RIGA TECHNICAL UNIVERSITY
Faculty of Electronics and Telecommunications
Institute of Telecommunications

Guntis Ancāns
Doctoral Student of the Study Programme "Telecommunications"

EVALUATION OF THE POSSIBILITIES FOR USING THE RADIO FREQUENCY SPECTRUM BAND 694–790 MHZ FOR WIRELESS TRANSMISSION SYSTEMS

Summary of the Doctoral Thesis

Scientific supervisor
Professor Dr. sc. ing.
VJAČESLAVS BOBROVS

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DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR THE PROMOTION TO THE SCIENTIFIC DEGREE OF DOCTOR OF ENGINEERING SCIENCES

To be granted the scientific degree of Doctor of Engineering Sciences, the present Doctoral Thesis has been submitted for the defence at the open meeting of the RTU Promotion Council on 19 December, 2019 at the Faculty of Electronics and Telecommunications of Riga Technical University, 12 Āzenes Street, Room 201.

OFFICIAL REVIEWERS

Associate Professor, Dr. sc. ing. Sandis Spolītis
Riga Technical University, Latvia

Researcher, Dr. sc. ing. Aleksejs Udaļcovs
RISE Research Institutes of Sweden AB, Kista, Sweden

Senior Expert, Dr. sc. ing. Jūlija Asmuss
State Education Development Agency, Latvia

DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for the review to Riga Technical University for the promotion to the scientific degree of Doctor of Engineering Sciences is my own. I confirm that this Doctoral Thesis had not been submitted to any other university for the promotion to a scientific degree.

Guntis Ancāns ………………………………….. (signature)
Date: ………………………

The Doctoral Thesis has been written in Latvian. It consists of an Introduction; 4 chapters; Conclusions; 65 figures; 43 tables; one appendix; the total number of pages is 132, not including the appendix. The Bibliography contains 128 titles.

ANNOTATION

The world is currently experiencing rapid growth of transmitted data and the mobile data traffic is projected to grow more than twice by 2022 compared with 2019, reaching 77 exabytes (77×10^{18} bytes) per month [12]. In the future, additional radio frequency spectrum resources will be needed in order to meet the increased demand of mobile communications users for higher data transfer rates, the development of new wireless services, as well as new radio technologies. Further development of existing radio systems will also require additional frequencies. The provision of mobile communications services requires steady radio coverage of the area that can be provided by using lower frequency bands, particularly frequency bands below 1 GHz.

The main objective of this Doctoral Thesis is to assess the appropriateness of the 694–790 MHz (700 MHz) band for the use of broadband wireless transmission systems. In the Doctoral Thesis, the aspects of radio frequency spectrum management are covered, the evaluation methods of the electromagnetic compatibility for wireless transmission systems are analysed, an evaluation of the electromagnetic compatibility between different radio systems in the 700 MHz band and in adjacent bands is given, the propagation of radio waves in the 700 MHz band is analysed and recommendations for the frequency arrangement are drawn up. Radio frequency spectrum is a limited resource, a national treasure that will become more valuable in the future.

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LIST OF ABBREVIATIONS

2G – second generation cellular technology
3G – third generation cellular technology
4G – fourth generation cellular technology
5G – fifth generation cellular technology
3GPP – The 3rd Generation Partnership Project
5G NR – 5G New Radio

A
AAS – Active Antenna Systems
APT – Asia-Pacific Telecommunity
ARNS – Aeronautical Radionavigation Service
ASMG – Arab Spectrum Management Group
ATU – African Telecommunications Union

B
BB-PPDR – Broadband Public Protection and Disaster Relief systems
BS – Base Station

C
CA – Carrier Aggregation
CDMA – Code Division Multiple Access
CEPT – European Conference of Postal and Telecommunications Administrations
CITEL – Interamerican Telecommunication Commission
CIoT – Cellular Internet of Things
CP – Cyclic Prefix
CQI – Channel Quality Indicator

D
DEC – Decision
DL – Downlink
dRSS – desired Received Signal Strength
DVB-T – Terrestrial Digital Video Broadcasting
DVB-T2 – Terrestrial Digital Video Broadcasting 2
DTTB – Digital Terrestrial Television Broadcasting

E
EB – Exabyte (1×10^{18} bytes)
ECC – Electronic Communications Committee
e.i.r.p. – Equivalent Isotropically Radiated Power

EC – European Commission
eMBMS – Evolved Multimedia Broadcast Multicast Services
EMC – Electromagnetic Compatibility
EMF – Electromagnetic Field
eNode-B (or eNB) – LTE base station
EU – European Union
ETF – Faculty of Electronics and Telecommunications
ETSI – European Telecommunications Standards Institute
E-UTRA – Evolved Universal Terrestrial Radio Access

F
FDD – Frequency Division Duplex
FDDx – number of the FDD frequency block

G
gNode-B (or gNB) – NR base station
GSM – Global System for Mobile Communications

I
ILR – Interfering Link Receiver
ILT – Interfering Link Transmitter
iRSS – Interfering Received Signal Strength
IMT – International Mobile Telecommunications
IMT-2020 – International Mobile Telecommunications-2020 (term developed by ITU meaning 5G)
IoT – Internet of Things
ITU – International Telecommunication Union
ITU-R – International Telecommunication Union – Radiocommunication Sector

J
JTG-4-5-6-7 – Joint Task Group 4-5-6-7 of ITU-R

L
LTE – Long Term Evolution (standard for wireless broadband communication for mobile devices)
LTE-A (LTE-Advanced) – an enhancement of the LTE standard
LTE-MTC – LTE Machine Type Communication

M
M2M – Machine-to-Machine Communication
MBMS – Multimedia Broadcast Multicast Services
MCL – Minimum Coupling Loss

MFCN – Mobile/Fixed Communications Networks. Includes IMT and other mobile and fixed service communications networks
MP – Medium Power DVB-T/T2 Transmitter
MPEG – Moving Picture Experts Group
MPEG-2 – MPEG-2 Standard
MPEG-4 – MPEG-4 Standard

N
NB-IoT – Narrowband Internet of Things
non-AAS – non-Active Antenna Systems
NMT – Nordic Mobile Telephony

O
OFDM – Orthogonal Frequency Division Multiplexing

R
RCC – Regional Commonwealth in the Field of Communications
RLS2 – Secondary radar RLS2
RRM – Radio Resource Management
RSBN – Radio System for Short Range (for short-range navigation)
RSPG – Radio Spectrum Policy Group of the European Commission
RSRP – Reference Signal Received Power
RSRQ – Reference Signal Received Quality
RSSI – Received Signal Strength Indicator
RTU – Riga Technical University

S
SCS – Subcarrier Spacing
SDL – Supplemental Downlink
SEAMCAT – Spectrum Engineering Advanced Monte Carlo Analysis Tool
SINR – Signal to Interference Noise Ratio
SJSC – State Joint Stock Company
SM – The Ministry of Transport of the Republic of Latvia
SPRK – Public Utilities Commission

T
T_x – Transmitter
TS – Technical Specification
TV – Television
TVWS – Television White Spaces (unused frequencies in TV broadcasting spectrum)

U

UE – User Equipment
UHF – Ultra High Frequency (also known as the decimetre band)
UL – Uplink

V

VARAM – the Ministry of Environmental Protection and Regional Development of the Republic of Latvia
VAS ES – The State Joint-Stock Company Electronic Communications Office of Latvia
VLR – Victim Link Receiver
VLT – Victim Link Transmitter

W

Wi-Fi – Wireless Fidelity (a wireless local area network)
WP 5D – Working Party 5D of the ITU-R
WP 6A – Working Party 6A of the ITU-R
WRC – World Radiocommunication Conference
WRC-12 – World Radiocommunication Conference 2012
WRC-15 – World Radiocommunication Conference 2015

GENERAL DESCRIPTION OF THE DOCTORAL THESIS

Topicality of the Research

Rapid circulation of information increases the amount of the transmitted data as well. According to the International Telecommunication Union (ITU) study [26], data traffic is expected to increase 25 times by 2020 compared to 2010. Today, there is a constant trend in demand for the availability of the radio frequency spectrum availability and higher data transmission rate. In order to ensure this amount of data transmission, IMT systems will require an additional radio frequency spectrum that is projected from 1340 MHz to 1960 MHz according to ITU estimates. Both of these figures include a spectrum that is already in use or is intended to be used for IMT systems.

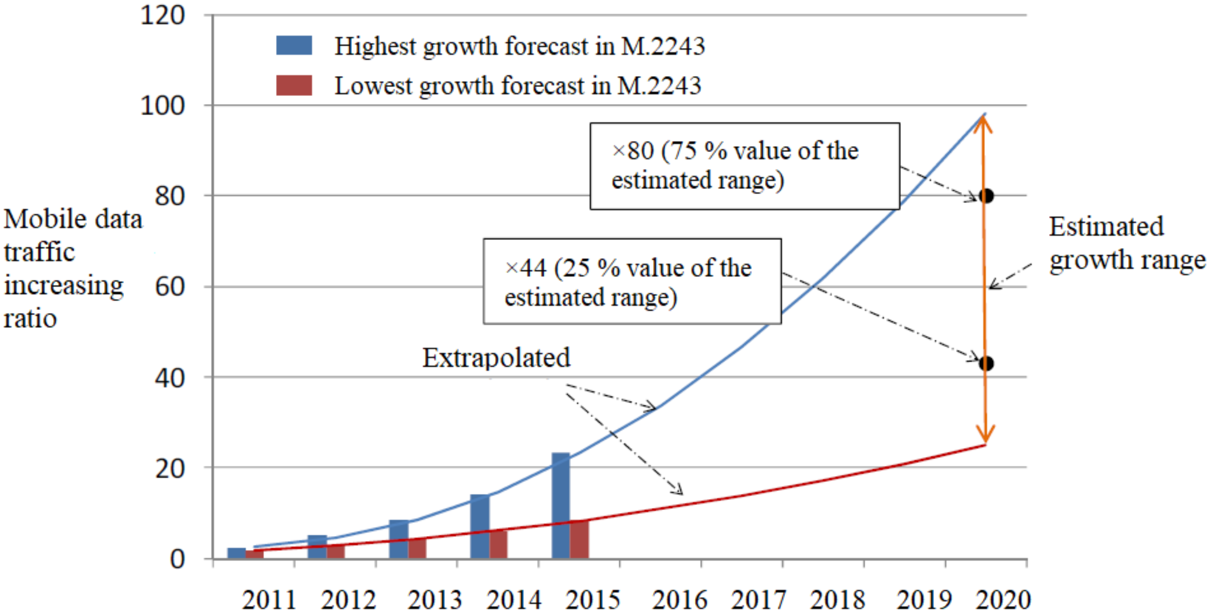

Fig. 1. Mobile data traffic forecast by 2020 [26].

The development of wireless networks requires a radio frequency spectrum and currently its role is increasing. Sufficient spectrum resources also contribute to the development of technology-based market sectors. Additional frequencies will be required for the development of both existing systems and new technologies. Currently, ITU has allocated several frequency bands for the IMT systems [24].

In the area of mobile communications, the generations of systems have been changing about every ten years. The first handheld cellular mobile phone (distinct from the car phone) was developed by *Motorola*. It (*DynaTAC 8000x*) was invented by engineer Martin Cooper who made the first call on 3 April 1973 [28]. The development of NMT (1G) networks in 1981, GSM900 system (2G) in the 1990s, UMTS (3G) in 2000 and the emergence of LTE (4G) networks in around 2010 followed Cooper's invention [10]. Currently, standardisation organisations are working on the development of a new generation of cellular network technology 5G, which is scheduled to be released for commercial use in around 2020.

Mobile communications mainly use frequencies up to 3 GHz. Increase on the frequency spectrum is required by IMT systems as well as other systems and radio services. Therefore, additional allocations or replanning of radio frequency spectrum from different services in favour of mobile service, particularly in frequency bands below 1 GHz, are required.

Existing 4G mobile communication systems as well as next generation wireless communication systems (5G) require additional frequency resources for the development of networks in the frequency bands below 6 GHz. 5G systems are expected to use radio frequency spectrum both below 6 GHz and above 24 GHz. The improvement of the capacity of the cellular networks with higher data transmission rates in a cell can be achieved by combining low and high frequencies.

The 2012 World Radiocommunication Conference (WRC-12) resolved to allocate the frequency band 694–790 MHz (700 MHz) in the ITU Region 1 to mobile, except aeronautical mobile, services. This allocation was effective immediately after WRC-15 [24]. The decimetre band UHF (470–862 MHz) has historically been used for television broadcasting. In Latvia, it is planned to continue using the 700 MHz band for terrestrial digital television broadcasting until 2022. In this respect, the decision of Latvia's neighbouring countries on the future use of the 700 MHz band is also important.

In order to determine the appropriateness of the use of the 700 MHz band for the broadband wireless transmission systems (LTE and the next generation) in Latvia, it is necessary to carry out the evaluation of the EMC with the radio systems operating in the 700 MHz band and in adjacent bands. It is also necessary to evaluate the propagation of radio signals in this frequency range, including an assessment of the need for cross-border frequency coordination.

The first commercial 5G networks are expected to appear in the range of 3.4–3.8 GHz. Work on the prospective use of 24.25–27.5 GHz and 700 MHz bands for the wireless transmission systems in Latvia continues [30].

The 5G networks are characterised by high data rate, low latency and improved capabilities for the development of various vertical services (e-health, autonomous cars, smart cities, radio telemetry and remote control of production processes, smart meters, etc.). It is expected that existing public cellular networks (2G, 3G, and 4G) will also operate alongside the 5G networks.

For frequency band 694–790 MHz, the following benefits may be identified.

- The frequency band is suitable for non-AAS (passive antennas); hence, the existing mobile antennas of the base stations can be used for this frequency band.
- Similarity of radio parameters affecting the electromagnetic compatibility of 4G and 5G technologies in this band.
- An additional frequency band below 1 GHz for steadier radio coverage (both in downlink and uplink), as well as for improved indoor radio coverage.
- Initially, the allocation points of existing base stations in the 800 MHz / 900 MHz bands might be selected for the planning of the radio network.

- Opportunities to increase the data transmission rates in the downlink using the inter-band Carrier Aggregation.
- Opportunities to combine uplink channels with downlink carriers of higher frequency bands, thus improving radio coverage in the higher frequency bands (3.5 GHz, 26 GHz, etc.).
- Opportunities for the implementation of various new services including national critical functions using the 4G/5G network as a platform.
- Allocation of a lower radio frequency band to mobile operators can be crucial to expand broadband internet services in rural areas, as well as can enable the availability of broadband services indoors and in more densely populated areas.

The Aim and Tasks of the Doctoral Thesis

Based on the assessment of the development directions of wireless broadband systems, **the aim of the Doctoral Thesis** was defined – to evaluate the suitability of the 694–790 MHz frequency band for the implementation of broadband wireless transmission systems.

In order to achieve the aim brought into focus, the following **basic tasks** had to be performed.

1. To evaluate the main principles of the radio frequency spectrum management applicable internationally and in Latvia, as well as to evaluate the current legal framework of the 694–790 MHz radio frequency band and adjacent bands in accordance with ITU, CEPT, EU and Latvian legislation.
2. To examine and analyse existing and prospective radio systems (LTE, DVB-T/T2, ARNS RSBN, 5G NR, M2M/IoT) for use in the 700 MHz radio frequency spectrum band and/or in the adjacent bands.
3. To perform the evaluation of the electromagnetic compatibility between the broadband wireless transmission systems (LTE) and the Terrestrial Digital Video Broadcasting system (DVB-T) in the 700 MHz band and in the adjacent band by using mathematical calculations, computer simulations and experimental measurements.
4. To perform the evaluation of the electromagnetic compatibility between LTE and Aeronautical Radionavigation Service (ARNS RSBN) in the 700 MHz frequency band by using the mathematical calculations and computer simulations.
5. To perform the evaluation of the electromagnetic compatibility between LTE systems in the 700 MHz frequency band by using computer simulations.
6. To perform the evaluation of the propagation of radio signals by using computer simulations and experimental measurements in the 700 MHz frequency band for the LTE system in the border area of Latvia.
7. To evaluate the results obtained and recommend the frequency arrangement for the 700 MHz band in order to use it for the broadband wireless transmission systems in Latvia.

Methodology of the Research

Mathematical calculations, computer simulations and experimental measurements under realistic conditions have been used in the implementation of the tasks and problem analysis of the Doctoral Thesis.

To evaluate the electromagnetic compatibility between LTE and Digital Terrestrial Television Broadcasting System (DVB-T/DVB-T2) in the 700 MHz band and in the adjacent band, between LTE and Aeronautical Radionavigation Systems (ARNS RSBN) in the 700 MHz band, between the LTE systems in the 700 MHz band, mathematical calculations and computer simulations with SEAMCAT software were used.

In addition, experimental measurements were made using measurement laboratory of the SJSC *Electronic Communications Office* to perform the evaluation of electromagnetic compatibility between LTE and DVB-T in the 700 MHz band and in the adjacent band.

Computer simulations with *Akis-R* software, as well as experimental measurements were performed using the measurement laboratory of SJSC *Electronic Communications Office* for the LTE radio signal propagation analysis according to the Latvian terrain in the 700 MHz radio frequency band and for the evaluation of intensity of the electromagnetic field strength generated by the LTE base stations.

Research Results and Scientific Novelty

Acquisitions of the Doctoral Thesis

1. Analytical models (scenarios) for the investigation of electromagnetic compatibility of radiocommunication systems with MCL and SEAMCAT Monte Carlo methods have been developed and the criteria of electromagnetic compatibility have been defined in the Doctoral Thesis.
2. New theoretical and experimental results have been obtained for the evaluation of propagation of the LTE radio signals in the 700 MHz frequency band according to the terrain of Latvia in the border area.
3. A method for evaluation of the propagation of signals transmitted by the base station is developed. Confirmation of the suitability of the radio wave propagation prediction model ITU-R P.1546-5 for the 700 MHz band for wireless communication systems in the Latvian border area was achieved.
4. A recommendation for a 700 MHz band frequency arrangement for the broadband wireless transmission systems in Latvia has been developed.

During the development of the Doctoral Thesis the following main conclusions were reached

1. In order to provide EMC between adjacent DVB-T high power transmitter and receiving LTE700 base stations (at 9 MHz frequency separation), these radio equipment should be installed with a separation distance of 13 km (±3.5 km) according to SEAMCAT Monte Carlo simulations.

2. According to the results of SEAMCAT Monte Carlo simulations, it is possible to provide EMC between the LTE base stations and ARNS RSBN receiving ground-based radio equipment operating in the 700 MHz co-channel. The separation distance of the radio equipment within the considered scenario shall be 112 km (±9 km).
3. According to the results of SEAMCAT Monte Carlo simulations, the separation distance required for the provision of EMC between the wireless transmission networks (LTE) is 26 km (±4 km) in case of a co-channel.
4. In order to estimate the propagation of a base station signal in a particular sector, 3 to 4 measurement points are required to compare the results of EMF strength measurements and theoretical calculations, moreover, the accuracy of the results of theoretical calculations is affected by the quality and resolution of the available topographic and earth's surface digital maps. Model ITU-R P.1546-5 is applicable for the prediction of radio wave propagation in the 700 MHz band.
5. Experimental measurements confirmed the theoretical results on the effect of the DVB-T station on receiving LTE700 base stations in the co-channel, as radio interference from the terrestrial television station (MP) at the distance of 94 km was observed at the LTE base station. According to SEAMCAT Monte Carlo simulations, the required separation distance between the transmitting DVB-T station (MP) and the receiving LTE700 base stations in the co-channel is 278 km.
6. According to the results of SEAMCAT Monte Carlo simulations, by applying the mitigation techniques of radio interference the required separation distance between the transmitting LTE700 base stations and DVB-T/T2 receivers in the co-channel case can be reduced from 152 km and 159 km to 82 km and 88 km, respectively.
7. Based on the results of experimental measurements and theoretical calculations, it can be concluded that the 700 MHz frequency band is suitable for the realisation of broadband wireless transmission systems, including the provision of a wide radio coverage.

The Practical Value of the Doctoral Thesis

The results of the scientific studies of the Doctoral Thesis were taken into account in the development of a recommendation when planning the use of the 700 MHz band in Latvia and in the preparation of proposals for the amendments to the National Radio Frequency Plan.

The results of the Doctoral Thesis were used

1. Developing of the SJSC *Electronic Communications Office* document *700 MHz band usage opportunities for mobile communications* that was submitted to the Ministry of Transport of the Republic of Latvia;
2. Developing of the SJSC *Electronic Communications Office* document *Concept for the Development of Future Broadband Mobile 5G network*. Preparing recommendations for the 700 MHz frequency arrangement for mobile communications in Latvia.

3. Preparing of the SJSC *Electronic Communications Office* proposals for the conditions of the use of mobile communication systems in the 700 MHz band in the border area (frequency coordination agreements);
4. Developing of the SJSC *Electronic Communications Office* methodology for the calculations of theoretical radio coverage of mobile communication networks, the guidelines of which are published in CEPT ECC Report 231 *Mobile coverage obligations*.

Theses Defended in the Doctoral Thesis

1. The minimum required separation distance between DVB-T high power transmitter and the receiving LTE700 base station operating in the adjacent band with a 9 MHz frequency separation is 13 km (±3.5 km).
2. The required separation distance between the LTE base stations and the ARNS RSBN receiving ground based receiving equipment operating in the 700 MHz band in the co-channel case for the provision of electromagnetic compatibility is 112 km (±9 km).
3. The required separation distance between the LTE700 base stations for electromagnetic compatibility of wireless networks is 26 km (±4 km) for a commonly used frequency channel, with a 5 % average throughput loss in the LTE network cell.
4. In order to estimate the propagation of a base station signals in a particular sector, 3 to 4 measurement points are required to compare the results of EMF strength measurements and theoretical calculations, moreover, the accuracy of the results of theoretical calculations is affected by the quality and resolution of the available topographic and earth's surface digital maps. Model ITU-R P.1546-5 is applicable for the prediction of radio wave propagation in the 700 MHz band.

In this Doctoral Thesis, the values (± km) correspond to accuracy of measurements, which were acquired by appropriate computer simulation recalculation (see also Chapter 3 of the Summary of the Doctoral Thesis).

Approbation of the Research Results

The main results of the Doctoral Thesis have been presented at 10 international scientific conferences and reflected in 9 publications in the scientific journals, in 5 publications in full-text conference proceedings, and in 1 chapter of a scientific monograph.

Reports at international scientific conferences

1. **Ancans, G.**, Stankevicius, E., Bobrovs, V., Osis, N. Analysis on Interference Impact of 4G/5G in 450 MHz on Digital Terrestrial Television Broadcasting // *Progress in Electromagnetics Research Symposium (PIERS)*. **China**, Xiamen, 17–20 December 2019 (approved publication).
2. **Ancans, G.**, Stankevicius, E., Bobrovs, V. Investigation of Electromagnetic Compatibility between DVB-T/T2 and LTE700 for Co-channel Case // *Progress in*

Electromagnetics Research Symposium (PIERS). **Singapore**, Singapore, 19–22 November 2017. (Scopus).
3. **Ancans, G.**, Sharashidze, T., Bobrovs, V. Electromagnetic Compatibility Assessment of LTE700 Networks for Co-channel Case // *Progress in Electromagnetics Research Symposium (PIERS)*. **Russia**, Saint Petersburg, 22–25 May 2017. (Scopus).
4. **Ancans, G.**, Bobrovs, V. Evaluation of LTE Broadcast Use in the 470-694 MHz Band // *Riga Technical University 57th International Scientific Conference*. **Latvia**, Riga, 14–18 October 2016.
5. **Ancans, G.**, Stankevicius, E., Bobrovs, V. Evaluation of LTE700 and DVB-T and DVB-T2 Electromagnetic Compatibility for Co-channel Case // *Progress in Electromagnetics Research Symposium (PIERS).* **China**, Shanghai, 8–11 August 2016. (Scopus).
6. **Ancans, G.**, Stankevicius, E., Bobrovs, V., Ivanovs, G. Evaluation of LTE and Aeronautical Radionavigation Service Electromagnetic Compatibility in 694–790 MHz Frequency Band // *20th International Conference ELECTRONICS 2016*. **Lithuania**, Palanga, 13–15 June 2016. (Scopus, Web of Science).
7. **Ancans, G.**, Stankevicius, E., Bobrovs, V., Ancans, A. Analysis on Interference Impact of Wi-Fi on Digital Terrestrial Television Broadcasting **//** *Wireless Telecommunications Symposium (WTS 2016). Global Wireless Communications: Europe and Beyond.* **Great Britain**, London, 18–20 April 2016. (Web of Science).
8. **Ancans, G.**, Stankevicius, E., Bobrovs, V., Paulikas, S. Evaluation of LTE700 and DVB-T Electromagnetic Compatibility in Adjacent Frequency Bands **//** *Progress in Electromagnetics Research Symposium (PIERS)*. **The Czech Republic**, Prague, 6–9 July 2015. (Scopus).
9. **Ancans, G.**, Bobrovs, V. Assessment of Spectrum Considerations for 5G Mobile Broadband Communication Systems // *Riga Technical University 56th International Scientific Conference*. **Latvia**, Riga, 14–16 October 2015.
10. **Ancans, G.**, Stankevicius, E., Bobrovs, V. Assessment of DVB-T Compatibility with LTE in Adjacent Channels in 700 MHz Band // *19th International Conference ELECTRONICS 2015*. **Lithuania**, Palanga, 15–19 June 2015. (Scopus, Web of Science).
11. **Ancans, G.**, Bobrovs, V., Ivanovs, Ģ. Evaluation of 700 MHz Band Use for Land Mobile Service // *Riga Technical University 55th International Scientific Conference*. **Latvia**, Riga, 14–16 October 2014.

Chapter in the scientific monograph

1. **Ancans, G.**, Bobrovs, V. Spectrum Usage for 5G Mobile Communication Systems and Electromagnetic Compatibility with Existent Technologies. In: *Broadband Communications Networks – Recent Advances and Lessons from Practice*. Haidine A., Aqqal, A., ed. **London**: IntechOpen, 2018, pp. 27–41. ISBN 978-1-78923-742-9.

Publications in scientific journals

1. Ancans, A., Petersons, E., **Ancans, G.**, Stetjuha, M., Ipatovs, A., Stankevicius, E. Technical and Economic Analysis of Transport Telecommunication Infrastructure // *Procedia Computer Science*. 2019, No. 149, pp. 206–214. (Scopus, Web of Science).
2. Ancans, A., Bogdanovs, N., Petersons, E., **Ancans, G.**, Umanskis, A., Vishnevskiy, V. Evaluation of Wi-Fi and LTE Integrated Channel Performance with Different Hardware Implementation for Moving Objects // *Procedia Computer Science*. 2017, Vol.104, pp. 493–500. (Scopus, Web of Science).
3. **Ancans, G.**, Stafecka, A., Bobrovs, V., Ancans, A., Caiko, J. Analysis of Characteristics and Requirements for 5G Mobile Communication Systems // *Latvian Journal of Physics and Technical Sciences*. 2017, Vol. 54, Iss.4, pp. 69–78. (Scopus).
4. **Ancans, G.**, Bobrovs, V., Ancans, A., Kalibatiene, D. Spectrum Considerations for 5G Mobile Communication Systems // *Procedia Computer Science*. 2017, Vol. 104, pp. 509–516. (Scopus, Web of Science).
5. **Ancans, G.**, Stankevicius, E., Bobrovs, V., Ivanovs, G. Evaluation of LTE and Aeronautical Radionavigation Service Electromagnetic Compatibility in 694–790 MHz Frequency Band // *Elektronika ir elektrotechnika*. 2016, Vol. 22, No. 6, pp. 99–103. (Scopus, Web of Science).
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7. **Ancans, G.**, Stankevicius, E., Bobrovs, V. Assessment of DVB-T Compatibility with LTE in Adjacent Channels in 700 MHz Band // *Elektronika ir elektrotechnika*. 2015, Vol. 21, No. 4, pp. 73–77. (Scopus, Web of Science).
8. **Ancans, G.**, Bobrovs, V., Ivanovs, G. Frequency Arrangement for 700 MHz Band // *Latvian Journal of Physics and Technical Sciences*. 2015, Vol. 52, Iss. 1, pp. 52–67. (Scopus).
9. **Ancans, G.**, Bobrovs, V., Ivanovs, G. Spectrum Usage in Mobile Broadband Communication Systems // *Latvian Journal of Physics and Technical Sciences*. 2013, Vol. 50, Iss. 3, pp. 49–58. (Scopus).
10. **Ancans, G.**, Stankevicius, E., Bobrovs, V., Ivanovs, G. Estimation of Electromagnetic Compatibility Between DVB-T/DVB-T2 and 4G/5G in the 700 MHz band for Co-channel Case // *Latvian Journal of Physics and Technical Sciences* (submitted for publication in 2019).

Publications in full-text conference proceedings

1. **Ancans, G.**, Stankevicius, E., Bobrovs, V., Osis, N. Analysis on Interference Impact of 4G/5G in 450 MHz on Digital Terrestrial Television Broadcasting // *Progress in Electromagnetics Research Symposium (PIERS)*. **China**, Xiamen, 17–20 December 2019 (accepted for publication).

2. **Ancans, G.**, Stankevicius, E., Bobrovs, V. Investigation of Electromagnetic Compatibility between DVB-T/T2 and LTE700 for Co-channel Case // *Proceedings of Progress in Electromagnetics Research Symposium (PIERS - FALL 2017).* Singapore, Singapore, 19–22 November 2017, pp. 875–878. (Scopus).
3. **Ancans, G.**, Sharashidze, T., Bobrovs, V. Electromagnetic Compatibility Assessment of LTE700 Networks for Co-channel Case // *Proceedings of Progress in Electromagnetics Research Symposium (PIERS 2017).* Russia, Saint Petersburg, 22–25 May 2017, pp. 2511–2514. (Scopus, Web of Science).
4. **Ancans, G.**, Stankevicius, E., Bobrovs, V. Evaluation of LTE700 and DVB-T and DVB-T2 Electromagnetic Compatibility for Co-channel Case // *Proceedings of Progress in Electromagnetics Research Symposium (PIERS 2016) Shanghai.* China, Shanghai, 8–11 August, 2016, pp. 4253–4257. (Scopus).
5. **Ancans, G.**, Stankevicius, E., Bobrovs, V., Ancans, A. Analysis on Interference Impact of Wi-Fi on Digital Terrestrial Television Broadcasting // *Proceedings of Wireless Telecommunications Symposium (WTS 2016). Global Wireless Communications: Europe and Beyond.* United Kingdom, London, 18–20 April 2016, p. 13. (Web of Science).
6. **Ancans, G.**, Stankevicius, E., Bobrovs, V., Paulikas, S. Evaluation of LTE700 and DVB-T Electromagnetic Compatibility in Adjacent Frequency Bands // *Proceedings of Progress in Electromagnetics Research Symposium (PIERS 2015)*. The Czech Republic, Prague, 6–9 July 2015, pp. 585–589. (Scopus).

Scope and Structure of the Doctoral Thesis

The total number of pages of the Doctoral Thesis is 132. It contains an introduction, four chapters, conclusions, bibliography and appendix.

An analysis of the radio frequency spectrum management aspects is carried out and an evaluation of the development directions of mobile communications is given in Chapter 1 of the Doctoral Thesis. An overview of the regulation of the 694–790 MHz band internationally and in Latvia is given.

Chapter 2 of the Doctoral Thesis is dedicated to the evaluation of EMC assessment methods for wireless transmission systems, as well as to the review of existing and prospective radio communication systems.

An evaluation of the EMC of wireless transmission systems between different various radio systems in the 700 MHz band and the adjacent band, as well as an evaluation of the radio coverage in the 700 MHz band are given in Chapter 3 of the Doctoral Thesis.

In Chapter 4, the implementation of the usage plan for the wireless transmission systems in the 694–790 MHz band is given.

The results of completed studies are summarised in the Doctoral Thesis. The main conclusions of the Doctoral Thesis are summarised and substantiated in Conclusions. Lists of scientific conferences and publications are presented in the appendix.

CHAPTER 1

The analysis of aspects of the radio frequency spectrum management (internationally and in Latvia) is carried out and the evaluation of the directions and trends of development of mobile communications is given in the **first chapter** of the Doctoral Thesis.

Based on the analysis performed **in Sub-chapter 1.1**, the access to the radio frequency spectrum due to the limits of the spectrum resources is regulated at the national and international level (at regional and global levels). An illustrative example of the organisation of the radio frequency spectrum management is given in Fig. 1.1. One of the elements of the radio spectrum management system, on the successful implementation of which the efficiency of the whole management system depends, is radio frequency planning [5], [14].

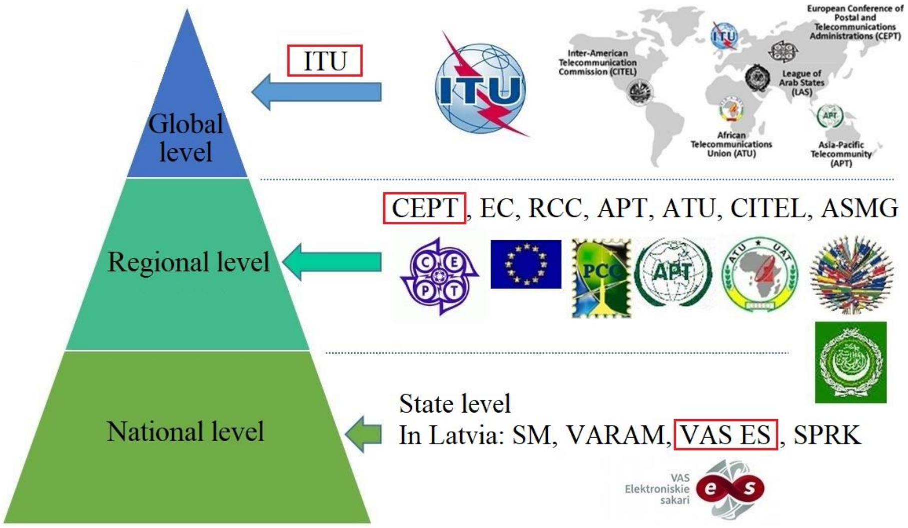

Fig. 1.1. Organisation of radio frequency spectrum management.

The radio frequency spectrum management comprises three important areas: planning (allocation) of the radio frequency spectrum, development of technical conditions necessary for the use of the radio frequency spectrum, and allotment of radio frequencies to the radio equipment. The radio monitoring of radio frequency spectrum and monitoring and preventive measures of the radio frequency spectrum are included in the radio frequency spectrum management as well.

The Radiocommunication Sector of International Telecommunication Union (ITU-R) plays an important role in the management of radio frequency spectrum on a global scale. The mission of the ITU Radiocommunication Sector is to ensure rational, equitable, efficient and economical use of the radio frequency spectrum by all radiocommunication services, including those using satellite orbits, and to carry out studies and adopt recommendations on radiocommunication matters. The primary objective of the ITU-R is to ensure interference free operations of radiocommunication systems [33].

In Europe at the regional level, the management of radio frequency spectrum is carried out by the Conference of European Postal and Telecommunications Administrations (CEPT) and by the European Union authorities, which are responsible for the use of radio frequency spectrum.

In Europe at the national level, the radio frequency spectrum management is carried out by the appropriate national authorities. In Latvia, the radio frequency spectrum management in the electronic communications sector is provided by SJSC *Electronic Communications Office* within the scope of its competence.

According to Cisco's forecast [12] given **in Sub-chapter 1.2**, 4G networks will continue to grow rapidly and faster than other networks, however, the percentage share will go down slightly to 71 % of all mobile data traffic by 2022. In 2022, 12 % of all mobile data traffic will be transmitted over 5G networks, but 17 % over 3G networks and only 1 % over 2G networks (see Fig. 1.2).

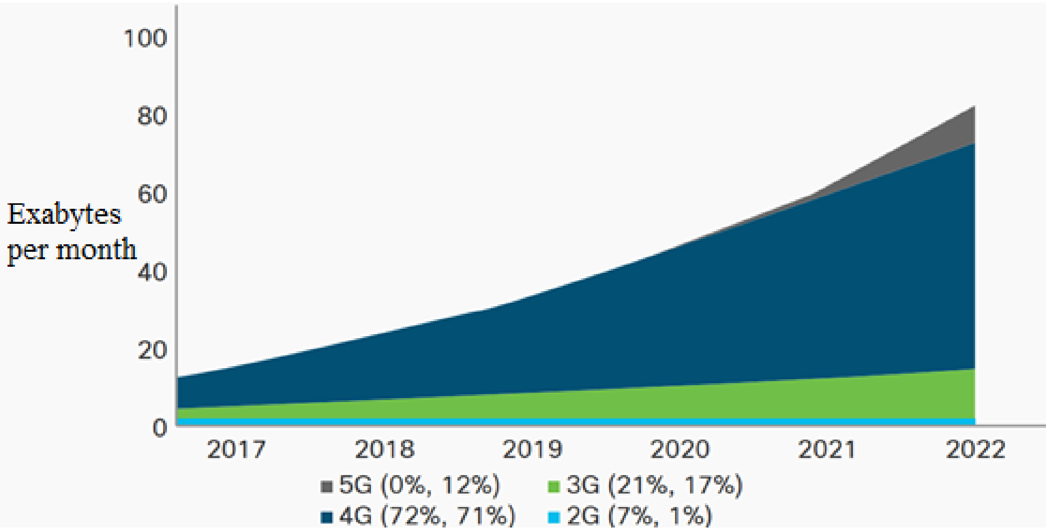

Fig. 1.2. Mobile data traffic forecast by the type of network.

In accordance with the evaluation given in **Sub-chapter 1.3**, the 2012 World Radiocommunication Conference (WRC-12) resolved to allocate the frequency band 694–790 MHz (700 MHz) in the ITU Region 1 to the mobile, except aeronautical mobile, service on a co-primary basis with other services to which this band is allocated on a primary basis. A band was also allocated to IMT [5].

Taking into account the characteristics of propagation of radio waves, and in order to reduce the harmful radio interference between neighbouring countries, a coordinated use of frequencies, particularly in border areas, is required. Thus, the efficiency of use of the radio frequency spectrum is improved.

When setting the implementation dates for mobile services in the 700 MHz band in the European Union, the Member States should take into account the potential difficulties of frequency coordination between mobile and broadcasting services, and aeronautical radionavigation systems, as well as the national situation of each of the Member States.

In the Latvian National Radio Frequency Plan [23], the 700 MHz band is currently allocated to the digital terrestrial television broadcasting and no change of its use is envisaged until 2022 (Fig. 1.3).

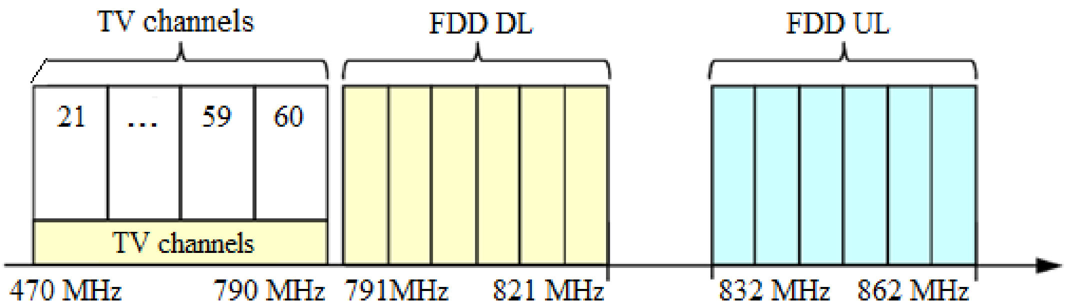

Fig. 1.3. Distribution of UHF radio frequency spectrum in Latvia.

CHAPTER 2

Existing and prospective radiocommunication systems in the 694–790 MHz band and adjacent bands, as well as an analysis of methods for the evaluation of electromagnetic compatibility for radiocommunication systems are considered **in Chapter 2** of the Doctoral Thesis.

Existing and prospective radiocommunication systems in the 694–790 MHz band and adjacent bands are analysed **in Sub-chapter 2.1** of the Doctoral Thesis.

LTE has become one of the most widely used broadband network technologies for mobile communications in recent years. Compared to the first mobile digital cellular networks (GSM), which more than 25 years ago, initially supported only voice connections, the difference in service supply is significant. LTE technology is in the early stages of its implementation, and along with the additions to the LTE standard, 3GPP is working on the next generation of 5G mobile communications standards. LTE, along with the latest 3GPP standards, will ensure 5G wireless access in the future [13].

The four basic Radio Resource Management (RRM) measurements in the Long Term Evolution (LTE) system are Channel Quality Indicator (CQI), Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), and Carrier Received Signal Strength Indicator (RSSI). A measurement of channel quality, which is represented by signal-to-interference-plus-noise ratio, is used to measure these parameters [29].

In digital television broadcasting, the video signal in the form of MPEG-2, MPEG-4 or otherwise coded data is transmitted, unlike analogue television. The standard for digital terrestrial television broadcasting used in Europe and Latvia is DVB-T (Digital Video Broadcasting – Terrestrial) or its improved versions. Other television broadcasting standards are used in other regions of the world as well.

The aeronautical radionavigation system (ARNS) may be used, in accordance with the ITU Radio Regulations [24], in the 694–790 MHz band on a primary basis. According to ITU Radio Regulations footnote No. 5.312 [24], in several countries, including Belarus, the Russian Federation and Ukraine the frequency band 645–862 MHz is also allocated to the ARNS on a primary basis.

Cellular IoT systems are among the next-generation of wireless systems to be used in the 700 MHz band. NB-IoT and LTE-MTC are expected to be part of the fifth generation mobile (5G) networks [14], [22]. Examples of applications for NB-IoT networks include smart homes, smart cities and smart transportation [31]. IoT networks can also be used for the management of transport infrastructure (traffic lights, traffic signs, parking in car parks, etc.).

The term **5G** means not only a new radio access technology, but it is also used in a much wider context, i.e., in the context of new services to be provided by the future 5G cellular networks. In ITU terminology, IMT-2020 stands for 5G.

5G wireless access includes both 5G NR and LTE enhanced versions (LTE Evolution) [6]. LTE technology and its advanced versions are intended for use in radio frequency spectrum below 6 GHz, while the 5G NR includes the spectrum up to 100 GHz (millimetre waves). 5G radio networks are expected to consist of networks based on NR and LTE technology

(Fig. 2.1) [14], [32]. Both technologies have been submitted to the ITU as candidate technology IMT-2020.

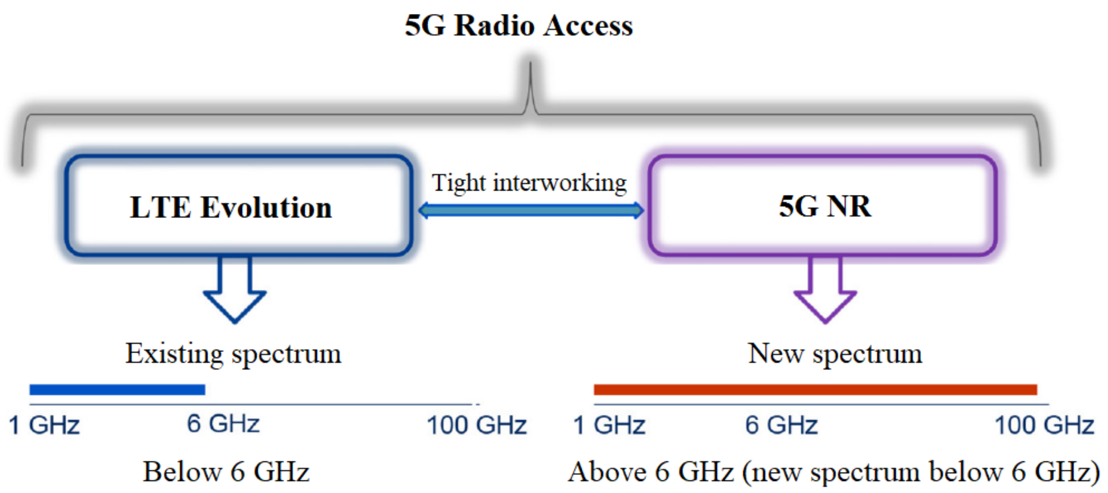

Fig. 2.1. 5G Radio Access Technologies [32].

According to [19] the use of ASS in the frequency bands below 1 GHz is not planned.

NR networks are primarily intended to be developed at higher frequencies (e.g., in 3.4–3.8 GHz band and in bands above 24 GHz). Such networks can be supplemented with LTE frequency carriers at lower frequencies (e.g., below 1 GHz) both in downlink and uplink.

Dual connection can improve uplink radio coverage, e.g., by combining 700 MHz band frequency carriers with 3.5 GHz or even 24 GHz band frequency carriers.

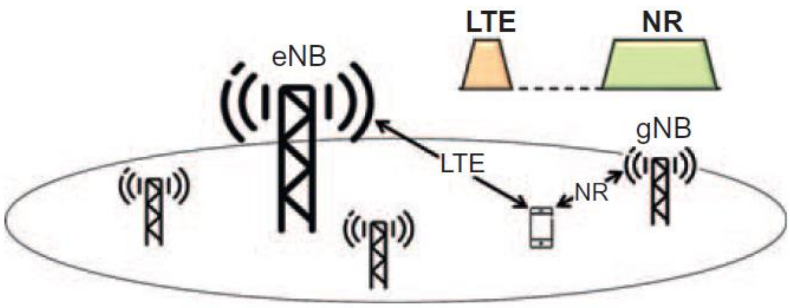

Fig. 2.2. An example of a NR/LTE dual connection in a scenario with multiple base station cells [14].

The list of LTE and 5G NR technology parameters for the 700 MHz band [1] is given in Table 2.1. It should be noted that both LTE and 5G NR provide frequency carrier aggregation (CA) functionality.

Table 2.1

Some Parameters of LTE and 5G NR Systems

Parameter	4G/5G (LTE)	5G (NR)
Technology	Long Term Evolution (LTE)	New Radio (NR)
Channel arrangement	FDD	FDD
Bandwidth	1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz, 20 MHz	5 MHz, 10 MHz, 15 MHz, 20 MHz
Modulation (downlink)	OFDM	OFDM
Duration on a radio frame/sub-frame	10 ms / 1 ms	10 ms / 1 ms
Cyclic Prefix (CP) type	Normal CP, extended CP	Normal CP (SCS 15 kHz and 30 kHz)
The number of symbols per time slot	7 symbols for a normal CP, 6 for an extended CP	14 symbols for a normal CP, 2,4 and 7 for a minislot
Number of resource blocks in a 5 MHz / 10 MHz wide channel	25/50	25/52
Type of antenna used	non-AAS	non-AAS
Emission and filter mask	Complies with 3GPP TS 36.104, 36.101	Complies with 3GPP TS 38.104, 38.101
Sensitivity threshold for a 10 MHz wide channel (SCS 15 kHz)	–101.5 dBm	–101.7 dBm
One subcarrier spacing	15 kHz	15 kHz, 30 kHz
3GPP Technical Specification Release	8–16	15, 16
Dual connection	3GPP Release 13	3GPP Release 15

Not all radio frequency spectrum in the UHF band is fully utilised. The part of the radio frequency spectrum that is allocated to the terrestrial television broadcasting service but is not used locally is called the Television White Space – *TVWS*.

TVWS technology [5] can be used, e.g., at the regional level to make more efficient use of the radio frequency spectrum of the television by ensuring electromagnetic compatibility with other radiocommunication systems. Unused frequency bands in the television spectrum can be used, e.g., for wireless broadband systems. In the author’s study [3], Wi-Fi was adopted as TVWS, which meets the 802.11af standard.

Broadband Public Safety and Disaster Response Systems (**BB-PPDR**) are radiocommunications that are used by responsible authorities and emergency services, which provide public safety, security and defence of life and property, disaster relief, etc. [23]. The infrastructure of the wireless broadband systems (e.g., 4G, 5G networks) can be used for the solutions of BB-PPDR systems.

There are possible alternative or combined solutions for the traditional terrestrial television broadcasting networks. The telecommunications sector is experiencing a gradual convergence of different telecommunications networks and a tendency to share both infrastructure and radio frequency resources between different electronic service providers.

In theory, traditional DVB-T/T2 can be substituted by cellular communication systems, e.g., the standardisation organisation 3GPP has developed **eMBMS** (Evolved Multimedia Broadcast Multicast Services) technology for LTE-based television networking platform (see Fig. 2.3).

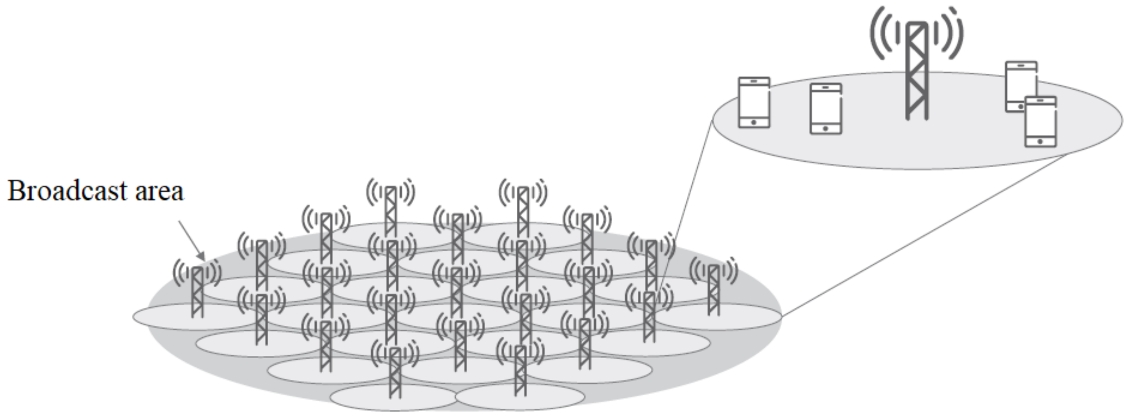

Fig. 2.3. LTE MBMS Broadcasting scenario [13].

An evaluation of the EMC methods is given **in Sub-chapter 2.2** of the Doctoral Thesis.

The deployment of new radio systems requires additional frequencies, which are necessary for the development of radiocommunication networks. The introduction of new radiocommunication systems in addition to the existing ones intensifies the use of the radio frequency spectrum and thus the likelihood of radio interference is increased.

Radio interference occurs when one system, while transmitting radio signals, interferes with the reception of signals by another system. Such radio interference might occur between systems operating in a co-channel or in adjacent channels.

The evaluation of radio interference involves theoretical calculations on a common frequency channel (co-channel) or on adjacent channels. Studies involving the evaluation of a shared frequency channel are commonly referred to as spectrum sharing studies, while adjacent channel studies are called electromagnetic compatibility studies.

Theoretical calculations are necessary because it is not always possible to carry out measurements with real equipment, especially when the new radiocommunication systems are under development. In EMC studies, two types of research are distinguished.

1. *Deterministic studies* – based on fixed parameters and Minimum Coupling Loss (MCL) method is applied. The worst-case scenario for radio interference is determined with this method. The result of the calculations is usually expressed as the minimum required separation (in space or in the frequency range) between two radiocommunication systems in order to ensure steady operation of these systems.

2. *Statistical research* – based on variable parameters using the Monte Carlo method. This method is more realistic for the evaluation of electromagnetic compatibility than MCL because the variations in several parameters and their randomisation, such as the relative positioning of the systems, are taken into account. The result of the evaluation is the probability (%) of radio interference in the affected scenario, which can be compared to the corresponding threshold value in order to determine whether the results obtained are considered as harmful interference.

Statistical research can be carried out with various software tools, one of which is SEAMCAT (Spectrum Engineering Advanced Monte Carlo Analysis Tool), which is open source software. This software was developed by CEPT [15], [18].

A graphical representation of the influenced and interfering network modelling in the SEAMCAT software is shown in Fig. 2.4.

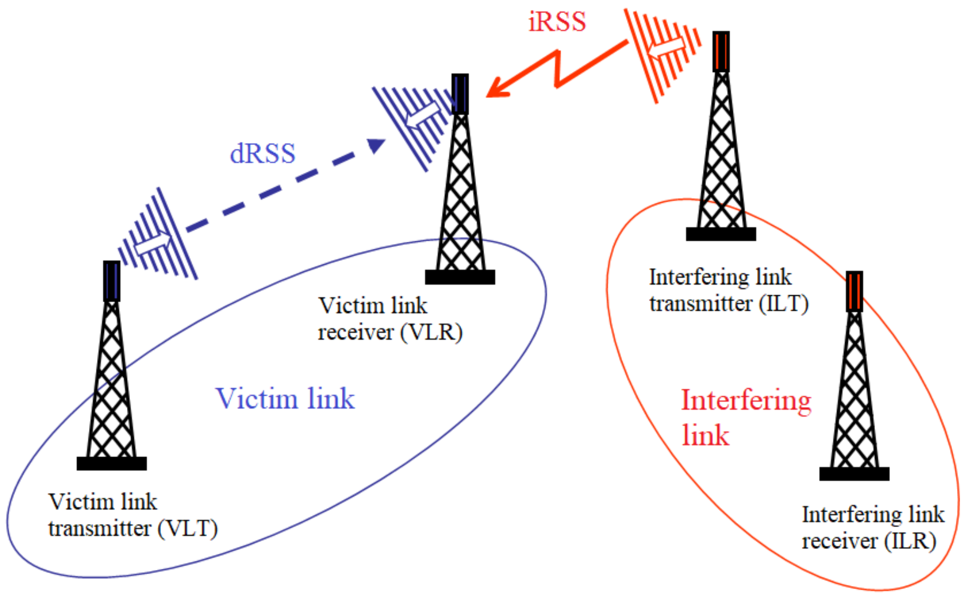

Fig. 2.4. Influenced and interfering network modelling in the SEAMCAT software [18].

CHAPTER 3

In **Chapter** 3 of the Doctoral Thesis, the electromagnetic compatibility of the wireless transmission systems with the systems operating in the band and in adjacent bands is evaluated, as well as the analysis and evaluation of the theoretical radio coverage and practical measurements of LTE700 base stations are carried out.

Summarisation of the developed computer simulation and experimental measurement scenarios for the evaluation of the electromagnetic compatibility is given **in Sub-chapter 3.1** of the Doctoral Thesis. The potential radio interference scenarios considered during the development of the Doctoral Thesis are summarised in Table 3.1.

Table 3.1

Potential Scenarios of Radio Interference

No.	Scenario of the radio interference	In co-channel / adjacent channel	Implemen-tation	Additional information
1	Impact of the DVB-T station on the LTE receiving base stations	In co-channel	Yes	*
2	Impact of the DVB-T station on the LTE receiving base stations	In adjacent channel	Yes	*
3	Impact of the DVB-T station on the LTE receiving user equipment	In co-channel	–	**
4	Impact of the DVB-T station on the LTE receiving user equipment	In adjacent channel	–	**
5	Impact of the LTE base station on the DVB-T receiving radio equipment	In co-channel	Yes	*
6	Impact of the LTE base station on the DVB-T receiving radio equipment	In adjacent channel	–	*
7	Impact of the LTE user equipment on the DVB-T receiving radio equipment	In co-channel	–	**
8	Impact of the LTE user equipment on the DVB-T receiving radio equipment	In adjacent channel	Yes	*
9	Impact of the LTE base station on ARNS receiving radio equipment	In co-channel	Yes	*
10	Impact of the LTE base station on ARNS receiving radio equipment	In adjacent channel	–	**
11	Impact of the ARNS station on the LTE receiving base stations	In co-channel	–	**
12	Impact of the ARNS station on the LTE receiving base stations	In adjacent channel	–	**
13	Impact of the LTE base station on the LTE receiving user equipment	In co-channel / adjacent channel	Yes	*
14	Impact of the LTE user equipment on the LTE receiving base stations	In co-channel / adjacent channel	–	**

* Critical scenario from the point of view of EMC and frequency cross-border coordination.

** Not a critical scenario from the point of view of EMC and frequency cross-border coordination.

The author of the Doctoral Thesis has developed Scenarios 1, 2, 5, 8, 9 and 13 for possible radio interference, which are described in Chapter 3 of the Doctoral Thesis.

Scenarios 3 and 4 are not critical from the point of view of EMC and frequency coordination because higher limits are to be expected in scenarios 5 and 6.

Scenario 10 is not critical from the point of view of EMC and frequency coordination because higher limits are to be expected in scenario 9.

Scenarios 11 and 12 are not critical from the point of view of EMC and frequency coordination (see also Sub-chapter 3.1.6).

Scenario 14 is not critical from the point of view of EMC and frequency coordination because higher limits are to be expected in scenario 13.

In all scenarios that were considered, the planning of the frequency duplex (FDD) channels containing the 2 × 30 MHz frequency block and corresponding to the lowest frequency of band No. 28 of 3GPP has been adopted: 703–733 MHz for the uplink and 758–788 MHz for the downlink with the bandwidth of 10 MHz.

The LTE/LTE-A parameters in Sub-chapter 3.1 are in accordance with the recommendations of the JTG 4-5-6-7 and WP 5D (IMT) working groups [16] and the ITU-R Report M.2292-0 [27].

The DVB-T and DVB-T2 parameters in Sub-chapter 3.1 are in accordance with the recommendations of the JTG 4-5-6-7 and WP 6A (DTTB) working groups [17].

The technical parameters of ARNS in Sub-chapter 3.1 are in accordance with ITU-R recommendations M.1830 [21] and M.1461-1 [20].

Measurement error

EMF strength measurements shall be performed in accordance with CEPT/ERC Recommendation 74-02 [11]. According to the above-mentioned recommendation and to the accuracy of measurement stated in the specifications of the measuring equipment, which was used in the Doctoral Thesis, the accuracy of measurement of the EMF intensity is within ± 3 dB, which is also considered the measurement error.

A summary of the radio interference scenarios is given further, for which the theses to be defended in the Doctoral Thesis are prepared.

Scenario 2: Impact of DVB-T station on LTE receiving base stations (adjacent channel)

The results of Scenario 2 are published in article *Assessment of DVB-T compatibility with LTE in adjacent channels in 700 MHz band* [8].

Within this scenario, the EMC between a DVB-T operating on TV channel No. 48 (686–694 MHz) and LTE700 working on the first channel (703–713 MHz) in uplink was studied.

Description of the scenario

Within this scenario, potential radio interference on the LTE700 base station receivers (in uplink) from adjacent DVB-T stations was studied. The scenario corresponds to the use of frequencies below 694 MHz for digital television in neighbouring countries or within the country. In this scenario, the LTE network is assumed to be within the coverage area of the DVB-T network. A corresponding SEAMCAT simulation scenario is shown in Fig. 3.1. In this case, the LTE network is assumed to consist of seven base stations.

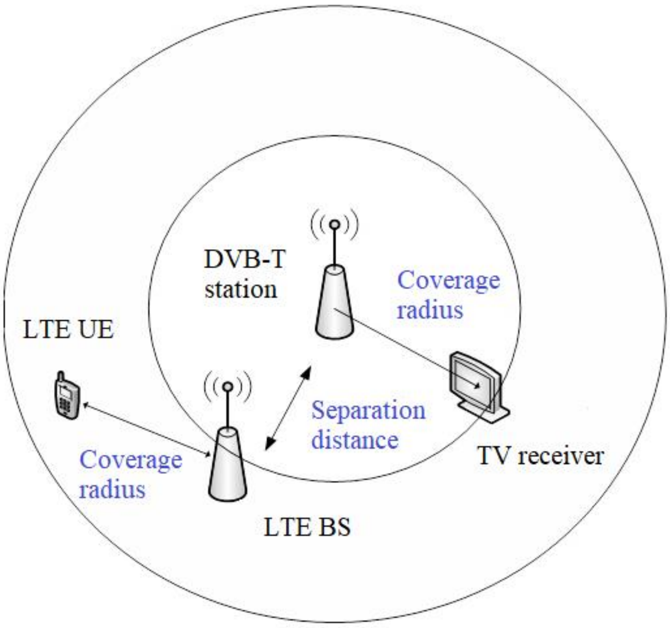

Fig. 3.1. SEAMCAT simulation scenario.

Summary

In this scenario, the method of MCL and Monte Carlo has been used to evaluate the electromagnetic compatibility of DVB-T and LTE systems. The MCL method is considered to provide more cautious results in EMC, while the SEAMCAT Monte Carlo simulation method provides results that are more realistic because the simulations take into account many system-specific parameters.

The results of MCL showed that the required geographic separation distance between the DVB-T transmitter and the receiving LTE700 base stations is 26.15 km. According to the results of SEAMCAT Monte Carlo, the minimum required separation between DVB-T transmitter and LTE base station receivers operating in the adjacent band is 13 km.

Scenario 9: Impact of the LTE base station on ARNS receiving radio equipment (in co-channel)

The results of Scenario 9 are published in the article *Evaluation of LTE and Aeronautical Radionavigation Service Electromagnetic Compatibility in 694–790 MHz Frequency Band* [9].

Description of the scenario

Within this study, the performance of LTE base stations in the 758–788 MHz (downlink) and 738–758 MHz (additional downlink) bands and the potential impact of these stations on ARNS systems in the 694–790 MHz band was considered. Two types of ARNS station were studied according to ITU-R Recommendation M.1830: RSBN receiving ground stations operating in 784 MHz, and RLS 2 Type 2 receiving ground stations operating in 740 MHz.

The potential impact of the LTE base station (downlink) on ARNS was considered in this research. The radio interference scenario for SEAMCAT simulations is shown in Fig. 3.2.

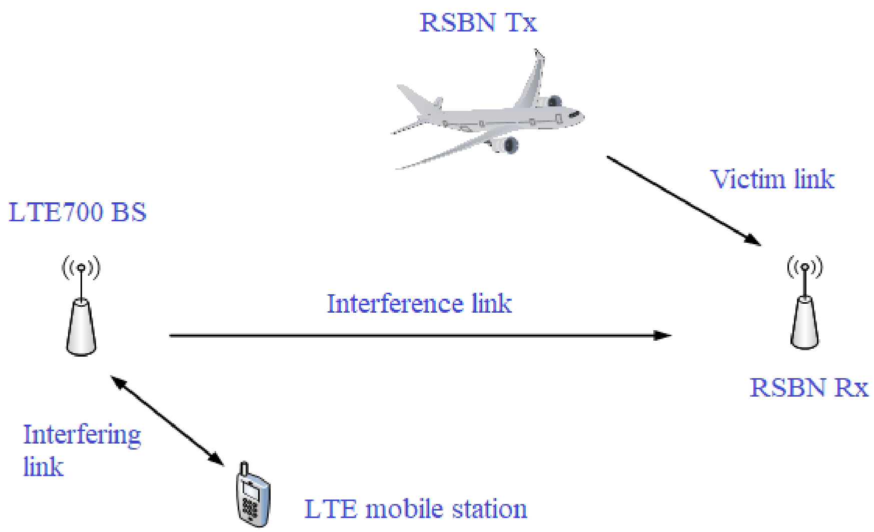

Fig. 3.2. The radio interference scenario for SEAMCAT simulations.

Summary

In this study, the results of the evaluation of the coexistence between LTE base stations and ARNS stations in the 700 MHz band are provided.

According to the results of the MCL calculations, the required system separation between the LTE base stations and ARNS RSBN receiving ground station is 132 km at a 10 m installation height of the receiving antenna. According to the results of SEAMCAT simulations, the separation of the systems shall be at least 112 km. However, according to the calculations of the EML intensity threshold values [21], the separation shall be at least 15 km for RSBN ground based radar and 45 km for RLS 2 Type 2 ground based radar. The results indicate that both systems can coexist (e.g., in neighbouring countries), however it is necessary to introduce frequency coordination measures, e.g., by establishing the minimum separation required between such radio equipment.

Additional suppression measures for the radio interference, such as aerial tilting, adjustment of the azimuth of the LTE network base stations, reduction of the maximum e.i.r.p. of LTE base stations, limiting the installation height of the base stations antennas, may be used to improve the electromagnetic situation.

Scenario 13: Impact of the LTE base station on the LTE receiving user equipment (in co-channel and adjacent channels)

The results of Scenario 13 (for the co-channel) are published in article *Electromagnetic Compatibility Assessment of LTE700 networks for Co-channel Case* [7]. From the point of view of radio interference and frequency coordination, this scenario for the adjacent channel is not critical, therefore it was not considered in detail in the Doctoral Thesis.

Description of the scenario

Within this study, the potential impact of the LTE base stations operation in the 758–788 MHz (downlink) band on the neighbouring network receiving user equipment (UE) in the co-channel was considered. 20 000 events were used in the SEAMCAT simulations. The radio interference scenario for SEAMCAT simulations is given in Fig. 3.3.

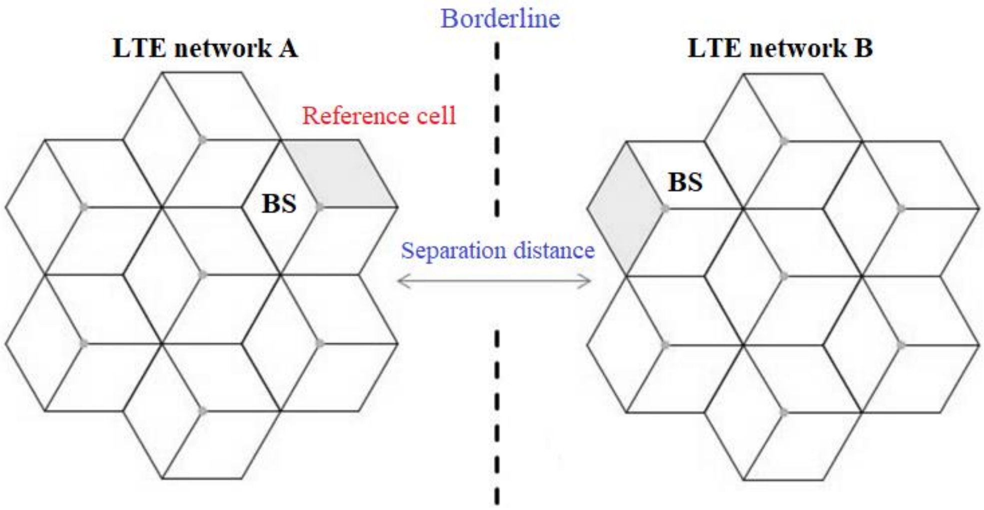

Fig. 3.3. The radio interference scenario for SEAMCAT simulations.

This scenario also corresponds to the introduction of cellular networks in the 700 MHz band in the neighbouring countries where LTE network A and LTE network B are located at their border.

Summary

This study provides an evaluation of EMC between cellular networks in the 700 MHz band for a co-channel. The SEAMCAT Monte Carlo method was used for EMC evaluation. According to the Monte Carlo simulations, the separation distance of these systems shall be 26 km to ensure the provision of an average throughput loss of not more than 5 % in the reference cell of the LTE network of the neighbouring countries.

According to the results of the study, additional measures to suppress the electromagnetic interference between cellular networks in the 700 MHz band can be applied, such as antenna tilting, turning the antennas of the LTE network base station away from the networks of the neighbouring countries, reduction of the maximum e.i.r.p. of LTE base stations, limiting the installation height of the base stations antennas, configuring base stations with narrower antenna diagrams, etc.

In Sub-chapter 3.2 of the Doctoral Thesis, a comparison of the results gained from the EMF intensity measurements and theoretical calculations of the signals transmitted by the cellular network base stations is carried out, as well as the propagation of the radio waves in the 700 MHz band corresponding to Latvian conditions (terrain, etc.) is analysed. Information on the methodology (used in the above measurements and calculations) developed by the author for comparing the results of the EML intensity measurements and theoretical calculations of the signals transmitted by the cellular network base stations is given in this sub-chapter.

Comparison of the results of the experimental measurements of EMF intensity and theoretical calculations

To compare the results of experimental measurements and theoretical calculations, measurements of the EMF for the LTE700 base station *Grobiņa* in 170° sector were performed. The measurement points of the signals transmitted by the LTE base stations are shown in Fig. 3.4.

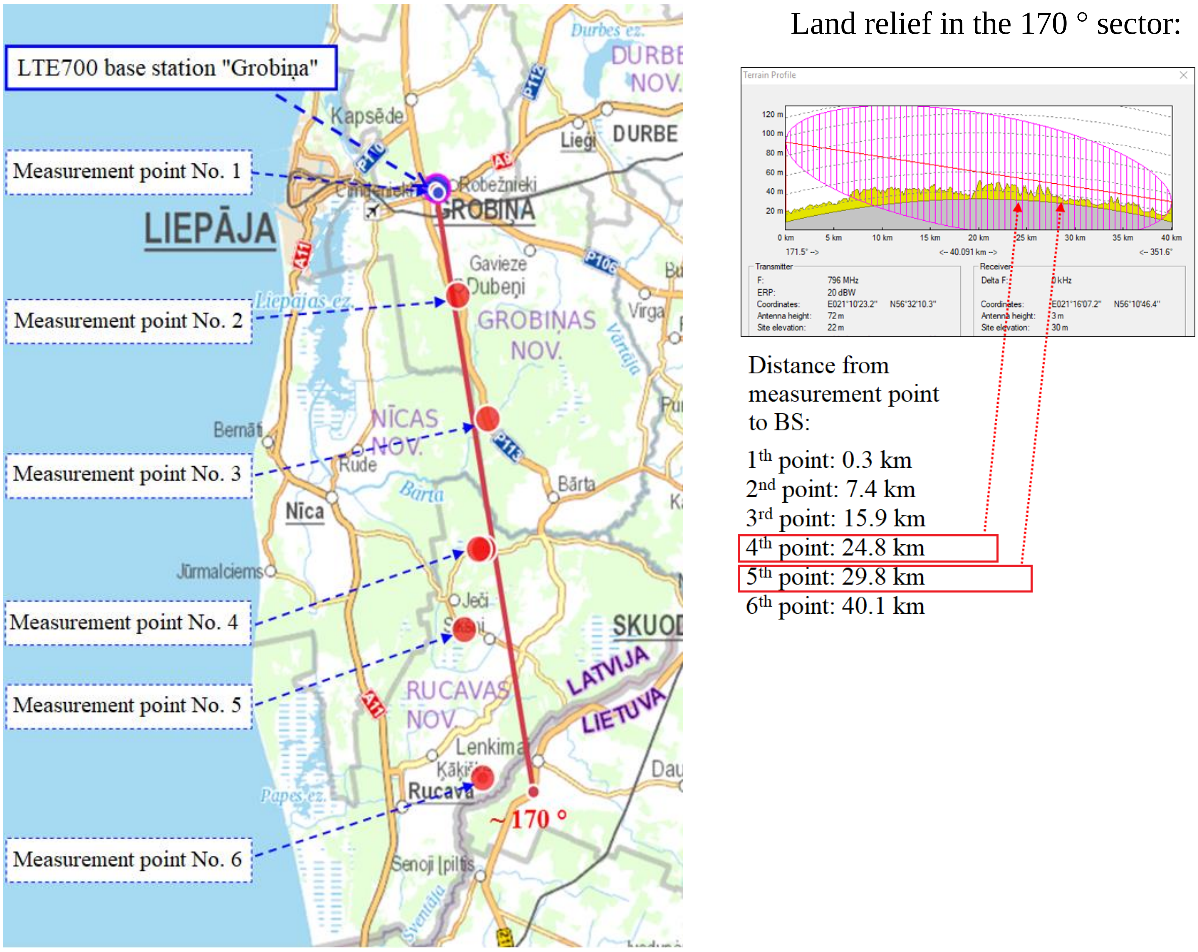

Fig. 3.4. Measurement points of the LTE700 base station signals in the 170° sector on map.

A summary of experimental measurements and theoretical calculations of the EMF intensity of the signals transmitted by the base station *Grobiņa* is given in Fig. 3.5. The experimental measurements were made at six points. It should be noted that at the measurement points 4 and 5, the LTE signal was not decoded because the level of the LTE measured signal was at the noise level of the measuring equipment. At these points, terrain dips are also visible on the map. The measurements were made by vertical polarisation of the antenna.

Calculations with the Akis-R software have been performed at T: 50 %, L: 50 %. As can be seen from the graphs, the results of the theoretical calculations and experimental measurements are similar and the trend of the measurement results corresponds to the empirical model curve of ITU-R P.1546-5 (with flat terrain).

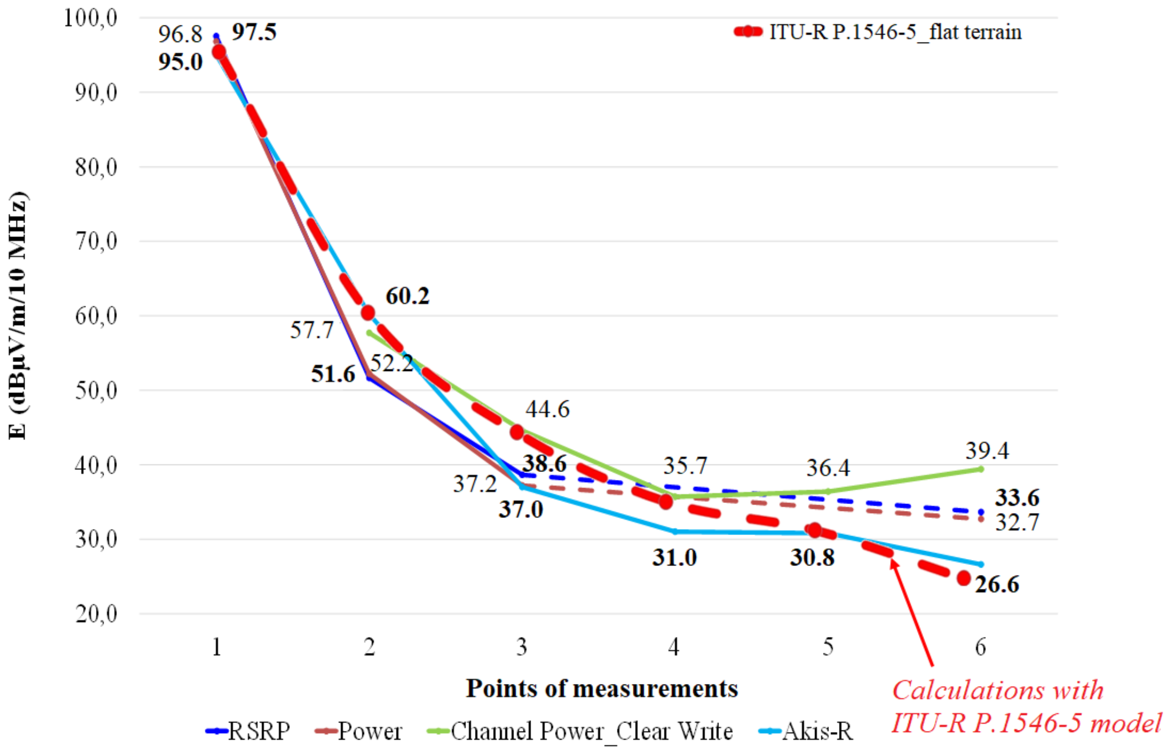

Fig. 3.5. Summary of the measurements of the EMF intensity of the signals transmitted by the LTE700 base station *Grobiņa*, dBµV/m.

Summary

It should be noted that the author of the Doctoral Thesis also performed theoretical calculations of EMF intensity with other prediction models of the radio wave propagation available in *Akis-R* software. Accordingly, the ITU-R Recommendation P.1546-5 [25] was found to be the most appropriate for the 700 MHz band when evaluating the results of the theoretical radio coverage calculations. The values of the RSRP and Power measurements are close to the results of the theoretical calculations (ITU-R Recommendation P.1546-5 is used in the calculations). In this case, the values of the RSRP and Power measurements at the second measurement point are lower than the results of the theoretical calculations, which can be explained by the relatively low installation height of the base station antennas and the wooded area, which adds additional attenuation of the radio signals.

The accuracy of the results of the theoretical calculations is affected by the quality and resolution of the available topographical and earth's surface digital maps. Clutters as well as constructions are not included in the calculations. The greatest difference between the results of the theoretical calculations and the experimental measurements was observed at the measuring points farther than 30 km from the base station. The elevation of the site (above sea level) has a major impact on the level of the measured signal at a given measurement point (it was also confirmed during the experimental measurements). It can be concluded that 3–4 measurement points are required to evaluate the propagation of the signals in a particular sector in order to compare intensity measurements of the EMF with the results of the theoretical calculations. From the results obtained, it can be concluded that the *Clear/write* mode of the *Channel Power* measurements gives an increase in the EMF strength of the perceived signal at measurement points 5 and 6. This could be explained by the fact that spectrum analyser FSH8 aggregates all received signals at the relevant frequencies (in this case, also from terrestrial television stations from the neighbouring country).

CHAPTER 4

In Chapter 4 of the Doctoral Thesis, the proposals for the radio frequency arrangement for wireless transmission systems in the 694–790 MHz band are presented and the scenarios for the future use of the 700 MHz band in Latvia for wireless transmission systems are analysed. Information on the development of the radio frequency arrangement and the possible usage scenarios are given **in Sub-chapter 4.1** of the Doctoral Thesis.

In publication *Frequency Arrangement for 700 MHz Band* [4], possible versions of the frequency arrangement for the 700 MHz band with an aim to identify the most appropriate options for the frequency arrangement to be used in Europe are analysed.

According to the results of the study of Chapter 3 of the Doctoral Thesis and the results of the analysis [4] the recommended radio frequency arrangement for the use of the 700 MHz band for wireless transmission systems in Latvia is shown in Fig. 4.1.

Guard band	FDD UL						Duplex gap	SDL				FDD DL						Guard band
	FDD1	FDD2	FDD3	FDD4	FDD5	FDD6		SDL1	SDL2	SDL3	SDL4	FDD1	FDD2	FDD3	FDD4	FDD5	FDD6	
694-703	703-708	708-713	713-718	718-723	723-728	728-733	733-738	738-743	743-748	748-753	753-758	758-763	763-768	768-773	773-778	778-783	783-788	788-791
9 MHz	30 MHz (6 × 5 MHz)						5 MHz	20 MHz (4 × 5 MHz)				30 MHz (6 × 5 MHz)						3 MHz

Fig. 4.1. Recommended radio frequency arrangement for the 700 MHz band.

A 9 MHz guard band is provided for the protection of digital terrestrial television broadcasting below 694 MHz from mobile service stations. Frequency bands 703–733 MHz / 758–788 MHz are provided for wireless transmission systems (uplink and downlink respectively). The 738–758 MHz band (additional downlink) is intended to provide additional capacity for the wireless transmission systems. In publication [4], the author of the Doctoral Thesis, on the basis of the analysis carried out for the optimal use of the 700 MHz band, recommends the use of 733–736 MHz and 788–791 MHz bands for the machine type communication (M2M) systems.

An evaluation of the conditions for the use of radio frequencies in the border areas is given in S**ub-chapter 4.2** of the Doctoral Thesis. According to the evaluation carried out, the use of the 700 MHz radio frequency band for the terrestrial television broadcasting and aeronautical radionavigation systems in Russia and Belarus would prevent the use of this frequency band for the wireless broadband transmission systems in a significant part of the territory of Latvia, which in turn would not ensure the efficient use of this radio frequency spectrum band. If the digital terrestrial television broadcasting systems were to be continued in one of the EU Member States, this could have an impact on the timely transition of its border-states to the use of mobile communications systems in that band. Therefore, coordinated and maximally harmonised use of frequencies between neighbouring countries is important.

THE MAIN RESULTS OF THE DOCTORAL THESIS

During the performance of the defined tasks, the following **main results and conclusions of the Doctoral Thesis have been obtained:**

1. In order to provide EMC between adjacent DVB-T high power transmitter and receiving LTE700 base stations (at 9 MHz frequency separation), these radio equipment should be installed with a separation distance of 13 km (±3.5 km) according to SEAMCAT Monte Carlo simulations.
2. According to the results of SEAMCAT Monte Carlo simulations, it is possible to provide EMC between the LTE base stations and the ARNS RSBN receiving ground-based radio equipment operating in the 700 MHz co-channel. The separation distance of the radio equipment within the considered scenario shall be 112 km (±9 km).
3. According to the results of SEAMCAT Monte Carlo simulations, the separation distance required for the provision of EMC between the wireless transmission networks (LTE) is 26 km (±4 km) in case of a co-channel use.
4. In order to estimate the propagation of the base station signals in a particular sector, 3 to 4 measurement points are required to compare the results of EMF strength measurements and theoretical calculations, moreover, the accuracy of the results of the theoretical calculations is affected by the quality and resolution of the available topographic and digital maps of earth’s surface. Model ITU-R P.1546-5 is applicable for the prediction of radio wave propagation in the 700 MHz band.
5. Experimental measurements confirmed the theoretical results on the effect of the DVB-T station on the receiving LTE700 base stations in the co-channel case, as radio interference from the terrestrial television station (MP) at the distance of 94 km was observed at the LTE base station. According to SEAMCAT Monte Carlo simulations, the required separation distance between the transmitting DVB-T station (MP) and the receiving LTE700 base stations in the co-channel case is 278 km.
6. According to the results of SEAMCAT Monte Carlo simulations, by applying the suppression techniques of the radio interference, the required separation distance between the transmitting LTE700 base stations and DVB-T/T2 receivers in the co-channel case can be reduced from 152 km and 159 km to 82 km and 88 km, respectively.

The results of the completed studies are summarised in the Doctoral Thesis. The results of the evaluation of electromagnetic compatibility can be used by the authorities of the radio frequency spectrum management, mobile operators, equipment manufacturers and other interested parties.

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