is a tool for strategic management of companies (Freeman & Reed 1983; Freeman 1984). According to an internal memorandum at the Stanford Research Institute in 1963 cited in (Freeman & Reed 1983), the term ‘stakeholder’ refers to “those groups without whose support the organization would cease to exist”. Freeman (1984) has defined a stakeholder as “any group or individual who

can affect or is affected by the achievement of the organization's objectives". A comprehensive state of the art review of stakeholder theory is presented in (Parmar et al. 2010).

The stakeholder analysis framework developed by Freeman (1984) consists of three levels of analysis that help the organization in its strategic management. At the *rational level* stakeholders are identified by discovering those groups and individuals who can affect and are affected by the achievement of an organization's purpose. The *process level* dwells into the organization's processes to manage the relationship with its stakeholders and how these fit with the stakeholder map. The *transactional level* defines and implements the stakeholder management actions.

Following Freeman (1984), Ackermann and Eden (2011) have developed a three-phased method for strategic management of stakeholders where the steps are to 1) identify who the stakeholders are in the specific situation; 2) explore the impact of stakeholder dynamics; and 3) develop stakeholder management strategies. Bunn et al. (2002) have developed a five-phased stakeholder analysis process in the context of multi-sector innovations where the steps were to 1) identify key sectors and stakeholders; 2) describe important characteristics of each stakeholder group; 3) analyse and classify stakeholders; 4) examine dynamic relationships among stakeholders; and 5) evaluate generic stakeholder management strategies.

In stakeholder analysis it is important to first identify the stakeholders in the considered context, noting that an organization could have highly distinct stakeholder maps depending on the context as discussed in Freeman (1984). The use of the generic stakeholder definition from Freeman (1984) can result in a long list of stakeholders when identifying a "group or individual who can affect or is affected by the achievement of the organization's objectives". There can be different types of stakeholders such as companies, governmental and non-governmental organizations and individuals, such as end users. As highlighted by (Ackermann and Eden 2011) paying attention to and managing a specific set of stakeholders and being clear around their significance in that context is important to avoid generic level analysis that does not help in stakeholder management. Therefore, for more detailed analysis, a relevant subset of stakeholders needs to be chosen for the specific topic of interest.

In the second step, the roles and relations of the stakeholders' networks are investigated. The relationships between stakeholders can reveal responses and counter responses to organizational actions (Ackermann and Eden 2011). According to Rowley (1995) stakeholder relationships don't occur in a vacuum of

dyadic ties but rather in a network of influences. Therefore, it is important to characterize the partner network of the key stakeholders carefully.

In the third step to develop stakeholder management strategies, the actions that managers have with the stakeholders are defined and implemented (Freeman 1984). One approach in defining management actions is to evaluate the stakeholders' saliences. Stakeholder salience is the degree to which managers give priority to competing stakeholder claims (Mitchell et al. 1997). To expand the traditional power and interest as the significant dimensions for stakeholder management, Mitchell et al. (1997) have developed a framework of Power – Legitimacy – Urgency attributes to assess stakeholders salience. In the framework the stakeholder salience is characterized by the possession of stakeholder's power to influence a firm, legitimacy of the stakeholder's relationship with a firm and urgency of the stakeholder's claim on a firm. According to Mitchell et al. (1997) power is the ability to purposefully impact decision making. Suchman (1995) has defined legitimacy as a generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions. According to (Agle et al. 1999) legitimacy denotes the ability to impact the decision making upon socially acceptable claim such as contract, legal right or moral concern. Urgency is the ability of a stakeholder to have immediate impact either due to time sensitivity or criticality of the issue. Power and legitimacy are considered as the core attributes and urgency as dynamic or catalytic attribute (Mitchell et al. 1997). Mitchell et al. (1997) highlighted that the stakeholder attributes are variable, not steady state which calls for dynamic theory of stakeholder salience.

According to Steurer (2006) the evolution of the stakeholder theory has expanded from the original corporate-centric perspective into a more comprehensive field that considers additionally stakeholder perspective and conceptual perspective. Steurer (2006) states that "corporate perspective focuses on how corporations deal with stakeholders, the stakeholder perspective analyses how stakeholders try to influence corporations and the conceptual perspective explores how particular concepts, such as the 'common good' or sustainable development, relate to business-stakeholder relations".

Friedman and Miles (2002) have explored the dynamics stakeholder relations and changes in the relations. Rowley (1997) has developed the network theory of stakeholder influences that provides "a mechanism for conceptualizing the simultaneous influence of multiple stakeholders and predicting organization responses to these forces". This stakeholder network modelling, that uses the tools

of social network analysis, can help in understanding the simultaneous influence of multiple stakeholders and predicting organizations' responses. Expanding the work of Rowley (1997), Jawahar and McLaughlin (2001) show that certain stakeholders will be more important than others at any given organizational life cycle stage, indicating that not only are different strategies needed to deal with different stakeholders, but different strategies are also needed to deal with the same stakeholder over time. In addition, new stakeholders can emerge that are not present in the current situation.

Many authors have applied the stakeholder analysis to project management for the management of project stakeholders, such as (Aaltonen & Kujala 2010; Olander 2007; Cleland 1986). The usefulness of stakeholder analysis in policy making was highlighted in (Brugha & Varvasovszky 2000). In fact, stakeholder analysis has been studied in the contexts of the management of natural resources (Stoll-Kleemann & Welp 2006; Lafreniere et al. 2013). Lafreniere et al. (2013) have noted that researchers and policy makers have attempted to increase the support and transparency for resource management problems by improving stakeholder participation. They specifically note that natural resource managers need to go beyond current practises and better understand how stakeholders have applied the stakeholder analysis to the management of water. However, there is very little work on stakeholder analysis in the research literature on spectrum management. While regulators often use the stakeholder terminology, there is no prior work on stakeholder theory in spectrum management beyond the thesis of Arvind (2009), who studied the stakeholders in the mobile services business.

Finally, defining stakeholder management actions is closely linked to understanding the tangible and intangible value flows between the stakeholders for shared value creation and capture (Bocken et al. 2013; Parmar et al. 2010). Solaimani et al. (2013) extend the stakeholder analysis to include an analysis of the dynamic interactions and processes of the stakeholders and combine existing stakeholder and business model approaches. Their work reveals potential operational conflicts and critical dependencies of the stakeholders in a networked business environment and also considers stakeholders' involvement in different phases. Dreyer et al. (2017) introduce "stakeholder value impacts" to refer to the overall value creation and/or value destruction effects resulting from the way the business operates as experience by the stakeholders. In particular, stakeholders have different and possibly competing views as to what is valuable (Lepak et al. 2007).



### **2.2.3 Business ecosystem**

While the stakeholder concept discussed in Section 2.2 deals with the identification and management of a group or an individual who can affect or is affected by the achievement of the organization's objectives, strategic management further requires understanding of how business is actually created by the stakeholders. Parmar et al. (2010), Bocken et al. (2013), and Dreyer et al. (2017) discuss the link between stakeholder theory and value creation and capture. The value chain and business ecosystem concepts describe the operational environment and the relations and positions of the stakeholders. Understanding the value creation and capture logics within the complex business ecosystem becomes important for the strategic decisions of the stakeholders.

To understand how stakeholders influence the value creation of an organization, the concept of business ecosystem (Moore 1993) brings together the different stakeholders to pursue a common goal. According to (Moore 1993) in business ecosystem "companies coevolve capabilities around a new innovation: they work cooperatively and competitively to support new products, satisfy customer needs, and eventually incorporate the next round of innovations". Business ecosystems are extended systems of mutually supportive organizations. They develop through four different stages including birth, expansion, leadership, and self-renewal or death. To succeed, a business ecosystem must have value in the experience of customers, economies of scale, continuing innovation, and expanding community of allies. A company can be in multiple business ecosystems in various stages of development. According to Moore (1998) business ecosystems are "communities of customers, suppliers, lead producers, and other stakeholders – interacting with one another to produce goods and services". Members of these industrial communities improve their capabilities and transform themselves while paying attention to other and actively relating with other members of the community.

Gossain and Kandiah (1998) expand the business ecosystem concept by highlighting the importance of creating value for customers through the provision of additional information, goods, and services. Everyone benefits in a business ecosystem and the number of ecosystem partnerships can change and evolve over time. In business ecosystem, partners work together to create new value for the customer through an integrated, seamless offering that extends each of their capabilities. Iansiti and Levien (2004) present a framework for assessing the health of the business ecosystem as individual companies' success is dependent on the success of the ecosystem. They emphasise that "for an ecosystem to function

effectively, each domain in it that is critical to the delivery of a product or a service should be healthy; weakness in any domain can undermine the performance of the whole”. Recently, Bosch-Sijtsema and Bosch (2015) discuss, how firms engage in multiple ecosystems simultaneously.

Similar to the business ecosystem, value networks are strategic management concept arising particularly in e-commerce business. Bovel and Joseph (2000) define value net as “a dynamic network of customer/supplier partnerships and information flows”. Value net creates value for all of its participants and its players operate within a collaborative and digitally linked network. Value net can solve customer problems, respond rapidly to customer demands, and build a strong brand based on valuable services and build barriers to competition. They encompass characteristics of being customer aligned, collaborative, agile and scalable, fast flow, and digital. A value-creating network is formed by key firms in the value chain that deliver value to the end customer (Kohandaraman & Wilson 2001).

The business ecosystem and value chain around mobile communications has been thoroughly presented in (Bovel & Joseph 2000; Maitland et al. 2002; Sabat 2002; Li & Whalley 2002; Olla & Patel 2002; Steinbock 2003; Peppard & Rylander 2006; Basole 2009; Pagani & Fine, 2008; Funk 2009; Cricelli et al. 2011; Zhang & Liang 2011; Lundborg et al. 2012; Grove & Baumann, 2012; Al-Debei et al. 2013; Doyle et al. 2014; Bauer 2015; Feasey 2015; Peitz & Valletti 2015; Lee et al. 2016; Weber & Scuka 2016). These studies have typically identified the following stakeholders and roles in the mobile business ecosystem and value chains: content providers, pure service providers that do not operate their own infrastructure, integrated operators covering both infrastructure and service provisioning, content and service aggregators, internet service providers as local access network providers, infrastructure vendors, and device makers with their distribution channels in addition to end users.

Regulators have held a significant influence on the competitive situation in the mobile markets when making decisions on allocating spectrum to MNOs (Lundborg et al. 2012). In addition to spectrum decisions, regulators’ have set requirements for interconnection and interoperability for the services, which has shaped the ecosystem for the benefit of end users and allowed a smaller network holder to gain access to the users and benefits of the larger network (Feasey, 2015), and prevented big firms from charging too much or denying access. This has been an important step in opening the market for competition. Most recently, competition has come outside the mobile communication domain and has not been caused by small entrants, but by very big companies. Feasey (2015) and Weber and Scuka

(2016) have described the path how the MNO market dominance has been shaken by internet giants who make money by offering over the top (OTT) services that can operate independently of the networks and remain outside the operator domain which has led to the decoupling of infrastructure and services. Pure OTT service providers that do not operate their own infrastructure have overtaken the money making role from operators over the past decade (Grove & Baumann, 2012).

Peppard and Rylander (2006) adopt a network perspective and introduce the concept of value networks. In value networks the value is co-created by a combination of players in the network. Value networks are composed of complementary nodes and links and consist of various stakeholders that work together to co-produce value. Focus is on the end product and the chain is built around the activities needed to develop the product. Pepper and Rylander (2006) present the case study of mobile communications where operators have gone through transition from monopoly operator to competitive operator and maturing.

Li and Whalley (2002) analyse the development of the telecommunications industry and identify the players in the mobile wireless value network. Sabat (2002) presents the mobile wireless value chain and identifies the key players and their existing offering, as well as new applications and services. Sabat (2002) differentiates three distinct functions of operators including customer relationship business, service and content innovation and commercialisation business, and infrastructure management business. Olla and Patel (2002) discuss the mobile telecom value chain especially in the United Kingdom and propose a new role of mobile data service provider that would concentrate on industrial sector including utilities, manufacturing, and logistics. Steinbock (2003) takes a global view on the mobile value system. By noting the differences in technology, market evolution, and public policies worldwide, he identifies and describes the different locational contexts for the wireless value including US, Western Europe, Japan, and Nordic countries. Evolution for the mobile industry value system over the different generations of cellular systems is also given.

Basole (2009) uses the business ecosystem concept to illustrate the mobile wireless industry by identifying the key players, segments, and their roles. The study identifies nearly 7000 global companies and over 18000 relationships to characterize the complex mobile business ecosystem. Convergence has added to the complexity of the mobile industry, where change factors including changing customer expectations, pressure to innovate, technological evolution, regulatory influence, global competition, formation of new partnerships and alliances, mergers and acquisitions, and emergence of new actors, have increased the dynamics.

Al-Debei et al. (2013) developed a reference model for value network analysis and design for mobile communications. The model includes seven design constructs: network-mode, actor, role, relationship, flow-communication, channel, and governance. Bauer (2015) further combines mobile business ecosystem with the challenges of designing effective governance mechanisms and highlights that more adaptive approaches to governance are needed combining regular monitoring of performance metrics with a reassessment of the prevailing policies and their modification or abandonment. These could benefit from international comparisons as long as different national conditions are sufficiently captured.

The prior work on describing the business ecosystem around mobile communications has considered the traditional situation where the mobile communication networks are deployed on spectrum bands exclusively licensed to the MNOs. There is no prior work characterizing the situation with spectrum sharing, thus the need for different stakeholders with conflicting goals has not been addressed. With the introduction of sharing-based spectrum governance models, new mobile communication systems will conflict with the incumbent wireless ecosystems.

## **2.3 Synthesis of literature review**

Spectrum management is a complex topic that has evolved from administrative allocation towards market-based mechanisms. Regulators are in the key position to shape the market around wireless systems through their spectrum allocation decisions (Melody 1980; Hazlett 2008; Bazelon 2009). Spectrum sharing has become increasingly important mechanism for more efficient spectrum use, which further complicates spectrum management decisions and calls for new approaches (Beltran 2017).

The main theoretical elements of this thesis are summarized in Table 2. Governance provides a framework to understand and develop management structures for exploiting natural resources in an efficient and sustainable way (Ostrom 2010; Ostrom et al. 2009; Dietz et al. 2003). Spectrum management can be seen as governance of common pool resources as recently pointed out in (Weiss et al 2015; Anker 2017) which forms the theoretical grounds for the development of new sharing-based governance models. Stakeholder analysis (Freeman & Reed 1983; Freeman 1984) is a strategic management tool for the identification, characterization, and management of the relevant groups and individuals who can affect or are affected by the achievement of the organization's

objectives. While stakeholder analysis is traditionally applied from one organization's perspective, it is also applicable for analysing a certain topic and deriving its stakeholders, their interactions, and management actions towards the achievement of the goal of that topic. More specifically, it can be applied to the management of natural resource to identify, explain, and manage stakeholder behaviour to achieve desired outcomes as shown in (Lafreniene et al. 2013).

In the process of the development of new sharing-based spectrum governance models, it is important to understand the key stakeholders and their perspectives to develop meaningful management strategies to achieve often conflicting goals. These conflicting goals stem from stakeholders' different views on value creation and value capture (Lepak et al. 2007; Parmar 2010; Dreyer et al. 2017). For the development of a successful governance model for the management of public goods, including radio spectrum, it is important to understand these value creation and capture logics of the different stakeholders involved. To better understand the different value creation and capture logics, the concept of business ecosystem broadens from focusing on a single organizational level to relating the organization to its surrounding environment. This is done by describing the business ecosystem as an extended system of mutually supportive organizations that coevolve their capabilities around a new innovation. They work both cooperatively and competitively to support the creation of something new that creates value for the customers and allows the organization to capture value.

The business ecosystem around mobile communications has been linked to governance in (Al-Debei et al. 2013; Bauer 2015) in the traditional spectrum management approach of exclusive licenses for MNOs. The development of new sharing-based spectrum governance models brings together different wireless business ecosystems with conflicting goals about the spectrum use. Stakeholder management is required to reach solutions that present a compromise between involved stakeholders' requirements. In particular, the mobile communication ecosystem as the entrant will conflict with the incumbent wireless ecosystems wishing to maintain their rights of use in long-term.

**Table 2. Main elements from literature review.**

Theoretical elements	Main concepts	Key references
Spectrum management	Spectrum management models	Levin 1966; Melody 1980; Hazlett 2008
	Spectrum sharing concepts	Beltran 2017;
	Spectrum governance	Anker 2017; Weiss et al. 2015
Governance models	Governance of common pool resources	Dietz et al. 2003; Ostrom 2010; Ostrom et al. 2009
Stakeholder analysis	Stakeholder analysis steps	Freeman 1984; Ackermann & Eden 2011; Bunn et al. 2002
	Stakeholder salience	Mitchell et al. 1997
Business ecosystem	Business ecosystem definition	Moore 1993; Gossain & Kandiah 1998
	Mobile communication value networks	Li & Whalley 2002; Basole 2009; Al-Debei et al. 2013; Feasey 2015

### 3 Research contribution

The research contribution of this thesis is based on the six original publications and is reviewed in the following sub-sections using the theoretical framework presented in Chapter 2.

#### 3.1 Spectrum governance

Development of effective governance models is at the heart of spectrum management. Spectrum can be considered as a common pool resource (Dietz et al, 2003; Ostrom et al., 1990) as pointed out in (Weiss et al. 2015; Anker 2017). Similar to governance of any common pool resource, spectrum management takes place at various levels including national, cross-border, regional, and international levels. In order to answer the first research question, *1) How is the radio spectrum managed?*, the existing spectrum regulatory framework and spectrum governance models are first presented followed by identification of upcoming sharing-based governance models.

##### 3.1.1 Spectrum regulatory framework

Paper I reviews the different levels of spectrum management including international, regional, and national levels and presents the major forums. Different radio systems that want to use spectrum such as broadcasting, mobile communications, satellite, and fixed and the specific systems within these services, need to be coordinated by mechanisms at various levels to manage the complicated interference scenarios. Thus, spectrum management discussion and spectrum sharing related activities take place at several levels in the policy making. While the actual awarding of spectrum access rights is done at the national level, spectrum sharing related developments need international level activities.

Figure 3 summarizes the three levels using Europe as the example. At the international level, the ITU-R has the central role in the global harmonization of spectrum matters through its Radio Regulations, and reports and recommendations. These are further discussed in Paper II. At the regional level, the European spectrum regulatory framework includes groups within the EC and the Electronic Communications Committee (ECC) of the CEPT. European level harmonization is done by defining which services operate in which bands and under which technical conditions. The national regulatory authorities in each country have the right to

authorize the use of spectrum subject to the international obligations arising from ITU Radio Regulations and EC decisions for EU member states.

### **3.1.2 *Sharing-based governance models***

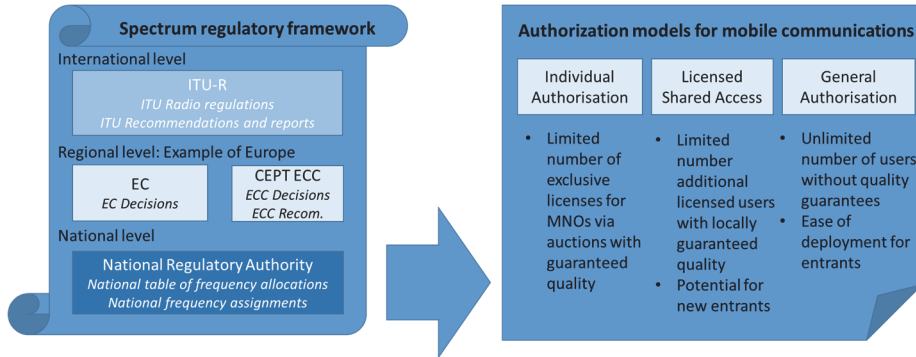
The traditional spectrum governance models include exclusive licensing and license-exempt operations (CEPT 2009). Cellular mobile communication systems have traditionally relied on licensed spectrum with long-term spectrum licenses, typically acquired from auctions. This results in a limited number of license holders who are the dominant MNOs. General authorization allows an unlimited number of users to access a spectrum band under given rules and conditions, communications is limited to short-range and users are not offered protection from interference. Recently, spectrum sharing has been seen as the primary solution to address growing mobile traffic demands. Spectrum sharing refers to the situation where two or more radio systems operate in the same spectrum band (ITU-R 2014). Spectrum sharing has gained significant interest in industry, academic, regulatory, and standardization domains.

Paper I presents an overview of the different spectrum governance levels and sharing-related activities in the different levels as summarized in Figure 3. Paper I identifies three sharing-based spectrum governance models including LSA, three-tier sharing model for providing citizens broadband radio service (CBRS) and collective use of spectrum (CUS). It then presents a comparison of the models considering different stakeholders' perspective. The LSA concept (ETSI 2013; CEPT 2014; Mustonen et al. 2014) allows the introduction of additional licensed users in a spectrum band that already includes incumbent spectrum users and defines sharing rules that allow both entrants and incumbents to provide a certain quality of service. The CBRS concept introduces two layers of additional entrant users while protecting the incumbents' rights. The CUS approach allows an unlimited number of independent users to access the spectrum under well-defined set of conditions.

Paper II presents the international level of spectrum management in more detail and reviews the spectrum sharing-related activities at the different groups at ITU-R. These activities included cognitive radio system studies for the mobile service, spectrum measurements and occupancy studies, and development of new spectrum management principles. Paper IV presents different spectrum options for the LSA concept, when the entrant system is mobile communications. The spectrum options



are characterized in terms of their licensing costs, interference environment, and suitability for use by mobile communication networks as summarized in Table 3.



**Fig. 3. Spectrum regulatory framework and governance models for mobile communications (modified from I).**

**Table 3. Spectrum options for mobile communication systems (IV) © [2014] IEEE.**

Description	Mobile as primary service	Mobile as co-primary service sharing with other primary services	Mobile as secondary service	License-exempt (ISM)
Example frequency band(s)	925–960 MHz/ 885–915 MHz	2.3–2.4 GHz	-	2.40–2.4835 GHz
Licensing and related cost	MNO typically acquires a license from the regulator Typically high license cost from auctions	Regulator decides on the need for license Potential band for LSA where an MNO could acquire an LSA license LSA license cost may be lower than traditional license	Regulator decides on the need for license	No license required due to common set of operational rules No licensing cost

Description	Mobile as primary service	Mobile as co-primary service sharing with other primary services	Mobile as secondary service	License-exempt (ISM)
Interference environment	Guaranteed operations without harmful interference from other services	Interference conditions agreed in the LSA license LSA guarantees operations without harmful interference from other services, but band availability may be interrupted	Interference from primary users is possible Interference from other secondary users is also possible	There is no protection from harmful interference and no coordination among license-exempt users, leading to uncontrolled interference environment
Suitability for mobile use	Wide coverage with high mobility is possible	Wide coverage with high mobility is possible depending on the agreed LSA rules	Need to protect primary service requires mechanisms for allowing mobility	Only short-range communication and limited mobility are possible due to restricted transmission powers

### 3.2 Stakeholder analysis for spectrum sharing

To respond to the second research question, 2) *How to develop sharing-based spectrum governance models?*, this research has formally introduced stakeholder analysis into the spectrum management domain. Paper III has presented a stakeholder analysis framework that is applicable to wireless communications specifically for the development of new sharing-based spectrum governance models. By analysing the applicability of the stakeholder analysis frameworks from (Freeman 1984; Ackermann & Eden 2011; Bun et al. 2002), Paper III has defined a three-step stakeholder analysis framework consisting of the following:

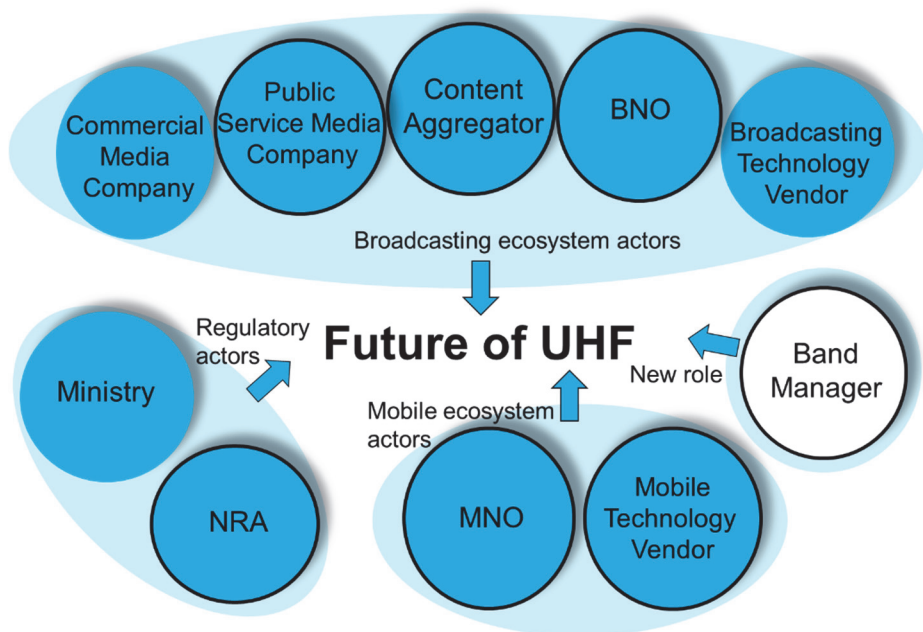
1. identification of stakeholders
2. stakeholder dynamics and interactions
3. stakeholder management actions.

The developed stakeholder analysis framework has been studied in two different spectrum sharing-based case studies: the future use of the UHF band (Case 1) and the Licensed Shared Access (LSA) concept (Case 2). Both cases have aimed at allowing entrant mobile communication systems to share with the incumbent wireless systems that are currently using the spectrum. For Case 1, two full-day

expert workshops were arranged with 20 participants from industry, regulation, and academia representing the actual stakeholders. For Case 2, several smaller workshops were organized with representatives from industry and academia. Additionally, feedback on the results was collected from regulators.

### ***3.2.1 Identification of stakeholders***

In the first step, the stakeholders are identified for the specific topic, which was done for Case 1 in paper III and Case 2 in Papers IV and V. The identified stakeholders for Case 1 are presented in Figure 4 where they are further grouped according to their wireless business ecosystem. This results in the mobile communication business ecosystem, broadcasting business ecosystem, regulators and a new mediator role for information exchange between the different ecosystems. Then the stakeholders were analysed in more detail by identifying their needs, benefits, and constraints, which can be highly conflicting. This is shown for the stakeholders of Case 1 in Table 4. The needs, benefits, and constraints of the stakeholders of Case 2 are presented in Table 5. This analysis makes a distinction between dominant and challenger MNOs whereof the first has a dominant market position with large amount of spectrum, while the latter has limited or no spectrum resources. Both case studies identify a new stakeholder role that does not exist in the traditional mobile communication ecosystem. In Case 1, a band manager role is identified for information exchange between the entrant and incumbent business ecosystems. In Case 2, this same role is denoted as the spectrum database provider.



**Fig. 4. Identification of stakeholders for the future use of the UHF band (III, published by permission of Inderscience).**

**Table 4. Stakeholders and their business benefits in the future use of the UHF band (III, published by permission of Inderscience).**

Stakeholder	Needs	Benefits	Constraints
Regulator (Ministry and NRA)	Efficient use of frequency bands Income from auctions Support innovation Support digitalization (digital agenda) Ensure equal access to public service media	Fair competition conditions Pro-development Versatility	Time scales for regulation changes International restrictions Political restrictions
Content Aggregator	Develop new and better services/customer experience to keep up with evolving market Provide personalized services to end users	Better position in competition More capacity for non-linear usage, especially with handheld devices	Regulation Handling of public service constraints (e.g. emergency alerts) Demand of linear vs. non- linear

Stakeholder	Needs	Benefits	Constraints
	Deliver content to users that don't use linear content/services		Coverage Cost (network + terminals)
BNO	UHF primary allocation for DVB Guarantee spectrum for current and new services (e.g. HD) DVB services secured and interference-free Flexible use of UHF band Mass delivery of AV contents	Service development of DVB (SD->HD) on UHF Cost efficient and good quality UHF DVB services Flexible use helps to utilize valuable spectrum AV mass delivery services to other terminals than DVB receivers	Cost efficiency, QoS and time scales of the SDL/eMBMS implementation Spectrum efficiency compared to the DVB Lack of LTE infrastructure
MNO	More spectrum to support growing traffic demand Additional capacity for coverage especially for areas of low population Finding new business models Efficient handling of local areas (venue casting)	Better quality, higher data rate for services Potential for new type of services Wide band of "available" spectrum Cost efficient coverage and capacity especially for rural and indoor urban Changing usage type of media Customer satisfaction Generate new revenue	Technological challenges from hybrid use Investment on solutions and spectrum Availability of the spectrum (potential requirement to provide free-to-air for BC) Availability of the equipment Constraints from neighboring countries Interference Administrative burden Dependency on regulation Time scales Availability of the information from/to other operators
Mobile Technology Vendor	Use of 4G/5G technology on UHF band	Expand accessible market/customer base into broadcast industry Leverage LTE scale harmonization	Dependency on regulation and politics Time scales Technical feasibility of eMBMS Initial network planning Delivery of the broadcasting data Encryption
Band Manager	Solid framework for spectrum sharing where the role of band manager is included	New business opportunity	Fulfillment of regulatory requirements Complexity of the solution Required development effort

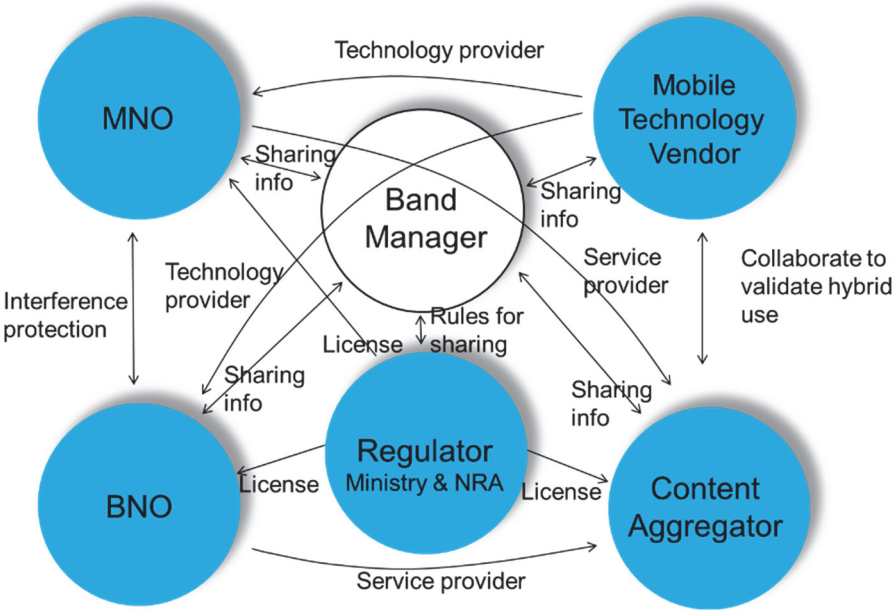
**Table 5. Stakeholders and their business benefits in LSA (V, published by permission of John Wiley & Sons).**

Stakeholder	Needs	Benefits	Constraints
NRA	Maximize the value of spectrum assets for society	Guarantee fair access to spectrum for different services to promote innovation	Uncertain business models; scale and harmonization; transaction costs
Incumbent	Maximize the value of own spectrum assets	Maintain existing rights to operate in the band and potentially gain new profit	Costs for developing new technology and sharing conditions; dependency on NRA; building new relations while sharing to others
Dominating MNO	Additional spectrum to respond to traffic growth	Rapid and cheaper access to additional spectrum to complement exclusive licenses	Costs for developing new technology and methods; regulatory uncertainty and fragmented standardization
Challenger MNO	Diversify into new business	More turnover and profit with minimum additional investment	Costs for developing new technology and methods; dependency on partners
Network equipment manufacturer	Sell more network solutions by expanding portfolio	More turnover and profit with reusing existing components	Costs for developing new components; uncertainty of LSA concept adoption; time to market constraints
Device manufacturer	Improve customer experience	Allow users to enjoy better quality of experience (QoE)	Using of standardized technology for LSA band operations for economies of scale
Standardization organization	Harmonized solutions and equal market opportunities for involved	Economies of scale, pro-competition and reduced time to market	Convergence and avoidance of de facto standardization
Spectrum database provider	Create new business with spectrum data	Enlarge market and give opportunity for new players to enter	Security issues; information sharing; high dependency on regulation and standardization

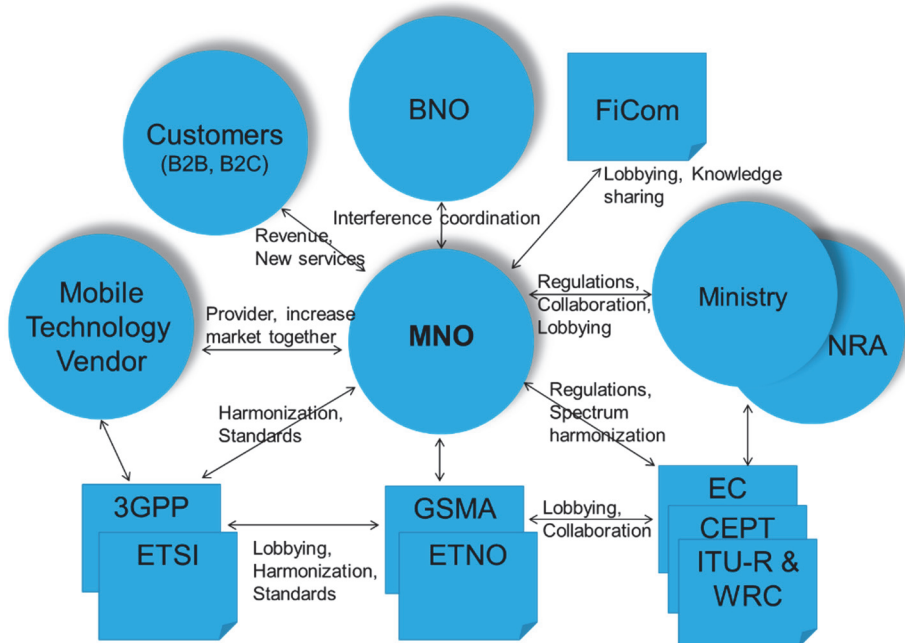
### 3.2.2 Stakeholder dynamics and interactions

The second step in the developed stakeholder analysis is to identify the dynamics and interactions of the stakeholders. Figure 5 presents the interactions between the stakeholders in high-level for Case 1. Then, a detailed analysis is done separately for each stakeholder to capture its interactions with its stakeholders. To achieve this, the stakeholders are separately identified for each stakeholder and their interactions

are briefly described. The results, for MNO stakeholder example are presented in Figure 6 for Case 1. Finally, this step concludes with analysis of stakeholder salience by assessing the legitimacy, power, and urgency attributes of each stakeholder. This part was only done for Case 1. First, each stakeholder was assessed to determine if it possessed each of the three salience attributes. Then, the relative salience of each stakeholder was obtained by weighting the individual salience attributes and calculating the fraction that each stakeholder’s salience was from the sum of all the saliences where the total over all stakeholders was 100%. The resulting saliences of the stakeholders are illustrated in Figure 7 for Case 1, where the size of the circle reflects its salience. Regulators were seen to possess high power and legitimacy. The stakeholders representing the mobile communication business ecosystem were seen to possess high urgency while the broadcasting ecosystem stakeholders had high legitimacy as the incumbent users of the spectrum band. Finally, the new stakeholder role, the band manager, had only low power, legitimacy, and urgency but regardless of its low salience, it emerged as a new role that has to be taken into account.

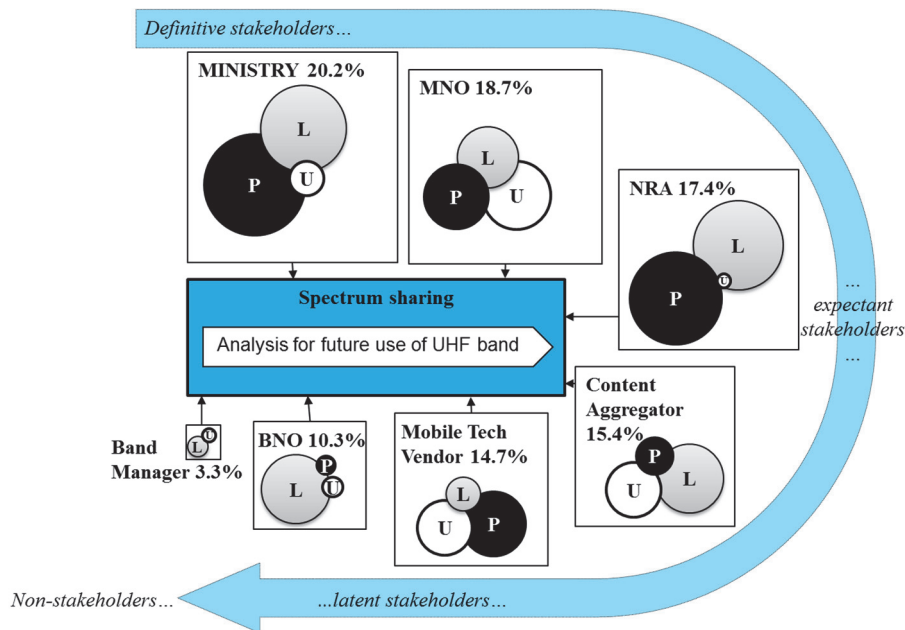


**Fig. 5. Stakeholders’ interactions in the future use of the UHF band (III, published by permission of Inderscience).**



**Fig. 6. MNO's stakeholder interactions in the future use of the UHF band (III, published by permission of Inderscience).**





**Fig. 7. Stakeholders' salience in the future use of the UHF band (III, published by permission of Inderscience).**

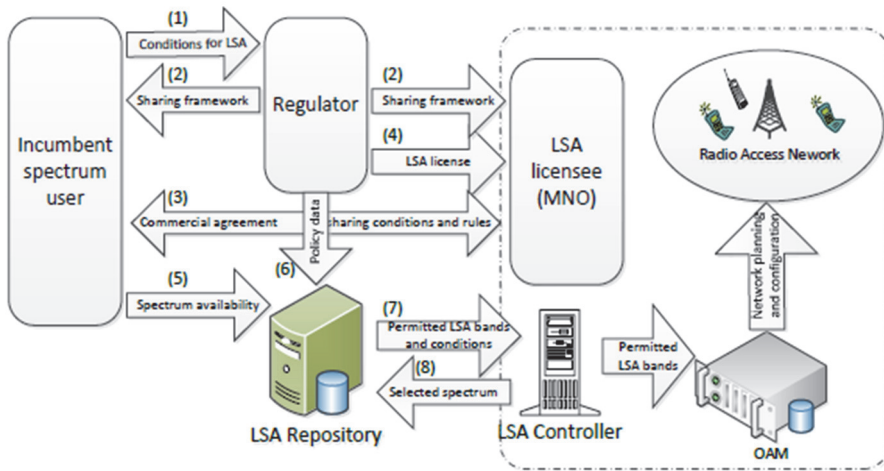
### 3.2.3 Stakeholder management actions

In the third step of the stakeholder analysis, stakeholder management actions are developed. This step defines what actions the key stakeholders need to take. It was done for Case 2. A work flow was created from the management actions of the stakeholders that included the identification of the main phases of the LSA concept, and the main actions of the stakeholders in the different phases in Paper IV. The work derived the tasks of the stakeholders, the order and relations of those tasks, and the required information to be exchanged between stakeholders. The results are summarized in Figure 8.

	Preparation		Licensing		Deployment		Release	
Incumbent	Assess own spectrum use	Define conditions and rules for sharing	Support the preparation of licensing agreement		Provide required info about LSA band availability	Send evacuation notifications when band is needed	Receive notifications on LSA band availability	Use the band when needed
NRA	Assess spectrum availability and demand for sharing	Define conditions and rules for sharing	Prepare licensing agreement	Issue the LSA license to MNO	Input any policy data	Monitor and react on demand	Assess the efficiency of sharing and rules/conditions for future use	
MNO	Assess the need for more spectrum	Define conditions and rules for sharing	Support the preparation of licensing agreement		Configure network to LSA band and start operations	Evacuate band on demand	Steer traffic from LSA band and stop transmissions	

**Fig. 8. Tasks of key stakeholders in different phases of LSA.**

In order to define more detailed stakeholder management actions, the key technical building blocks needed to implement the LSA concept were developed with a real world new entrant and incumbent wireless system. The case study considered LSA concept in the 2.3 GHz band in the Finnish setting, where mobile communication system is the entrant, and wireless cameras from the broadcasting business ecosystem are the incumbent. The introduction of LSA concept requires that the traditional wireless systems are complemented with two new building blocks, including the LSA Repository and LSA Control (ETSI 2013; CEPT 2014). The resulting architecture and key building blocks are presented in Paper IV and summarized in Figure 9.



**Fig. 9. Key stakeholders' tasks and high-level architecture for LSA (IV) © [2014] IEEE.**

After identifying the technical building blocks needed to bring the LSA concept closer to practise to consider the different stakeholders' requirements, the world's first live LSA field trial was done in Finland in April 2013 and documented in Paper VI. After the first trial, several consecutive enhanced public live trials were presented at various forums for different stakeholders including industry, academic, regulatory, and standardization events (Palola et al. 2014; Matinmikko et al. 2015).

In addition to the three key stakeholders of LSA (NRA, MNO, and incumbent), the practical deployments highlighted the role of the end user, as operations in shared bands should not result in performance degradations to them. In fact, the end user was identified as a stakeholder in Case 2 in Paper V. The trial showcased the LSA concept's feasibility and the actions of the different stakeholder in different steps. For the MNO, the trial showed how the mobile communication network can be adapted to the changing LSA spectrum availability and how users can be moved to other network resources to maintain user satisfaction. For incumbents, the trial showed the additional components needed to protect their operations and the feasibility of spectrum sharing. For the NRA, the trial demonstrated the practical feasibility of the entire LSA concept as a mechanism to introduce additional licensed users on spectrum bands with existing incumbents with reasonable complexity. Finally, for end users, the trial resulted in good quality of service level

and negligible service interruption upon the arrival of the incumbent which makes the concept feasible from the end user perspective.

### **3.3 Results synthesis**

The business ecosystem around mobile communication has evolved and expanded over the years into a complex value network of a large number of entities and their interactions. During this time spectrum management frameworks have remained static and exclusive licensing has remained the principal means by which MNOs are granted long-term wide-area spectrum access rights. The introduction of sharing-based spectrum governance models further complicates the situation by bringing together several business ecosystems from different wireless communication services that compete for the use of the same precious natural resource. In this case, the entrant mobile communication ecosystem needs to interact with the incumbent ecosystem, such as broadcasting, satellite, and government, each with distinct goals for operations. This interaction is in the centre of the development of a successful sharing-based governance model by the regulators, but it is not well-understood in the current research literature.

With the help of governance theory, this research has analysed the existing spectrum management models for mobile communications. With the aid of stakeholder analysis, the identification of the groups or individuals who can affect or are affected by the achievement of the organization's objective was noted to be important in the development of any new future oriented concept. Gaining understanding of who are the relevant stakeholders in the development of a new spectrum sharing concept is critical to develop of an acceptable model. By introducing stakeholder analysis into spectrum management, this research has developed a three-step stakeholder analysis framework for the development of sharing-based spectrum governance models. Spectrum management decisions require the assessment of the importance of the stakeholders' requirements in the specific topic through the classification of stakeholders and the assessment of their saliences.

The proposed stakeholder analysis framework was further developed using two case studies that included the details of the three-step stakeholder analysis. For stakeholder identification step, the case studies revealed the emergence of a new stakeholder role that was not present in the existing business ecosystems. The developed framework further proposed to analyse the needs, benefits, and constrains of the identified stakeholders. For the stakeholder dynamics and



**Table 6. Research questions and main results.**

Research questions	Papers	Main results
1) How is the radio spectrum managed?	I, II	Comprehensive understanding of spectrum management framework and models
1A) What are the existing spectrum governance models?	I	Review of spectrum management models
	II	Review of international spectrum management framework
1B) What are the upcoming sharing-based spectrum governance models?	I	Review of recent spectrum sharing concept in scientific, regulatory and other forums
	II	Review of spectrum sharing in international level
2) How to develop sharing-based spectrum governance models?	III, IV, V, VI	Stakeholder analysis introduced into the development of spectrum sharing concepts
2A) How to take into account different stakeholders views?	III	Stakeholder analysis framework developed and salience derived in UHF band case study
	III, V	Stakeholder identification and business benefits derived in UHF and LSA case studies
2B) What management actions need to be taken?	IV	Work flow for stakeholders' management actions developed in LSA case study
	VI	World's first live LSA trial showcasing how stakeholders' requirements are considered

## **4 Discussion**

### **4.1 Theoretical implications**

This research has explained how the theoretical frameworks of governance of common pool resources, stakeholder analysis, and business ecosystems can be applied to better understand the complex process of spectrum management and to develop new spectrum sharing concepts. This study has revealed that although the term stakeholder often appears in spectrum related discussions in different forums, the theory of stakeholder analysis has not been studied or applied to the management of the radio spectrum before. Therefore, the key theoretical contribution of this research is the introduction of stakeholder analysis into spectrum management research and specifically into the development of new sharing-based governance models for mobile communication networks. This thesis has adopted an interdisciplinary approach that builds upon engineering and experimental research to construct a new framework for the development of sharing-based spectrum governance models.

Spectrum management is closely related to governance models and this research has discussed spectrum management in the perspective of governance of common pool resources as recently pointed out by Weiss et al. (2015) and Anker (2017). As Ostrom et al. (1999) derived in their extensive studies on the governance of common pool resources of various natural resources, the self-organization of resource management among the users can work. Both case studies of the thesis identified the need for a new stakeholder role, resource manager that acts as the intermediary between the different wireless ecosystems. In fact, the entrants and the incumbents could agree upon the rules and conditions for sharing by negotiations under the governance of the NRA.

The lessons learned in governance of common pool resources (Dietz et al. 2003) further indicate that the development of new governance models highlights three strategies for meeting the requirements for governance of environmental resources: analytical deliberations, nesting, and institutional variety. Analytical deliberations call for well-structured dialogue involving interested parties, and hence the need to introduce stakeholder analysis into the governance of natural resources. More specifically, Dietz et al. (2003) identified the following elements for effective commons governance: 1) the resources and their use can be monitored, 2) rates of change are moderate, 3) communities maintain frequent face to face contacts to

increase the potential for trust, 4) outsiders can be excluded at relatively low cost from using the resource, and 5) users support effective monitoring and rule enforcement. This thesis has developed stakeholder management actions for Case 2 on the LSA concept based on these elements.

The case studies of this thesis confirmed the preliminary conclusions of Levin (1966) on spectrum sharing, i.e. entrants would prefer to gain access rights on shared basis if their costs remain low, the incumbents normally have little economic incentive to accommodate entrants and that the existing spectrum governance models strengthen the incumbents' rights. These are critical to take into account in the development of sharing-based spectrum governance models.

This thesis has expanded the step-based stakeholder analysis framework of Freeman (1984), Ackermann & Eden (2011), and Bunn et al. (2002) by developing three-step approach that is applicable to spectrum management in wireless communications. The thesis has proposed specific sub-tools for the three steps and provided examples of them using two real world case studies. The research has confirmed the suitability of stakeholder analysis in policy making (Brugha & Varvasovszky 2000) by applying it to the topic of spectrum policy making. Moreover, this research has confirmed the findings of the study on the use of stakeholder analysis in the management of natural resources in (Lafraniere et al. 2013) that suggested that understanding of stakeholder perspectives is important in the development of management strategies of the natural resources.

As Moore (1998) has defined business ecosystem, they are extended systems of mutually supportive organizations. They are communities of stakeholders interacting with one another to produce goods and services. Gossain and Kandiah (1998) emphasized the importance of creating value for the customer. They also claim that in a business ecosystem everyone benefits. This thesis has shown how the development of sharing-based spectrum governance models brings together several wireless business ecosystems with conflicting goals. The entrant systems and incumbent spectrum users encompass different ecosystems, such as mobile communications, satellite, broadcasting, etc. For a sharing model to work, it must provide clear benefits for both ecosystems. It is difficult to convince incumbent spectrum users that sharing is possible, as they often claim overly protective sharing rules and conditions. Moreover, the current governance models typically prevent the incumbent spectrum users from obtaining monetary compensations for permitting shared access to their spectrum bands. In both UHF band and LSA case studies, the relevant stakeholders were seen to span several business ecosystems: the incumbent and the entrant system typically operate in distinct business



ecosystems such as the broadcasting and mobile communication ecosystems. In both case studies, a new role was foreseen to emerge between the two ecosystems and the emergence of the new sharing-based concepts requires a new business ecosystem that is at the intersection of existing ecosystems. The existing business ecosystem descriptions of mobile communications (Li & Whalley 2002; Basole 2009; Al-Debei et al. 2013) do not include this which is why they will need to be expanded to accommodate spectrum sharing.

**Table 7. Theoretical implications**

Key findings	Research questions	Theoretical implications
Governance of common pool resources provides guidelines for spectrum sharing concept development	RQ1	Requirements for efficient governance need to be take into account in the development of spectrum sharing concepts
Stakeholder analysis is an appropriate tool for spectrum management	RQ1	This thesis opened a new research domain by introducing stakeholder analysis into spectrum management research
New three-step stakeholder analysis model developed for spectrum sharing	RQ2	Concrete steps for the stakeholder analysis were proposed to form the basis for the development of spectrum sharing concepts
Business ecosystems with conflicting requirements meet in spectrum sharing	RQ2	Prior mobile communication business ecosystem descriptions are inadequate and need to be expanded due to the introduction of spectrum sharing

## 4.2 Managerial implications

Radio spectrum forms the basis for all wireless communication businesses, whose impact to society is enormous. Mobile communications alone has a significant role in people's everyday life, and one of the key infrastructures in the society. Spectrum regulators make fundamental spectrum management decisions that form the foundation on which each wireless business ecosystem is built by defining and granting the rights to operate different wireless services. Ideally, the spectrum regulators efficiently determine who is allowed to make business while aiming to make the best use out of the scarce spectrum resources.

Spectrum management is a strategic management topic and stakeholder analysis as specific tool has the potential to find the long-term balance between conflicting stakeholder claims. While regulators have collected views from their

interest groups and even used the term stakeholder in their daily work, there are no formal tools with theoretical foundations. One important factor driving the need for sharing-based spectrum governance models has arisen from the realization that existing incumbent usage in different spectrum bands varies by location and time. This is leading towards a new spectrum management landscape where rules are more local and dynamic. This is evident from the on-going 5G discussions, see (RSPG 2018). Management of this new situation calls for development of new tools to address the growing complexity.

As a result of this research, the notion of stakeholder analysis has been introduced into spectrum management and particularly to the development of new sharing-based spectrum governance models. When developing a future oriented new sharing concept whose adoption and acceptance are uncertain, it is important to apply strategic management tools in order to develop a model that is acceptable to involved stakeholders, that it provides business benefits for them, and that it fulfils the regulators' ultimate goals of maximizing its value, efficient utilization, and benefits to society. This thesis has developed a new tool in the context of spectrum management for distinguishing between different actors, their goals and interests.

### **4.3 Practical implications**

This research has produced new knowledge regarding the development of sharing-based spectrum governance models by introducing stakeholder analysis with three concrete steps as a new tool to the spectrum management in wireless communications. The steps were illustrated with two different case studies in which examples of the steps were developed. An understanding about the practical importance of the work was gained through extensive dissemination of results throughout the process. This helped guide the real world development of the sharing-based spectrum governance models for mobile communication networks that were able to protect the incumbents' rights during the introduction of new entrants. This research has specifically presented substantial contributions to the development of the new LSA concept in research, regulation, and standardization domains. The results of this research have been widely disseminated in various forums including publications in research forums, and contributions in regulation and standardization. Moreover, the functionality of the LSA concept has demonstrated to various stakeholders with live trials in industry, academic, regulation, and standardization events globally.

This research is expected to have practical implications to different audiences. For regulators, stakeholder analysis presents a well-defined strategic management tool to address conflicting needs of interest groups. With upcoming spectrum decisions for 5G networks, it is important to consider different stakeholders views and identify the potential emergence of new stakeholders such as local 5G micro operators. The case studies detailed practical results of the LSA concept, and how it presents a controlled way of introducing additional licensed users on spectrum bands with current usage, thus allowing the incumbents to preserve their rights while meeting the requirements of new entrants.

The mobile communication industry is seen to benefit from this research in a number of ways. For mobile network operators, the developed approach when adopted by spectrum regulators would allow MNOs to gain access to new spectrum bands to meet their growing needs. For network equipment manufacturers this means more business. For end users increasing consumption of mobile services is possible with quality of service guarantees. Finally, the academic domain can find the developed stakeholder analysis as a useful tool with strong theoretical basis when bringing together companies, authorities, and public sector to develop new spectrum management models.

#### **4.4 Quality of research**

Key criteria for assessing the quality of business and management research are reliability, replicability, and validity (Bryman & Bell 2015). The research in this thesis is qualitative, and its reliability and validity can be assessed by answering the following four questions (Bryman and Bell 2015): 1) How trustworthy are the results? 2) Are the results valid in another environment? 3) Are the findings likely to occur at other times (repeatability)? 4) To what extent have the researcher's own values influenced the results?

The *trustworthiness* is concerned with the degree to which the research results correspond with the real world. This research has considered the spectrum management with real wireless systems in the development of the new sharing-based spectrum governance models. Both entrant (mobile communication) and incumbent (broadcasting) wireless systems considered in the research present realistic settings and the research process has constantly cross-checked the results with the experts representing the different ecosystems from industry, standardization, regulation, and academia. Moreover, the practical trial of Case 2

has showcased the functioning LSA concept in the 2.3 GHz band in realistic settings with real world wireless systems in Finland.

The *validity* of the results in another environment is addressed by developing solutions that are expandable to different sets of entrant and incumbent systems. The developed stakeholder analysis framework was applied to two different spectrum sharing situations with different groups of experts' participation. Case 1 considered spectrum sharing between mobile communication and broadcasting business ecosystems aiming to reach long-term compromises about the future use of the UHF broadcasting band. For Case 2 results were generic for the broad LSA concept as defined in (RSPG 2013; ETSI 2013; CEPT 2014) but, at the same time, specific for the specific wireless systems operating in the given case study (i.e. entrant mobile communication systems in the 2.3 GHz band with incumbent wireless cameras from broadcasting ecosystem). However, the developed principles are directly expandable to other entrant and incumbent settings as well as different spectrum bands.

*Repeatability* of the research has been addressed by conducting the research in a step-wise approach where results have been produced iteratively and exposed to comments from academia, industry, and regulators. The steps are well documented and published which makes it possible to repeat the research. In fact, a series of research and trialling activities has followed Case 2 by others and presented in (Guiducci et al. 2017).

*Researcher's own influence* on the results in this thesis deserves a careful consideration as the researcher has strong personal technical background in the field of thesis topic, see (Matinmikko 2012). To avoid biased results, data has been collected from workshops, interviews, and discussions with a large number of participants representing all key stakeholders over a long time span. Additionally, the papers of the thesis have been written in close collaboration with several people with different backgrounds to get comments and broader view on the topics.

## **4.5 Recommendations for further research**

This thesis has introduced stakeholder analysis into spectrum management, which has appeared to be a promising way to understand the complexity around spectrum sharing and to develop new spectrum sharing concepts. In the governance of common pool resources, like the radio spectrum, the development of efficient governance models is crucial. Regarding Case 2 on the LSA concept, further research is needed to develop effective rules for awarding the access rights to use

the spectrum. The mechanisms for awarding of the LSA licenses from the governance perspective should be perceived by all users as being legitimate, fair, and effective, and from the NRA's perspective be fair, transparent, and non-discriminatory. The development of such models that allow local licenses is an open topic.

In terms of stakeholder analysis, there is a need to understand the standpoints of the key stakeholders in more detail in order to bring the sharing concepts to reality and to develop case specific rules and conditions that meet the requirements of the involved stakeholders. In the business ecosystem domain, future research is needed to look into business opportunities for the involved key stakeholders in more detail, including business scenarios and business models. In particular, the business incentives to attract the attention of incumbents to participate in both case studies are important as the adoption of the sharing-based spectrum governance models requires rules and conditions that are feasible for both entrants and incumbents.

The entire sharing-based spectrum governance is about convincing the involved stakeholders of the functioning of the new models with real world wireless communication systems. This can only be realized by bringing the stakeholders together to study real deployment situations that consider the different stakeholders' conflicting requirements. Simulations and ultimately trialling are then recommended. Before the trials, there is the need to develop detailed technical approaches for the specific case studies that build on the key enabling technologies. Regarding Case 2, detailed studies for specific bands and wireless systems are needed to expand the current work of the LSA case for sharing between LTE and wireless camera systems in the 2.3 GHz band to other systems and bands. Moreover, expansion to more complicated setting, with multiple different types of incumbents and multiple LSA licensees in different areas deserves attention. Finally, the stakeholder analysis should be conducted for the upcoming spectrum decisions for the deployment of 5G networks in order to identify the key stakeholders including the possibility of new emerging local operators, such as micro operators (Matinmikko et al. 2018).



## References

- Aaltonen, K., & Kujala, K. (2010). A project lifecycle perspective on stakeholder influence strategies in global projects. *Scandinavian Journal of Management*, 26, 381-397.
- Ackermann, F., & Eden, C. (2011). Strategic management of stakeholders: Theory and practice. *Long Range Planning*, 44, 179-196.
- Agle, B. R., Mitchell, R. K., & Sonnenfeld, J. A. (1999). Who matters to CEOs? An investigation of stakeholder attributes and salience, corporate performance, and CEO values. *Academy of Management Journal*, 42(5), 507-525.
- Ahokangas, P., Matinmikko, M., Yrjölä, S., Okkonen, H., & Casey, T. (2013). "Simple rules" for mobile network operators' strategic choices in future spectrum sharing networks. *IEEE Wireless Communications*, 20, 20-26.
- Akyildiz, I. F., Lee, W. Y., Vuran, M. C., & Mohanty, S. (2008). A survey on spectrum management in cognitive radio networks. *IEEE Communications Magazine* 46, 40-48
- Al-Debei, M. M., Al-Lozi, E., & Fitzgerald, G. (2013). Engineering innovative mobile data services. *Business Process Management Journal*, 19, 336-363.
- Anker, P. (2017). From spectrum management to spectrum governance. *Telecommunications Policy*, 41, 486-497.
- Arvind, A. S. (2009). Stakeholder value network analysis for the mobile services ecosystem. M.Sc. thesis. Massachusetts Institute of Technology. 92 p.
- Basole, R. C. (2009). Visualization of interfirm relations in a converging mobile ecosystem. *Journal of Information Technology*, 24, 144-159.
- Bauer, J. M. (2010). Regulation, public policy, and investment in communications infrastructure. *Telecommunications Policy*, 34, 65-79.
- Bauer, J. M. (2014). Platforms, systems competition, and innovation: Reassessing the foundations of communications policy. *Telecommunications Policy*, 38, 662-673.
- Bauer, J. M. (2015). Governing the mobile broadband ecosystem. *International Telecommunications Policy Review*, 22, 1-26.
- Bazelon, C. (2009). Licensed or unlicensed: The economic considerations in incremental spectrum allocations. *IEEE Communications Magazine*, 47, 110-116.
- Bazelon, C., & McHenry, G. (2013). Spectrum value. *Telecommunications Policy*, 37, 737-747.
- Beltran, G. (2017). Accelerating the introduction of spectrum sharing using market-based mechanisms. *IEEE Communications Standards Magazine*, 1, 66-72.
- Bocken, N., Short, S., Rana, P., & Evans, S. (2013). A value mapping tool for sustainable business modelling. *Corporate Governance*, 13, 482-497.
- Bosch-Sijtsema, P. M., & Bosch, J. (2015). Plays nice with others? Multiple ecosystems, various roles and divergent engagement models. *Technology Analysis & Strategic Management*, 27, 960-974.
- Bovel, D., & Joseph, M. (2000). From supply chain to value net. *Journal of Business Strategy*, 21, 24-28.
- Bunn, M. D., Savage, G. T., & Holloway, B. B. (2002). Stakeholder analysis for multi-sector innovations. *Journal of Business & Industrial Marketing*, 17, 181-203.

- Brugha, R., & Varvasovszky, Z. (2000). Stakeholder analysis: A review. *Health Policy and Planning*, 15, 239-246.
- Bryman, A., & Bell, E. (2015). *Business research methods*. USA: Oxford University Press.
- Carter, K. R. (2006). Policy lessons from personal communications services: Licensed vs. unlicensed spectrum access. *CommLaw Conspectus*, 15, 93-117.
- Cave, M. & Nicholls, R. (2017). The use of spectrum auctions to attain multiple objectives: Policy implications. *Telecommunications Policy*, 41, 367-378.
- Cave, M., & Pratt, N. (2016). Taking account of service externalities when spectrum is allocated and assigned. *Telecommunications Policy*, 40, 971-981.
- CEPT, "Light licensing, license-exempt and commons", ECC Report 132, June 2009.
- CEPT, "Licensed shared access", ECC Report 205, 2014.
- Chhotray, V., & Stoker, G. (2009). *Governance theory and practice: A cross-disciplinary approach*. Palgrave Macmillan.
- Cramton, P. (2013). Spectrum auction design. *Review of Industrial Organization*, 42, 161-190.
- Cricelli, L., Grimaldi, M., & Ghiron, N. L. (2011). The competition among mobile network operators in the telecommunication supply chain. *International Journal of Production Economics*, 131, 22-29.
- Dietz, T., Ostrom, E., & Stern, P. C. (2003). The struggle to govern the commons. *Science*, 302, 1907-1912.
- Donaldson, T., & Preston, L. E. (1995). The stakeholder theory of the corporation: Concepts, evidence and implications. *The Academy Management Review*, 20, 65-91.
- Doyle, L., Kibilda, J., Forde, T. K., & DaSilva, L. (2014). Spectrum without bounds, networks without borders. *Proceedings of the IEEE*, 102, 351-365.
- Dreyer, B., Lüdeke-Freund, F., Hamann, R., & Faccar, K. (2017). Upsides and downsides of the sharing economy: Collaborative consumption business models' stakeholder value impacts and their relationship to context. *Technological Forecasting and Social Change*, 125, 87-104.
- EC. (2012). Promoting the shared use of radio spectrum resources in the internal market, COM (2012) 478, European Commission.
- EC. (2016). Connectivity for a competitive digital single market - Towards a European gigabit society, COM (2016) 587, European Commission.
- EC. (2017). Study on spectrum assignment in the European Union, Doc. SMART 2016/0019.
- Ehrenhard, M., Kijl, B., & Nieuwenhuis, L. (2014). Market adoption barriers of multi-stakeholder technology: Smart homes for the aging population. *Technological Forecasting and Social Change*, 89, 306-315.
- ETSI. (2013) Mobile broadband services in the 2 300 MHz – 2 400 MHz frequency band under Licensed Shared Access regime, European Telecommunications Standards Institute, TR 103 113.
- Faulhaber, G. R. (2006). The future of wireless telecommunications: Spectrum as a critical resource. *Information Economics and Policy*, 18, 256-271.
- Feasey, R. (2015). Confusion, denial and anger: The response of the telecommunications industry to the challenge of the Internet. *Telecommunications Policy*, 39, 444-449.



- Fjeldstad, O. D., Becerra, M., & Narayanan, S. (2014). Strategic action in network industries: An empirical analysis of the European mobile phone industry. *Scandinavian Journal of Management*, 20, 173-196.
- Freeman, R. E., & Reed, D. L. (1983). Stockholders and stakeholders: A new perspective on corporate governance. *California Management Review*, 25, 88-106.
- Freeman, R. E. (1984). *Strategic management: A stakeholder approach*. Boston: Pitman Publishing Inc.
- Freyens, B. (2009). A policy spectrum for spectrum economics. *Information Economics and Policy*, 21, 128-144.
- Friedman, A. L., & Miles, S. (2002). Developing stakeholder theory. *Journal of Management Studies*, 39, 1-21.
- Funk, J., L. (2009). The emerging value network in the mobile phone industry: The case of Japan and its implications for the rest of the world. *Telecommunications Policy*, 33, 4-18.
- Gnyawali, D. R., & Park, B. J. R. (2011). Co-opetition between giants: Collaboration with competitors for technological innovation. *Research Policy*, 40, 650-663.
- Gossain, S., & Kandiah, G. (1998). Reinventing value: The new business ecosystem. *Strategy & Leadership*, 26, 28-33.
- Grove, N., & Baumann, O. (2012). Complexity in the telecommunications industry: When integrating infrastructure and services backfires. *Telecommunications Policy*, 36, 40-50.
- Guiducci, E. et al. (2017). Regulatory pilot on Licensed Shared Access in a live LTE-TDD network in IMT band 40. *IEEE Transactions on Cognitive Communications and Networking*, 3, 534-549.
- Hardin, G. (1968). The tragedy of the commons. *Science*, 13, 1243-1248.
- Hazlett, T. W. (2008). Optimal abolition of FCC spectrum allocation. *Journal of Economic Perspectives*, 22, 103-128.
- Hazlett, T. W. & Muñoz, R. E. (2009). A welfare analysis of spectrum allocation policies. *The RAND Journal of Economics*, 40, 424-454.
- Hearn, G., & Pace, D. (2006). Value-creating ecologies: Understanding next generation business systems. *Foresight*, 8, 55-65.
- Holland, O., De Nardis, L., Nolan, K., Medeisis, A., Anker, P., Minervini, L. F., Velez, F., Matinmikko, M., & Sydor, J. (2012). Pluralistic licensing. *Proceedings - IEEE International Symposium on Dynamic Spectrum Access Networks (DYSPAN)*, 33-41, Bellevue, Washington, USA.
- Iansiti, M., & Levien, R. (2004). Strategy as ecology. *Harvard Business Review* 82, 68-78.
- ITU-R. (2014). "Cognitive radio systems in the land mobile service," International Telecommunication Union, Report ITU-R M.2330.
- Jawahar, I., & McLaughlin, G. (2001). Towards a descriptive stakeholder theory: An organizational life cycle approach. *Academy of Management Review*, 26, 397-414.
- Johansson, M. (2012). Interaction in dynamic networks: Role-playing and its implications for innovation. *The IMP Journal*, 6, 17-37.
- Järvinen, P. (2001). *On research methods*. Tampere, Finland: Opinpaja.

- Kasanen, E., Lukka, K., & Siitonen, A. (1993). The constructive approach in management accounting research. *Journal of Management Accounting Research*, 5, 241-264.
- Keiser, B. E. (1977). Frequency management techniques: Shifting the demands on the spectrum. *IEEE Transactions on Electromagnetic Compatibility*, 19, 323-326.
- Klemperer, P. (2002). What really matters in auction design. *Journal of Economic Perspectives*, 16, 169-189.
- Kotharandaram, P., & Wilson, D. T. (2001). The future of competition: Value-creating networks. *Industrial Marketing Management*, 30, 379-389.
- Lafreniere, K. C., Deshpande, S., Bjornlung, H., & Hunter, M. G. (2013). Extending stakeholder theory to promote resource management initiatives to key stakeholders: A case study of water transfers in Alberta, Canada. *Journal of Environmental Management*, 129, 81-91.
- Lee, S., Kim, W., Lee, H., & Jeon, J. (2016). Identifying the structure of knowledge networks in the US mobile ecosystem: Patent citation analysis. *Technology Analysis & Strategic Management*, 28, 411-434.
- Lepak, D. P., Smith, K. G., & Taylor, M. S. (2007). Value creation and value capture: A multilevel perspective. *Academy of Management Review*, 32, 180-194.
- Letaifa, S. (2014). The uneasy transition from supply chains to ecosystems – The value-creation/value-capture dilemma. *Management Decision*, 52, 278-295.
- Levin, H. J. (1966). New technology and the old regulation in radio spectrum management. *The American Economic Review*, 56, 339-349.
- Levin, H. J. (1970). Spectrum allocation without market. *The American Economic Review*, 60, 209-218.
- Li, F., & Whalley, J. (2002). Deconstruction of the telecommunications industry: From value chains to value networks. *Telecommunications Policy*, 26, 451-472.
- Lundborg, M., Reichl, W., & Ruhle, E. O. (2012). Spectrum allocation and its relevance for competition. *Telecommunications Policy*, 36, 664-675.
- Maitland, C. F., Bauer, J. M., & Westerveld, R. (2002). The European market for mobile data: Evolving value chains and industry structures. *Telecommunications Policy*, 26, 485-504.
- Matinmikko, M. (2012). Spectrum sharing using cognitive radio system capabilities: Methods to obtain and exploit knowledge of spectrum availability. VTT Science 20. Doctoral thesis at University of Oulu.
- Matinmikko, M., Palola, M., Mustonen, M., Rautio, T., Heikkilä, M., Kippola, T., Yrjölä, S., Hartikainen, S., Tudose, L., Kivinen, A., Kokkinen H. & Mäkeläinen M. (2015). Field trial of Licensed Shared Access (LSA) with enhanced LTE resource optimization and incumbent protection. *Proceedings - IEEE International Symposium on Dynamic Spectrum Access Networks (DYSPAN)*, pp. 263-264, Stockholm, Sweden.
- Matinmikko, M., Latva-aho, M., Ahokangas, P., & Seppänen, V. (2018). On regulations for 5G: Micro licensing for locally operated networks. *Telecommunications Policy*, 42, 622-635.
- Melody, W. H. (1980). Radio spectrum allocation: Role of the market. *The American Economic Review*, 70, 393-397.

- Minervini, L. F. (2014). Spectrum management reform: Rethinking practices. *Telecommunications Policy*, 38, 136-146.
- Mitchell, R. K., Agle, B. R., & Wood, D. J. (1997). Toward a theory of stakeholder identification and salience: Defining the principle of who and what really counts. *Academy of Management Review*, 22, 853-886.
- Moore, J. F. (1993). Predators and prey: A new ecology of competition. *Harvard Business Review*, 82, 75-86.
- Moore, J. F. (1998). The rise of a new corporate form. *The Washington Quarterly*, 21, 167-181.
- Mustonen, M., Chen, T., Saarnisaari, H., Matinmikko, M., Yrjölä, S., & Palola, M. (2014). Cellular architecture enhancement for supporting the European Licensed Shared Access concept. *IEEE Wireless Communications*, 21, 37-43.
- Mustonen, M., Matinmikko, M., Holland, O. & Roberson, D. (2017). Process model for recent spectrum sharing concepts in policy making. *Telecommunications Policy*, 41, 391-404.
- Noam, E. M. (1995). Taking the next step beyond spectrum auctions: open spectrum access. *IEEE Communications Magazine*, 33, 66-73.
- Olander, S. (2007). Stakeholder impact analysis in construction project management. *Construction Management and Economics*, 25, 277-287.
- Olla, P., & Patel, N. V. (2002). A value chain model for mobile data service providers. *Telecommunications Policy*, 26, 551-571.
- Ostrom, E., Burger, J., Field, C. B., Norgaard, R. B., & Policansky, D. (1999). Revisiting the commons: Local lessons, global challenges. *Science*, 284, 278-282.
- Ostrom, E. (2010). Beyond markets and states: Polycentric governance of complex economic systems. *American Economic Review*, 100, 641-672.
- Pagani, M., & Fine, C. H. (2008). Value network dynamics in 3G-4G wireless communications: A systems thinking approach to strategic value assessment. *Journal of Business Research*, 61, 1102-1112.
- Palola, M., Matinmikko, M., Prokkola, J., Mustonen, M., Heikkilä, M., Kippola, T., Yrjölä, S., Hartikainen, V., Tudose, L., Kivinen, A., Paavola, J. & Heiska, K. (2014). Live field trial of Licensed Shared Access (LSA) concept using LTE network in 2.3 GHz band. *Proceedings - IEEE International Symposium on Dynamic Spectrum Access Networks (DYSPAN)*, pp. 38-47, McLean, VA, USA.
- Parmar, B. L., Freeman, R. E., Harrison, J. S., Wicks, A. C., Purnell, L., & Colle, S. (2010). Stakeholder theory: The state of the art. *The Academy of Management Annals*, 4, 403-445.
- Payne, A. F., Storbacka, K., & Frow, P. (2008). Managing the value co-creation of value. *Journal of the Academy of Marketing Science*, 36, 83-96.
- Peitz, M., & Valletti, T. (2015). Reassessing competition concerns in electronic communications markets. *Telecommunications Policy*, 39, 896-912.
- Peppard, J., & Rylander, A. (2006). From value chain to value network: Insight for mobile operators. *European Management Journal*, 24, 128-141.

- Rhodes, R. A. W. (1996). The new governance: Governing without government. *Political Science*, 44, 652-667.
- Rowley, T. (1997). Moving beyond dyadic ties: A network theory of stakeholder influences. *Academy of Management Review*, 22, 887-910.
- RSPG. (2011). Report on Collective Use of Spectrum (CUS) and other sharing approaches. European Commission, Radio Spectrum Policy Group, RSPG11-392.
- RSPG. (2013). RSPG Opinion on Licensed Shared Access. European Commission, Radio Spectrum Policy Group, RSPG13-538.
- RSPG. (2018). Strategic spectrum roadmap towards 5G for Europe. RSPG Second Opinion on 5G networks. European Commission, Radio Spectrum Policy Group, RSPG18-005.
- Sabat, K. S. (2002). The evolving mobile wireless value chain and market structure. *Telecommunications Policy*, 26, 505-535.
- Savage, G. T., Nix, T. W., Whitehead, C. J., & Blair, J. D. (1991). Strategies for assessing and managing organizational stakeholders. *Academy of Management Executive*, 5, 61-75.
- Solaimani, S., Guldmond, N. & Bouwman, H. (2013). Dynamic stakeholder interaction analysis: Innovative smart living design cases. *Electronic Markets*, 23, 317-328.
- Soroos, M. S. (1982). The commons in the sky: The radio spectrum and geosynchronous orbit as issues in global policy. *International Organization*, 36, 665-677.
- Steinbock, D. (2003). Globalization of wireless value system: from geographic to strategic advantages. *Telecommunications Policy*, 27, 207-235.
- Steurer, R. (2006). Mapping stakeholder theory anew: From the 'stakeholder theory of the firm' to three perspectives on business-society relations. *Business Strategy and the Environment*, 15, 55-69.
- Stoker, G. (1998). Governance as theory: five propositions. *International Social Science Journal*, 50, 1468-2451.
- Stoll-Kleemann, S., & Welp, M. (2006). (Eds.). *Stakeholder dialogues in natural resources management: Theory and practice*. Berlin: Springer.
- Suchman, M. C., (1995). Managing legitimacy: Strategic and institutional approaches. *Academy of Management Review*, 20, 571-610.
- Toikka, A. (2011). Governance theory as framework for empirical research – A case study on local environmental policy-making in Helsinki, Finland. Doctoral dissertation, University of Helsinki.
- Wasserman, S., & Faust, K. (1994). *Social network analysis: Methods and applications*. Cambridge: Cambridge University Press.
- Weber, A., & Scuka, D. (2016). Operators at crossroads: Market protection or innovation? *Telecommunications Policy*, 40, 368-377.
- Weiss, M. B. H., Lehr, W. H., Acker, A., & Gomez, M. M. (2015). Socio-technical considerations for Spectrum Access System (SAS) design. *Proceedings - IEEE International Symposium on Dynamic Spectrum Access Networks (DYSPAN)* pp. 35-46, Stockholm, Sweden.
- Zhang, J., & Liang, X. (2011). Business ecosystem strategies of mobile network operators in the 3G era: The case of China Mobile. *Telecommunications Policy*, 33, 156-171.

## Original publications

- I Matinmikko, M., Mustonen, M., Roberson, D., Paavola, J., Höyhty, M., Yrjölä, S. & Röning, J. (2014). Overview and comparison of recent spectrum sharing approaches in regulation and research: From opportunistic unlicensed access towards licensed shared access. *Proceedings of IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN)*, 92-102.
- II Matinmikko, M., & Mustonen, M. (in press). Spectrum sharing policy at global level. In W. Zhang (Ed.), *Handbook of cognitive radio*. Singapore: Springer. 21 p.
- III Matinmikko, M., Mustonen, M., & Haapasalo, H. (2017). Stakeholder analysis for future use of the ultra-high frequency (UHF) band. *International Journal of Technology, Policy and Management*, 17, 159-183.
- IV Matinmikko, M., Okkonen, H., Palola, M., Yrjölä, S., Ahokangas, P., & Mustonen, M. (2014). Spectrum sharing using Licensed Shared Access: The concept and its workflow for LTE-Advanced networks. *IEEE Wireless Communications*, 21, 72-79.
- V Matinmikko, M., Okkonen, H., Yrjölä, S., Ahokangas, P., Mustonen, M., Palola, M., Gonçalves, V., Kivimäki, A., Luttinen, E., & Kemppainen, J. (2015). Business benefits of Licensed Shared Access (LSA) for key stakeholders. In O. Holland, H. Bogucka, & A. Medeisis (Eds.), *Opportunistic spectrum sharing and white space access: The practical reality* (pp. 407-424). New Jersey: John Wiley & Sons.
- VI Matinmikko, M., Palola, M., Saarnisaari, H., Heikkilä, M., Prokkola, J., Kippola, T., Hänninen, T., Jokinen, M. & Yrjölä, S. (2013). Cognitive radio trial environment: First live authorized shared access-based spectrum-sharing demonstration. *IEEE Vehicular Technology Magazine*, 8, 30-37.

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ISBN 978-952-62-2050-5 (Paperback)  
ISBN 978-952-62-2051-2 (PDF)  
ISSN 0355-3213 (Print)  
ISSN 1796-2226 (Online)