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DEVELOPING BUSINESS MODEL FOR GEO-LOCATION DATABASE FOR THE OPERATION OF COGNITIVE RADIO IN THE TV WHITE SPACE BANDS

Master thesis

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ABBREVATIONS

ARNS	Aeronautical Radionavigation
ATV	Analogue Television
AT&T	American multinational telecommunications corporation
BS	Broadcasting Service
CAPEX	Capital Expenditure
CEPT	Conference on Postal and Telecommunications Administrations
COGEU	COGnitive radio systems for efficient sharing of TV white spaces in European context
COST	European Cooperation in Science and Technology
CR	Cognitive Radio
CPC	Cognitive Pilot Channel
DECT	Digital Enhanced Cordless Telecommunications
ECC	European Communication Committee
e-CFR	Electronic Code of Federal Regulations
ESF	European Science Foundation
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
GDB	Geo-location Database
IBBT	Institute for Broadband Technology –
SMIT	Centre for Studies on Media, Information and Telecommunication
M2M	Machine-to-Machine
OET	Office of Engineering and Technology
OPEX	Operational Expenditure
PMSE	Programme Making and Special Events
RAS	Radio Astronomy
RAT	Radio Access Technology
RF	Radio Frequency
RRT	Ryšių Reguliavimo Tarnyba
RSBN	Radio System of Short-range Navigation
STSM	Short Term Scientific Mission
SS	Spectrum Sensing
T-DAB	Terrestrial Digital Audio Broadcasting
UHF	Ultra High Frequency
U.S.	United States

VHF Very High Frequency

VUB Vrije Universiteit Brussel

WRC World Radio Conference

WS White Space

WSD White Space Device (Cognitive Radio Devices)

ABSTRACT

Author of Master Thesis:	Gintarė Sukarevičienė
Full title of Master Thesis:	Developing Business Model for Geo-location Database for the operation of Cognitive Radio in the TV White Space bands
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The **aim** of this thesis is to analyze how technological, economic, political and social factors can be integrated into Business Model for Geo-location database as a controlling entity for operation of Cognitive Radio devices in the TV White Space spectrum range.

Tasks of thesis:

- to perform an analysis of scientific literature in the context of TVWS and to identify technologies of TVWS management;
- to find factors influencing Geo-location Database Business Model;
- to put forward Geo-location Database scenarios;
- to construct classification of Business Model for the Geo-location Database;
- to provide experimental study of feasibility to deploy distinct classification of Business Model for the distinct scenarios of Geo-location Database.

Qualitative methods chosen for the research: exploratory literature analysis, consultations with experts/specialists and conceptual modelling based on scenarios.

The exploratory part of the thesis describes existing spectrum shortage problem and presents potential technologies that can solve this problem.

The theoretical part of this work introduces research methodology and the concept and principles of Business Model for technology innovation.

Analytical part of the thesis seeks to identify potential Business Model configurations for the operations of Geo-location database in the TV White Space spectrum range. This part ends with presenting experimental study of the feasibility of Geo-location Business Model.

The final part of the thesis concludes with the **main results** that propose optimal Business Model configuration for the Geo-location Database that can be used for further research.

SANTRAUKA

Magistro darbo autorius:	Gintarė Sukarevičienė
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Šio darbo **tikslas** – išanalizuoti, kaip technologiniai, ekonominiai, politiniai ir socialiniai faktoriai gali būti integruoti į verslo modelį, skirtą TV spektro tuštumų geografinei duomenų bazei, naudojančiai sumaniojo radijo ryšio sistemas.

Tikslui pasiekti išsikelti **uždaviniai**:

- atlikti mokslinės literatūros analizę TV spektro tuštumų tema ir identifikuoti spektro tuštumų valdymo technologijas;
- nustatyti veiksnius, įtakojančius geografinės duomenų bazės verslo modelį;
- sudaryti geografinės duomenų bazės verslo scenarijus;
- sudaryti geografinės duomenų bazės verslo modelių klasifikaciją;
- nustatyti sudarytos verslo modelių klasifikacijos tinkamumą kiekvienam scenarijui bei nustatyti optimalią verslo modelio konfigūraciją.

Uždaviniams įgyvendinti taikyti **kokybiniai metodai**: mokslinės literatūros analizė, konsultacijos su ekspertais bei specialistais, konceptualus modeliavimas, paremtas scenarijų metodu.

Pirmoje darbo dalyje aprašomos egzistuojančios spektro trūkumo problemos ir apžvelgiamos potencialios technologijos, kurios gali išspręsti išanalizuotą problemą.

Antroji darbo dalis pristato tyrimo metodus ir nagrinėja verslo modelį bei jo principus, galinčius įtakoti technologijos inovaciją.

Trečioji darbo dalis siekia identifikuoti ir įvertinti potencialius TV spektro tuštumų geografinės duomenų bazės verslo modelius.

Pateikiamos darbo išvados atsižvelgiant į darbo naudingumą, praktiškumą ir esamus apribojimus. Pagrindiniai darbo **rezultatai:** nustatyta optimali verslo modelių konfigūracija, kuria remiantis būtų galima vykdyti tolimesnius tyrimus.

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INTRODUCTION

Wireless communications now plays a significant role in offering wide range of new opportunities that lead to more dynamic, "on-the-go" environment, enhanced productivity and much more. On the other hand, today's increasing variety of wireless communication systems is not a sign that radio spectrum is being used efficiently. Vice versa, due to the fact that radio spectrum is practically limited resource, emergence of new wireless systems enlarges the risk that radio spectrum will be crowded and different devices will interfere with each other, because applications need to share a practically limited resource, the radio spectrum. As a result, it can bring degrading performance, information loss or other unwanted issues. Moreover there is a lot of potentially available radio spectrum (TV White Space) that is enabled by the transfer from analogue to digital broadcasting and it can be used by new wireless communication systems. Taking into account, all factors refers to the need of more efficient spectrum management.

Cognitive Radio (CR) could fulfil this need but sharing of spectrum by CR would make it difficult to detect excessive sources of interference. This means that CR needs the controlling entity, which can help monitor spectrum for interference and to identify available channels and frequencies as well. Geo-location Database (GDB), Spectrum Sensing (SS) and Cognitive Pilot Channel (CPC) in the context of TV white space (TVWS) can contribute to control TVWS, but this does not imply that CR will be successful in operating in TVWS. CR is being existed for more that 10 years, but it is still not a commercial product. Due to this, it becomes clear that to be successful, CR needs to be more than just technically feasible; it needs to find a market that demands the unique benefits that the technology can offer. Thus in this thesis it will be focus on two areas of existing problem: informatics and business, such as not only technological but also political, economical and social factors.

The aim of the thesis is to develop Business Model for GDB for the more efficiently operation of CR in the context of TVWS bands by focusing on the actors' roles and scenarios-based development.

Tasks of the thesis:

1. To perform an analysis of scientific literature in the context of TVWS and to identify technologies of TVWS management.

2. To find factors influencing GDB Business Model.

3. To put forward GDB scenarios.

4. To construct classification of Business Model.

5. To provide experimental study of feasibility to deploy distinct classification of Business Model for the distinct scenarios of GDB.

The novelty of this research is seeking to find an effective Business Model for the integration of technological, economic, political and social challenges; because the new knowledge of GDB Business Models will help better understand how CR system can be deployed using a Business Model which is acceptable not only for the government (Communications Regulatory Service, The Department of Standardization, etc.), but also for the industry and the consumers. Parts of this master thesis have been published in the proceedings of "17-oji Tarpuniversitetinė magistrantų ir doktorantų konferencija" (see Appendix 7) as well as submitted to IEEE conference CAMAD 2012 (see Appendix 8).

The thesis is divided into three parts: exploratory, theoretical and analytical. Each part consists of several chapters, as follows:

- exploratory part: Overview of TV White Space as the next generation technology innovation;
- theoretical part: Knowledge approach to thesis methodology;
- analytical part: Identification of Business Model Configuration and Implementation of Business Model for Geo-location Database.

1. OVERVIEW OF TV WHITE SPACE AS THE NEXT GENERATION TECHNOLOGY INNOVTION

This part contains theoretical approach to the existing problem of subject of the study – **the need for more efficient spectrum management**. It is necessarily to give a short overview of essential theory that can base why it is matter of great relevance to our society. Furthermore, in this part of master thesis **TV White Space (TVWS)** and **technologies** that can help manage spectrum more effective in the context of TVWS are introduced.

Here the focus is only on the theory which is relevant to TVWS, because it is not reasonable to try to cover all bands. WS is wide and TVWS is just a small part of all existing bands. Due to this, access to TVWS can be a stepping stone to facilitate future dynamic access to WS in other bands.

1.1. Radio spectrum shortage problem

Today's world of wireless systems is rapidly evolving. According to the Cisco, global mobile data traffic is more than doubling for the fourth year in a row and the number of mobile-connected devices will exceed the number of people on earth by the end of 2012 [5].

On one hand, both in Europe and in all word, development of wireless systems creates new opportunities, puts technological and political basis for various innovations that can help faster and easier use additional functions. Today almost everywhere, every time we can use wireless communications, electronic ticketing, real time monitoring systems and many other wireless technologies that can help save time, money and provide wide-ranging opportunities to enter the international market or improve existing wireless systems. Wireless technology opens up an endless market of wireless communication applications, too [20].

On the other hand, as more and more wireless systems and their applications emerge in various sectors, the need for more efficient spectrum management also grows due to the limited nature of radio spectrum. Radio frequencies in Lithuania, according to the National Radio Frequency Allocation Table [58], are distributed from 9 kHz to 275 GHz (see Appendix 9). Frequency bands that are the most usable are used for data transmission: 136-174 MHz, 400-512 MHz, 800-960 MHz, 2.4 GHz and 5GHz, 10-12 GHz, 30-35 GHz and higher. In Lithuania the main part of 2.6 GHz radio frequency bands is used for so-called satellite television. It is expected to release in almost after year [19].

Moreover, despite new opportunities to communicate and create of constantly emerging wireless technologies, there still actual problems of:

- accessibility of communication;

- not overloaded wireless communication systems.

Moreover, the consumer content and applications that are offered by new wireless technology become not supported by previous generations of wireless devices and the emergence of all new wireless systems requires a separate radio channel or even several of them for data transferring. For example monthly basic mobile data traffic is as above [5]:

- single Smartphone can generate as much traffic as 35 basic-feature phones;
- single Handheld Gaming Console can generate as much traffic as 60 basic-feature phones;
- single Tablet can generate as much traffic as 121 basic-feature phones;
- single Mobile Phone Projector can generate as much traffic as 300 basic-feature phones;
- single Laptop can generate as much traffic as 498 basic-feature phones.

Therefore the risk increases that radio spectrum will become scare resource and wireless bandwidth will become more crowded and different devices will interfere with each other in near future. According to the Federal Communications Commission's (FCC) estimates, the surplus turns into a deficit as early as next year in providing voice, text and Internet services to its customers by the U.S. mobile phone industry (see Figure 1).

Figure 1. Spectrum Utilization [15]

Different colors in represent different use of spectrum: blue color shows the forecasting data spectrum, red – the spectrum assumed for voice services and green – the spectrum surplus/deficit over time

The FCC identified in its National Broadband Plan the need for at least 500MHz of spectrum to be auctioned off over the next decade to keep up with demand for wireless data [28]. If nothing is done the demand of radio spectrum will exceed available spectrum and it will have large influence by slowing down data speeds, reducing wireless innovation, increasing prices and much more for wireless customers. Even nowadays influence of spectrum scare is already appreciable to consumers, for example American multinational telecommunications corporation (AT&T) reduced unlimited data plans and throttled data transmission speeds due to the spectrum shortage [52].

One of the key step sources to satisfy the growing demand for the spectrum is radio channels used by analogue television (ATV); because high power TV broadcasts using the same frequency need to leave spaces between their coverage areas to avoid interference [39]. It is so-called **TVWS**. In other words, TVWS is these channels that have been allocated for terrestrial television broadcasting but which have not been assigned to the provision of television services in a particular license area [38]. Thus, TVWS arise for three reasons [38]:

- the need for guard spaces between ATV services in the same license area for the purpose to avoid mutual interference between the two services;
- the need for geographic separation between TV services that are different license areas but are broadcasting on the same channel that refers to the areas where the channel is unable to be used for TV services;
- the existence of areas where channels are not allocated to broadcasters for TV services, either because of the limited supply of broadcasting services or because there is limited demand for broadcasting services.

The range of spectrum available in between the signals used by television stations that denote TVWS is frequency in the UHF bands, between 470-790 MHz, because after the digital switch over, not all channels from 470 MHz to 790 MHz are occupied at each location. It is challenging to think of a TVWS use because spectrum is a fixed of nature and the only way to get more spectrum is to reallocate it or to allocate unused spectrum. Overall, spectrum that is already in use can be bought, sold and traded for more efficient use but it is impossible to grow, manufacture or import it [29]. Thus, emerging technological system has a choice of three possible options:

- *the use of existing channels*. But existing channels are already allocated to certain technologies, such as FM radio frequencies can only be used for FM radio transmitters, GSM phone frequencies – GSM phones, etc.
- *the selection of new channels*. New channels are assigned in World Radio Conference (WRC) that is proceeded only once per two years. During the WRC, adaptation of regulations of communication within radio spectrum refers to the systematization of the radio spectrum and determination of what areas of spectrum use must be taken into account in the framework of cross-border issues [12]. Thus, new channels allocation process is slow and difficult because the selection of new channels requires waiting for almost the "whole world" permission.
- *the use of unlicensed channels*. Unlicensed channels are used for Wi-Fi and for cordless phones of home networks (DECT systems). However, the risk that certain frequency channel will be crowded as well as communicating devices that use different channels will interfere with each other is very high by using unlicensed frequencies. In essence, the use of unlicensed channels could be a problem to the existing communication patterns.

In Lithuania ATV will be turned off on 29th October 2012 [59]. Forerunners to turn off ATV are: Netherlands, Finland and Sweden [21]. These important changes open up that the concept of TVWS can play a significant role in fully exploiting the advantages of spectrum, because untapped spectrum vacated by recent switchover to digital TV transmission can enable the TVWS communication opportunity between lower-power devices. TVWS can increase overall spectrum efficiency and innovative new services. According to the FCC Chairman Julius Genachowski, it has the potential to exceed even the many billions of dollars in of economic growth [14].

Besides the opportunities above, the concept of TVWS vacated by such the switch is nationwide and free to use, because it is not owned by any company although guided by rules. FCC rules are very important around the world, because United States (U.S.) was the first country to develop such regulations and because the rules evolved over many years [54]:

- *July 2008*: FCC decides to test prototype of CR devices (so-called White Space Device in TV broadband spectrum (TV WSD)) on unoccupied channels. Test caused discussion that there is the need of protection from entertainment industry, TV broadcasters and wireless microphone users (stadium events, theatres, etc.);
- *November 2008*: FCC allowed WS access with obligatory use of Spectrum Sensing (SS) and Geo-location Database (GDB) and added that there would still be need for additional development of TV WSD and testing before implementing WS access.
- *2009*: there are little legal grounds in order for U.S. National broadcasters to rule out the FCC's decision of November 2008 to allow WS access as there is no evidence that unacceptable levels of interference are to be endured.
- *2010*: FCC finalizes TVWS regulations, creating rules that will allow unlicensed wireless devices to operate in unused parts of TV spectrum, because they would create opportunities for investment and innovation in advanced Wi-Fi technologies and a variety of broadband services.
- *September 23, 2010*: WS regulations became official. Rules require TV WSD to consult GDB before accessing the broadband spectrum.

Thus, FCC rules require that unlicensed TV band devices contact an authorised database system to obtain a list of channels that are not occupied by authorized radio services and are available for their operations at their individual locations. These devices must operate only on those channels and do not interfere with incumbent services/systems. There have been concerns that using TVWS for Internet services would interfere with other wireless devices like microphones in nearby frequencies [25].

In other regions of the globe rules share similarities with those in the U.S., but also differs in a number of the ways; the main reason to differ is that the final regulations must be provided by the individual European member states, which could each be a little different. In Europe the different possible TVWS regulations has been studied by the Conference on Postal and Telecommunications Administrations (CEPT) [4]:

- *July 2008*: European white spaces were defined, with a main conclusion that further research and study was needed;
- *May 2009*: the European Communication Committee (ECC), within CEPT, has established a project called SE43 on CR systems in the TVWS.
- *December 2010*: technical, operational, and regulatory issues that need to be considered before TV WSDs can be implemented in the digital dividend bands were discussed in the 8th meeting of ECC CEPT's working group SE43.

As a consequence, discussion of December 2010 leaded to ECC report 159 [9]. Report depict that technologies should:

- protect broadcast service (BS) that refers to the fixed (rural and urban), portable and hand-held conditions;
- protect programme making and special events (PMSE) that refers to many different wireless production systems operating in a number of frequency bands;
- protect Radio Astronomy in the 608-614 MHz frequency band that refers to the secondary allocation to the RAS used for observations in a number of European countries;
- protect Aeronautical radionavigation in the 645-790 MHZ frequency band that refers to the radio system of short-range navigation (RSBN), air traffic control secondary radars, airfield and route primary radars;
- protect Mobile/Fixed services that refers to the band 790-862 MHz which is expected to be widely used by mobile communications networks in Europe very soon and band 450-470 MHz which is already used by mobile systems today.

It becomes clear, that freeing up more spectrum will not be enough to solve problem. The need of protection requirements means that there is the need for an electronically available central register of spectrum availability, license ownership and rights of use. Uncertainty currently exists concerning the way in which TVWS will be managed.

How to manage TVWS has been under debate in the U.S. at the FCC for years and now also in Europe. More efficient spectrum management, based on the **Cognitive Radio (CR)** principle, could help to address constraints for current and future radio communications [27]. CR could potentially contribute to solve this problem by enabling effective use of radio spectrum, of which TVWS is the first commercial opportunity. Based on a public workshop in Mainz (Germany) on 2-3 May 2012, organised jointly with CEPT ECC and also with involvement of European Telecommunications Standards Institute (ETSI), TVWS is only one use case for CR: many more use cases will follow if this is successful. Other spectrum bands where CR could be considered for deployment will follow some initial prime candidates:

- 1452-1492 MHz [30] and VHF T-DAB band. 1452-1492 MHz refers to so-called L Band and T-DAB refers to the bands that are allocated for public DAB services.
- Radar bands, fixed service bands. It refers to the wide band of transmitted frequencies in which radars system and fixed service works.
- 2.3-2.4 GHz frequencies.

Taking into account, CR can make more efficient use of the radio spectrum, because it is a technically viable novel form of wireless communication which would fulfil the regulators' strives for technology and service neutrality in spectrum management. CR can remove barrier to innovation by intelligently detecting which communication channels are in use and which are not, and instantly moving into vacant channels while avoiding occupied ones. In essence, CR is a promising new technology for enabling access to additional spectrum that is so badly needed [38]. Vice versa, CR must ensure that the TVWS devices do not cause harmful interference to the incumbent services operating in the occupied TV channels [45]. There is a variety of technologies developed that can ensure protection of the licensed services. It is likely that some technologies will be used widely in the future to allow commercial wireless systems to share spectrum with incumbent systems.

1.2. Prospective CR applications for TVWS

In the context of building the business case, CR paradigm in the wireless communications holds promise for new and better services to many markets, including public safety, military, and the consumer [40]. Some argue that in the long term, the cognitive approach could transform the whole wireless industry as it offers flexibility (it can be implemented in any frequency band and in any service), but this is yet to be proven and will require large investments in research [7]. Based on the same public workshop in Mainz (Germany) that is mentioned in previous chapter, it appears that in terms of envisaged CR applications, three came to the fore as likely leaders: indoor broadband, rural broadband and Machine-to-Machine (M2M).

First of all, CR may be used for **indoor broadband** that refers to the self-organization that is important requirement due to the increasing complexity of the future wireless networks [48].

Indoor broadband can include home-networking, cellular femtocells, Wi-Fi like and much more. For example, home network can help users perform complex optimization and management tasks in the context of CR concept by combining cross-layer optimization and learning mechanisms. There is increased interest in the deployment of small cells, because femtocells may help to improve cellular coverage and overall capacity by providing better cell-signal performance for both voice calls and cellular-data applications [3]. Wi-Fi like system constructed on top of UHF WS may reduce the time to detect transmissions in variable channel width systems by analyzing raw signals in the time domain [34].

A second prospective CR application for TVWS as likely leader is **rural broadband**. CR in the context of TVWS can be as a genuine solution to the problems of providing broadband in rural areas due to the TVWS low frequency ability to allow for signals to travel farther and to penetrate in the stone and brick walls, trees and the buildings. Richard Traherne, head of wireless at Cambridge Consultants, said: “We believe that WS, as a pioneering CR wireless technology, has the potential to change the way that people communicate, especially in rural areas” [6]. BT, the Official Communications Services Partner and a Sustainability Partner for the London 2012 Olympic & Paralympic Games [53], is already working with a consortium of the universities and vendors to test the potential suitability of the TVWS spectrum for rural broadband.

Furthermore, there might also be benefit with regard to the cognitive **M2M** that has a good potential for Lithuania as important contributor to Lithuanian economy in Lithuanian business such as transit/logistics [49]. The presence of CR capability in a wide range of future machines will allow those machines to talk to each other more ubiquitously than today [46]. M2M [61]:

- very low cost technology needed;
- very low power consumption;
- ability to handle large numbers of terminals efficiency;
- of small data packets efficiency;
- ability to work with a small and a simple antenna at the receiver.

Overall, the future impact of CR technology is still under debate in industry, academia, and in regulatory bodies, particularly for future exploitable and commercially viable prototypes and products [46]. In order to make these and others prospective CR applications exploitable and to create new business opportunities on CR technology, CR must be enabled by other technology that can provide a real-time knowledge on spectrum occupancy in order to identify available channels and frequencies and to protect incumbent services.

1.3. CR enablers

CR can be enabled by a variety of technologies of which **Cognitive Pilot Channel (CPC)** [41], **Spectrum Sensing** [43] or **Geo-location Database** [31] are the most considered ones (see Figure 2). It is this last CR technology that it will be focus on in this master thesis, because TVWS, regulators across the globe have been showing a preference towards a GDB approach. Nevertheless, there will be the short overview of the first two technologies, too.

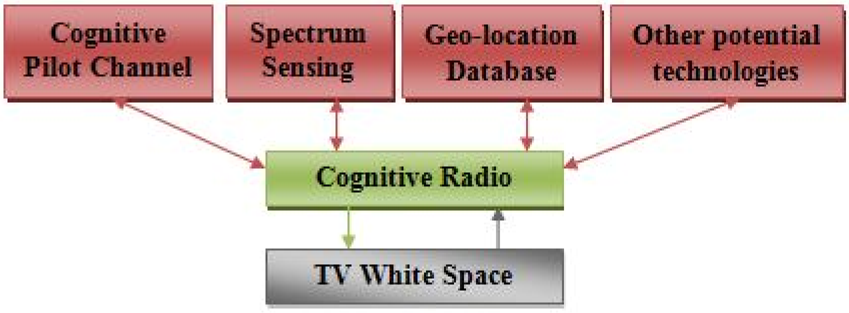

Figure 2. CR enablers in the context of TVWS (designed by author)
Double-arrow refer to the intelligent decisions of CR

The first CR technology refers to the overarching, active registry entity that could eliminate the need for continuous scanning of the entire spectrum (which would be very time and battery-consuming), while allowing services and Radio Access Technologies (RATs) to be changed without limits [41]. In a flexible spectrum management context, the concept of CPC has been proposed as a mechanism for providing the terminal with the necessary radio awareness at a given time and place [33]. Beside this, a harmonized CPC frequency could improve the cross-border functionality of devices on a regional or global scale. CPC refer to the info that is always available and have no hidden node problem. It could potentially communicate data such as pricing information and usage policies and could even be used to transmit missing protocols [41]. In essence, CPC can be developed in two different and complementary missions [33]:

- as enabler of the switch-on process that allows the mobile terminal to get in touch with the network side;
- as enabler of an efficient decentralized management along the on-going communication phase.

The second CR technology used to protect incumbent systems, referred to the literature as Spectrum Sensing (SS), is a technology embedded in the WSD that makes measurements of the radio frequency (RF) TV channels [38]. RF measurements help SS determine which channels are occupied by incumbent systems and which are unoccupied and are hence TVWS. The Radio Spectrum Policy Group defines SS as a real-time "map" of the radio environment [8]. Some factors, such as complexity of SS, absence of optimal reliability and being too costly, contribute to the removal of SS as obligatory measure to avoid interference. From ECC Final report 159 [9] it becomes clear that although it is possible to protect RAS by using SS, SS fails to protect Broadcast service and PMSE and there is need of further study due to protecting ARNS. SS as obligatory measure to avoid interference was removed on September 23th, 2010 in U.S.

The third technology, as mentioned above, despite the advantages of first two technologies, is the most feasible option to avoid possible interference. In ECC Report 159 [44][9], both SS and GDB were considered, while evaluating how both cognitive enablers meet the proposed technical requirements for protecting incumbent services (e.g. broadcasting, PMSE, RAS and ARNS) from interference from TV WSDs. From this report it becomes clear that GDB is clearly preferred over SS: GDB is preferred to protect both Broadbcast service and PMSE over SS. The FCC [17] came to this same conclusion earlier in 2010, when it decided to make use of a GDB mandatory for WSDs in the TVWS.

In the context of WS and CR technologies, the concept of GDB refers to an entity which contains current information about available spectrum as well as available services and other types of information at any given location [32]. Communication processes between GDB and TV WSDs that required providing their geographic location are real-time. The term "real-time" refers to the ability to view the spectrum usage in the TV band by location, and communicate the available frequencies to TVWS devices prior to letting them operate at this band. The FCC now says that giving devices geo-location capability and access to a spectrum database will be sufficient to protect broadcasters' spectrum from interference [2]. Ofcom expects that such a database may need to service millions of requests per day and that servicing each request may require a material amount of data processing [44].

From a business perspective, GDB controlling mechanism is not only as enabler for more efficient spectrum management, but the way in which they operate also helps define the rules of the game, from interacting with competitors, acquiring spectrum, getting access to users etc. [41].

Concerning the use of GDB for overarching, active controlling of the frequencies, there still uncertainty:

- *implementation* (who will pay for it, who can access it). It is not clear how to guarantee third-party database availability and interoperability of database. In particular, it is important whether the third-party database service provider will be policed by regulators.

- *database structure* (what it would look like). It is obvious that there can be quite some variation in "how" GDB completes different tasks such as acquiring, processing, storing and distributing geographic location information and what kind of information it actually uses and distributes as well as how GDB will get input and how frequent it will get update. There is the need multiple database to be checked due to the signals of feasible signals of the border of a region.

- *database administrator* (who would run it). On January 26, 2011 FCC appointed 9 TVWS database administrators: Comsearch, Frequency Finder Inc., Google Inc., KB Enterprises LLC and LS Telcom, Key Bridge Global LLC, Neustar Inc., Spectrum Bridge Inc., Telcordia Technologies and WSdb LLC (+ Microsoft).

Taking into account these uncertainties, GDB is proof-of-concept and can be cheaper than other CR technologies. For GDB there is no need of sensing hardware and there can be cheap services or even free services. Despite this, GDB has many opportunities concerning the rising geo-location applications. Thus, a good database should fulfil the needs of specific applications. Distinct needs for the database of specific wireless applications can lead to different GDB characteristics, of which the most important ones can be as follows:

- *Allowed degradation*. A database can allow some level of degradation, due to interference [42], to wireless signals within a specific frequency band. Of course, one of the main reasons for implementing GDB is to limit this kind of interference, so the allowed degradation should always be set low. However, some wireless applications would require GDB with allowed degradation close to zero percent. To serve these applications, a distinct type (e.g. more precise) of GDB is needed [47].

- *Database updating frequency*. Some applications require GDB to be able to update the info it contains quickly enough to enable the end-devices to base their decisions on accurate positional information [10]. The choice of database updating frequency for the wireless applications can be between high (every minute) and low updating (every day).

- *Channel reservation possibilities*. This GDB characteristic can guarantee that there will always be available channels for a certain subset of wireless applications. For example, in the U.S., there are always two reserved TVWS-channels in each market area for use by unlicensed wireless microphones. In case of a special event, wireless microphone venues can be registered beforehand. This makes sure that there are always channels available for wireless microphones and that they are protected from interference from other TV White Space devices [16].

- *Location data accuracy*. This characteristic refers to the GDB's level of detail of its location data. Some applications would require a database to have very location-specific data on the spectrum occupancy of that particular location, while other applications would only need information on a wide area in general. Therefore, the choice of location data accuracy can be between high (e.g. up to 1m accurate) and low location accuracy (e.g. up to 500m accurate) when devising GDB.

- *Harmonization*. Some wireless applications will also require GDB to be harmonized within a certain region, as these applications possibly operate across borders. A harmonized GDB would allow these applications to have unified access to GDB in all countries of the harmonized region. Furthermore, the harmonized GDB could provide cross-border spectral occupancy information.

- *The scope of spectral information*. It is a possibility for GDB to provide information on multiple frequency bands or on just one single, selected frequency bands. The latter occurs in GDB for TVWS. For TVWS devices, the only relevant spectral information that they require is the information on the TV bands. However, some wireless applications might switch between multiple frequency bands. For those applications, GDB with a larger scope of spectral information (e.g. not only limited to TVWS-bands, but also including bands such as the ISM-bands) is required.

- *Processing power*. Some GDBs will get consulted a lot more, while others might get limited database queries. This largely depends on the type of applications and number of end-devices using the services of the GDB. Furthermore, some databases will have to perform a high number of difficult calculations, thus requiring higher processing capacities, in order to support decision-making with regard to spectrum/channel selection.

- *Synchronization possibilities with own (local) database*. This could be the case for GDBs consulted by devices that already work in local networks and have some sort of centralized control entity in the form of a database. For those applications, GDBs are recommended to synchronize with this local database, while such a feature is not always needed in other situations.

GDB will always consist of a combination of the above listed characteristics.

1.4. Summary

Spectrum scare refers to the not well managed spectrum. Due to the limited spectrum, in more and more countries interest in telecommunications use of TVWS is fuelled by the now, because Internet usage still growing and the demand for wireless broadband access is still increasing. TVWS is a potentially useful source of spectrum, which can be shared by different communication technologies and services under the CR regulatory framework. But this leads to a new risks and challenges related to effective spectrum designation and control. Establishment of another controlling entity such as GDB can help to monitor spectrum usage under CR framework.

There is a range of different organizations that supervise and assess the environment in which the new technologies are developing. They look for ways to implement new technologies. Globally, GDB is currently well on its way as a candidate to enable CR and operate within the TVWS. There are some key works on this topic by variety of companies such as Spectrum Bridge

[60], Microsoft [26], Motorola [18]. Besides this, the development of radio communication issue is already included in the agenda of WRC and Lithuanian-run ESF COST Action “TERRA” [62] has the ability to impact the word’s radio communications development. The 5th COST-TERRA meeting had been held in Vilnius on 25-27 April 2012.

Many have questioned the Business Models which would lead to commercial development of CR and could also provide additional value and competitive advantage. It remains to be seen, however, how collaboration between different actors can be established around the use of GDB – i.e., what is the potential impact of different GDB Business Model configurations on different actors. Taking into account, there is the need to develop conceptual model to better understand the relationships between different elements of GDB and between GDB and market players.

2. KNOWLEDGE APPROACH TO THESIS METHODOLOGY

There is plenty of scientific literature about methodology of potential methods and models of scientific research. Business Models have been defined in the literature in numerous ways, too. It is argued that proper methods and models selection can influence the total success of the study because inadequate methods cannot help even genial scientist. Vice versa, relevant approaches that are well prepared and fitted can greatly facilitate the research and can improve the dependability of results of the research.

This part of master thesis presents **the framework of the scientific research process**, describes **chosen research approach** to be used to the study of the developing Business Model for GDB for the operation of CR in the TVWS space bands and introduces the **concept of Business Model** for TVWS operation.

2.1. Framework of the scientific research process

Scientific research should contribute to a body of science and follow the scientific method. Science refers to a systematic and organized body of knowledge in any area of inquiry that is acquired using the scientific method that refers to a standardized set of techniques for building scientific knowledge, such as how to make valid observations, how to interpret results, and how to generalize those results [1]. In the Oxford English Dictionary scientific method is defined as "a method or procedure that has characterized natural science since the 17th century, consisting in systematic observation, measurement, and experiment, and the formulation, testing, and modification of hypotheses" [23].

Based on scientific literature, scientific research works can be classified in numerous ways according to the applicable scientific methods such as methodology and the purpose of the research. Vice versa, all process of the research can be shown in the research cycle that constantly iterates between theory and observations (see Figure 3).

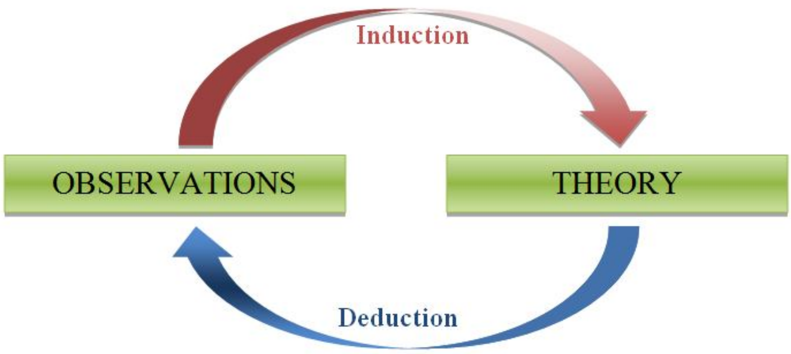

Figure 3. The Cycle of Research [1]
Different colored arrows denote different processes: red arrow shows generalization from observations, blue – testing of hypotheses

Two main possible forms of the cycle of research are induction and deduction. Depending on a researcher's training and interest, scientific inquiry may take one or two of them [1]. Inductive form of research refers to the theory-building, while deductive form refers to the theory-testing. Although both forms are critical for the advancement of science, goals of the researcher differ in the context of inductive or deductive research [1]:

- in inductive research, the goal of a researcher is to infer theoretical concepts and patterns from observed data;
- in deductive research, the goal of a researcher is to test concepts and patterns known from theory using new empirical data.

Most traditional research tends to be deductive and functionalistic in nature [1]. Developing Business Model for GDB for the operation of CR in the TVWS space bands can be so-called scientific induction that differs from the other types of induction because it can be used in combination with deduction. It is important to understand that results of the research are not valuable if they do not match with reality. Due to this, in this case deduction can help avoid accidental findings, equally, the results still expected in nature [57]. Figure 4 provides a schematic view of such the research project.

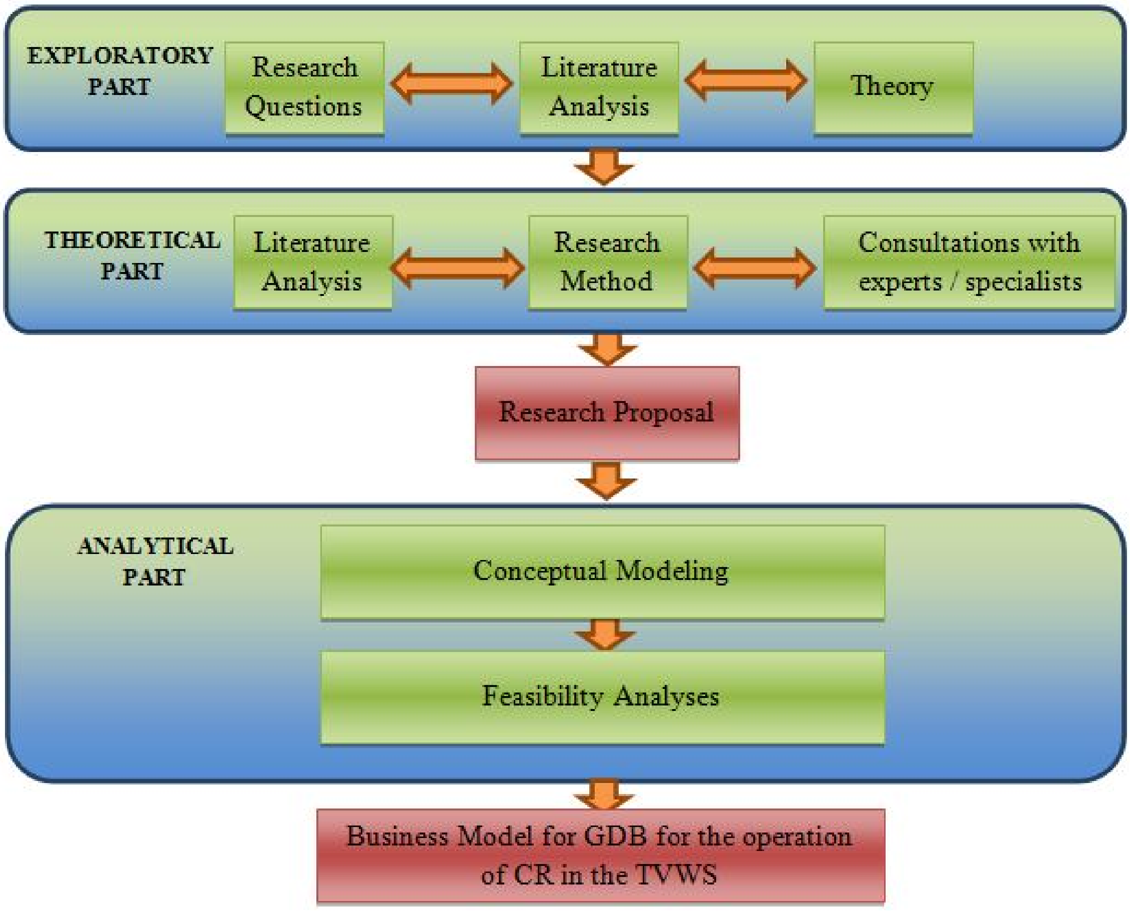

Figure 4. Developing Business Model for GDB process (designed by author)
The design of process of developing Business Model for GDB was modified from the functionalistic research process [1] to fit the needs of this master thesis

Exploratory phase of developing Business Model for GDB is proposed in the first part of this thesis. It is necessary to understand current stage of knowledge and gaps in knowledge, to identify key authors, articles, theories, and findings in the concept of TVWS before developing Business Model for GDB for the operation of CR in TVWS. In essence, published literature and theories helped answer questions that may lead to the construction of the proper Business Model for the proper technology – GDB that can enable CR in different ways. CR would be impossible to enter the market, if a number of economic and political issues haven't been solved. It becomes clear, that literature review should be reasonably complete, and not restricted to a few journals, a few years, or a specific methodology [1].

Due to this, literature analysis as a data collection strategy continues in the next – **theoretical phase** of process of developing Business Model for GDB. This phase also includes choosing research methodology and other data collection strategy such as consultations with experts/specialists. Research methodology must be chosen carefully. Not properly chosen methodology can influence the correctness of the results of the research. Which research method is employed and why, will be detailed in the next chapter. The next chapter will give short but detailed overview about performed consultations with experts/specialists, too.

Having decided the subject of the study, concepts that have to be measured and research method to be applied, the **analytical phase** can be performed. At this stage conceptual modelling and feasibility analysis based on the expert knowledge of the author are included. In this section of the thesis, the focus is on the characteristics of conceptual model because knowledge of GDB Business Model should be acceptable not only for the industry, but also for the governmental agencies (Communications Regulatory Service, The Department of Standardization, etc) – all players will benefit from having knowledge on what to expect from CR systems, how the innovation will proceed, in which technologies to invest, which technologies must be standardized, etc. Identification of Business Model Configurations and implementation of Business Model for GDB will be put forward in the 3 and 4 sections of this thesis.

Research proposals are discussed in the summaries of previous and present parts of the thesis. It is a good idea to write research proposals detailing all of the decisions made in the preceding stages of the research process and the rationale behind each decision. It can allow other researchers to replicate study, test the findings, or assess whether the inferences derived are scientifically acceptable [1].

Finally, having completed all the aforementioned phases, **Business Model for GDB for the operation of CR in the TVWS bands** can be developed. The Business Model will be discussed in more detail in the summary of the last part of this thesis.

2.2. Research methodology

All factors contribute to the importance of proper chosen research methodology. Depending on the type of data collected (quantitative or qualitative), methods may be **quantitative** or **qualitative** [1].

On one hand, **quantitative** methods are based on mathematical logic. Typically, they measure the variables. The quantitative study more attention could give to the context of ongoing activities, but the problem of this thesis is broad, not specifically defined and can't be quantified.

On the other hand, **qualitative** methods empower ideas and events. One of the major reasons for doing qualitative research is to become more experienced with the phenomenon in which researcher is interested in. Moreover, qualitative research can foresee hypotheses, register events, issues that can affect the description of Business Model for GDB. It becomes clear, that qualitative methods in this exploratory case study are more effective that quantitative.

Besides this, qualitative data analysis can be based on several data analysis methods. Data collection strategies used in this master thesis:

- literature analysis that helped describe CR in conceptual way;
- conceptual modelling that helped identify actors' roles;
- consultations with experts/specialists that helped cover wide range of concepts that are relevant to the developing Business Model for GDB in the context of TVWS.

It is this last strategy that it will be focus on here, because consultations with experts/specialists had a significant impact in response to many questions. Consultations were with researchers from IBBT-SMIT group of Vrije Universiteit Brussel (VUB) during the Short Term Scientific Mission (STSM) from 15/03/2012 to 30/04/2012. As much knowledge as possible from this group on specifics of Business Models for CR were gotten: it was a possibility to meet with different people at this department and asked them to tell about the research they do, so that to get as broad idea about Business Models and CR as well.

New Business Modelling methodology to be applied to the development and administration of TVWS database Information System has been learned during the first two weeks of STSM. VUB researchers Matthias Barrie, Simon Delaere, Olivier Braet and Prof. Pieter Ballon introduced to the specifics of Business Models that can be used for CR in the context of TVWS database development/commercialization. Matthias Barrie holds Masters Degrees in Communication Sciences and Marketing Management, Simon Delaere holds Masters Degrees in Communication Sciences and Communications Policy, Olivier Braet focuses on the economical and industrial dimensions of new information and communication technologies and Prof. Pieter Ballon specialises in Business Modelling, open innovation and the mobile telecommunications industry.

Consultations were also held with Vânia Gonçalves who graduated from Informatics and Computer Engineering and holds a master degree in Technology Policy [50].

Moreover, the Business Models and roles are illustrated in this thesis with the aid of the GDB that is under development by Dainius Jankūnas (VDU IF 1[nd] year MSc student) for the operation of CR in the TVWS bands.

2.3. Developing Business Model for TVWS operation

The concept of a Business Model can be defined as a way to describe the "architecture of a business". Barney, which can be situated in the resource and competence based literature, makes a distinction between:

- a firm's resources;
- capabilities/competences.

These two elements are leveraged to create products and services, which are bought to market with the aspiration of appealing to customers, and as such create customer value, which then translates into profits, cash flow and firm value (see Figure 5).

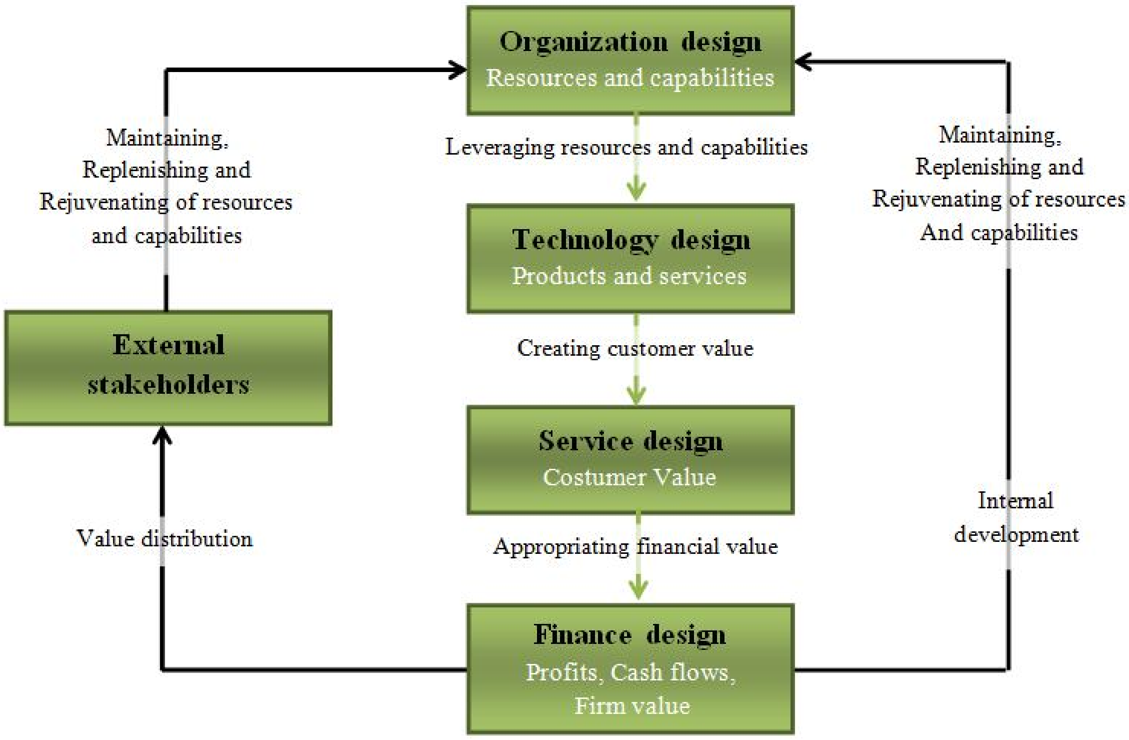

Figure 5. Value designs inspired by J. B. Barney [22]
Left and right sides represent two decisions of companies: on the right – profits reinvesting, on the left – revenue sharing with external stakeholders

Value designs inspired by J. B. Barney result in a circle of continuity (see Figure 6), which today acts as starting point to describe Business Models and which is the basis for Business Modelling Framework (see Figure 7), with 2 additions to Barney's work [37]:

- mobilizing resources and capabilities by creating shareholder value don`t necessarily take place in a chronological order – circular approach. All elements are not linear. Companies can depart from a vision to create customer value – the service design phase – and assess which organization and technology design is required to put this into the market.
- in the context of broad Business Modelling, there is a possibility to assess the impact of other actors surrounding the technical phases, namely external actors (competitors and suppliers) and surrounding the design phases, namely external stakeholders (consumers and their group).

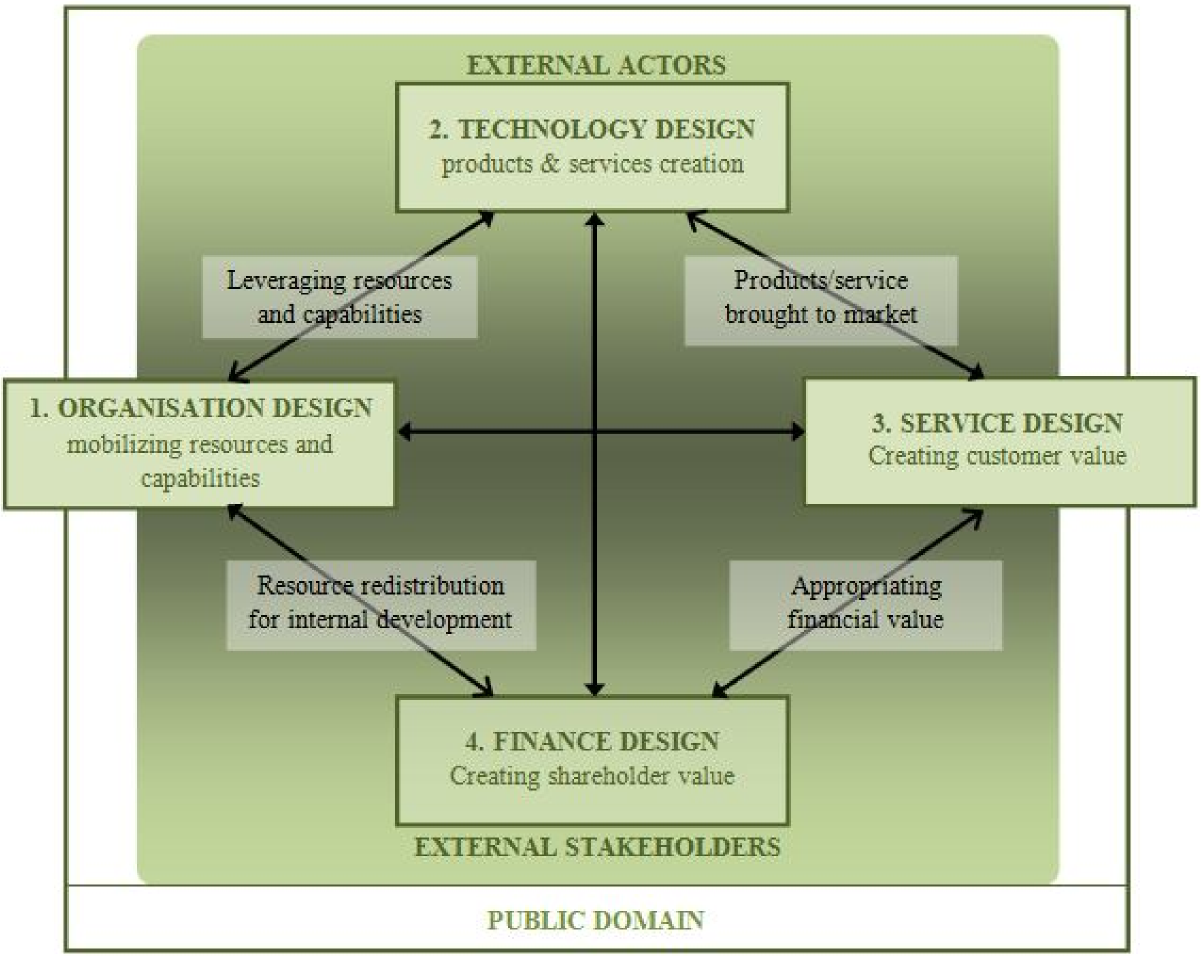

Figure 6. The circle of Continuity [37]
Public domain in this figure refers to the Government, Standardizing bodies, Societal resources and institutions

Thus, today the focus of Business Modelling has gradually shifted from the single firm to networks of firm, and from simple concepts of interaction or revenue models to extensive concepts encompassing [13][35]:

- the value network;
- the functional architecture;
- the financial model;
- the eventual value proposition made to the user.

All these elements combined create the Business Modelling matrix used to analyze the different potential Business Models for GDB presented in the analytical part of this thesis (see Figure 7).

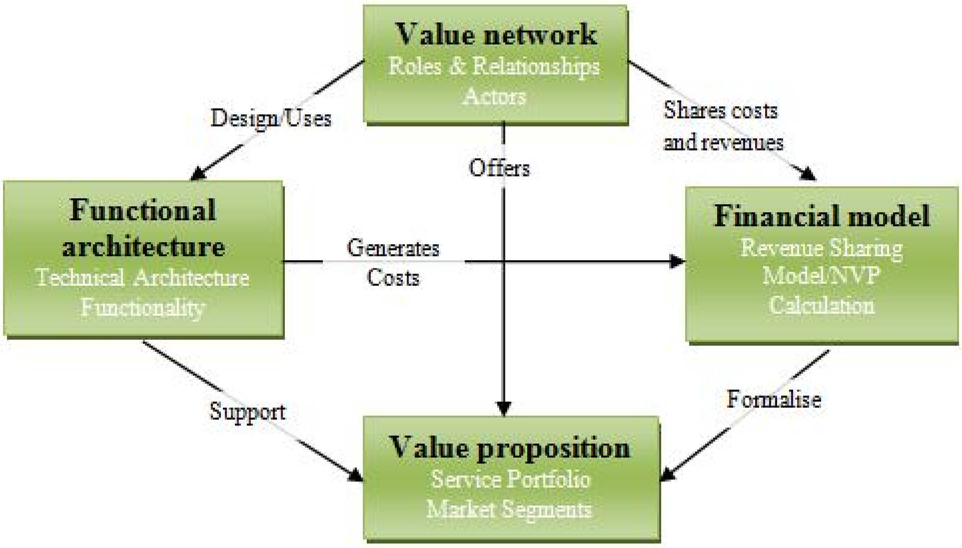

Figure 7. Business Modelling matrix adapted from Ballon [36]
In this framework value network refers to the organisation, functional architecture – to the technology and product, value proposition to the service and the financial model to the profit

Business Model design represented above helped distinguished between four "levels" of Business Modelling [36]:

- the level of the **value network**. At the value network level, three basic design concepts are needed, i.e. roles, actors and relationships. These design concepts refer to the distinct value-adding activity (roles), to the commercial entity active in the marketplace (actors) and to the expression of an interaction between roles or actors. The most basic design parameters for the value network are: the specific combination of assets, the level of vertical integration and the consumer ownership.
- the level of the **functional model.** The functional architecture is defined by the modules and interfaces between them, the distribution of intelligence within the system and the interoperability with other systems. At the functional level it is important to deal with technical systems composed of at least one building block or module.
- the level of the **financial model**. At the financial level, the most basic blocks are: cost (sharing) model, revenue model and revenue sharing model that refers to the way in which gained revenues are shared between actors.
- the level of the **value proposition**. At the value proposition level the most basic choices are to determine how to position the new service or product vis-à-vis existing services and products; whether a "finished" value proposition is made at all, or whether to allow substantial customer

involvement in constructing the value of the service and what the main value proposed to the market primarily consists of.

2.4. Summary

The target of this chapter was to define framework of the research, the proper methods and data collection strategies to be used to the development of the Business Model for GDB for the operation of CR in the TVWS. Business Model framework was also introduced in this chapter.

Qualitative research methods were chosen as a backbone for this research, such as:

- **exploratory literature analysis** as an independent method that helped find the latest works of other specialist, correct the progress of research, find solutions that can base the results of the research.
- **consultations with experts/specialists** from the IBBT-SMIT group of VUB that helped identify factors influencing implementation of CR, development of Business Model for GDB for the operation of CR in the TVWS bands.
- **conceptual modelling based on scenarios** that distinguish different GDB use in terms of economic/business aspects. Conceptual modelling with the aid of different scenarios can help express a number of complex events in the prospects of the development of the Business Model for GDB.

In this case induction helped analyze each of the made scenarios, search for the essential features and deny for random ones.

Developing Business Model for TVWS operation is based on **Business Modelling framework that is adapted from Ballon**.

3. IDENTIFICATION OF BUSINESS MODEL CONFIGURATIONS

Development of CR enabled by GDB demands on finding compromise solution in a complex task that requires technological, economic, political and social bases. Finding of compromise solution leads to the developing Business Model for GDB for the operation of CR in the TVWS bands.

This part of master thesis is based on the framework of Business Model presented in the theory part. It starts with **identifying factors, parameters, actors and roles in the future marketplace of GDB service** and ends with **categorization of Business Models for GDB** based on proposed parameters. In order to do so, GDB scenarios first putted forward.

3.1. Factors influencing GDB Business Model

Although GDB as enabler of CR can already be technically viable, it stills demanding to find an effective Business Model for the integration of economic, political, social and technological factors that refer to two problem areas: informatics (technological factors), and business (economic, political and social factors) (see Figure 8).

Figure 8. Factors influencing GDB Business Model (designed by author)
Different colors of problem areas refer to the current stage of solutions of the problem: green color denotes that informatics-only solutions for GDB exist already, but red color means that versatile approach is needed

Economic factors include costs (Capital and Operational Expenditure (CAPEX/OPEX)) and profit. It is important to analyse how GDB can influence economic indicators. The analysis should answer such questions as:

- how much and who should invest;
- how much expenditure it will need to support GDB;
- for what and who will make profit, etc.

Perhaps GDB may help reduce current number of unemployment by creating new potential workplaces in many fields of industry. Already now there is strong industry interest in the development of GDB although it is not implemented yet. In essence, it can open the door to the development of a new and exciting range of consumer and business applications.

Political factors are also important for the GDB implementation, because government can affect so many factors that are necessary for business:

- income tax;
- tax concession;
- price control;
- protection of consumer interests, etc.

Due to this it is very important position of government of GDB for the operation of CR. It becomes clear, that GDB must be validated; therefore legitimate factors are also very important.

Finally, **social factors** can influence further usage of GDB, because attitudes of consumers and government are also important due to the fact that GDB can be effective only when it is usable. Note that in order to use GDB not within the region, relationships between countries can become also essential factor that can influence the Business Model for GDB.

Business Models for GDB for the operation of CR in the TVWS bands is also influenced by:

- various **actors** and **roles** in value networks;
- **resources** owned and to be acquired;
- **capabilities** that emerge when mobilizing resources mentioned above.

3.2. Business Model implications of GDB

The framework of Business Model presented in the theory part follows the multi-parameter approach by defining four levels on which Business Model for GDB operates: the value network level, the functional architecture level, the financial level and the value proposition level.

First of all, at the **value network** level it is a key to show which actors take up which roles and how actors interact between each other. Here is the need to contract value chain in industry, because different stakeholders have different perceptions, expectations and understanding of the GDB. Even GDB can be implemented in different ways by two different companies that have the same associates and the same resources, because their interests and concerns differ from each other. In this regard, devising a Business Model for GDB should be concerned with the relationships between GDB and four five roles:

- TV WSD (technology). TV WSD determines its location and makes use of a database to get information on available frequencies at its current location by providing communications of broadband data and other services for consumers and businesses. The main question is how the GDB is foreseen to be used for TV WSDs.

- TVWS broker/user (market). Plenty of spectrum is available, but it is guided by rules. Furthermore, the amount of TVWS available at any given location differs depending on spectrum occupancy by the primary services, pre-defined conditions and criteria for "unused spectrum" and transmitter parameters and operational mode of the device that operate in the TVWS [7].
- administrator for developing and operating a TV bands database. On January 26, 2011, the Office of Engineering and Technology (OET) issued an Order designating nine entities to serve as TV white spaces database administrators [55].
- operators that offer services to consumers with the associated functions of TV WSD that promise a wide range of new opportunities due to the large variety of existing and emerging wireless applications. The most important thing to operators is the value that they could reach through GDB-enabled services.

GDB and regulators (policy) can be defined as actors that integrate these roles (see Figure 9). All devices and entities that are using GDB need to be accredited by an authority, ensuring that protocols and restraints/constraints are implemented and are available on any TV WSDs in order to comply with the database instructions and limitations.

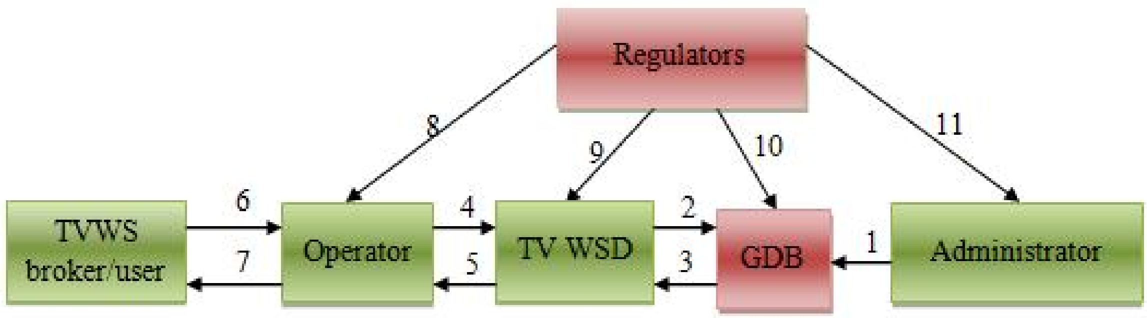

Figure 9. Business Model for GDB actor and roles (designed by author)
Numbers on arrows indicate different relationships between roles (green color) and actors (red color)

The one way in which relationships between the roles and actor could be defined is as fallow:

- arrow "1": developing and operating GDB;
- arrow "2": consulting GDB (asking which frequencies are free: TV channels that are vacant and can be used at device's location);
- arrow "3": responding with a list of the vacant channels (unused spectrum) and incumbent licenses operations entitled to interference protection; providing the TV WSDs with suitable operational parameters depending on its situation;
- arrow "4": consulting of available communications of broadband data and other services;
- arrow "5": providing communications of broadband data and other services;

- arrow “6”: subscribing the operator (TVWS broker also subscribes the operator as a customer but broker respectively provides retail and wholesale access to different technologies);
- arrow “7”: offering services to consumers and TVWS brokers with associated functions of TV WSD;
- arrow “8”: rules of licensed operators;
- arrow “9”: regulatory and technical conditions for TV WSDs, including transmit power limits and frequency or distance separation required to protect the broadcasting service and other incumbent services, including radio microphones in order to make device authorised [7];
- arrow “10”: regulatory and technical conditions for GDB;
- arrow “11”: allowance to make GDB available if the rules (e-CFR) and conditions are satisfied [11] [55].

Secondly, at the **functional architecture level** the most important goal is to deal with GDB technical system that is governed by certain rules and that interwork with other technical systems such as TV WSDs. Moreover, a good database should fulfil the needs of specific applications. In TVWS, the protection of incumbent services is the most important need. Therefore, some requirements that support the protection have to be met by the database. For example, a database for TVWS in the U.S. must acquire information from the FCC databases and synchronize with the FCC databases at least once a week [51]. From the CAMAD paper that is awaiting review results (see Appendix 8), it becomes clear that a database that is just meeting the minimum requirements for broadband through TVWS access, will not be sufficient for other, more demanding applications, such as the local conferencing system, for example. This conclusion can be the starting point for discussion on how the future of GDB will look like and which implementations (combinations of database characteristics) will prove viable.

At the third level (**the financial level**) in which Business Model for GDB can operate, costs can vary between high and low. The costs are high in small volume production, especially to introduce new technology such as that for GDB [42]. The main question here is how the different costs (capital expenditure, operational expenses, etc.) associated with starting up GDB. Costs can consider: cost of database system, extra software required (if extra to database system), extra hardware required (extra/upgraded Servers, broadband link, etc.), data transfer, training, data protection issues, maintenance of equipment and/or database system, upgrades of equipment and/or database system, backups, etc. Costs of energy, throughput, infrastructure and maintenance of GDB can be reasonable, while costs of hardware are low due to the possibility to reuse transceiver. Administrative costs may be also reasonable or low but special reuse of GDB depends on performance. Taxation of GDB can vary between:

- free access of database;

- free registration of devices;
- devices registration as well as database consulting fee (database consulting means asking which frequencies are free);
- subscription fee per manufacturer/operator.

Moreover, it is important to identify how GDB could influence the way in which revenue is generated for operators and whether or not revenue sharing model between operators need to be established.

Finally, at the **value proposition level**, the main question is how to position the new GDB's services vis-à-vis existing services and how GDB could influence services being delivered through market positioning. There can be discussion on how the future of GDB would look like. Will there be a generalization, a "one-database-supports-all", solution? Or will there be a fragmentation and specialization, a "one-database-supports-one-application" solution?

In case of generalization, GDB will have to consist of a combination of the GDB characteristics meeting the strictest application demands. Not only this GDB will need to compile all spectral information, it will also need to rapidly process and transmit this information. Furthermore, it will need huge amounts of processing power, along with added-value services (such as channel reservation). All of this will come at a significant price, while the monetization of such GDBs is still unclear.

In case of specialization, the major issue can be the compatibility of these specialized GDBs. While these distinct GDBs all serve applications with specific demands, their "client"-applications most likely operate in a heterogeneous wireless environment. This entails that there will be a need for good cooperation between the different technologies and applications within an area. As a result, good cooperation between their GDBs is evenly crucial. Making a large number of these specialized GDBs compatible could prove to be very complex.

A reasonable, initial approach could be to start off with a basic GDB for TVWS, such as the ones currently being developed by companies such as Spectrum Bridge, Microsoft and Neul, and gradually improving the database's scope, both in terms of spectral information (e.g. broader spectral information, more detailed information) and supported applications (e.g. not only broadband through TVWS, but also short ranged applications). GDB could then gradually grow, based on current market needs, and move closer towards a one-database-supports-all type of GDB.

3.3. Identification of GDB scenarios

Identification of GDB service deployment scenarios (see Figure 10) in terms of economic/business aspects can be based on three parameters: ownership, generalization, tradability.

First of all, **ownership** refers to the possible owner of GDB. Ownership of the GDB can either be unlicensed/licensed or public/private. In case of public ownership, the database administrator is the national or regional regulator. In case of private ownership, administrators can be commercial companies. The latter is found in GDBs for TVWS in the U.S., where multiple database administrators can set-up and manage the GDB [55].

Second parameter, **generalization**, refers to the exclusivity to be assigned to a licensee. Generalized GDB could not be exclusivity assigned to the licensee while specialised GDB could be exclusivity assigned to a licensee.

Finally, **tradability** refers to the possibility to trade TVWS bands.

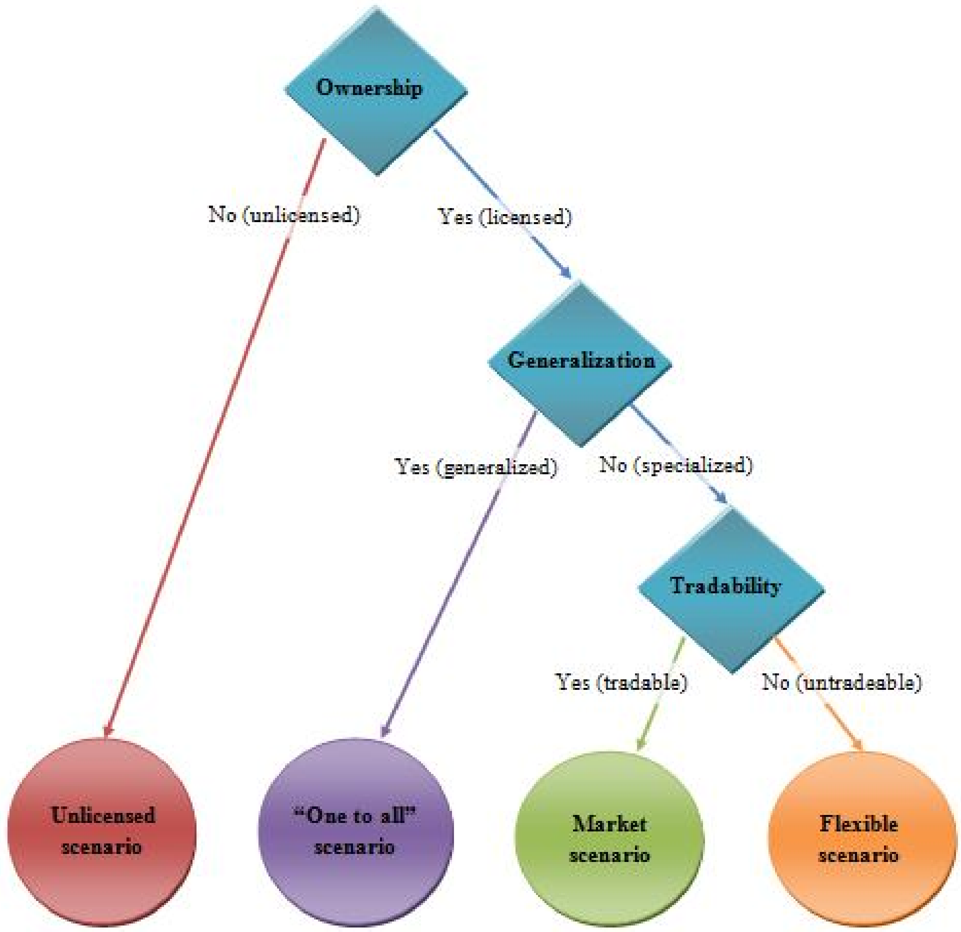

Figure 10. Identification of business scenarios for GDB service deployment (designed by author) Identification of business scenarios for GDB service deployment is inspired by identification of spectrum sensing scenarios published in the IEEE paper of M. Barrie, S. Delaere, P. Ballon [27]

Unlicensed scenario refers to the use of GDB within TVWS on a license-exempt basis. It becomes clear that such the use could be a problem to the existing communication patterns, such as Wi-Fi and DECT systems that use unlicensed channels (it could cause interference to broadcasting services). On the other hand, a license-exempt basis could have benefit to allow introduction of GDB for the operation of CR in the TVWS.

“One to all” scenario refers to the solution of generalized GDB that supports all databases. It is likely that no exclusive frequency band can be assigned to every single licensee although license ownership of GDB is the fact.

Market scenario refers to the allowance to specific bands to be tradable.

Finally, **flexible scenario** refers to the flexible bands (flexible operator) and to the flexible services (flexible user) that can enable to operators to dynamically coordinate TVWS channels and to users to switch between multiple operators.

3.4. Classification of Business Models for GDB

Classification of Business Models here is understood as distribution of different Business Models depending on common parameters, because here can be plenty of variations of Business Models for GDB for the operations of CR in the TVWS bands. It is clear, that some Business Models perform better than others. In order to get better view of possible Business Models for GDB, all models could be grouped in several classes depending on the main parameters that directly influence Business Model for GDB. Parameters on which classification of Business Models for GDB could be performed vary between control and value parameters (see Table 1). The more parameters are used to performed classification, the more detailed classes of Business Models could forth come.

Based on our previous research (see Appendix 8), it can be suggested that control parameters, such as **vertical integration** and **interoperability** are parameters that directly affect the Business Model of GDB. These parameters are related to the value network and functional architecture of Business Modelling matrix (see Table 1 and Figure 7 in Section 2.3).

Table 1

Business Model matrix [36]

CONTROL PARAMETERS				VALUE PARAMETERS			
Value Network parameters		Functional Architecture Parameters		Financial Model Parameters		Value Configuration Parameters	
Combination		Modularity		Cost (Sharing) Model		Positioning	
Concentrated	Distributed	Modular	Integrated	Concentrated	Distributed	Complement	Substitute
Vertical integration		Distribution of Intelligence		Revenue Model		User Involvement	
Integrated	Disintegrated	Centralized	Distributed	Direct	Indirect	High	Low
Customer Ownership		Interoperability		Revenue Sharing Model		Intended Value	
Direct	Intermediated	Yes	No	Yes	No	Price/ Quality	Lock-in

The first parameter that can lead to the classification of Business Models for GDB is **vertical integration**. Using this parameter all possible Business Models could be split between integrated and disintegrated models (see Figure 11). It is two ways in which roles are combined by actor, because the level of integration relates to the scope of the firm in terms of markets and industries in which it competes:

- strong vertical integration could be if there is one entity that supports GDB business activity and is involved in other parts of communications process;
- weak integration could be if GDB can be as dependent business activity not involved in any other parts of communications process.

The second parameter that can lead to the classification of Business Models for GDB is **interoperability**. Based on this parameter, all possible Business Models for GDB could be classified into interoperable and non-interoperable Business Model classes. As mentioned in other chapters of this thesis, there is uncertainty addressing the question on how the future of GDB would look like. Blind notes that interoperability with the products, services or systems of competitors is ambivalent [24].

Bases on these two parameters it is possible to distinguish between four Business Model configurations (see Figure 11):

- outsource-based configuration;
- operator-based configuration;
- broker-based configuration;
- user-based configuration.

Business Model configurations above are understood as more detailed Business Models classifications (disintegrated, integrated, interoperable and non-interoperable Business Models).

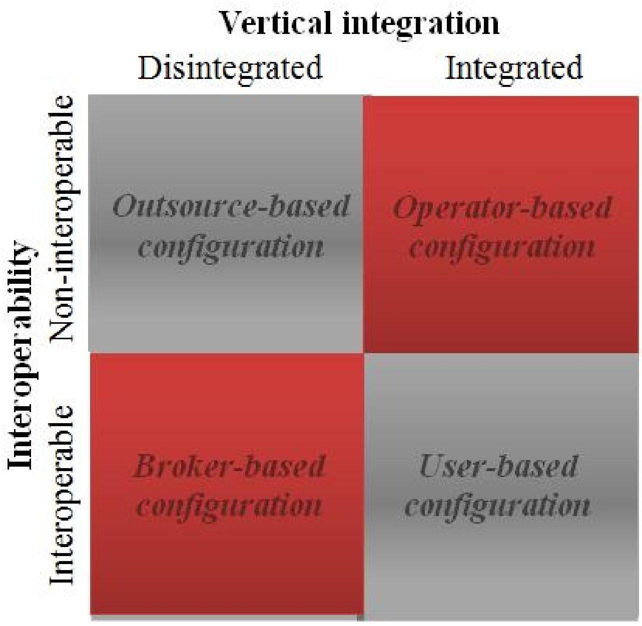

Figure 11. Business Model for GDB matrix based on two parameters (designed by author)
Matrix inspired by Business Model Configuration matrix published in the IEEE paper of M. Barrie, S. Delaere, P. Ballon [27]

Grey color in the matrix refers to the hybrid system (see Figure 12). Figure 12 illustrates, that the matrix view (presented in Figure 11) is determined by the following relationships (more detailed explanation of relationships presented in Appendix 10):

- vertically integrated GDB refers to the independent GDB ("one-database-supports-all" solution), and vice versa, disintegrated GDB refers to the dependent GDB ("one-database-supports-one-application" solution).
- interoperable GDB refers to "one-database-supports-one-application" solution, and, on the other hand, non-interoperable GDB refers to the dominant GDB ("one-database-supports-all" solution).

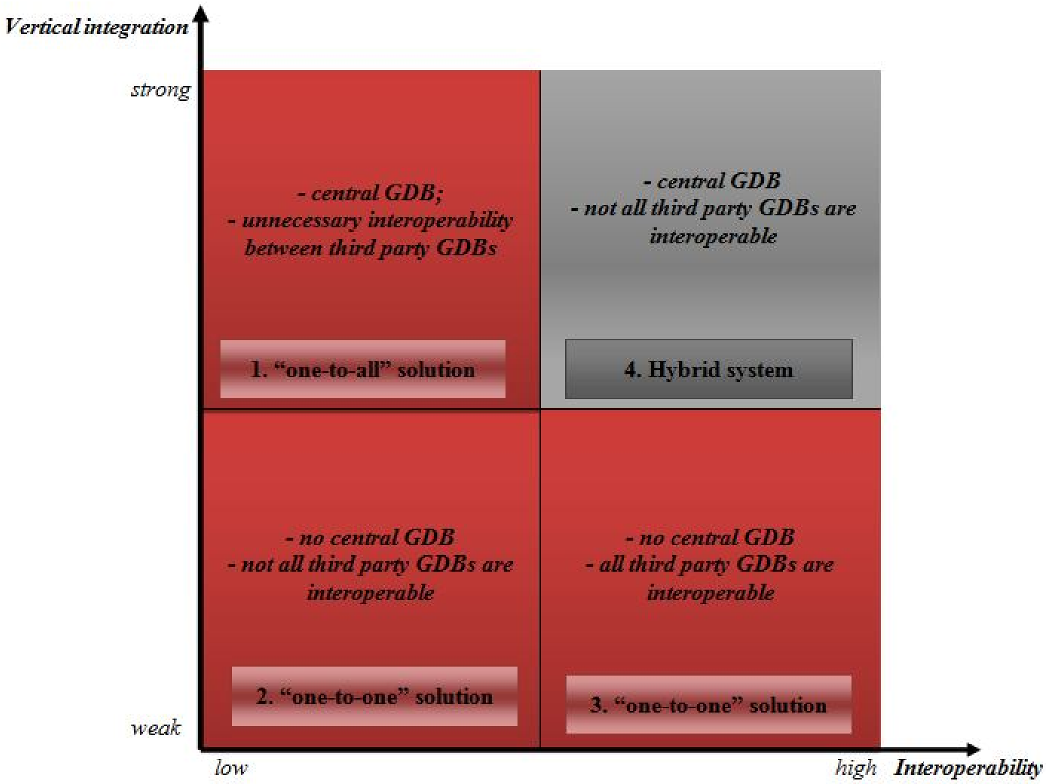

Figure 12. Business Model for GDB matrix from the factors point of view (designed by author) Hybrid system refers to the integration of both "one-to-one" and "one-to-all" solutions

In the case of **outsource-based configuration,** the main role is played by third party, which is aided by administrator who develops and operates GDB.

In the case of **operator-based configuration,** the main role is played by operator, although available channels are managed by GDB.

In the **broker-based configuration,** TVWS broker distributes available channels to various service providers.

Finally, in the case of **user-based configuration,** the main role is played by the users' devices (TV WSDs) in handling available channels.

It must be note, though, that while Business Model configurations as outlined above are theoretically possible, does not guarantee their implementation in the future.

3.5. Summary

Overview of this chapter with the main results and how they were perceived:

- Based on the basic Business Model design framework of Ballon to the concept of a GDB, four basic Business Model issues can be distinguished: **value network**, **functional architecture**, **financial approach** and **value proposition**.
- Based on three parameters (ownership, generalization and tradability), four groups of business scenarios for GDB service deployment can be found: **unlicensed scenario**, **"one to all" scenario**, **market scenario** and **flexible scenario**.
- Based on two control parameters (vertical integration and interoperability), four groups of Business Model configurations can be constructed: **outsource-based configuration**, **operator-based configuration**, **broker-based configuration** and **user-based configuration**.

4. IMPLEMENTATION OF BUSINESS MODEL FOR GDB

Business Model for GDB must be understandable for governmental and industrial agencies, also for service providers in order to commercialize CR technology in ways that will allow capturing value from their investments to the technology.

This part of master thesis provides experimental study of **feasibility to deploy distinct Business Model classification for the distinct scenarios of GDB** and the **main results** based on the analysis on the viability of developed Business Models for GDB for operations in TVWS. The goal of this part is to identify the optimal Business Model configuration in every scenario, based on the potential viability of each configuration and to choose the best solution to be implemented in the future for the use of GDB.

Analysis provided in this section was inspired by work of Barrie et al. [27] on viability of third party mobile service platforms to Spectrum Sensing. In this thesis, the method developed by [27] is adopted to the analysis of viable Business Models for GDB operation in TVWS bands.

4.1. Identification of Business Models within each scenario

Different GDB Business Models can be matched by different GDB service deployment scenarios. Within each scenario of GDB service deployment one or several Business Model configurations are possible (Table 2). Further evaluation of the viability of each Business Model configuration is in the following paragraph

Table 2

GDB service deployment scenarios and their possible Business Model configurations (designed by author)

		Scenarios			
		unlicensed scenario	"one to all" scenario	market scenario	flexible scenario
Business Model Configurations	outsource-based configuration		●		
	operator-based configuration		●	●	●
	broker based configuration			●	
	user-based configuration	●	●	●	●

Unlicensed scenario Business Model configurations. Unlicensed scenario refers to the so-called "win-win" situation, when there are plenty of license-exempt users that use different TV WSDs for the operations in TVWS for a range of broadcasting applications and they all feel that they perceive available spectrum as positive and don't think that they lose out in the process. On the other hand, different WSDs can interfere with each other on the large scale and can create very low barriers to entry for vacant channels. Thus on this unlicensed scenario Business Model configuration only the role of TV WSDs (WSDs' manufacturers) can benefit from transmitting radio signals by WSDs assisted by GDB that determines which TV channels and wireless microphones are being used in the device's area. The role of GDB as control entity in this Business Model configuration is likely to be mandatory in order to protect incumbent services but responsibility of it is the part of the WSDs' manufacturers without having information about this technology to the users (see Figure 13).

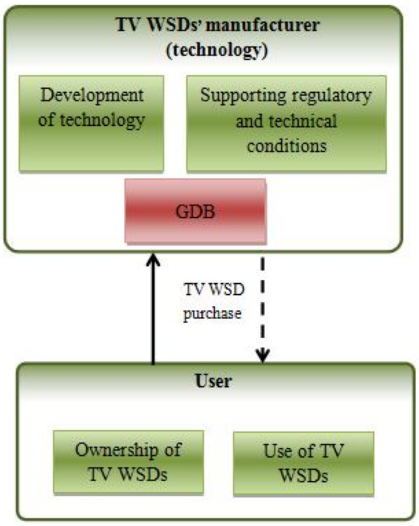

Figure 13. User-based configuration of unlicensed scenario (designed by author)
The dotted arrow refers to the fact that profit is gained by TV WSDs' manufacturers

However, since there is the first phase of a GDB introduction to the industry, one more aspect of this Business Model configuration could be to the administrators of GDB, as they can benefit from developing GDB while users enjoy free access to the database. Overall, such scenario is possible only within the user-based Business Model configuration (see Table 2).

"one-to-all" scenario Business Model configurations. On the contrary to the unlicensed scenario, "one-to-all" scenario can be possible not for only one Business Model configuration (see Table 2). This scenario can explain the way how GDB can support a large variety of existing and emerging wireless applications. In such scenario GDB can be used by licensed operator, user or third party to provide offloading capacity.

First of all, operator-based configuration refers to the directly communication between GDB and WSDs' (see Figure 14). In this configuration operators respect current actors and their roles and in such the way avoid interference that is the most important need for the GDB for the operation in the TVWS. All operators with the aid of GDB fulfill the needs of specific applications in their base stations' covered areas with the best quality of service to their users. The user might have opportunity to connect with different operators that offer different types of services.

Although the risk to interfere with other operators is low this configuration requires high investments into operators' infrastructure. On the other hand there is a need to develop and standardized GDB that can support all applications and all interfaces of operators. All operators need to have usage rights for GDB. Overall, in this Business Model configuration value network control and value proposition will inherently be higher than in other configurations, because:

- large parts of the value network are controlled by one licensed operator that possesses both technical and user-related intelligence in this way fixing relationship between TV WSDs' user and operator;
- the fact that the GDB resides within the domains of the operators that are selecting in view of the requirements posed by a specific services might make the technical infrastructure of GDB easier to maintain.

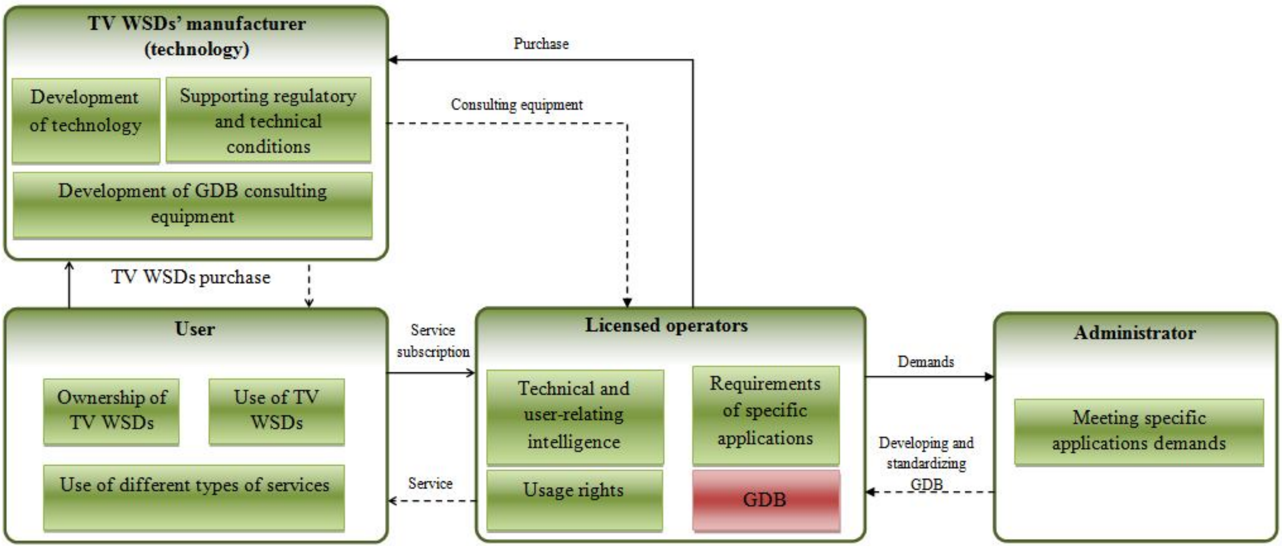

Figure 14. Operator-based configuration of "one-to-all" scenario (designed by author)
The dotted arrow between "User" and "TV WSDs manufacturer" refers to the fact that profit is gained by TV WSDs' manufacturers

Secondly, in user-based configuration (see Figure 15) the role of operators is independent, because TV WSD picks the best radio frequency channels out directly from the GDB. This implies that users act as customers of the services provided by licensed operators also of TV WSDs developed by manufacturers that must support regulatory and technical conditions. Factors that contribute to the viability of this configuration:

- operators do not need to pay the entire costs of consulting GDB, because users contribute to this by purchasing TV WSDs which have directly relationships with GDB;
- operators can not allocate more frequencies than needed by their consumers because frequencies allocation decision is made on a local level by users of TV WSDs.

On the other hand, this means that operators have no tight control of managing their frequency bands and they could become just infrastructure providers.

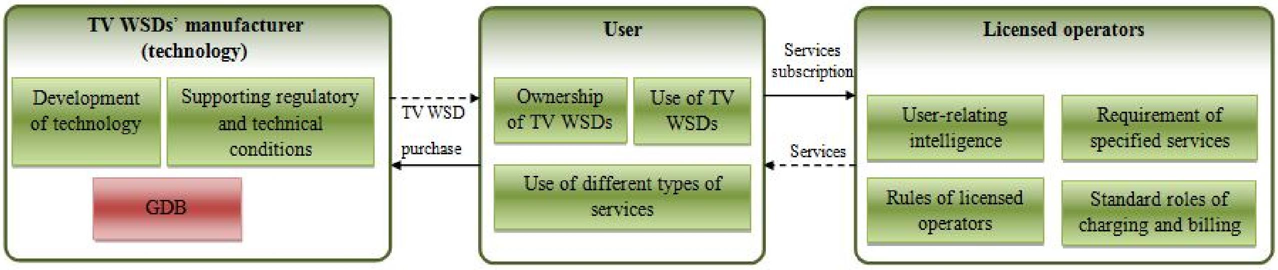

Figure 15. User-based configuration of "one-to-all" scenario (designed by author)
The dotted arrow between "User" and "TV WSDs manufacturer" refers to the fact that profit is gained by TV WSDs' manufacturers

Finally, outsource-based configuration refers to the optimized decisions, the best allocation and distribution of frequencies made by the third party with the aid of GDB (see Figure 16). This means that the cost of consulting GDB could be contributed by the third party and for each operator there is no need to bear whole amount of consulting fee – each operator needs to bear only small part of the total amount. On the contrary, this could become quite complex system due to the third party. Third party would need to create necessary interfaces and plans for distributing and allocating frequencies to the operators that have specific requirements for the frequency usage. This could come at a significant price.

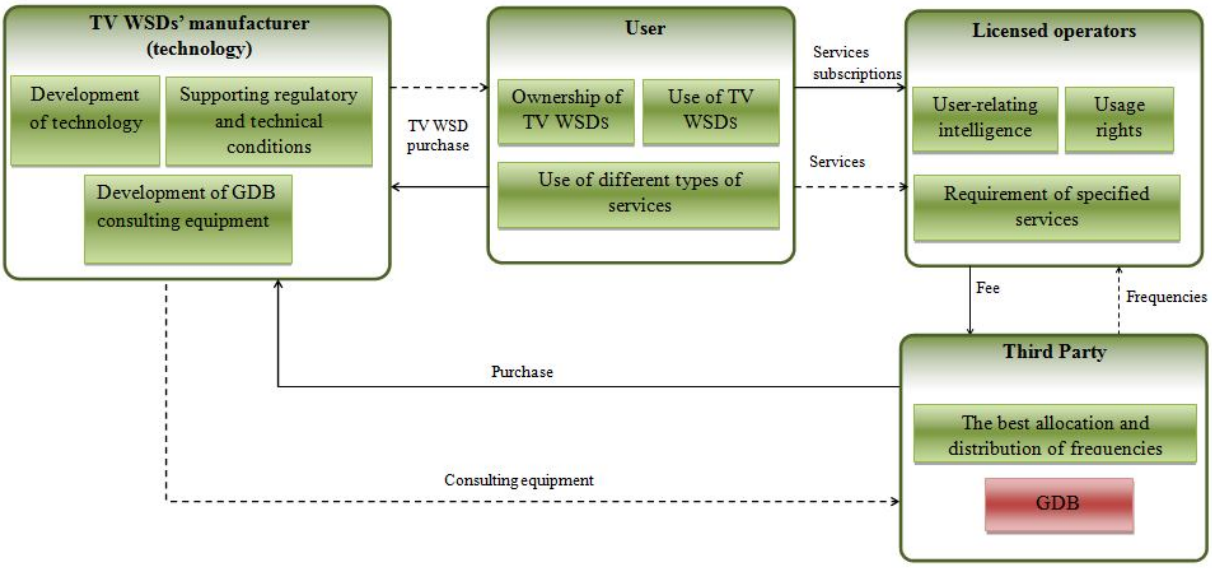

Figure 16. Outsource-based configuration of "one-to-all" scenario (designed by author)
The dotted arrow between "User" and "TV WSDs manufacturer" refers to the fact that profit is gained by TV WSDs' manufacturers

Outsource-based configuration of the "one-to-all" scenario above is the most likely to be implemented from the three theoretically possible scenario configurations. The main factor contributing to the viability of this model is that it might optimize decisions, the best allocation and distribution of frequencies. Well managed spectrum is very important to the current situation of spectrum shortage. Another factor that leaded to this decision is that outsource-based configuration is sufficiently optimal at a fair cost due to the fact that each operator needs to bear only small part of the total price.

It must be noted, however, that preferring one configuration over the other does not imply that other two configurations have no chance to be implemented in the future or that there can not be other configurations based on the "one-to-all" scenario, because there new actors (and factors) could come about.

Market scenario Business Model configurations. Like "one-to-all" scenario, market scenario also has three possible Business Model configurations: operator-based, user-based and broker-based. However, operator-based and user-based Business Model configurations are not the same as in "one-to-all" scenario, because market scenario fundamentally differs from the previous scenario: the same roles and actors interact between each other in different ways and their interests and concerns also differ. In this scenario there might be unknown and tradable frequencies that refer to the additional spectrum for some services.

In operator-based configuration licensed operator could allow to access his frequency to other operators that can be defined as secondary users (see Figure 17). Therefore, GDB in this configuration can be used not only for providing the device with suitable operational parameters depending on its situation but also to the discovery of usable spectrum from other licensed operators. Such Business Model configuration can benefit to the specialized GDB as there can be full data for many, but it is not useful to secondary users: they have no ultimate control over the frequencies but have to invest into GDB infrastructure and interfaces, because they must guarantee good cooperation between their GDB and licensed operator. Moreover, secondary use of spectrum owned by a primary user must not cause interference to the primary user(s).

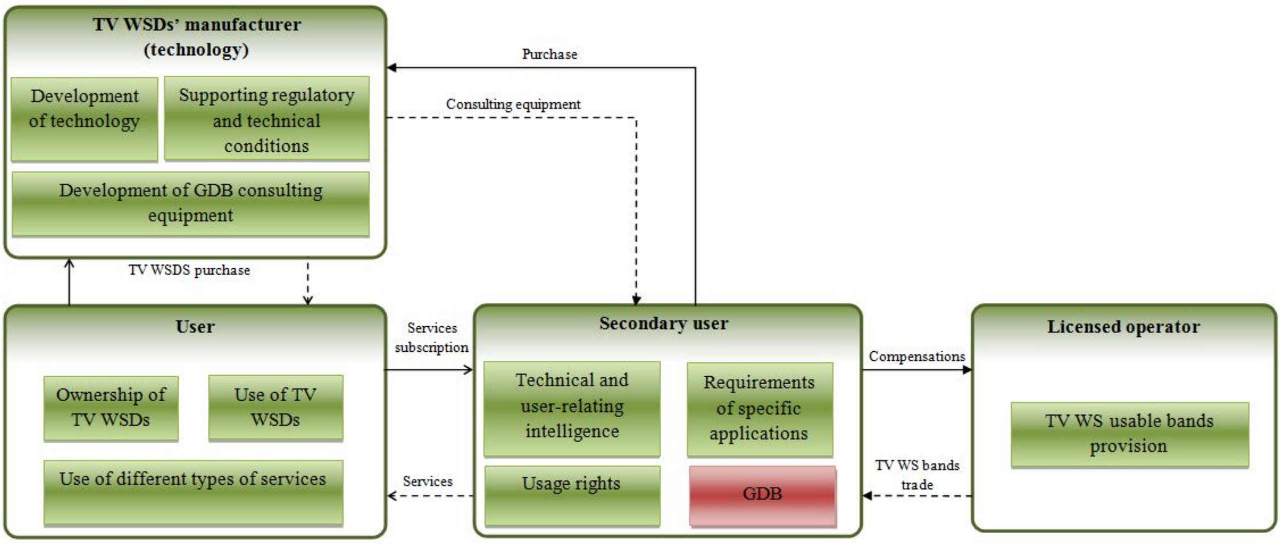

Figure 17. Operator-based configuration of market scenario (designed by author)
The dotted arrow between "User" and "TV WSDs manufacturer" refers to the fact that profit is gained by TV WSDs' manufacturers

Secondly, user-based configuration (see Figure 18) refers to the main role of user to find unutilized frequency allocation as the licensed operator could also allow other operators accessing its frequency. On the contrary to operator-based configuration, in user-based configuration there is no need for secondary users to scale the total infrastructure cost investment. In such scenario also users bear a part of the total cost, because they have direct relationship between TV WSDs that support GDB.

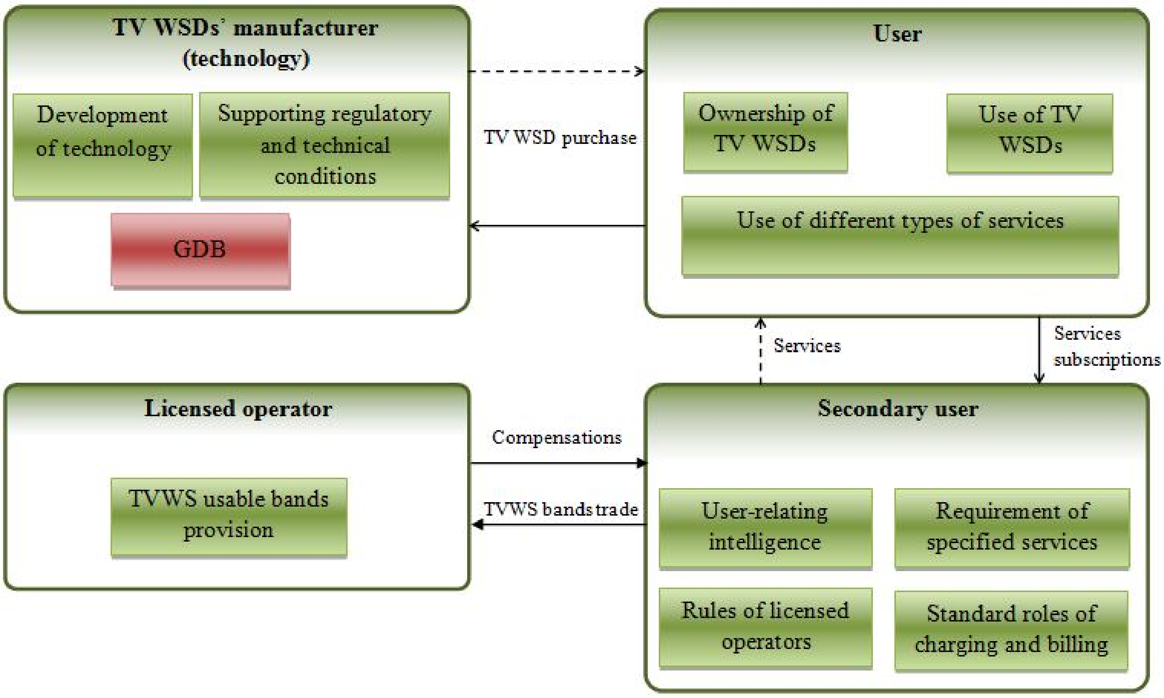

Figure 18. User-based configuration of market scenario (designed by author)
The dotted arrow between "User" and "TV WSDs manufacturer" refers to the fact that profit is gained by TV WSDs' manufacturers

Finally, broker-based configuration (see Figure 19) refers to the dynamically (automatically or not) look for the best possible available frequencies from licensed operators while avoiding one-to-one queries and negotiations over trading of TVWS bands with every single licensed operator. This brings additional costs to secondary users, but guarantee, that there will be assured quality of services, avoided interference and the optimal utilization of frequencies traded from licensed operators. Moreover this Business Model configuration can enable different multiple payment options, such as:

- secondary user could pay directly to licensed operator or operators and TVWS Broker;
- secondary user can pay only directly to TVWS Broker that in turns takes care of paying the licensed operators or operators.

Later on in this configuration, the broker's information about excess frequencies of licensed operators can be used in the GDB as specialized domain of the GDB.

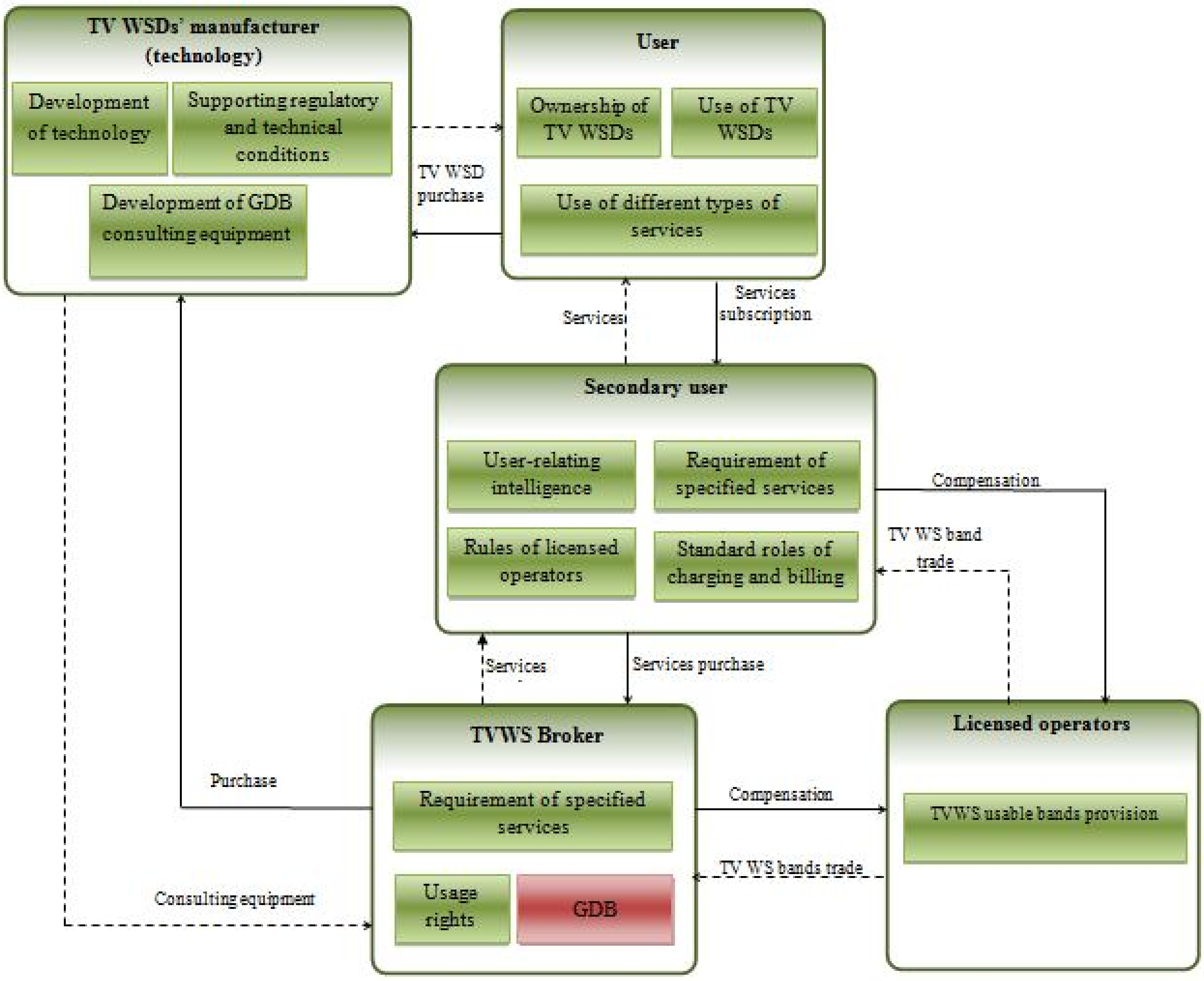

Figure 19. Broker-based configuration of market scenario (designed by author)
The dotted arrow between "User" and "TV WSDs manufacturer" refers to the fact that profit is gained by TV WSDs' manufacturers

In market scenario of all three theoretically possible Business Model configurations, it is likely that broker-based configuration has the best chances to be implemented because of the low cost of consulting GDB and additional options, for example, the choice of multiple payments for secondary user.

Flexible scenario Business Model configurations. In this scenario frequencies can not be traded and no other operators can access bands that are not exclusively assigned to them as stated in their license agreement. From the user side, user could choose between listed operators by optimizing their preferences. In this scenario there can be two preferable Business Model configurations: operator-based and user-based configurations.

First of all, operator-based configuration could be used for GDB in such scenario (see Figure 20). This means that operators are exclusively assigned frequency band and consulting the GDB could only make a list to the TV WSDs of available frequencies linked with specific operators assigned to these frequencies. Moreover, the cost of GDB consulting equipment is included into TV

WSDs purchase and in such way distributed among users. It is the main benefit of this configuration to operators.

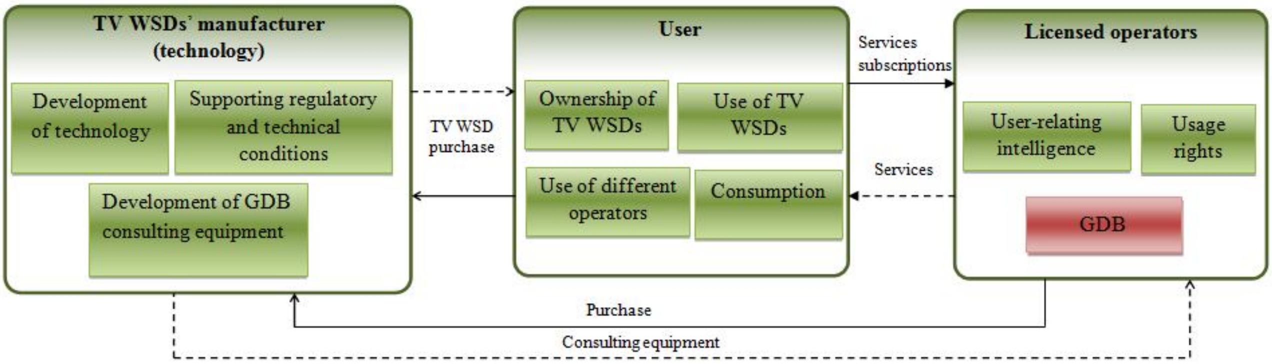

Figure 20. Operator-based configuration of flexible scenario (designed by author)
The dotted arrow between "User" and "TV WSDs manufacturer" refers to the fact that profit is gained by TV WSDs' manufacturers

In user-based configuration (see Figure 21) possibility to discover multiple operators (switching between available networks) can provide the user with the best subscription service. Overall, increasing efficiency of services of the operators could reduce Capital and Operational Expenditure (CAPEX/OPEX) or value to the user.

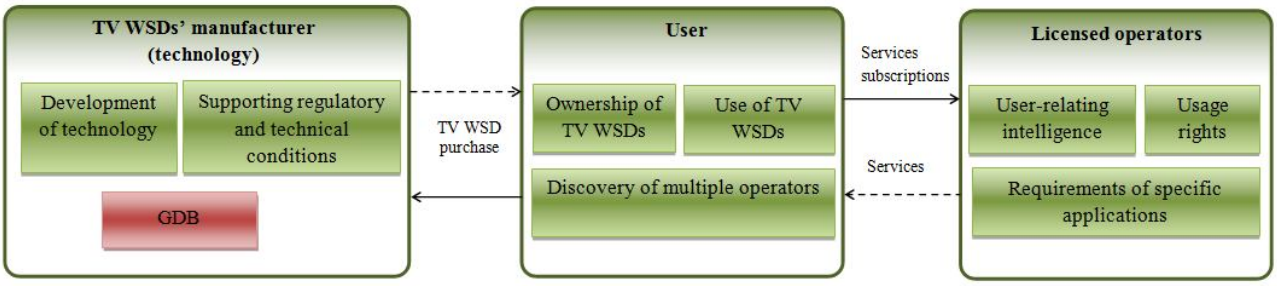

Figure 21. User-based configuration of flexible scenario (designed by author)
The dotted arrow between "User" and "TV WSDs manufacturer" refers to the fact that profit is gained by TV WSDs' manufacturers

From both (operator and user) point of view, in this flexible scenario both Business Model configurations have slightly good chances of success.

4.2. Summary

This chapter was for evaluating the potential viability of each Business Model configuration. Evaluation showed that the most optimal Business Model configuration for the future to the GDB use for the operation of CR in the TVWS band is **outsource-based configuration** (see Table 3). In Table 3, outsource-based configuration is possible only in "all-to-all" scenario but it stands the best chance to be implemented in the future. Although **user-based configuration** is possible in the unlicensed and in the flexible scenarios, it is not certain that this configuration will be implemented in the future, because user-based configuration in unlicensed scenario can benefit only in the first phase of GDB introduction and the same configuration in flexible scenario has very low probability to happen in the near future. One liability in the chance of success of such Business Model configuration in the flexible scenario implementation is agreement of operators on such a Business Model. Similar to the user-based configuration, **operator-based configuration** has also not the best chances of success. Finally, **broker-based configuration** due to the enormous power shift towards the broker is not one of perspective Business Model configuration, too.

Table 3

Most viable Business Model configurations per scenario (designed by author)

Business Model Configurations	Scenarios: unlicensed scenario	"one to all" scenario	market scenario	flexible scenario
outsource-based configuration		🟢		
operator-based configuration		🔴	🔴	🟢
broker based configuration			🟢	
user-based configuration	🟢	🔴	🔴	🟢

🟢 – the most viable Business Model configurations

🔴 – suboptimal Business Model configurations

CONCLUSIONS

The original goal of this thesis was to analyze how technological, economic, political and social factors can be integrated into Business Model for Geo-location database as a controlling entity for operation of Cognitive Radio devices in the TV White Space spectrum range. However, the findings of this work have pointed out that there is no single best solution available within each scenario, but outsource-based Business Model configuration stands the best chance of being implemented in the future.

It is necessary to experiment the proposed business architectures with regard to both technical and business-oriented parameters in order to get a better view on the opportunities and challenges that they pose. Given the nascent nature of the Cognitive Radio technology and qualitative approach used in this study (more) precise and detailed recommendations could not be given here.

The important conclusion, however, is that, overall, TVWS is today's way to solve spectrum scarcity problem. Successful deployment of TVWS spectrum cannot be achieved without assured protection from interference services in TVWS band, as well as licensed communication services in adjacent bands. In scientific literature there are several specified methods that can be used to protect incumbent services. One of the most likely method to be used for this task is Geo-location database deployment of which is currently well on its way. Although there is much variety of opinion with regard to the sufficiency of the GDB as CR enabler, there seems to be some regulatory preference (both in the US, as well as in Europe) with regard to this option for exploiting so-called TV White Spaces.

Usefulness/practicality of this thesis:

1) New approach to the design of GDB. Informatics-only solutions for GDB already exist, for example, COGEU [56], Spectrum Bridge projects, Microsoft and Neul projects, but versatile, comprehensive approach that shows influence of economic/political/social factors is needed.

2) New opportunities to use GDB for other than TVWS radio bands. If GDB will prove good for TVWS it can also be used for other radio bands.

3) Possibility to motivate Communication Regulatory service (RRT). In Lithuania, RRT is taking a passive stance with regard to TVWS utilization for CR applications. This work can motivate them to run trials, allow service innovation, etc. It is already discussed about this work with delegates of RRT and findings presented in this thesis are expected to be brought to the attention of RTT.

4) Plans to publish the results of this work. Business Model for GDB for the operation of CR in the TVWS developed in this work is considered to be presented/published in the nearest conference.

Limitations:

1) **CAMAD paper is awaiting review results** – if accepted, it will be a proof of validity of research findings. However, the findings presented in the paper have already been discussed with colleagues and will be used in further research, for example, specific GDB projects for hospitals.

2) **The analysis part of this thesis is based on expert knowledge of the author.** The results presented, therefore, have to be validated with a number of different stakeholders of CR, policy, academic researchers, industry, etc.

Acknowledgements:

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APPENDICES

Appendix 1

Summary of the 1st research work in English

ABSTRACT

Author of research paper:	Gintarė Sukarevičienė
Full title of research paper:	The main Lithuania's political parties' marketing activities
Supervisor:	dr. Lina Pilelienė
Presented at:	Vytautas Magnus University, Faculty of Economics and Management, Kaunas, December 2010
Number of pages:	30
Number of tables:	4
Number of pictures:	7
Number of appendices:	3

The aim of the work: to propose opportunities for the improvement of the main Lithuania's political parties' image.

Used methods in the work:

1. Analysis and generalization of the scientific literature;

2. Usage of *Google Trends* tool for comparing multiple websites;

3. Analysis of statistical data, carried out researches and prepared marketing programmes of the main Lithuania's political parties.

Lithuanian and foreign authors' books and literature in the *Internet* have been used for the research.

The basics results of the work:

In first part of this research paper the concepts of public relations, model for political marketing, political image, as well as various authors' approaches to the analyzed topics are reviewed.

In the second part of this research paper analysis of the main Lithuania's political parties have been done. Importance of proper political image to the political parties has been validated. Moreover, analysis of the popularity of social networks has been accomplished. In order to do so, establishment of sources for image representation of the main Lithuania's political parties has first been completed.

In the third part of this research suggestions for the improvement of the main Lithuania's political parties' images have been proposed.

Appendix 2

Summary of the 1st research work in Lithuanian

SANTRAUKA

Darbo autorius:	Gintarė Sukarevičienė
Darbo pavadinimas:	Pagrindinių Lietuvos partijų marketingo veiklos tyrimas
Vadovas:	dr. Lina Pilelienė
Darbas pristatytas:	Vytauto Didžiojo Universitetas, Ekonomikos ir Vadybos fakultetas, Kaunas, 2010 gruodis
Puslapių skaičius:	30
Lentelių skaičius:	4
Paveikslų skaičius:	7
Priedų skaičius:	3

Darbo paskirtis: pateikti pagrindinių Lietuvos politinių partijų įvaizdžio gerinimo galimybes.

Darbe naudojami metodai:

1. Mokslinės literatūros analizė ir apibendrinimas;

2. Internetinių svetainių palyginimo priemonė: *Google Trends*.

3. Statistinių duomenų, atliktų tyrimų bei parengtų politinių partijų marketingo programų analizė.

Tyrimui naudota spausdinta ir internete pateikta Lietuvos bei užsienio autorių literatūra.

Pagrindiniai darbo rezultatai:

Pirmoje dalyje pateikta glausta teorinės informacijos interpretacija. Šioje darbo dalyje teoriškai analizuojamos viešųjų ryšių, politinio marketingo modelio bei politinio įvaizdžio sampratos, taip pat pateikiamas įvairių autorių požiūris į analizuojamas temas.

Antroje dalyje atliekama pagrindinių Lietuvos politinių partijų analizė, pagrindžiama tinkamo įvaizdžio pateikimo svarba politinėms partijoms, nustatomi pagrindiniai pagrindinių Lietuvos politinių partijų įvaizdžio pateikimo šaltiniai, atliekama socialinių tinklų populiarumo analizė.

Trečioje darbo dalyje pateikiami pasiūlymai kaip Lietuvos politinės partijos gali gerinti savo įvaizdį.

Summary of the 2nd research work in English

ABSTRACT

Author of research paper:	Gintarė Sukarevičienė
Full title of research paper:	Visualization and analysis of political data
Supervisor:	dr. Tomas Krilavičius
Presented at:	Vytautas Magnus University, Faculty of Informatics, Kaunas, June 2011
Number of pages:	20
Number of tables:	4
Number of pictures:	8
Number of appendices:	3

The aim of the work: to analyze different multidimensional scaling models and to apply them to the main Lithuanian political parties' data visualization.

Used methods in the work:

1. Analysis and summation of scientific and experimental achievements in multidimensional scaling;

2. Search and filing of the information.

3. Programmable simulation with "R" statistical package, which uses "R" keynote and has several graphical user interfaces (*GUIs*).

Lithuanian and foreign authors' books and literature in the *Internet* have been used for the research.

The basics results of the work: multidimensional scaling models and their adaptability have been analyzed; main Lithuanian political parties have been compared.

Appendix 4

Summary of the 2nd research work in Lithuanian

SANTRAUKA

Darbo autorius:	Gintarė Sukarevičienė
Darbo pavadinimas:	Politinių duomenų vizualizavimas ir analizė
Vadovas:	dr. Tomas Krilavičius
Darbas pristatytas:	Vytauto Didžiojo Universitetas, Informatikos fakultetas, Kaunas, 2011 birželis
Puslapių skaičius:	20
Lentelių skaičius:	4
Paveikslų skaičius:	8
Priedų skaičius:	3

Darbo paskirtis: išanalizuoti skirtingus daugiamačių skalių analizės modelius ir pritaikyti juos vizualizuojant pagrindinių Lietuvos politinių partijų duomenis.

Darbe naudojami metodai:

1. Mokslinių ir eksperimentinių pasiekimų daugiamačių skalių analizės srityje analizė ir apibendrinimas;

2. Informacijos paieška ir sisteminimas;

3. Programinis modeliavimas naudojantis statistikos paketu „R“, naudojančiu „R“ kalbą ir turinčiu kelias grafines vartotojo sąsajas.

Tyrimui naudota spausdinta ir *Internete* pateikta Lietuvos bei užsienio autorių literatūra.

Pagrindiniai darbo rezultatai: išanalizavus daugiamačių skalių modelius ir jų taikymo ypatumus, jie buvo pritaikyti lyginant pagrindinių Lietuvos politinių partijų panašumus ir skirtumus skleidžiant apie save informaciją *Internete*.

Appendix 5

Summary of the 3rd research work in English

ABSTRACT

Author of research paper:	Gintarė Sukarevičienė
Full title of research paper:	Cognitive radio: technology evolutionary perspective
Supervisor:	Dr. Vladislav V. Fomin
Presented at:	Vytautas Magnus University, Faculty of Informatics, Kaunas, December 2011
Number of pages:	26
Number of tables:	1
Number of pictures:	2
Number of appendices:	2

The aim of the work: to find features of Cognitive Radio technology development.

Used methods in the work:

Searching and filling of the information. Lithuanian and foreign authors' books and literature in the internet have been used for the research.

The basics results of the work: the main problems and their solution (use of cognitive radio systems) have been defined. Also the use of cognitive radio systems' infrastructure along three functional dimensions and the use of scientific researches models, methods have been described.

Appendix 6

Abstract of the 3rd research work in Lithuanian

SANTRAUKA

Darbo autorius:	Gintarė Sukarevičienė
Darbo pavadinimas:	Sumaniosios radijo sistemos: technologijos vystymosi plėtra
Vadovas:	Dr. Vladislav V. Fomin
Darbas pristatytas:	Vytauto Didžiojo Universitetas, Informatikos fakultetas, Kaunas, 2011 gruodis
Puslapių skaičius:	26
Lentelių skaičius:	1
Paveikslų skaičius:	2
Priedų skaičius:	2

Darbo paskirtis: išsiaiškinti sumaniųjų radijo sistemų technologijos vystymosi ypatumus.

Darbe naudojami metodai:

Informacijos paieška ir sisteminimas. Tyrimui naudota spausdinta ir internete pateikta Lietuvos bei užsienio autorių literatūra.

Pagrindiniai darbo rezultatai: įvardijus darbo problemas apibrėžtas jų sprendimo būdas – sumaniųjų radijo sistemų taikymas. Taip pat, atsižvelgiant į esminius bevielio ryšio trūkumus numatyta sumaniųjų radijo sistemų infrastruktūros plėtros studijavimas remiantis 3 matmenų infrastruktūros plėtros modeliu. Be to, išanalizavus mokslinio tyrimo metodus numatytas jų taikymas baigiamajame magistro darbe siekiant išsiaiškinti sumaniųjų radijo sistemų technologines galimybes ir veikimo principus.

Paper to the „17-oji Tarpuniversitetinė magistrantų ir doktorantų konferencija"

BUSINESS MODEL ANALYSIS: THE CASE OF TV WHITE SPACE DATABASES

Gintarė Sukarevičienė[1], Vladislav V. Fomin[2]

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Abstract. The concept of TV White Space (TVWS) now plays a significant role in fully exploiting the advantages of spectrum, which is potentially available for use by new wireless communication systems. It is a stepping stone for future access to WS in other bands. Despite the large potential benefit of new technologies, the increasing amount of wireless communication systems becomes an increasing problem, which is clearly related to crowded, poorly coordinated and insufficiently harmonized frequencies. The Cognitive Radio (CR) paradigm, can help solve the spectrum shortage problem. However, development of Cognitive Radio demands finding an effective business model for the integration of technological, economic, political and social challenges. In this paper, the potential impact of different Geo-location Database (GDB) configurations between different stakeholders on business models is explored.

Keywords: ***Business Model, Cognitive Radio, Geo-location Database, TV White Space.***

I. Introduction

Today, extensive usage of information and communication technologies changes traditional way of life of human to more dynamic, "on-the-go", creating a need for radio spectrum as a medium for wireless communications. One of the sources to satisfy the growing demand for the spectrum is radio channels used by analog television (TV). In Lithuania analog TV will be turned off on 29th October 2012 [16]. The concept of untapped spectrum (TVWS) vacated by such the switch is nationwide and free to use because it is not owned by any company although guided by rules.

Uncertainty currently exists concerning the way in which TVWS will be managed. How to manage TVWS has been under debate in the U.S. at the Federal Communications Commission[1] (FCC) for years and now also in Europe, because there have been concerns that using TVWS for Internet services would interfere with other wireless devices like microphones in nearby frequencies [6]. FCC specified several methods of how to protect licensed communication services which are already using the channels:

- Geo-location database;
- Spectrum sensing;
- TVWS Markets.

While attempting sensing and geo-location techniques to provide protection of interfere with other wireless services, Spectrum sensing was removed as it is too costly, too complex and has no optimal reliability. This means that there is a need to employ geo-location with access to database [4]. There are some key works on this topic by variety of companies such as Spectrum Bridge[2], Microsoft[3], Motorola[4].

This paper introduces the concept of Geo-location database (GDB) as controlling entity of WS and outlines a number of potential configurations between different stakeholders for deployment of the GDB for TVWS using CR. Subsequently, it seeks to provide an analytical framework for the potential impact of these configurations on business models for TVWS database. In this paper we report on a work in progress. In further research we will seek answering such questions as, what TVWS database scenarios can be best used for, if any. Future work should also examine which technical requirements (e.g., accuracy (in meters), power levels, and frequency of updates (in ms)) are critical for enabling the use of GDB for the identified scenarios.

II. The CR as enabler of WS management

The CR is a technically viable novel form of wireless communication which would fulfill the regulators' strives for technology and service neutrality in spectrum management [18]. CR can remove barrier to innovation, because CR can intelligently detect which communication channels are in use and which are not, and instantly move

[1] http://www.fcc.gov/

[2] http://www.spectrumbridge.com/Home.aspx

[3] Microsoft, BT test white-space broadband in Cambridge, ZDNet UK's daily newsletter, 27 June 2011

[4] Fixed TV white Space Solutions for Wireless ISP Network Operators, TV White Space Position Paper, USA 11/08

into vacant channels while avoiding occupied ones. Freed up or not utilized spectrum can be used by incumbent and new service providers to offer innovative services to consumers [11].

CR includes the introduction of secondary trading of spectrum into the market. Such introduction could become a universal panacea for all involved groups of stakeholders because of optimizing the use of available spectrum while minimizing interference to other users. The operators would achieve more efficient spectrum utilization, which would decrease the cost per delivered bit and allow reduce end-user prices for and increase access to the broadband offer [7]. The advent of CR technology promises optimization of the radio networks through load balancing, spectrum re-farming, and radio resource usage optimization, among other [11].

Due to the fact that freed up or not utilized spectrum (WS) is large and can be made available to a variety of services deploying different types of radio modulations, there is the need for an electronically available central register of spectrum availability, license ownership and rights of use. Weiss also argued that establishing an information registry can reduce the cost and the risk of characterizing spectrum use [20]. For this purpose the next section introduces the GDB as a controlling entity, which can help to monitor spectrum for interference, because sharing of spectrum by CR would make it difficult to detect excessive sources of interference.

III. The GDB as a controlling entity for TVWS

In the context of WS and CR technologies, the database is an entity which contains current information about available spectrum at any given location and other types of information [15]. Ofcom expects that such a database may need to service millions of requests per day and that servicing each request may require a material amount of data processing [13].

As argued in previous paragraph of the article, the concept of GDB refers to an overarching, active controlling of the frequencies as well as available services in certain geographic locations. Geo-location is the most promising way to gain access to spectrum, because WS devices (WSDs) are required to provide their geographic location. Communication processes between such services and GDB are real-time. The term 'real-time' refers to the ability to view the spectrum usage in the TV band by location, and communicate the available frequencies to TVWS devices prior to letting them operate at this band. There may also be secondary uses such as Programme Making and Special Events (PMSE) which are there at some times but not others [3]. See Figure 1 for the concept.

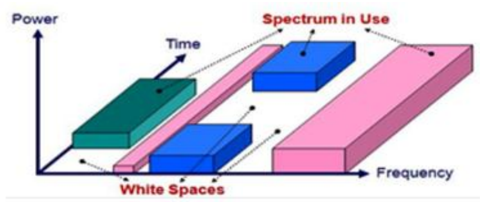

Figure 1. TVWS spectrum usage by different services [3].
Different color bars denote different services. The services can utilize frequencies for different length of time (the length of a bar) and require different power for operation (the height of a bar)

The lower power applications (PMSE), such as theatre microphones and wireless TV cameras, are usually based on managed databases which identify where the white space opportunities are. This principle of 'geo-location' - with better and more detailed databases, is at the heart of ideas for use of white space spectrum by cognitive devices - cognitive as part of a wider system of management (see Figure 2). For example, during the wireless conference if one or several channels are chosen for PMSE, these channels should not be used by other WS devices (WSD) and thus a decrease of the available spectrum would occur [3].

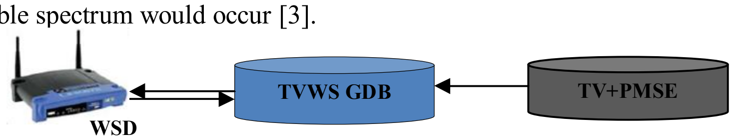

Figure 2. Principle of GDB

While it is not clear what applications will emerge in the TVWS, suggestions have included rural broadband, Wi-Fi routers with increased range, city-wide broadband data networks, increased wireless device interconnectivity, hospital data networks and much more [13].

The requirements for Ofcom TVWS database broadcasting [13]:

- Accuracy: e.g. 100m accurate;
- Speed: e.g. how frequent update (e.g. once every week);
- Non-interference: 0,1% allowed degradation.

From a business perspective, GDB controlling mechanism is not only as enabler for more efficient spectrum management, but the way in which they operate also helps define the rules of the game, from interacting with competitors, acquiring spectrum, getting access to users etc. [2]. The section below analyses business impact of the GDB.

IV. Business model implications of the GDB

A business model describes the rationale of how an organization creates, delivers, and captures economic, social, or other forms of value [8]. Different rationales result in different business models, which are used to describe and classify businesses, to explore possibilities for future development. CR future development is complicated by technological, economical, social and political challenges [7]. Thus, proper understanding, devising and implementing GDB business model is critical for the success of such technology innovation.

Different spectrum control models can be matched by different GDB service deployment scenarios [12]. Different stakeholders have different perceptions, expectations and understanding of the GDB. Their interests and concerns are important too. In this regard, devising a business model for GDB should be concerned with the relationships between GDB and these four roles:

- WSD;
- spectrum broker;
- administrator;
- regulator.

Importance of GDB is in its central role in which it mediates information between WS device and the administrator. Spectrum broker provides retail and wholesale access to different WSDs. Offering services to consumers and the logistics management of the physical network is taken together in the role of administrator. Finally, regulator may also play an important role as it may incorporate the GDB with requirements of technology and EU harmonized standards [2].

Following the basic business model design framework of Ballon [1], there can be three different business model perspectives on GDB from the viewpoint of either an operator or a user: value network and customer control, cost - revenue structure and value of user. Analysis of these three different concepts can reveal different deployment scenarios of the GDB business model. The main question is how the design of GDB control will impact on the value created for its users. Firstly, value network and customer control exerts onto the value network by integrating roles within the combined essential resources, i.e. whether it is possible to make use of the services of different providers both from a technological as from a strategic viewpoint. Secondly, cost and revenue structure exerts onto the costs associated with starting up a service such as investment costs as well as operational costs. Finally, user value refers to the influence of the GDB on how services being delivered through market positioning [2].

Overall it still unclear how the structure and administrator of the Geo-location database can to be organized. In the US, Spectrum Bridge[5] pioneered the development of a Geo-location database for TVWS and is now one of ten FCC-approved TVWS database administrators. The U.K. regulator Ofcom[6] has also been studying how Geo-location database could be used to protect incumbent TV band users, and plans to issue guidelines on Geo-location database requirements for prospective administrators [19]. Eventually, Lithuanian regulatory authorities will have to establish rules for the use of TVWS, too, and our work can help the regulator in charting the rules for the TVWS operation

V. Conclusions and expected contributions

Due to growing popularity of wireless technologies, there is also a growing demand for availability of radio spectrum. TVWS is a potentially useful source of spectrum, which can be shared by different communication technologies and services under the CR regulatory framework. But this leads to a new risks and challenges related to effective spectrum designation and control. Establishment of another controlling entity such as GDB can help to monitor spectrum usage under CR framework. It remains to be seen, however, how collaboration between different stakeholders can be established around the use of GDB – i.e., what is the potential impact of different GDB business model configurations on different stakeholders. Further research on GDB business model related issues, taking into account technological, economic, political and social challenges has to be undertaken.

The aim of this research is to develop conceptual model to better understand the relationships between different elements of GDB and between GDB and market players. The study will be based on qualitative research methods, such as exploratory literature analysis and experts' interviews.

After the completion of this research work, the new knowledge of GDB business models will help better understand how CR system can be deployed using a business model which is acceptable not only for the government (Communications Regulatory Service, The Department of Standardization, etc.), but also for the industry and the consumers.

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Appendix 8

Paper to IEEE conference CAMAD 2012

Identifying Geolocation database requirements for distinct wireless applications

Gintarė Sukarevičienė, Matthias Barrie, Simon Delaere, Pieter Ballon, Vladislav V. Fomin

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Abstract – **Today's world of wireless systems is rapidly evolving. As a consequence it promises a wide range of new opportunities. On the other hand it becomes clear that the emergence of new wireless systems increases the risk that radio spectrum will become more crowded and different devices will interfere with each other. Cognitive Radio (CR), enabled by either a Geolocation Database (GDB), a Cognitive Pilot Channel (CPC) or Spectrum Sensing could potentially contribute to solve the spectrum scarcity problem by making more efficient use of the radio spectrum. The purpose of this paper is to explain how a GDB can support a large variety of existing and emerging wireless applications. Globally, the GDB is currently well on its way as a candidate to serve wireless applications within the TV White Spaces (TVWS). However, it remains unclear whether this same GDB can be used for the wireless applications in different contexts, outside the TVWS. Our hypothesis is that distinct wireless applications in varying contexts have different needs with regard to a GDB's capabilities and characteristics. Subsequently, this paper will identify these distinct categories of wireless applications and match them with the appropriate GDB requirements. In order to do so, a classification of database requirements, based on essential characteristics, will first be constructed. Finally, this paper ends with analysis on the viability of sustaining distinct and coexisting database types.**

***Index Terms*: cognitive sharing, deployment strategies, femtocells, MVNO**

I. INTRODUCTION

Wireless technology opens up an endless market of wireless communication applications [1]. As more and more wireless applications emerge in various sectors, the need for more efficient spectrum management also grows due to the limited nature of radio spectrum. One solution is Cognitive Radio (CR), a paradigm in the wireless communications that hold promise for new and better services to many markets, including public safety, military, and the consumer [2]. CR is proclaimed to remove the barriers to innovation, because it allows radios to select channels and frequency bands in the most optimum manner by interacting with surrounding environment, learning about the environment and using the learned knowledge to improve communication [1]. Furthermore, CR can also be of use to avoid interference when spectrum is shared amongst multiple radios.
CR can be enabled by a variety of technologies of which Cognitive Pilot Channel (CPC) [3], Geolocation Database (GDB) [4] or Spectrum Sensing [5] are the most considered ones.

For the so-called TV White Spaces (TVWS), regulators across the globe have been showing a preference towards a GDB approach. In ECC Report 159 [6][7], both spectrum sensing and GDB were considered, while evaluating how both cognitive enablers meet the proposed technical requirements for protecting incumbent services (e.g. broadcasting, PMSE, radio astronomy and aeronautical radio navigation) from interference from White Space Devices (WSDs). From this report it becomes clear that a GDB is clearly preferred over spectrum sensing. The FCC [8] came to this same conclusion earlier in 2010, when it decided to make use of a GDB mandatory for WSDs in the TVWS.

A good database should fulfil the needs of specific applications. In TVWS, the protection of incumbent services is the most important need. Therefore, some requirements that support the protection have to be met by the database. For example, a database for TVWS in the U.S., must acquire information from the Federal Communications Commission's (FCC) databases and synchronize with the FCC databases at least once a week [9].

However, there still remains uncertainty with regard to the database requirements for wireless applications outside of the TVWS scope. First of all, this paper will identify categories of wireless applications that are so distinct by nature that they require a specific type of database to meet the applications' needs. For example, it is obvious that a wireless heart rate monitor in a medical setting is absolutely distinct from a Wi-Fi home-network, both in

terms of technical characteristics of the wireless applications themselves, as well as for the requirements for a GDB.
This paper will be organized as follows; the constructed classification of databases will be proposed in section 2. This classification will be based on possible variation in the technical characteristics of the database. In section 3, the paper proposes a categorization of wireless applications with distinct needs for the database. The categorization will be based on the ideal practice of clustering, which strives to categorize groups that are both internally consistent and external exclusive. Section 4 will describe how each category of applications can be matched with the distinct classes of databases. This will lead to different requirements that each category of applications demand from a GDB. Equally, discussion on the viability of sustaining distinct and coexisting database types, alongside the paper's conclusions, will be provided in section 5.

II. CLASSIFICATION OF GDB CHARACTERISTICS

A GDB is a digital archive that acquires, processes, stores and distributes geolocation information. It is obvious that there can be quite some variation in "how" a GDB completes these different tasks and what kind of information it actually uses and distributes. This variation can lead to different GDB characteristics, of which we have defined the most important ones as follows: allowed degradation, database updating frequency, channel reservation possibilities, location data accuracy, harmonization, the scope of spectral information, processing power and synchronization possibilities with own (local) database. A GDB will always consist of a combination of the above listed characteristics.

First of all, a database can allow some **level of degradation**, due to interference [10], to wireless signals within a specific frequency band. Of course, one of the main reasons for implementing a GDB is to limit this kind of interference, so the allowed degradation should always be set low. However, some wireless applications would require a GDB with allowed degradation close to zero percent. To serve these applications, a distinct type (e.g. more precise) of GDB is needed [11].

A second GDB characteristic is the **frequency** of when the database gets **updated**. Some applications require a GDB to be able to update the info it contains quickly enough to enable the end-devices to base their decisions on accurate positional information [12]. We consider that the choice of database updating frequency for the wireless applications can be between high (every minute) and low updating (every day).

A third GDB characteristic is the possibility to **reserve specified channels**. This GDB characteristic can guarantee that there will always be available channels for a certain subset of wireless applications. For example, in the U.S., there are always two reserved TVWS-channels in each market area for use by unlicensed wireless microphones. In case of a special event, wireless microphone venues can be registered beforehand. This makes sure that there are always channels available for wireless microphones and that they are protected from interference from other TV White Space devices [13].

A fourth GDB characteristic is **location accuracy**. This characteristic refers to the GDB's level of detail of its location data. Some applications would require a database to have very location-specific data on the spectrum occupancy of that particular location, while other applications would only need information on a wide area in general. Therefore, we consider the choice between high (e.g. up to 1m accurate) and low location accuracy (e.g. up to 500m accurate) when devising a GDB.

Some wireless applications will also require a GDB to be **harmonized** within a certain region, as these applications possibly operate across borders. A harmonized GDB would allow these applications to have unified access to the GDB in all countries of the harmonized region. Furthermore, the harmonized GDB could provide cross-border spectral occupancy information.

Another GDB characteristic is the **scope of spectral information**. It is a possibility for the GDB to provide information on multiple frequency bands or on just one single, selected frequency bands. The latter occurs in a GDB for TVWS. For TVWS devices, the only relevant spectral information that they require is the information on the TV bands. However, some wireless applications might switch between multiple frequency bands. For those applications, a GDB with a larger scope of spectral information (e.g. not only limited to TVWS-bands, but also including bands such as the ISM-bands) is required.

Furthermore, there might also be some variation with regard to a GDB's processing power. Some GDBs will get consulted a lot more, while others might get limited database queries. This largely depends on the type of applications and number of end-devices using the services of the GDB. Furthermore, some databases will have to perform a high number of difficult calculations, thus requiring higher processing capacities, in order to support decision-making with regard to spectrum/channel selection.

Some GDBs may also need to be able to **synchronize** with other, more local (intra-network) databases. This could be the case for GDBs consulted by devices that already work in local networks and have some sort of centralized control entity in the form of a database. For those applications, GDBs are recommended to synchronize with this local database, while such a feature is not always needed in other situations.

III. CATEGORIZATION OF WIRELESS APPLICATIONS' NEEDS

Much like GDBs, wireless applications can be categorized, based on some application characteristics. This paper proposes such categorization based on three domains: time, location and technical architecture. Based on these domains, eight essential application characteristics can be distinguished. Of course other characteristics of applications can be made, but these are the most relevant for identifying GDB requirements. Furthermore, this categorization is based on the ideal practice of clustering, which strives to categorize groups that are both internally consistent and external exclusive.

First of all, within the **time domain**, wireless applications can be:

- **Periodic vs. real-time:** in case of real-time applications, communications (and signal transmissions) are live. One example of this is mobile telephony. On the other end of the spectrum, there can be applications with periodic transmissions of data packets (e.g. M2M communications). Real-time application will demand more robust CR solutions, hence a GDB that keeps the signal degradation close to zero, while this is less strict for periodic applications.
- **time-dynamic vs. always-on:** while the behaviour of always-on applications is very predictable, this is not the case for time-dynamic applications. These last applications can have instant peaks of spectrum demand and a GDB will need to cope with the sudden queries that come along with this. As a result, time-dynamic applications will require a high database updating frequency, while this is less stringent for always-on applications.
- **planned vs. unplanned:** some wireless applications can be planned, like the use wireless microphones at planned events, while the use of other applications is mostly unplanned. The latter applications will not require possibility to reserve channels, while for planned use, a GDB in which channel reservation is possible, might be very useful.

Within the **location domain**, applications can be:

- **indoor vs. outdoor:** indoor applications, short ranged application, such as Bluetooth enabled devices would require high location accuracy from a GDB, while outdoor , long-range applications (e.g. city-wide broadband) tend to require more "high level", less detailed, geolocation information.
- **cross-border vs. domestic:** while some applications operate within the country, other applications might transcend local boundaries. While use of a harmonized GDB is not strictly necessary for the first category of applications, it is highly recommended for the latter category.
- **single-band vs. multi-band:** applications can locate their operations in one single band, but (and this is especially expected in the future) it is also possible that these applications might operate in multiple bands. The latter applications will obviously require a broader scope of spectral information provided by the GDB.

Within the **technological domain,** applications can be categorized as follows:

- **high amount of nodes vs. low amount of nodes**: applications that are run by millions of devices (e.g. M2M) can substantially raise the amount of queries the GDB has to answer. As a result, a GDB might need more processing power to successfully deal with these high amounts of queries.
- **networked applications vs. stand-alone applications**: there exist devices that already work in local networks and have some sort of centralized control entity in the form of a database. It will be most efficient if a GDB can synchronize with these central controls, rather than obtaining from, and providing spectral information to, each individual device.

IV. MATCHING APPLICATIONS AND DATABASE REQUIREMENTS

The above application characteristics require different database capabilities. A summary of what has been discussed in the previous sections can be found in Table 1.

Database characteristics		Application-types	Domain
Allowed degradation	low	periodic/buffering/non-real-time	Time
	close to zero	real-time	
DB Updating frequency	high	time-dynamic	
	low	always-on	
Channel reservation	possible	planned	
	not possible	unplanned	
Location accuracy	high	indoor	Location
	low	outdoor	
Harmonization	recommended	cross-border	
	not necessary	domestic	
Spectral information	single-band	single-band	
	multi-band	multi-band	
Processing power	high	high amount of nodes	Technical Architecture
	low	low amount of nodes	
Synchronization with own (local) DB	recommended	networked	
	optional	stand-alone	

TABLE 1: APPLICATION- AND CORRESPONDING GDB-CHARACTERISTICS

As mentioned before, both applications as well as GDBs, are combinations of these characteristics. To show that distinct applications require different database capabilities, this paper will apply the above table for two applications: a wireless conferencing system and city-wide broadband using TVWS.

The use-case of the wireless conference goes as follows; it is used for an international conference room at the European Parliament, serving 500 people, speaking five different languages and using wireless microphones [15].

The second use-case is city-wide broadband that runs over TVWS. Speeds of such broadband are proclaimed to be promising up to 22Mbps for devices as far as 100-kilometres away from the nearest transmitter, mainly because of the ideal propagation characteristics of the TV-band spectrum [16]. City-wide broadband, using TVWS, has already been proven successful in trials such as in Cambridge [17], UK, as well as in Wilmington [18], US.

In this case, the wireless conferencing system can be categorized, within the time-domain, as a real-time, time-dynamic and planned activity. As a result, a GDB should meet the stringent corresponding demands, including the possibility to reserve channels, very frequent GDB updates and close-to-zero allowed signal degradation.

These requirements are in contrast with the demands to be met for supporting city-wide broadband using TVWS. Within the time domain, this application can be categorized as periodic (as data packets can be "buffered" and interruptions can be allowed), always-on (the so-called "white-fi" network will always be available) and unplanned. As a result, this city-wide broadband needs less strict database requirements: more signal degradation is allowed, the database does not need to be updated as frequent and there should not need to be any channel reservation possibilities.

Within the location domain, the local conferencing system is clearly an indoor and domestic application. Furthermore, it can arguable be categorized as a multi-band operation (for robustness purposes) [15]. The latter characteristic makes it possible to provide optimum sound conditions and look for available spectrum in other bands that can give better quality of service. These factors again refer to some specific requirements for GDBs: high location accuracy, unnecessary harmonization and multi-band spectral information.

The city-wide broadband, in turn, can be categorized as domestic, similar to the conferencing system, but also outdoor (when considering the "White-Fi" access points) and single-band (the TV White Spaces). As a result, the database requirements are, again, less demanding, as there can be a lower degree of location accuracy, arguably unnecessary harmonization and only spectral information provision of just one single band.

Within the technical architecture, both use-cases display a low amount of devices that would communicate with the GDB. In case of city-wide broadband, only the access points would need to communicate, while for the wireless conferencing system, only the central controls need to access the GDB. As a result, both use-cases will not test the limits of the GDB's processing power. Furthermore, in both cases, the end-devices are networked. This means that the GDB will need to synchronize with the local control entity, rather than with every individual end-device.

From the above, it becomes clear that a database that is just meeting the minimum requirements for broadband through TVWS access, will not be sufficient for other, more demanding applications, such as the local conferencing system explained above. This conclusion can be the starting point for discussion on how the future of geolocation databases will look like and which implementations (combinations of database characteristics) will prove viable.

V. CONCLUSIONS

The academic community, telecoms regulators and industry have all contributed to momentum of interest that the geolocation database is currently enjoying. Although there is much variety of opinion with regard to the sufficiency of the GDB as CR enabler, there seems to be some regulatory preference (both in the US, as well as in Europe) with regard to this option for exploiting the so-called TV White Spaces.

These TVWS and the geolocation database are now so conceptually interlinked, that it is challenging to think of a GDB beyond TVWS. This paper has argued that most wireless applications would require different database characteristics than those envisaged purely for TVWS use. While a geolocation database can enable broadband through TVWS, meeting rather simple requirements, such a GDB will not be sufficient for other, more demanding applications, such as the local conferencing system use-case explained in the sections above.

There can be discussion on how the future of a GDB would look like. Will there be generalization, a "one-database-supports-all", solution? Or will there be fragmentation and specialization, a "one-database-supports-one-application" solution?

In case of generalization, a GDB will have to consist of a combination of the GDB characteristics meeting the strictest application demands. Not only will this GDB need to compile all spectral information, it will also need to rapidly process and transmit this information. Furthermore, it will need huge amounts of processing power, along with added-value services (such as channel reservation). All of this will come at a significant price, while the monetization of such GDBs is still unclear.

In case of specialization, the major issue can be the compatibility of these specialized GDBs. While these distinct GDBs all serve applications with specific demands, their "client"-applications most likely operate in a heterogeneous wireless environment. This entails that there will be a need for good cooperation between the different technologies and applications within an area. As a result, good cooperation between their GDBs is evenly crucial. Making a large number of these specialized GDBs compatible could prove to be very complex.

A reasonable, initial approach could be to start off with a basic GDB for TVWS, such as the ones currently being developed by companies such as Spectrum Bridge, Microsoft and Neul, and gradually improving the database's scope, both in terms of spectral information (e.g. broader spectral information, more detailed information) and supported applications (e.g. not only broadband through TVWS, but also short ranged applications). A GDB could then gradually grow, based on current market needs, and move closer towards a one-database-supports-all type of GDB.

This paper is fundamental in nature and has set as goal to introduce the idea of a GDB transcending TVWS, clearly showing the different GDB characteristics required to serve a wide range of wireless applications. While this idea is intended to spark discussion, further research is needed to validate the proposed framework of applications- and corresponding database-characteristics. Furthermore, research with regard to the future of the GDB, whether it will move towards generalization or specialization, might be of interest.

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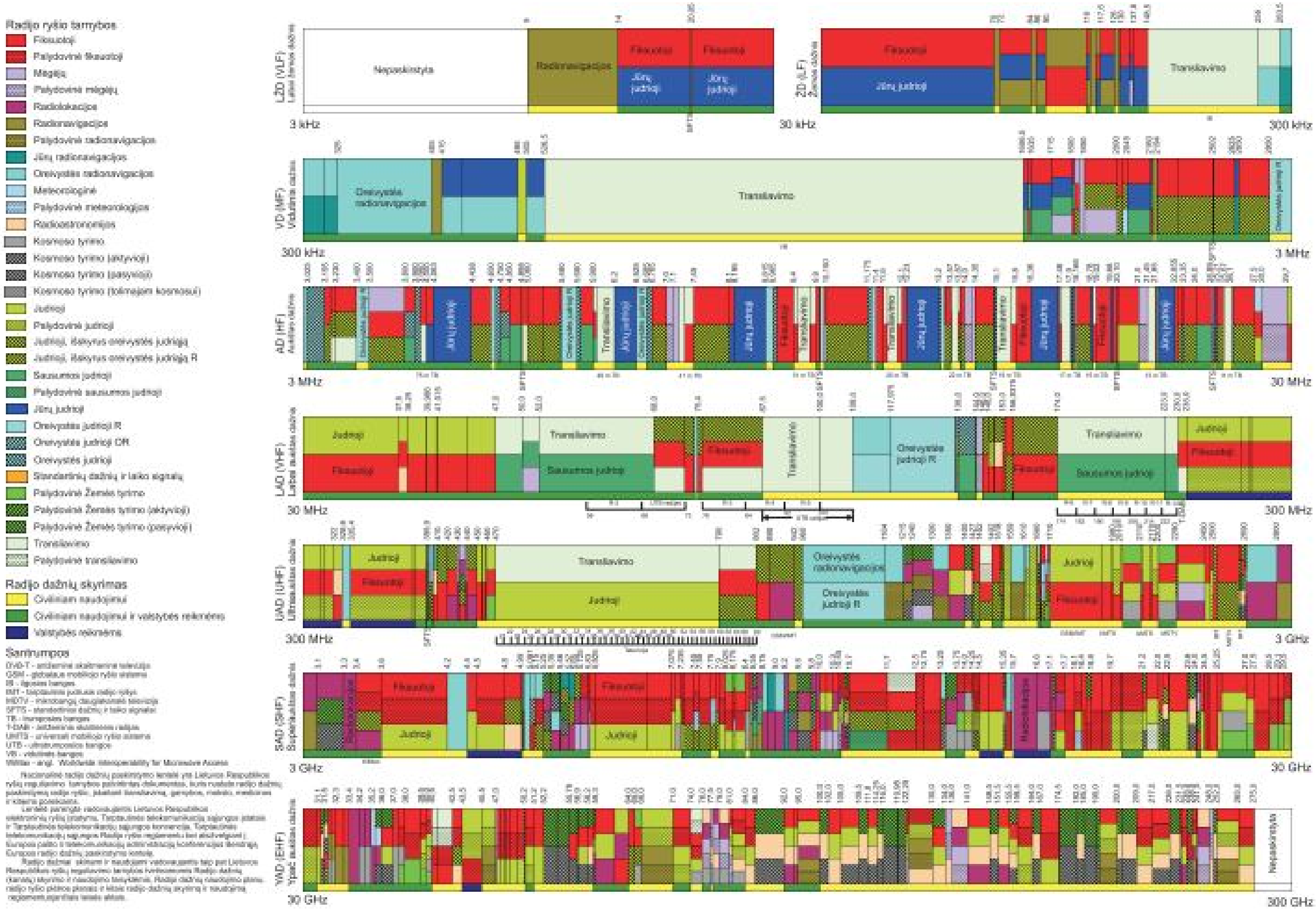
National Radio Frequency Allocation Table in Lithuania



Explanation of relationships of Figure 12

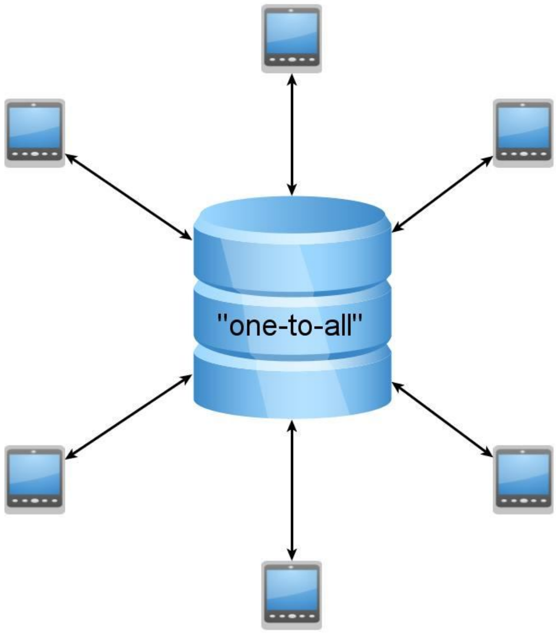


Figure 1. "One-to-all" solution

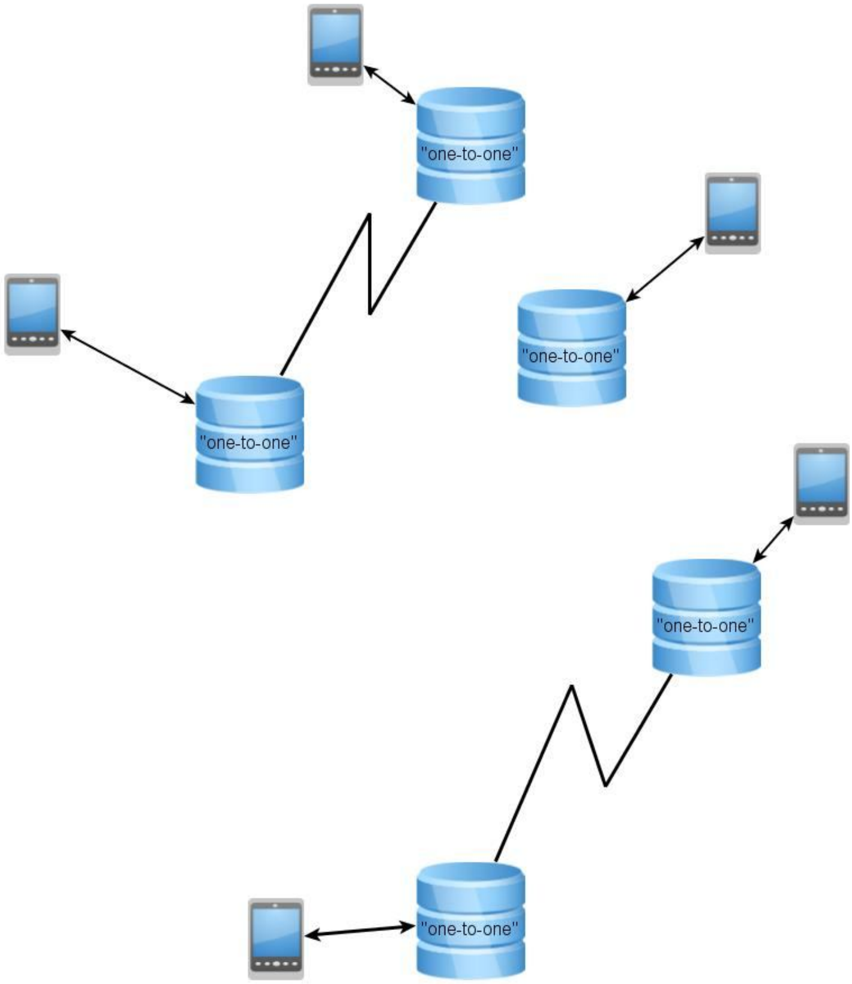


Figure 2. "One-to-one" solution

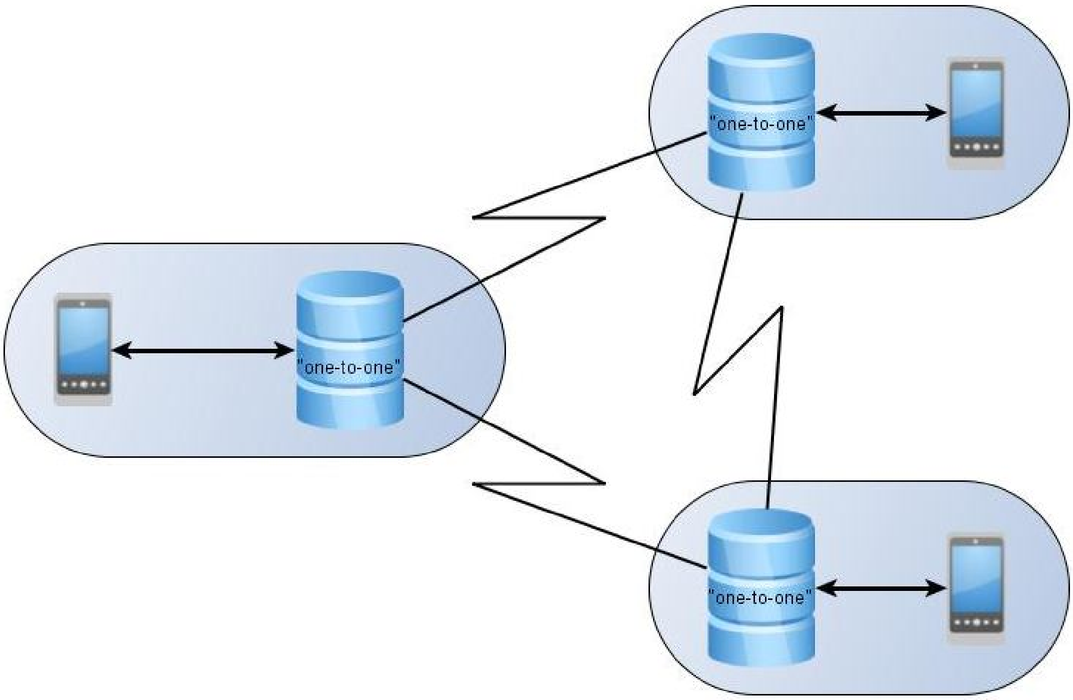


Figure 3. "One-to-one" solution

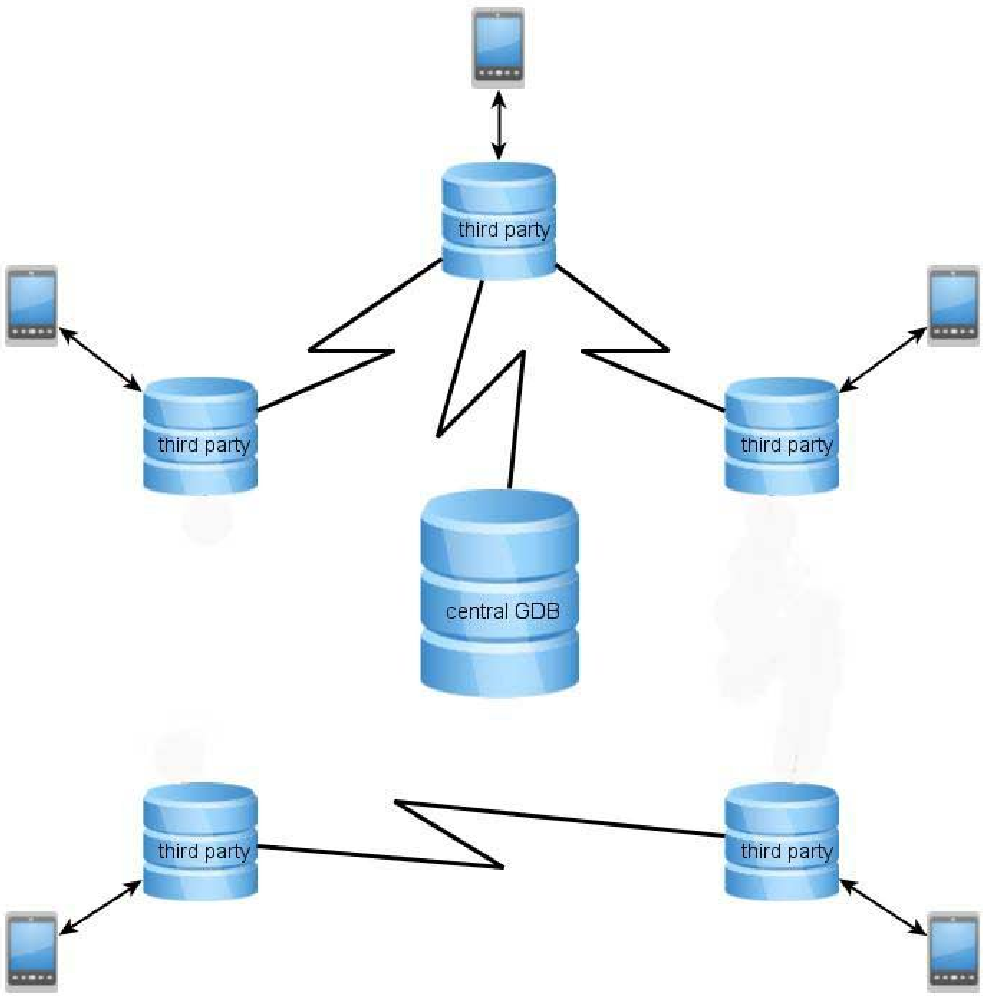


Figure 4. Hybrid solution