SAPHYRE

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Abstract

This document summarises the dissemination actions undertaken within SAPHYRE project throughout its duration. Various technical, standardisation and regulatory bodies were interfaced in order to advertise the research outcomes achieved in this project. External Advisory Board established within SAPHYRE project was extensively used for the industry feedback collection on the technical concepts being developed.

Keywords

Dissemination, standardisation, regulation, spectrum sharing, network sharing, sharing, inter-operator.

Contents

Abbreviations

3GPP	3rd Generation Partnership Project
ALUD	Alcatel-Lucent Deutschland AG
CFR	Consorzio Ferrara Ricerche
COST	European Cooperation in Science and Technology
CTU	České vysoké učení technické v Praze (Czech Technical University in Prague)
D#	SAPHYRE Deliverable (number)
DFG	Deutsche Forschungsgemeinschaft (German Research Foundation)
DoW	Description of Work
EAB	External Advisory Board
EC	European Commission
ECM	EURECOM
ETSI	European Telecommunications Standards Institute
FhG	Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. – Fraunhofer Institut für Telekommunikation
HHI	Heinrich-Hertz-Institut
ICC	IEEE International Conference on Communications
ICT	Information and Communications Technology
IPR	Intellectual Property Rights
LiU	Linköpings universitet
LTE(-A)	Long Term Evolution (Advanced)
NGMN	Next Generation Mobile Network
QMR	Quarterly Management Report
RAN	Radio Access Network
RAS	Radio Access and Spectrum
T#	SAPHYRE Task (number)
TI	Telecom Italia S.p.A.
TNO	Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek
TUD	Technische Universität Dresden
TUIL	Technische Universität Ilmenau
WP#	SAPHYRE Work Package (number)
WRC	Wrocławskie Centrum Badań EIT+ Sp. z o.o. (Wrocław Research Centre EIT+)
WWRF	Wireless World Research Forum

1 Executive summary

This document provides summary of all knowledge dissemination and exploitation actions, which were performed under work package WP7 framework of the SAPHYRE project throughout its duration, based on the research outcomes of the project. Various technical, standardisation and regulatory bodies were interfaced in order to advertise the research outcomes achieved in this project. Project dissemination was organised through different channels, including exploitation of the consortium members expertise, as well as external experts involvement, where the key role was devoted to the External Advisory Board, which was established within SAPHYRE project and extensively used for the industry feedback collection on the technical concepts being developed.

Based on the research outcomes, an extensive list of the scientific papers and SAPHYRE contributions has been included and described. Consortium partner specific dissemination plans were summarised, as well.

Note: Parts of the content provided in this deliverable were already presented in the Periodic reports PER#1 and PER#2. New contributions will reappear in the PER#3 while the Final report will provide another summary on dissemination activities undertaken in the frame of the SAPHYRE project.

2 SAPHYRE impact

The research work performed in the SAPHYRE project (Sharing Physical Resources – Mechanisms and Implementations for Wireless Networks) was constructed and performed based on pan-European collaboration, covering several fundamental building blocks such as wireless communication systems, information theory, game theory, networking, business and regulatory models, as well as the interdisciplinary connections between these fields. This project was intimately connected to the FP7-ICT goals, in particular the goals "simplicity, efficiency, and trust" of the eMobility strategic research agenda.

Economics aspects were considered to be mayor aspect of the work performed within this project, due to the importance of mobile communications to society, citizens and business. Based on the observation, that the success in global markets was developed from the results of EU-funded collaborative research on 2nd and 3rd generation mobile technologies towards formulation of successful global standards, this project was focused on the evolution towards the future broadband services provision in mobile networks, with was considered as the driver for economy growth. Being aware of the evolving radio technologies and user requirements, markets, competition, regulations and policies, SAPHYRE recognised the need for a holistic approach to implement the idea of resource sharing in a timely, efficient and successful way.

SAPHYRE goal was to reinforce European research and industrial leadership and competitive position in spectrum and infrastructure sharing by enabling network operators to adapt to the new business opportunities and improve their value added chain, enabling regulatory bodies to agree on easily maintainable sharing mechanisms, and enabling vendors to develop the new base stations and mobiles using the required radio technologies.

Due to constant need for higher data rates in wireless networks, development of more efficient frequency sharing strategies was seen as the pre-requisite for broadband applications. Thereby, SAPHYRE was promoting an open and competitive market model for information society and media services, being the enabler for new services to support inclusion, better public services and quality of life.

Contribution to EC policies

SAPHYRE was aiming to addresses the following long-term objectives of the Future Internet in Europe:

1. In order to comprehensively and consistently address the multiple facets of Future Internet, it was recognised that only a cross-layer and cross-disciplinary approach can solve the resource sharing problem in future wireless broadband systems. The main effects of sharing were investigated at the physical layer, while the need for sharing occurs at the service and system, in connection with the business models and considering the infrastructure aspects. SAPHYRE has developed the novel sharing mechanisms, which were necessary to operate in time-varying environments with different resource and sharing allocations. All

dimensions (spectral, temporal, spatial) were considered in multi-carrier and multi-antenna systems evaluations, presenting new ways of radio spectrum usage, which lead to cost and energy-reduction in cellular networks.

2. Regulatory bodies in Europe were expected to consider only such sharing methods, which would provide efficient co-ordination and control mechanisms, protecting against selfish or malicious users behaviour by using incentive compatible mechanisms. SAPHYRE proposed sharing mechanisms which were incentive compatible and which were requiring limited regulatory efforts. This development was done with the consideration of the European regulatory experts feedback.
3. Provision of broadband Internet access to all European citizens has been considered as one of the main goals ICT should pursue in the near future. SAPHYRE proved to have potential to provide results to considerably increase the percentage of population having access to wireless broadband Internet thus fulfilling European Commission's goal of providing broadband Internet access to all European citizens, which is considered as one of the most important factors for socio-economic impact. This could be realised by sharing physical resources for network deployments in areas where it would otherwise not be economical justified. In this way wireless broadband internet services would become available to a larger part of the population. Furthermore, increasing the possibilities for competition, while still enabling use of fewer physical resources, the cost base for wireless services could be reduced, offering an advantage to the subscribers.
4. SAPHYRE allows energy efficiency of wireless systems, by improved allocation algorithms at physical and multiple access layer allowing sharing of the resources, potentially leading to fewer physical networks deployments, as the largest power consumption in mobile networks takes place in the base stations. This aspect of SAPHYRE provides a cost efficient way to improve the physical environment thanks to fewer emissions and thus contributes to the common goal of reducing the European CO_2 footprint.

3 Knowledge dissemination and exploitation

The professional management of the knowledge delivered by the research activities of SAPHYRE has been acknowledged as being of paramount importance to the project achieving a significant impact in Europe and world-wide. Therefore, a specific work package (WP7 "Dissemination and Exploitation", [168] has been proposed to manage the corresponding activities, ensuring that all public documents generated by the project are collected.

In this section we provide the summary of all knowledge dissemination and exploitation actions, which were performed under work package WP7 (T7.1 "Dissemination to Scientific Peers and General Public", of the SAPHYRE project throughout its duration, based on the research outcomes of the project. The primary objective of the SAPHYRE WP7 was to efficiently and broadly disseminate and exploit the scientific results of the technical packages work results and to set up industrial/commercial interface and involvement in order to ensure proper exploitation of outcomes achieved within the project. Various technical, standardisation and regulatory bodies were interfaced in order to advertise the research outcomes achieved in this project. Project dissemination was organised through different channels, including exploitation of the consortium members expertise, as well as external experts involvement, where the key role was devoted to the External Advisory Board (EAB), which was established within SAPHYRE project and extensively used for the industry feedback collection on the technical concepts being developed.

Based on the project work description [168], following technical reports were covered:

- SAPHYRE deliverables (Section 3.1);
- SAPHYRE White Papers (Section 3.2);
- SAPHYRE Newsletter [146].

The above mentioned technical reports were generated based on the results from the work packages research which was captured in various dissemination documents, written in such fields like signal processing, information theory, communications theory, wireless networks, economy and regulatory aspects.

It was anticipated that depending on the consortium project partners, the knowledge use plans will differ and could be classified as follows:

- Industrial partners with operator background providing their business network to service providers, operators and regulatory bodies for dissemination and feedback;
- Industrial partners with hardware and technology background provide their technological network to hardware manufacturers and vendors for dissemination and feedback;
- Public research institutes and universities plan to disseminate the project results to scientific peers, other national and international academic research projects by conferences, workshops, tutorials, special sessions and journal publications.

Project outcomes were grouped into the below presented categories and described in more details in the following subsections. The presented categorisations were resulting from the evolving exploitation strategy, being constantly updated during projects duration, in order to maximise the impact of its outcomes. The dissemination focus was set on technical publications, but it was found to be important to address the commercial publication as well as those addressing decision making people and general public.

- Book chapters;
- Master theses;
- Journal papers;
- Conference publications;
- Invited talks;
- Special sessions;
- Workshops, including EC and industry workshops;
- Demonstrations;
- Tutorials/guest lectures;
- COST action initiatives;
- EAB meetings with network operators and regulators;
- Collaboration within related European activities, including other projects;
- Contributions to standardisation and regulation bodies;
- Internal workshops;
- Project web-site.

Based on the research outcomes, an extensive list of the scientific papers and SAPHYRE contributions has been included and described in the following subsections.

3.1 SAPHYRE deliverables

The full list of SAPHYRE deliverables is given [168]. In addition to the technical reports, the Co-ordinator of the project was providing supplementary Quarterly Management Reports (QMR) every three months except when a periodic report was requested. QMRs are summarising key outcomes achieved during the reporting period, including technical progress and achievements, project status, work started, work delayed and work completed. They also provide an overview on spent person months and expenditures.

Table 1: SAPHYRE deliverables

Number	Name of deliverable	Due date
D1.1	Set-up of Public Web Page	M01
D1.2	Public Project Presentation	M01
D1.3a/b/c	Quality Handbook (initial/updated/final)	M02/12/ M21
D1.4a/b	Planning for the Next Period	M13/25
D1.5a/b/c	Periodic Report	M12/24/ M36
D1.6	Final Report	M36
D1.7	Report on the Distribution of the Community's Contribution	30 d after fin. paym.
D1.8a–i	Quarterly Management Report (QMR)	each 3 months
D2.1a/b	Basic Limits for System Design (initial/final)	M12/30
D2.2a/b	Applied Game Theory (initial/final)	M12/30
D2.3a/b	Interference and Utility Modelling (initial/final)	M09/24
D3.1a/b	Adaptive and Robust Signal Processing in Multi-User and Multi-Cellular Environments (initial/final)	M12/36
D3.2a/b	Network, Resource and Interference Aware Coding and Decoding (initial/final)	M12/36
D3.3a/b	SAPHYRE Reference Scenario Parameters and Novel Interference Models (initial/final)	M12/24
D4.1	Resource Allocation and Interference Management Strategies	M24
D4.2	Networking Protocol Design for Resources Sharing	M30
D4.3	System Level Evaluation Methodology and Asymptotic Analysis Assessment	M24
D4.4	System Level Performance Evaluation	M36
D5.1a/b/c	Reference Scenarios for Resource Sharing (initial/updated/final)	M06/18/ M36
D5.2	Reference Business Scenario and Reference Regulatory Situation	M24
D5.3	Business Models, Cost Analysis and Advises for Spectrum Policy and Regulation for Scenario I (Spectrum sharing)	M30
D5.4	Business Models, Cost Analysis and Advises for Spectrum Policy and Regulation for Scenario II (Infrastructure sharing)	M30
D5.5	Business Models, Cost Analysis and Advises for Spectrum Policy and Regulation for Scenario III (Full sharing)	M34
D6.1a/b	Scenario Definition and Test Case Selection for Demonstrator Platform Evaluation (initial/final)	M12/30
D6.2	Internal Report on Demonstrator Platform Development	M12
D6.3a/b	Test Case Implementation and Evaluation on the Demonstrator Testbed (initial/final)	M24/36
D7.1a/b	Overview of Regulators' and Operators' Views on Resource Sharing (initial/final)	M12/36
D7.2a/b/c	Regulation and Standardisation Plan (initial/updated/final)	M06/18/ M36
D7.3	Overall Assessment and Analysis of Sharing Scenario I	M24
D7.4	Overall Assessment and Analysis of Sharing Scenarios II and III	M36
D7.5	Final Plan for Use and Dissemination of Knowledge	M36

3.2 SAPHYRE White Papers

Based on the research outcomes and findings, it was decided to generate three high-level summary reports (called White Papers), covering selected resource sharing scenarios, i.e. spectrum sharing, infrastructure sharing and full sharing. Content of the below listed White Papers was presented to and discussed with EAB members. It was planned, to use these White Papers, in order to disseminate SAPHYRE findings towards various industry forums and bodies, once completed.

[1] Eduard A. Jorswieck, Leonardo Badia, Torsten Fahldieck, Martin Haardt, Eleftherios Karipidis, Jian Luo, Rafał Pisz: "Resource sharing improves the network efficiency for network operators", SAPHYRE White Paper #1, December 2011.

[2] Jan Sýkora, Martin Haardt, Zuleita K.-M. Ho, Eduard A. Jorswieck, Jian Luo, Johannes Richter, Michał Szydełko, Jianshu Zhang: "Infrastructure and Relay Sharing in Interference Relay Networks Improves Coverage and Efficiency", SAPHYRE White Paper #2, July 2012.

[3] Leonardo Badia, Torsten Fahldieck, Francesco Guidolin, Eleftherios Karipidis, Remco Litjens, Irene Pappalardo, Haibin Zhang, Michał Szydełko: "Resource Sharing among Wireless Network Operators: Spectrum, Infrastructure, and Full Radio Access Network Sharing", SAPHYRE White Paper #3, December 2012.

3.3 Book chapters

Based on the project research outcomes achieved in SAPHYRE, the following book chapters were created, fulfilling the project's publishing goal in this category:

[4] Florian Römer, Eduard A. Jorswieck, Martin Haardt: "Efficient spatial processing and resource allocation for amplify and forward two-way relaying", in Cross Layer Designs in WLAN Systems (Nizar Zorba, Charalambos Skianis, Christos Verikoukis, eds.), Troubador Publishing Ltd, Leicester, UK, November 2011.

[5] Erik G. Larsson, Eduard A. Jorswieck: "Game Therory", in Mathematical Foundations for Signal Processing, Communications, and Networking, CRC Press, Boca Raton, Florida, USA, December 2011.

Additionally, TUD took the initiative to prepare and publish a White Paper booklet, based on the project outcomes, summarising findings on resource sharing in inter-operator environment. This booklet was distributed during FNMS 2012 [132] (for more details on this event, please refer to Section 3.9), as well as towards EAB members.

3.4 Theses

Work covered by technical work packages on the SAPHYRE project, was supported by students, leading to formulation of the following master and PhD theses:

[6] Ioanna Chatzicharistou: "Infrastructure sharing in Mobile Service market: Investigating the final decisions of the network operators", Master thesis, Delft University of Technology, The Netherlands, December 2010.

[7] Johannes Richter: "Erreichbare Ratenregion in Mehrantennennetzwerken mit Netzwerkcodierung", Diplomarbeit at Technische Universität Dresden, Germany, February 2011.

[8] Fieke H. S. Offergelt: "SAPHYRE: Cooperation among competitors – Analysing sharing scenarios for mobile network operators using game theory", Master thesis at Leiden University/TNO, The Hague, The Netherlands, June 2011.

[9] Li Li: "Pareto Boundary of Achievable Rate Region for MIMO Interference Channels: The Two-Link Case", Master thesis at Technische Universität Dresden, Germany, January 2012.

[10] Luca Anchora: "Spectrum sharing in mobile cellular networks: an alternative approach for efficient resource utilization", PhD Thesis at the IMT Institute for Advanced Studies of Lucca, Italy, March 2012.

3.5 Journal papers

Relevant publications like technical journals, magazines, IEEE transactions as well as IEEE and Elsevier letters were used to disseminate project visions and results. Below, we present list of the completed journal papers:

[11] Johannes Lindblom, Erik G. Larsson, Eduard A. Jorswieck: "Parameterization of the MISO IFC Rate Region: The Case of Partial Channel State Information", IEEE Trans. on Wireless Communications, doi: 10.1109/TWC.2010.02.081371, February 2010.

[12] Leonardo Badia, Marco Levorato, Federico Librino, Michele Zorzi: "Cooperation techniques for wireless systems from networking perspective", IEEE Wireless Communications Magazine, doi: 10.1109/MWC.2010.5450665, April 2010.

[13] Zhijiat Chong, Rami Mochaourab, Eduard A. Jorswieck: "Pricing in Noncooperative Interference Channels for Improved Energy-Efficiency", EURASIP Journal on Wireless Communications and Networking, vol. 2010 (2010), article ID 704614, doi: 10.1155/2010/704614, June 2010.

[14] Tomáš Uřičář, Jan Sýkora: "Design Criteria for Hierarchical Exclusive Code with Parameter Invariant Decision Regions for Wireless 2-Way Relay Channel", EURASIP Journal on Wireless Communications and Networking, vol. 2010 (2010), article ID 921427, doi: 10.1155/2010/921427, June 2010.

[15] Eduard A. Jorswieck, Erik G. Larsson: "Monotonic Optimization Framework for the Two-User MISO Interference Channel", IEEE Trans. on Communications, doi: 10.1109/TCOMM.2010.07.090068, July 2010.

[16] Simon Järmyr, Björn Ottersten, Eduard A. Jorswieck: "Statistical Precoding With Decision Feedback Equalization Over a Correlated MIMO Channel", IEEE Transactions on Signal Processing, vol. 58, no. 12, pp. 6298–6311, doi: 10.1109/TSP.2010.2070499, December 2010.

[17] Pavel Procházka, Jan Sýkora: "Karhunen-Loève based reduced-complexity representation of the mixed-density messages in SPA on Factor Graph and its

impact on BER", EURASIP Journal on Wireless Communications and Networking, vol. 2010, article ID 574607, doi: 10.1155/2010/574607, December 2010.

[18] Francesco Rossetto, Michele Zorzi: "Mixing Network Coding and Cooperation for Reliable Wireless Communications", IEEE Wireless Communications Magazine, doi: 10.1109/MWC.2011.5714021, February 2011.

[19] Rami Mochaourab, Eduard A. Jorswieck: "Optimal beamforming in Interference Networks with Perfect Local Channel Information", IEEE Trans. on Signal Processing, vol. 59, no. 3, doi: 10.1109/TSP.2010.2094612, March 2011.

[20] Alessio Zappone, Stefano Buzzi, Eduard A Jorswieck: "Energy-Efficient Power Control and Receiver Design in Relay-Assisted DS/CDMA Wireless Networks via Game Theory", IEEE Communications Letters, 15(7):701-703, July 2011.

[21] Tomáš Uřičář, Jan Sýkora: "Non-uniform 2-slot constellations for bidirectional relaying in fading channels", IEEE Communications Letters, 15(8):795-797, August 2011.

[22] Jan Sýkora, Alister G. Burr: "Layered design of hierarchical exclusive codebook and its capacity regions for HDF strategy in parametric wireless 2-WRC", IEEE Trans. on Vehicular Technology, 60(7):3241-3252, September 2011.

[23] Miroslav Hekrdla, Jan Sýkora: "Design of uniformly most powerful alphabets for HDF 2-way relaying employing non-linear frequency modulations", EURASIP Journal on Wireless Communications and Networking, 2011(128):1-18, October 2011.

[24] Konstantin Avrachenkov, Laura Cottatellucci, Lorenzo Maggi: "Algorithms for uniform optimal strategies in two-player zero-sum stochastic games with perfect information", Operation Research Letters, Elsevier, 40(1):56-60, January 2012.

[25] Haifan Yin, David Gesbert, Miltiades C. Filippou, Yingzhuang Liu: "A coordinated approach to channel estimation in large-scale multiple-antenna systems", IEEE Journal on Selected Areas in Communications, February 2012. — accepted. [Online]: http://arxiv.org/pdf/1203.5924

[26] Alessio Zappone, Eduard A. Jorswieck: "Resource Allocation in Amplify-and-Forward Relay-Assisted DS/CDMA Systems", IEEE Transactions on Wireless Communications, vol. 11, no. 4, April 2012.

[27] Miroslav Hekrdla and Jan Sýkora: "Optimised constellation prerotation for 3-terminal 1-relay network with wireless network coding", IEEE Communications Letters, 16(8):1200-1203, August 2012.

[28] Zuleita K.-M. Ho, Eduard A. Jorswieck: "Improper Signaling on the Two-user SISO Interference Channel", IEEE Trans. on Wireless Communications, vol. 11, no. 9, pp. 3194–3203, September 2012.

[29] Jianshu Zhang, Florian Römer, Martin Haardt: "Relay assisted physical resource sharing: Projection based separation of multiple operators (ProBaSeMO) for two-way relaying with MIMO amplify and forward relays", IEEE Trans. on Signal Processing, vol. 60, pp. 4834–4848, September 2012.

[30] Tomáš Uřičář, Jan Sýkora: “Non-uniform 2-slot constellations for relaying in butterfly network with imperfect side information”, IEEE Communications Letters, 16(9):1369-1372, September 2012.

[31] Rami Mochaourab, Eduard A. Jorswieck: “Robust Beamforming in Interference Channels with Imperfect Channel Information”, Signal Processing, vol. 92, issue 10, pp. 2509–2518, October 2012.

[32] Arash Khabbazibasmenj, Florian Römer, Sergiy A. Vorobyov, Martin Haardt: “Sum-rate maximization in two-way AF MIMO relaying: Polynomial time solutions to a class of DC programming problems”, IEEE Trans. on Signal Processing, vol. 60, pp. 5478–5493, October 2012.

[33] J. Lindblom, E. Karipidis, and E. G. Larsson: “Efficient computation of Pareto optimal beamforming vectors for the MISO interference channel with multiuser decoding”, IEEE Trans. on Signal Processing, October 2012 — submitted. [Online]: http://arxiv.org/abs/1210.4459

[34] Luca Anchora, Marco Mezzavilla, Leonardo Badia, Michele Zorzi: “A Performance Evaluation Tool for Spectrum Sharing in Multi-Operator LTE Networks”, Computer Communications (ComCom), Elsevier, vol. 35 iss. 18, pp. 2218–2226, November 2012.

[35] Eduard A. Jorswieck, Leonardo Badia, Torsten Fahldieck, Martin Haardt, Eleftherios Karipidis, Jian Luo, Rafał Pisz: “Spectrum sharing improves the network efficiency for wireless operators”, IEEE Communications Magazine, November 2012. — submitted.

[36] Pan Cao, Shuying Shi, Eduard A. Jorswieck: “On the Pareto Boundary for the Two-User Single-Beam MIMO Interference Channel”, IEEE Trans. on Signal Processing, revised in November 2012.

[37] Zuleita K.-M. Ho, Eduard A. Jorswieck: “Instantaneous Relaying: Interference Neutralization and Optimal Strategies”, IEEE Trans. on Signal Processing, vol. 60, no. 12, pp. 6655–6668, December 2012.

[38] Di Yuan, Vangelis Angelakis, Lei Chen, Eleftherios Karipidis, Erik G. Larsson: “On optimal link activation with interference cancellation in wireless networking”, IEEE Trans. on Vehicular Technology, vol. 62, no. 2, pp. 939–945, February 2013.

[39] Johannes Lindblom, Eleftherios Karipidis, Erik G. Larsson: “Achievable outage rate regions for the MISO interference channel”, IEEE Wireless Communications Letters, February 2013. — submitted. [Online]: http://arxiv.org/abs/1106.5615

Special issues

Special issue in highly cited IEEE journals were also considered, with successful submission to the IEEE Journal on Selected Topics in Signal Processing and its special issue on Game Theory in Signal Processing.

[40] Rami Mochaourab, Eduard A. Jorswieck: “Exchange Economy in Multiple Antenna Interference Channels”, IEEE Journal on Selected Topics in Signal

Processing, Special Issue on Game Theory in Signal Processing, vol. 6, no. 2, pp. 151–164, April 2012.

[41] Konstantin Avrachenkov, Laura Cottatellucci, Lorenzo Maggi: "Confidence Intervals for Shapley Value in Markovian Dynamic Games", Dynamic Games and Applications: Special issue on "Stochastic Games", September 2012. — accepted.

Based on the above presented list of submitted journal articles, including Special issues, relevant journals and their 5-year impact factors (as of December 2012) are listed in Table 2. The most important publications were published in the IEEE Communications Magazine and in the IEEE Journal on Selected Areas in Communications, both having impact factor above 3.0.

Table 2: Impact factors of journals addressed by SAPHYRE contributions

Journal title	**ISSN**	**5-year impact factor**
IEEE COMMUNICATIONS MAGAZINE	0163–6804	3.785
IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS	0733–8716	3.413
IEEE JOURNAL ON SELECTED TOPICS IN SIGNAL PROCESSING	1932–4553	2.880
IEEE TRANSACTIONS ON SIGNAL PROCESSING	1053–587X	2.628
IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS	1536–1276	2.586
IEEE WIRELESS COMMUNICATIONS MAGAZINE	1536–1284	2.575
IEEE TRANSACTION ON VEHICULAR TECHNOLOGY	0018–9545	1.921
IEEE TRANSACTIONS ON COMMUNICATIONS	0090–6778	1.677
IEEE COMMUNICATIONS LETTERS	1089–7798	0.982
EURASIP JOURNAL ON WIRELESS COMMUNICATIONS AND NETWORKING	1687–1499	0.870
ELSEVIER OPERATION RESEARCH LETTERS	0167–6377	0.536
SPRINGER DYNAMIC GAMES AND APPLICATIONS	2153–0785	–
IEEE WIRELESS COMMUNICATIONS LETTERS	2162-2337	–

3.6 Conferences

Conference papers to the following conference were submitted and accepted, including the IEEE flagship conferences[1] (ICC and GLOBECOM), as well as IEEE core conferences (DySPAN, INFOCOM, WCNC):

CrownCom, IEEE DySPAN, EUSIPCO, EW, FNMS, IEEE GLOBECOM, ICASSP, IEEE ICC, ICIN, IEEE INFOCOM, ISABEL, ISSPIT, ISSSE, ISWCS, ITA, TELFOR, VTC, IEEE WCNC, WNC3.

[1] According to http://www.comsoc.org/conferences/portfolio-events

The Wireless World Research Forum (WWRF) which was established with the objective to provide a discussion platform as think tank on the evolution of wireless technology, was also impacted by SAPHYRE [44], [75], [109].

Moreover, partners from the SAPHYRE consortium are technical program committee member at various important and relevant conferences, including the FNMS, IWCLD, SPAWC, CrownCom, ICC, INFOCOM, ICASSP and ISIT.

In the following subsections, we are presenting conference publications (Section 3.6.1), as well as special sessions during various scientific conferences attended by SAPHYRE consortium representatives (Section 3.6.2).

3.6.1 Conference publications

Variety of publication submissions has been successfully undertaken during the project, which are listed below, including invited papers and poster sessions organised during scientific conferences. According to the SAPHYRE description of work, it was planned to publish around 25–35 papers (including journals and conferences papers), dealing with all technical aspects covered by the project. Based on the dissemination outcomes overview presented in this report, this plan has been completed and exceeded.

[42] Eduard A. Jorswieck: “Framework for Beamforming in Interference Networks: Multicast, MISO IFC and Secrecy Capacity”, in Proc. of the Int. Zurich Seminar on Communications, Zurich, Switzerland, 3–5 March 2010. — invited.

[43] Eduard A. Jorswieck, Aydin Sezgin: “Transmit Strategies for the MIMO Two-Way Amplify-Forward Channel with Multiple Relays and MMSE Receiver”, in Proc. of the Int. Conference on Acoustics, Speech, and Signal Processing (ICASSP), Dallas, Texas, USA, 14–19 March 2010.

[44] Stefan Gustafsson, Peter Trommelen, Coen de Vos: “A New Regime for Future Telecommunication Network Operations”, in Proc. of the Wireless World Research Forum (WWRF), Malaysia, 12–14 April 2010.

[45] Johannes Lindblom, Eleftherios Karipidis: “Cooperative beamforming for the MISO interference channel”, in Proc. of the European Wireless Conference (EW), Lucca, Italy, 12–15 April 2010.

[46] Zuleita K.-M. Ho, Mariam Kaynia, David Gesbert: “Distributed Power Control and Beamforming on MIMO Interference Channels”, in Proc. of the European Wireless Conference (EW), Lucca, Italy, 12–15 April 2010.

[47] Jan Sýkora, Alister G. Burr: “Network coded modulation with partial side-information and hierarchical decode and forward relay sharing in multi-source wireless network”, in Proc. of the European Wireless Conference (EW), Lucca, Italy, 12–15 April 2010.

[48] Jan Sýkora, Alister G. Burr: “Hierarchical alphabet and parametric channel constrained capacity regions for HDF strategy in parametric wireless 2-WRC”, in Proc. of the IEEE Wireless Communications and Networking Conference (WCNC), Sydney, Australia, 18–21 April 2010.

[49] Zuleita K.-M. Ho, David Gesbert: “Balancing Egoism and Altruism on Interference Channel: The MIMO Case”, in Proc. of the IEEE Int. Communications Conference (ICC), Cape Town, South Africa, 23–27 May 2010.

[50] Eleftherios Karipidis, Erik G. Larsson: “Efficient Computation of the Pareto Boundary for the MISO Interference Channel with Perfect CSI”, in Proc. of the Wireless Networks: Communication, Cooperation and Competition (WNC3) Avignon, France, 31 May 2010.

[51] Eduard A. Jorswieck, Rami Mochaourab: “Beamforming in Underlay Cognitive Radio: Null-Shaping Constraints and Greedy User Selection”, in Proc. of the Int. Conference on Cognitive Radio Oriented Wireless Networks and Communications (CrownCom), Nice, France, 9–11 June 2010. — invited.

[52] Eduard A. Jorswieck, Zhijiat Chong, Rami Mochaourab: “Pricing in Noncooperative Interference Channels for Improved Energy-Efficiency”, in Proc. of the Int. Conference on Cognitive Radio Oriented Wireless Networks and Communications (CrownCom), Nice, France, 9–11 June 2010.

[53] Eduard A. Jorswieck, Leonardo Badia, Torsten Fahldieck, David Gesbert, Stefan Gustafsson, Martin Haardt, Zuleita K.-M. Ho, Eleftherios Karipidis, Andreas Kortke, Erik G. Larsson, Hrjehor Mark, Maciej Nawrocki, Radosław Piesiewicz, Florian Römer, Martin Schubert, Jan Sýkora, Peter Trommelen, Bram van den Ende, Michele Zorzi: “Resource sharing in wireless networks: The SAPHYRE approach”, in Proc. of the Future Network and Mobile Summit, Florence, Italy, 16–18 June 2010.

[54] Florian Römer, Jianshu Zhang, Martin Haardt, Eduard A. Jorswieck: “Spectrum and infrastructure sharing in wireless networks: A case study with relay-assisted communications”, in Proc. of the Future Network and Mobile Summit, Florence, Italy, 16–18 June 2010.

[55] Rami Mochaourab, Eduard A. Jorswieck, Zuleita K.-M. Ho, David Gesbert: “Bargaining and Beamforming in Interference Channels”, in Proc. of the Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, California, USA, 7–10 November 2010. — invited.

[56] Zuleita K.-M. Ho, David Gesbert, Eduard A. Jorswieck, Rami Mochaourab: “Beamforming on the interference MISO interference channel with multi-user decoding capability”, in Proc. of the Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, California, USA, 7–10 November 2010. — invited.

[57] Göran Bergqvist, Erik G. Larsson: “Overview of recent advances in numerical tensor algebra”, in Proc. of the Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, California, USA, 7–10 November 2010.

[58] Kristoffer Eriksson, Shuying Shi, Nikola Vučić, Martin Schubert, Erik G. Larsson: “Globally optimal resource allocation for achieving maximum weighted sum rate”, in Proc. of the IEEE Global Communications Conference (GLOBECOM), Miami, Florida, USA, 3–4 December 2010.

[59] Alessio Zappone, Eduard A. Jorswieck: “Resource Allocation in Relay-assisted DS/CDMA Interference Channels: a Stackelberg game approach”, in Proc. of the IEEE Int. Symposium on Signal Processing and Information Technology (ISSPIT), Luxor, Egypt, 15–18 December 2010.

[60] Nicolò Michelusi, Osvaldo Simeone, Marco Levorato, Petar Popovski, Michele Zorzi: “Optimal Cognitive Transmission Exploiting Redundancy in the Primary ARQ process”, in Proc. on Information Theory and Applications (ITA), San Diego, California, USA, 6–11 February 2011.

[61] Lei Xiao, Laura Cottatellucci, Konstantin Avratchenkov: “Equilibriums in Slow Fading Interfering Channels with Partial Knowledge of the Channels”, in Proc. of the IEEE Int. Conference on Computer Communications (INFOCOM), Shanghai, China, 10–15 April 2011.

[62] Alister G. Burr, Jan Sýkora: “Extended mappings for wireless network coded butterfly network”, in Proc. of the European Wireless Conference (EW), Vienna, Austria, 27–29 April 2011.

[63] Jianshu Zhang, Florian Römer, Martin Haardt: “Beamforming design for multi-user two-way relaying with MIMO amplify and forward relays”, in Proc. of the IEEE Int. Conference on Acoustics, Speech, and Signal Processing (ICASSP), Prague, Czech Republic, 22–27 May 2011.

[64] Johannes Lindblom, Eleftherios Karipidis, Erik G. Larsson: “Closed-form parameterization of the Pareto boundary for the two-user MISO interference channel”, in Proc. of the IEEE Int. Conference on Acoustics, Speech and Signal (ICASSP), Prague, Czech Republic, 22–27 May 2011.

[65] Alessio Zappone, Eduard A. Jorswieck: “Game-theoretic Resource Allocation in Relay-assisted DS/CDMA System”, in Proc. of the IEEE Int. Conference on Acoustics, Speech and Signal Processing (ICASSP), Prague, Czech Republic, 22–27 May 2011.

[66] Eleftherios Karipidis, Di Yuan, Erik G. Larsson: “Mixed-integer linear programming framework for max-min power control with single-stage interference cancellation”, in Proc. of the IEEE Int. Conference on Acoustics, Speech and Signal Processing (ICASSP), Prague, Czech Republic, 22–27 May 2011.

[67] Jian Luo, Andreas Kortke, Wilhelm Keusgen, Jianhui Li, Martin Haardt, Pavel Procházka, Jan Sýkora: “A Flexible Hardware-In-the-Loop Test Platform for Physical Resource Sharing Mechanisms in Wireless Networks”, in Proc. of the Future Network and Mobile Summit (FNMS), Warsaw, Poland, 15–17 June 2011.

[68] Jianhui Li, Jianshu Zhang, Florian Römer, Martin Haardt, Christian Scheunert, Eduard A. Jorswieck, Miroslav Hekrdla, Jan Sýkora: “Relay-assisted spectrum and infrastructure sharing between multiple operators”, in Proc. of the Future Network and Mobile Summit (FNMS), Warsaw, Poland, 15–17 June 2011.

[69] Eleftherios Karipidis, David Gesbert, Martin Haardt, Zuleita K.-M. Ho, Eduard A. Jorswieck, Erik G. Larsson, Jianhui Li, Johannes Lindblom, Christian Scheunert,

Martin Schubert, Nikola Vučić: "Transmit beamforming for inter-operator spectrum sharing", in Proc. of the Future Network and Mobile Summit (FNMS), Warsaw, Poland, 15–17 June 2011.

[70] Rami Mochaourab, Eduard A. Jorswieck: "Robust Pareto Optimal Beamforming in Two-User Multiple-Input Single-Output Interference Channel", in Proc. of the European Signal Processing Conference (EUSIPCO), Barcelona, Spain, 29 August – 2 September 2011.

[71] Jianhui Li, Florian Römer, Martin Haardt: "Spectrum and infrastructure sharing in the MIMO interference relay channels", in Proc. of the European Signal Processing Conference (EUSIPCO), Barcelona, Spain, 29 August – 2 September 2011.

[72] Pavel Procházka, Jan Sýkora: "Symbol-wise processing implementation of semiiterative tubor principle in multi-hop relay networks", in Proc. of the European Signal Processing Conf. (EUSIPCO), Barcelona, Spain, 29 August – 2 September 2011.

[73] Jan Sýkora, Eduard A. Jorswieck: "Network coded modulation with HDF strategy and optimized beam-forming in 2-source 2-relay network", in Proc. of the IEEE Vehicular Technology Conference (VTC 2011-Fall), San Francisco, California, USA, 5–8 September 2011.

[74] Frank Berkers, Fieke H. S. Offergelt, Gijs Hendrix: "If You Can't Beat 'Em, Join 'Em – Cooperative and Non-Cooperative Games in Network Sharing", Proc. of the Int. Conference on Intelligence in Next Generation Networks (ICIN), DOI 10.1109/ICIN.2011.6081073, Berlin, Germany, 4–7 October 2011.

[75] Eduard A. Jorswieck, Leonardo Badia, Torsten Fahldieck, Martin Haardt, Eleftherios Karipidis, Jian Luo, Rafał Pisz, Christian Scheunert: "Resource sharing improves the network efficiency for network operators", 27th Meeting of the Wireless World Research Forum (WWRF), Düsseldorf, Germany, 19 October 2011.

[76] Alessio Zappone, Stefano Buzzi, Eduard A. Jorswieck: "Green Power Control and Receiver Design in Relay-Assisted Interference Channel Wireless Networks: A Game-Theoretic Approach", in Proc. of the Int. Symposium on Applied Sciences in Biomedical and Communication Technologies (ISABEL), Barcelona, Spain, 26–29 October 2011.

[77] Luca Anchora, Marco Mezzavilla, Leonardo Badia, Michele Zorzi: "Simulation Models for the Performance Evaluation of Spectrum Sharing Techniques in OFDMA Networks", in Proc. of the ACM Int. Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWiM), Miami, Florida, 31 October – 4 November 2011.

[78] Zuleita K.-M. Ho, Eduard A. Jorswieck: "Improper Gaussian Signaling on the two-user SISO interference channel", in Proc. of the IEEE Int. Symposium on Wireless Communication Systems (ISWCS), Aachen, Germany, 6–9 November 2011 — invited.

[79] Miroslav Hekrdla, Jan Sýkora: “Uniformly most powerful alphabet for HDF twoway relaying designed by non-linear optimization tools”, in Proc. of the Int. Symposium on Wireless Communication Systems (ISWCS), Aachen, Germany, 6–9 November 2011.

[80] Rajeev Gangula, Paul de Kerret, David Gesbert, Maha Al-Odeh: “Optimized Data Symbol Sharing in Multiple Antenna Interference Channels”, in Proc. of the Asilomar Conference on Signals and Systems, Pacific Grove, California, USA, 6–9 November 2011 — invited.

[81] Jianshu Zhang, Florian Römer, Martin Haardt, Arash Khabbazibasmenj, Sergiy A. Vorobyov: “Sum rate maximization for multi-pair two-way relaying with single antenna amplify and forward relays”, in Proc. of the IEEE Int. Conference on Acoustics, Speech, and Signal Processing (ICASSP), Kyoto, Japan, 25–30 March 2012.

[82] Mohammad Fathi, Eleftherios Karipidis: “Distributed Resource Optimization in Multicell OFDMA Networks”, in Proc. of the IEEE Wireless Communications and Networking Conference (WCNC), Paris, France, Paris, France, 1–4 April 2012.

[83] Lorenzo Maggi, Laura Cottatellucci: “Retrospective Interference Alignment for Interference Channels with Delayed Feedback”, in Proc. of the IEEE Wireless Communications and Networking Conference (WCNC), Paris, France, 1–4 April 2012.

[84] Michał Szydełko, Jaroslaw Byrka, Jakub Oszmianski: “Dynamic valuation function based definition of the primary spectrum user in colocated cellular networks”, in Proc. of the Int. ICST Conference on Cognitive Radio Oriented Wireless Networks and Communications (CrownCom), Stockholm, Sweden, 18–20 June 2012.

[85] Tomáš Uřičář, Jan Sýkora: “Systematic design of hierarchical network code mapper for butterfly network relaying”, in Proc. of the European Wireless Conference (EW), Poznan, Poland, 18–20 April 2012.

[86] Frederic Gabry, Nan Li, Nicholas Schrammar, Maksym Girnyk, Eleftherios Karipidis, Ragnar Thobaben, Lars K. Rasmussen, Erik G. Larsson: “Secure Broadcasting in Cooperative Cognitive Radio Networks”, in Proc. of the Future Network and Mobile Summit (FNMS), Berlin, Germany, 4–6 July 2012.

[87] Lei Yu, Eleftherios Karipidis, Erik G. Larsson: “Coordinated Scheduling and Beamforming for Multicell Spectrum Sharing Networks Using Branch & Bound”, in Proc. of the European Signal Processing Conference (EUSIPCO), Bucharest, Romania, 27–31 August 2012. — invited.

[88] Luca Anchora, Leonard Badia, Eleftherios Karipidis, Michele Zorzi: “Capacity Gains due to Orthogonal Spectrum Sharing in Multi-Operator LTE Cellular Networks”, in Proc. of the IEEE Int. Symposium on Wireless Communation Systems (ISWCS), Paris, France, 28–31 August 2012.

[89] Miltiades C. Filippou, David Gesbert, Haifan Yin: “Decontaminating Pilots in Cognitive Massive MIMO Networks”, in Proc. of the IEEE Int. Symposium on

Wireless Communications Systems (ISWCS), Paris, France, 28–31 August 2012. — invited.

[90] Zuleita K.-M. Ho, Eduard A. Jorswieck: "Interference neutralization on relay assisted interference networks", in Proc. of the IEEE Int. Symposium on Wireless Communication Systems (ISWCS) 2012, Paris, France, 28–31 August 2012.

[91] Rami Mochaourab, Nizar Zorba, Eduard A. Jorswieck: "Nash Equilibrium in Multiple Antenna Shared and Protected Bands", in Proc. of the Int. Symposium on Wireless Communication Systems (ISWCS), Paris, France, 28–31 August 2012.

[92] Luca Ancora, Leonardo Badia, Haibin Zhang, Torsten Fahldieck, Jianshu Zhang, Michał Szydełko, Martin Schubert, Eleftherios Karipidis, Martin Haardt: "Resource Allocation and Management in Multi-Operator Cellular Networks with Shared Physical Resources", in Proc. of the IEEE Int. Symposium on Wireless Communication Systems (ISWCS) 2012, Paris, France, 28–31 August 2012.

[93] Jian Luo, Johannes Lindblom, Jianhui Li, Rami Mochaourab, Andreas Kortke, Eleftherios Karipidis, Martin Haardt, Eduard A. Jorswieck, Erik G. Larsson: "Transmit Beamforming for Inter-Operator Spectrum Sharing: From Theory to Practice", in Proc. of the IEEE Int. Symposium on Wireless Communation Systems (ISWCS), Paris, France, 28–31 August 2012.

[94] Alister G. Burr and Jan Sýkora: "Cooperative wireless network coding for uplink transmission on hierarchical wireless networks", in Proc. of the Int. Symp. on Signals, Systems and Electronics (ISSSE), Potsdam, Germany, 3–5 October 2012.

[95] Michał Szydełko: "Business model analysis for spectrum sharing with the spectrum broker", in Proc. of the IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN), Bellevue, Washington, USA, 16–19 October 2012.

[96] Jianshu Zhang, Florian Römer, Martin Haardt: "Distributed beamforming for two-way relaying networks with individual power constraints", in Proc. of the Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, California, USA, 4–7 November 2012.

[97] Jianshu Zhang, Seyed O. T. Motlagh, Jian Luo, Martin Haardt: "Full duplex wireless communications with partial interference cancellation", in Proc. of the Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, California, USA, 4–7 November 2012.

[98] Michał Szydełko: "Business model analysis for the spectrum spot market scenario", in Proc. of the Telecommunications Forum (TELFOR), Belgrade, Serbia, 20–22 November 2012.

[99] Osman Aydin, Wahid Jamil, Stefan Valentin: "A Two-Step Scheduler for the Dynamic Sharing of Wireless Channel Resources Among Operators", IEEE Vehicular Technology Conference (VTC 2013-Spring), Dresden, Germany, 2–5 June 2013. — accepted.

[100] Rajeev Gangula, David Gesbert, Johannes Lindblom, Erik G. Larsson: "On the Value of Spectrum Sharing among Operators in Multicell Networks", IEEE

Vehicular Technology Conference (VTC 2013-Spring), Dresden, Germany, 2–5 June 2013. — accepted.

[101] Remco Litjens, Haibin Zhang, Ivo Noppen, Lei Yu, Eleftherios Karipidis, Kai Börner: "System-level assessment of non-orthogonal spectrum sharing via transmit beamforming", IEEE Vehicular Technology Conference (VTC 2013-Spring), Dresden, Germany, 2–5 June 2013. — accepted.

[102] Haifan Yin, David Gesbert, Miltiades C. Filippou, Yingzhuang Liu: "Decontaminating pilots in massive MIMO systems", IEEE Global Communications Conference (GLOBECOM), Budapest, Hungary, 9–13 June 2013. — submitted.

3.6.2 Special sessions

Special sessions, which were organised during conferences and workshops, in order to present SAPHYRE outcomes, were listed below:

[103] Panel session at the CrownCom 2010 conference: "Physical Resource Sharing in Networks", organised and co-chaired by the SAPHYRE Technical Manager Eduard A. Jorswieck, Int. Conference on Cognitive Radio Oriented Wireless Networks and Communications (CrownCom), Cannes, France, 16–18 June 2010.

[104] Special session of SAPHYRE "Spectrum and infrastructure sharing between operators in wireless interference networks" at the European Signal Processing Conference (EUSIPCO), Barcelona, Spain, 29 August – 2 September 2011, was co-organised by TUIL.

[105] A special session on "Efficient Algorithms for Spectrum and Infrastructure Sharing", IEEE Int. Workshop on Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), San Juan, Puerto Rico, 13–16 December 2011, was co-organised by TUIL and LiU.

3.7 Invited talks

The most experienced researchers from the SAPHYRE consortium were invited to multiple venues including universities as well as industry, for the research talks covering the project outcomes:

[106] Jan Sýkora, Alister G. Burr: "Wireless network coding", invited research talk, Imperial College, London, UK, 22 September 2010.

[107] Eduard A. Jorswieck: "Stable Matchings for Resource Allocation in Wireless Networks", IEEE Int. Conference on Digital Signal Processing (DSP), Corfu, Greece, 6–11 June 2011. — invited.

[108] Eleftherios Karipidis: "Transmit beamforming for inter-operator spectrum sharing", NGMN (Next Generation Mobile Network) Innovation Day, Stockholm, Sweden, 15 September 2011.

[109] Martin Haardt, Jianshu Zhang, Florian Römer: "Spectrum and relay sharing via the projection based separation of multiple operators (ProBaSeMO)", 27th

Meeting of the Wireless World Research Forum (WWRF), Düsseldorf, Germany, 19 October 2011.

[110] Martin Haardt, Florian Römer, Jianshu Zhang: "Efficient two-way relaying schemes for amplify and forward relays with multiple antennas", Stanford University, Smart Antennas Research Group, Palo Alto, California, USA, 10 November 2011.

[111] Martin Haardt, Florian Römer, Jianshu Zhang: "Efficient two-way relaying schemes for amplify and forward relays with multiple antennas", The University of York, Research Seminar of the Department of Electronics, Inaugural Lecture as "Honorary Visiting Professor", York, United Kingdom, 11 June 2012.

[112] Martin Haardt, Florian Römer, Jianshu Zhang: "Efficient two-way relaying schemes for amplify and forward relays with multiple antennas", Wireless Research/ Physical Layer Seminar Series, Bell Labs, Alcatel-Lucent, Stuttgart, Germany, 13 September 2012.

3.8 Workshops

Contributions to the following workshops were submitted and accepted, including the workshops at IEEE flagship conference[2] ICC (GeT ReAl workshop):

> *BMMP, CAMAD, CAMSAP, GeT ReAl, ICIP, MACOM, NRN, RAWNET, SPAWC, WNC3, WSA.*

It should be noted that the *Best Student Paper Award* has been granted to the SAPHYRE contribution during CAMSAP 2011 and SPAWC 2012 workshops.

Below, a list of workshops is given, where SAPHYRE results have been presented:

[113] Nikola Vučić, Shuying Shi, Martin Schubert: "DC programming approach for resource allocation in wireless networks", in Proc. of the Workshop on Resource Allocation in Wireless Networks (RAWNET), Avignon, France, 4 June 2010.

[114] Eduard A. Jorswieck, Rami Mochaourab: "Beamforming in Underlay Cognitive Radio: Null-Shaping Design for Efficient Nash Equilibrium", in Proc. of the Int. Workshop on Cognitive Information Processing (ICIP), Elba Island (Tuscany), Italy, 14–16 June 2010. — invited.

[115] Frank Berkers, Gijs Hendrix, Ioanna Chatzicharistou, Thomas de Haas, Dominik Hamera: "To share or not to share? Business aspects of network sharing for MNOs", in Proc. of the Int. Workshop on Business Models for Mobile Platforms (BMMP), Berlin, Germany, 14 October 2010.

[116] Eduard A. Jorswieck: "SAPHYRE – Sharing physical resources: from PHY to spectrum policy", Panel session at the COGEU Workshop on the Efficient Use of TV White Spaces in Europe, Munich, Germany, 10 November 2011.

[117] Luca Anchora, Luca Canzian, Leonardo Badia, Michele Zorzi: "A Characterization of Resource Allocation in LTE Systems Aimed at Game Theoretical Approaches",

[2] According to http://www.comsoc.org/conferences/portfolio-events

in Proc. of the IEEE Int. Workshop on Computer-Aided Modeling Analysis and Design of Communication Links and Networks (CAMAD), Miami, Florida, USA, 3–4 December 2010.

[118] Jianhui Li, Aydin Sezgin, Martin Haardt: "Coordinated beamforming for MIMO interference relay channel with multiple stream transmission", in Proc. of the Int. ITG Workshop on Smart Antennas (WSA), Aachen, Germany, 24–25 February 2011.

[119] Jalil S. Harsini, Michele Zorzi: "Effective Capacity Analysis for Multi-Rate Relay Channels Exploiting Adaptive Cooperative Diversity", in Proc. of the IEEE Int. Communications Conference (ICC) – Workshop on Game Theory and Resource Allocation for 4G (GeT ReAl), Kyoto, Japan, 5 June 2011.

[120] Luca Anchora, Leonardo Badia, Michele Zorzi: "Joint scheduling and resource allocation for LTE downlink using Nash Bargaining Theory", in Proc. of the IEEE Int. Communications Conference (ICC) Workshop on Game Theory and Resource Allocation for 4G (GeT ReAl), Kyoto, Japan, 5 June 2011.

[121] Rami Mochaourab, Eduard A. Jorswieck: "Walrasian Equilibrium in Two-User Multiple-Input Single-Output Interference Channel", in Proc. of the IEEE Int. Communications Conference (ICC) – Workshop on Game Theory and Resource Allocation for 4G (GeT ReAl), Kyoto, Japan, 5 June 2011.

[122] Luca Canzian, Leonardo Badia, Michele Zorzi: "Relaying in wireless networks modeled through cooperative Game Theory", in Proc. of the Int. Workshop on Computer-Aided Modeling Analysis and Design of Communication Links and Networks (CAMAD), Kyoto, Japan, 10–11 June 2011.

[123] Rami Mochaourab, Eduard A. Jorswieck: "Coalition Formation in MISO Interference Channels", in Proc. of the IEEE Int. Workshop on Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), San Juan, Puerto Rico, 13–16 December 2011. — invited; **BEST STUDENT PAPER AWARD**.

[124] Johannes Lindblom, Eleftherios Karipidis, Erik G. Larsson: "Efficient computation of the Pareto boundary for the two-user MISO interference channel with multi-user decoding capable receivers", in Proc. of the IEEE Int. Workshop on Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), San Juan, Puerto Rico, 13–16 December 2011. — invited.

[125] Jianhui Li, Florian Römer, Martin Haardt: "Efficient Relay Sharing (EReSh) between multiple operators in amplify-and-forward relaying systems", in Proc. of the IEEE Int. Workshop on Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), San Juan, Puerto Rico, 13–16 December 2011. — invited.

[126] Jianshu Zhang, Nib Bornhorst, Florian Römer, Martin Haardt, Marius Pesavento: "Optimal and suboptimal beamforming for multi-operator two-way relaying with a MIMO amplify-and-forward relay", in Proc. of the Int. ITG Workshop on Smart Antennas (WSA), Dresden, Germany, 7–8 March 2012.

[127] Johannes Lindblom, Erik G. Larsson: "Does Non-Orthogonal Spectrum Sharing in the same Cell Improve the Sum-Rate of Wireless Operators?", in Proc. of the

IEEE Int. Workshop on Signal Processing Advances in Wireless Communications (SPAWC), Cesme, Turkey, 17–20 June 2012. — invited.

[128] Pan Cao, Shuying Shi, Eduard A. Jorswieck: "Efficient Computation of the Pareto Boundary for the Two-User MIMO Interference Channel", in Proc. of the IEEE Int. Workshop on Signal Processing Advances in Wireless Communications (SPAWC), Cesme, Turkey, 17–20 June 2012. — **BEST STUDENT PAPER AWARD**.

[129] Jan Sýkora, Alister G. Burr: "Network Coded Modulation for Random Channel Class in WNC with HDF Relaying Strategy", Int. Workshop on Network Coding in Wireless Relay Networks (NRN), Sydney, Australia, 9 September 2012. — submitted.

[130] Tomáš Hynek, Jan Sýkora: "Initialization procedure of wireless network coding with hierarchical decode & forward strategy in random connectivity networks", in Proc. of the Int. Workshop on Multiple Access Communications (MACOM), Dublin, Ireland, 19–20 November 2012.

3.9 Demonstrations

Based on the work completed within SAPHYRE WP6 "Demonstrator Testbed", presentation of the spectrum sharing demonstrators were planned. Based on FhG initiatives, the SAPHYRE demonstrator has been presented to various audiences.

It shall be highlighted that SAPHYRE was awarded as 'Best Demonstration Stand' for its exhibits at the Future Network and Mobile Summit 2012 [170], having one of the largest exhibition stands. The presented hardware-in-the loop demo has shown the spectrum sharing between two operators. The real-time testbed, developed by Fraunhofer HHI and further enhanced in the course of the project, was based on LTE/ Advanced techniques, thus supporting the next generation of mobile communication. A considerable number of conference attendees visited the exhibit, including researchers, business people and members of the European Commission and the European Parliament, providing ample evidence of a high level of interest in the project's objectives and results.

The EAB has been invited for guided tours in FhG laboratories to show the SAPHYRE demonstrators during the final EAB meeting [133], [134].

[131] FhG spectrum sharing scenario with the LTE-Advanced testbed, Mobile World Congress (MWC), in Barcelona, Spain, 27 February – 1 March 2012.

[132] FhG LTE-Demonstrator and poster presentation at the FNMS 2012: "Inter-operator spectrum sharing demonstration based on LTE-Advance", Future Network and Mobile Summit (FNMS), Berlin, Germany, 4–6 July 2012, **BEST DEMONSTRATION STAND AWARD**.

[133] Hardware-in-the-loop demo – non-orthogonal spectrum sharing between two operators, demonstration for the EAB, FhG, Berlin, Germany, 20 November 2012.

[134] Spectrum sharing scenario with the LTE-Advanced testbed, demonstration for the EAB, FhG, Berlin, Germany, 20 November 2012.

According to the planned dissemination actions to demonstrate the key results of SAPHYRE with the exploitation of the demonstrators, two "open house" events on the FhG testbed were planned. Based on the list of the completed actions, demonstrator dissemination plan has been fulfilled.

3.10 Tutorials/guest lectures

Teaching activities were also considered within SAPHYRE, relying on the initiatives undertaken by universities participating in the consortium. On the one side several intra-project exchanges have been organised (Zuleita K.-M. Ho from ECM at TUD, Rami Mochaourab from TUD at LiU, Michał Szedełko from WRC at TUD). On the other side, results from this project were reflected in the tutorials and guest lecturers offered to students.

[135] Aydin Sezgin: "Summer school on multi-user information theory", Dresden, Germany, 16–20 August 2010.

[136] Jan Sýkora, Alister G. Burr: "Wireless network coding: The network aware PHY layer", in Proc. of the Int. Symposium of Wireless Communication Systems (ISWCS) – tutorial, York, United Kingdom, 19 September 2010.

[137] Jan Sýkora, Alister G. Burr: "Wireless network coding: Network coded modulation in the network aware PHY layer", in Proc. of the IEEE Wireless Communications and Networking Conference (WCNC), Cancun, Mexico, 28–30 March 2011 — tutorial.

[138] Eduard A. Jorswieck: "Game Theory – Fundamentals and Applications in Signal Processing and Communications", guest lectures at the Czech Technical University, DiRaC group, Prague, Czech Republic, 11–13 April 2011.

[139] Erik G. Larsson, Eduard A. Jorswieck: "Game-Theory in Signal Processing and Communications", IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), Prague, Czech Republic, 23 May 2011. — tutorial.

Based on fruitful research grant application, WRC representative visited TUD, where research collaboration has been conducted under supervision of Prof. Eduard A. Jorswieck, based on the research finding of the SAPHYRE project [140], [141].

[140] Michal Szydełko: "Game theoretic approach to the dynamic spectrum sharing and resources allocation", Oberseminar presentation at Technische Universität Dresden, 2 March 2012.

[141] FP7 UNITE grant, WRC member visiting Prof. Eduard A. Jorswieck at TU Dresden: "Future research development in the area of spectrum sharing in future cellular networks", July–September 2012.

3.11 External Advisory Board

In order to achieve maximum impact with SAPHYRE's dissemination and exploitation plans, the consortium established an External Advisory Board (EAB), being the subject of T7.3. The EAB provided feedback on project results ensuring that SAPHYRE

considers topics relevant for the European industry, complements current activities in standardisation and regulation, and keeps track of recent developments in these areas. Secondly, the EAB was an important channel to disseminate the results of SAPHYRE. It was the direct way to inform the industry and business partners about the project outcomes.

Establishing an EAB with representatives from industry and regulators from different countries ensured that SAPHYRE addresses the most important issues related to spectrum and infrastructure sharing as faced by operators and regulators. Based on formal agreement including the non-disclosure agreement, the EAB consisted of the following high profile, key business members from national regulators, MNOs and industry-driven consortia:

- Regulatory bodies
  - DG Energy and Telecom, The Netherlands;
  - Bundesnetzagentur, Germany;
  - RTR-GmbH, Austria;
  - Comreg, Ireland.
- Operators
  - Vodafone Group Research and Development;
  - PTK Centertel (Orange Poland);
  - T-Mobile Netherlands B.V.;
  - Swisscom AG (Schweiz);
  - KPN, The Netherlands.
- Industry-driven consortia
  - NGMN (Next Generation Mobile Network) Alliance;
  - GSM-A (GSM Association);
  - ETNO (European Telecommunications Networks Operations Association).

Throughout the project, the relevant actors, institutes and associations were supplied with information on the activities in the project with regards to the key SAPHYRE concepts and to possible barriers in existing standards and legislation. EAB was supporting the SAPHYRE project right from its beginning by reviewing of user requirements and system specifications. During the project we were able to organise a planned series of four physical meetings with the EAB members, with good attendance of the members. Highly interactive discussion about SAPHYRE sharing scenarios, business and regulatory aspects and demonstrations were facilitated and generated valuable feedback, shaping the development direction and future strategies within SAPHYRE. Two of EAB meetings were kindly hosted by an EAB member (GSM-A, NGMN). During these physical meetings the EAB members gave valuable feedback on the project approach and results, leading to improved quality of the deliverables. During

the final EAB meeting, LTE-A spectrum sharing as well as the hardware in the loop platform developed by FhG has been demonstrated to EAB members [134].

[142] First EAB meeting, hosted by GSM-A Brussels, Belgium, 30 September 2010.

[143] Second EAB meeting, hosted by NGMN, Frankfurt/Main, Germany, 27 September 2011.

[144] Third EAB meeting, hosted by TNO, Amsterdam, Netherlands, 27 March 2012.

[145] Final EAB meeting, hosted by FhG-HHI, Berlin, Germany, 20 November 2012.

During EAB meeting at NGMN Alliance premises, additional dissemination channel has been established, based on the NGMN web-site for communication purposes with its participants and members:

[146] SAPHYRE newsletter communication via NGMN, http://www.ngmn.org/fileadmin/user_upload/News/Partner_News/SAPHYRE_Newsletter_v05_new.pdf

What has to be highlighted is that cooperation under the SAPHYRE project has also resulted in further NGMN members board extension, as SAPHYRE participants decided to join NGMN Alliance. Currently, Fraunhofer Heinrich Hertz Institute as well as TNO are the NGMN Advisors.

Apart from the physical meetings, some EAB members were involved in the following actions, improving quality of SAPHYRE outcomes and shaping its development directions:

- Discussions on selection of the most promising sharing scenarios for future cellular networks, considering business and regulatory aspects;
- Review of SAPHYRE technical reports, leading to quality improvements, e.g. White Papers, business and regulatory related deliverables from WP5 “Business models, cost analysis and advices for spectrum policy and regulations”;
- Involvement of EAB members for further dissemination of the SAPHYRE results to a broader audience, e.g. introduction to the RSPG [165] and CEPT FM [166] via EAB members of the regulatory bodies;
- Distribution of a questionnaire to the regulatory offices in Europe.

3.12 Collaboration within related European activities

The SAPHYRE consortium partners were aware of ongoing related activities on European level, which were monitored in order to identify and select the most relevant ones for SAPHYRE outcomes dissemination and its impact enhancements. Therefore, EC related dissemination channels were also actively used for to spread project outcomes among decision-making people in business development and regulation. One of them, was the European Commission hosted EU workshop on "Promoting the shared use of radio spectrum resources in Europe", chaired by the study team from SCF Associates, which brought high attention from the regulators, operators as well as from

the industry representatives (e.g. Nokia, Qualcomm, Cisco, Microsoft and more), resulting in the audience of ~150 registered participants:

[147] EC workshop on "Promoting the shared use of radio spectrum resources in Europe" attended, with great audience participating and SAPHYRE project results being recognised and advertised, Michał Szydełko, Brussels, Belgium, 16 December 2011.

This workshop generated technical report, where SAPHYRE project was recognised as the one who is loudly stating to go for more dynamic spectrum access, showing that adaptive sharing among separate networks using beamforming techniques can support much more intensive spectrum utilisation than the static partitioning of frequencies and operating areas, assuming a certain level of cooperation among the MNOs [171].

As technical conclusion, it was stated, that the sharing by cooperation, competition, or mix of them is expected as the solution for the future spectrum usage, but sharing itself will not solve the inefficient spectrum usage.

This workshop gave SAPHYRE great opportunity to be recognised by the industry and regulatory participants.

3.12.1 Concertation meetings and technology clusters

SAPHYRE was actively participating in activities organised at programme level relating to the ICT Future Networks area with the objective of providing input towards common activities. These activities included Concertation meetings organised by the EC and the ICT Future Network and Mobile Summit (FNMS). SAPHYRE activities towards FNMS were addressed by actions in Sections 3.3, 3.6, 3.9 and contributions in [67]–[69], [86], [132] and [133].

The purpose of the Concertation meeting is to bring together the ongoing FP7 projects funded under the Future Networks objective and facilitate exchange of results and achievements, and build consensus. SAPHYRE was focused on one of Future Networks clusters, which was Radio Access and Spectrum, i.e. RAS Cluster.

SAPHYRE was present at 5th EC Concertation meeting [148] and participating in RAS workshop on "Cognitive Radio – Technology and Regulation" [149]. SAPHYRE has provided significant inputs also to the RAS Cluster White Paper [152]. This White Paper was presented during recent EC Concertation meeting [150].

[148] European Commission: "Future Networks 5th FP7 Concertation meeting", Brussels, Belgium, 26–28 January 2010, http://ec.europa.eu/information_society/events/future_networks/5th_concertation/index_en.htm

[149] RAS Workshop: "Cognitive Radio – Technology and Regulation", 28 January 2010, http://www.saphyre.eu/news-events/ras-workshop-cognitive-radio-technology-and-regulation

[150] European Commission: "Future Networks 10th FP7 Concertation meeting", Brussels, Belgium, 10–11 October 2012, http://ec.europa.eu/information_society/events/future_networks/concertation/index_en.htm

3.12.2 Collaboration with related European projects

In order to get broader knowledge of the project results and challenges, the project was planning to arrange workshops, with the aim to disseminate information of overall challenges related to infrastructure and spectrum sharing to the general public, as well as to exchange knowledge with other experts in the field that will be invited to participate. It was realised by collaboration with other FP7 funded projects.

[151] "Joint QUASAR, SAPHYRE, ACROPOLIS workshop on Cognitive Radio", Stockholm, Sweden, 16–17 November 2011, co-organised by TUD, LiU and KTH.

[152] Radio Access and Spectrum (RAS) Cluster: "White paper on spectrum sharing", October 2012, http://www.ict-qosmos.eu/fileadmin/documents/Dissemination/White_Papers/RAS_Cluster_white_paper.pdf

[153] Eduard A. Jorswieck: "SAPHYRE – Sharing physical resources: from PHY to spectrum policy", Panel session at the COGEU Workshop on the Efficient Use of TV White Spaces in Europe, Munich, Germany, 10 November 2011, http://www.ict-cogeu.eu/diss_workshops.html

The following FP7 funded ICT projects were collaborating in the above referred actions:

- [151]: ACROPOLIS, QUASAR, SAPHYRE;
- [152]: ACROPOLIS, BeFEMTO, COGEU, EXALTED, FARAMIR, OneFIT, QoSMOS, SAPHYRE, WHERE2;
- [153]: COGEU, SACRA, as well as CEPT, EC and ETSI RRS.

3.13 COST Actions

COST is an intergovernmental framework for European Cooperation in Science and Technology, allowing the coordination of nationally funded research on a European level. SAPHYRE consortium partners were participating in the following COST actions, dissemination research outcomes by contributions in [154]–[164]:

- COST IC1004: Cooperative Radio Communications for Green Smart Environments;
- COST IC0902: Cognitive Radio and Networking for Cooperative Coexistence of Heterogeneous Wireless Networks;
- COST IC0905: Techno-Economic Regulatory Framework for Radio Spectrum Access for Cognitive Radio/Software Defined Radio.

[154] Jan Sýkora, Eduard A. Jorswieck: "Optimized beam-forming and achievable rates of network coded modulation with HDF strategy in 2-source 2-relay network", COST IC1004 1st MCM (Management Committee Meeting), TD(11)01007, Lund, Sweden, 20–21 June 2011.

[155] Alister G. Burr, Jan Sýkora: "Cooperative wireless network coding for uplink transmission on hierarchical wireless networks" COST IC1004, 3rd MCM

(Management Committee Meeting), TD(12)03047, Barcelona, Spain, 8–10 February 2012.

[156] Tomáš Uřičář, Jan Sýkora: "Hierarchical network code mapper design for adaptive relaying in butterfly network" COST IC1004, 3rd MCM (Management Committee Meeting), TD(12)03048, Barcelona, Spain, 8–10 February 2012.

[157] Jan Sýkora, Alister G. Burr: "Design and rate regions of network coded modulation for random channel class in WNC with HDF relaying strategy", COST IC1004, 4th MCM (Management Committee Meeting), TD(12)04030, Lyon, France, 2–4 May 2012.

[158] Tomáš Uřičář, Jan Sýkora: "Non-uniform 2-slot constellations: Design algorithm and 2-way relay channel performance", COST IC1004, 4th MCM (Management Committee Meeting), TD(12)04041, Lyon, France, 2–4 May 2012.

[159] Miroslav Hekrdla, Jan Sýkora: "Suppression of relative-fading by diversity reception in wireless network coding 2-way relaying", COST IC1004, 4th MCM (Management Committee Meeting), TD(12)04033, Lyon, France, 2–4 May 2012.

[160] Michał Szydełko, Jarosław Byrka, Jakub Oszmianski: "Dynamic valuation function based definition of the primary spectrum user in collocated cellular networks", 2nd Int. Summer School on Cognitive Wireless Communications: Highlight on Game Theory – poster session, COST IC0902, Paris, France, 10–13 July 2012.

[161] Pavel Procházka, Jan Sýkora: "Block-structure based extended layered design of network coded modulation for arbitrary individual using hierarchical decode & forward strategy", COST IC1004, 5th MCM (Management Committee Meeting), TD(12)05054, Bristol, UK, 24–26 September 2012.

[162] Miroslav Hekrdla, Jan Sýkora: "Lattice-constellation indexing for wireless network coding 2-way relaying with modulo-sum relay decoding", COST IC1004, 5th MCM (Management Committee Meeting), TD(12)05057, Bristol, UK, 24–26 September 2012.

[163] Tomáš Hynek, Jan Sýkora: "Wireless network coding initialization procedure through multi-source automatic modulation classification in random connectivity networks", COST IC1004, 5th MCM (Management Committee Meeting), TD(12)05041, Bristol, UK, 24–26 September 2012.

[164] Michał Szydełko: "Business Models, Advices and Cost Analysis for Spectrum Sharing Scenarios", presentation at COST IC0905 TERRA, Brussels, Belgium, 26–28 November 2012.

3.14 Contributions to regulations and standards

Within T7.2, standardisation and regulatory activities were developed throughout the project, considering discussions and participation at relevant industry and regulatory meetings. The relevant actors and institutes were supplied with information on the activities in the project with regards to the key SAPHYRE concepts and to possible barriers in existing standards and legislation. Based on the feedback and additional

support of External Advisory Board representatives received and considering relevant experience of the consortium members (especially ALUD being actively involved in the standardisation process, but also ECM, TNO and WRC), proposals for the potential implementation of future standardisation items, as well as new and modified rules and regulations were discussed and structured. Some of the project partners were actively involved in the LTE-A standardisation process, providing valuable experience to the project.

The regulation and standardisation plan was captured in Deliverable D7.2 [169].

3.14.1 Standardisation actions

Standardisation activities were assuming interactions with international standardisation bodies, like ETSI, or 3GPP. Due to diversity of technical contributions within this project, it was decided to limit analysis scope to the SAPHYRE White Papers content. Based on the SAPHYRE White Papers [1]–[3] analyses of potential future standardisation directions were discussed from the spectrum and infrastructure sharing point of view, considering various technical concepts from the SAPHYRE technical work packages and analysing their applicability and potential influence on standards specifications. The aim was to provide the most concrete and detailed proposals of the SAPHYRE research results consideration in the 3GPP developments [169]. The attempt was to identify potential impact of the SAPHYRE research on the technical work being under continuous developed within 3GPP, as well as to identify the technical working groups, which might be attracted by the scenarios evaluated within our project (with focus on the 3GPP TSG RAN and TSG SA). Based on the analysis of the 3GPP meetings calendar [169] it was found, that the most suitable meeting for SAPHYRE results dissemination opportunity towards 3GPP, would be the general future technology meeting, called "On Release 12 and onwards" [172], being the TSG RAN group workshop. Its main goal was the investigation on what are the main changes that could be brought forward to evolve RAN toward Release 12 and beyond. Contributions to this workshop were required to include requirements, potential technologies and technology roadmap for future 3GPP releases.

Argumentation for the above proposed meeting was as follows:

- The industry audience attending this meeting would be the most competent discussion partner, to identify potential business cases and opportunities for the sharing scenarios to be incorporated in future standardisation processes, which were developed within SAPHYRE project;
- Future oriented research conducted in SAPHYRE is more suitable to the future standardisation forecasting, instead of being presented during ordinary (i.e. regular meetings for specification development) working group meetings, which are shaping the currently developed 3GPP specification releases;
- 3GPP workload was another aspect, which played crucial role in the selection of the most appropriate meeting for the research results dissemination. Based on the analysis of TSG RAN working groups meeting reports [173], regular working group meetings were considered as not being the appropriate audience

for research project outcomes dissemination due to their continuous overload and focus on currently developed specifications.

As WP7 leader, WRC initiated a discussion with the TSG RAN chairman, i.e. chairman of the above mentioned workshop, in order to identify possible dissemination opportunities during this meeting. It was planned to provide presentation, covering findings described in the SAPHYRE White Papers (for more details on the identified linkage between 3GPP work and SAPHYRE findings, please refer to [169]).

Unfortunately, extremely tight schedule of this workshop did not allowed to reserve timeslot for SAPHYRE outcomes presentation. This action has resulted in strict workshop participation rules definition, which were captured in [174] by the statement that only 3GPP members are invited to provide their presentation in the workshop. Therefore, alternative actions have been considered by the SAPHYRE consortium in order to compensate this refusal. Furthermore, TNO representatives have participated in this workshop as one of nearly 250 workshop attendees, reporting the workshop discussion highlights back to the SAPHYRE Management Board.

Based on the meeting summary report [174], the following issues were found to be relevant for the SAPHYRE work:

- Spectrum sharing were raised in number of discussions and some of the network operators have already recognised this solution as potential feature for future networks, e.g. Deutsche Telecom;
- RAN sharing was short-listed by CEWiT as the solution, especially attractive for indoor deployments [175]. Inter-operator scenarios were discussed, indicating challenges in the interference mitigation – topic, which was specifically addressed in SAPHYRE, by development of the non-orthogonal sharing mechanisms for inter-operator scenarios. Furthermore, it was referred that the spectrum sharing was allowed by new national telecom policy in India.

The above referred examples are showing increasing interest in various resource sharing scenarios within 3GPP, what justifies the research directions undertaken in SAPHYRE project.

3.14.2 Regulatory actions

Regulatory activities were assuming interactions with international certification bodies, like CEPT, or RSPG groups. RSPG meeting gathered audience of 50–60 experts [165], mostly familiar with spectrum policy and spectrum management, with the e on the sharing concepts and possible regulatory implications.

[165] SAPHYRE presentation at RSPG plenary meeting by TNO, 8 November 2012.

[166] SAPHYRE presentation at CEPT WG FM by TNO, planned for March 2013.

3.15 Co-operation with national research programmes in Europe

SAPHYRE consortium partners were aware of the related research activities ongoing on the European level. Therefore, some of the national research programmes to which individual SAPHYRE partners are linked to, were interfaced.

1. Czech Republic

   CTU's key personnel, Prof. Jan Sýkora, was leading a closely related national research project "Mobile Radio Communication Systems with Distributed, Cooperative and MIMO Processing" financed by Czech Science Foundation (Grantová agentura České republiky, GAČR,) #102/09/1624. Collaboration between SAPHYRE and the GACR #102/09/1624 was considered as strong. The project concentrated on the research of physical layer algorithms (modulation, coding, signal processing) of the communications systems with distributed, co-operative and MIMO processing. The project investigated the fundamental limits of the systems with suitable performance metric, synthesise the design criteria and analyse modulations, coding and signal processing schemes.

2. Germany

   The need for novel interference management in future wireless communication networks was recognised by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) and reflected by the DFG focus Program 1397 "Communications in Interference Limited Networks" (COIN). The goal of this DFG Focus Program was to understand means to handle interference as a central problem of operating wireless networks. Centralised and decentralised methods to avoid and handle interference are to be investigated as well as approaches that resolve interference constructively. This basic research project was well aligned with the goals in SAPHYRE and three partners from the consortium have submitted project proposals there.

3.16 Project web-site

Public SAPHYRE web-site was used for provision of general information on the project as well as for dissemination actions [167]. This portal was meant to attract the attention of the public to the project and to spectrum and resource sharing technologies in general. This communication channel has been defined as Deliverable D1.1 ("Set-up of public web page") in Table 1.

Secure web-based portal was also established as the workspace for consortium partners, providing services for electronic documents management, working groups management, event notification, etc. All project deliverables and other dissemination actions were summarised on this Intranet portal, which was continuously update during the project's duration.

[167] SAPHYRE project public web-site, http://www.saphyre.eu

European Commission's Project Officer and reviewers were given access to a sub-set of the Intranet containing technical and contractual documentation whose circulation was restricted.

3.17 Patents

Based on the SAPHYRE DoW [168], relevant discoveries by SAPHYRE partners were planned to be patent-registered in order to strengthen the European position in this field. Subject to a mutually acceptable agreement thereon between the SAPHYRE partners, the patents may be licensed to both established and emerging companies so that they can directly benefit from SAPHYRE research. All SAPHYRE partners defined jointly the IPR strategy and their approach on project level in the Consortium agreement, defining in detail partners' rights and obligations with specific regard to confidentiality and IPR handling.

4 Individual marketing strategies

Based on initial exploitation plans of individual consortium partners specific dissemination plans are summarised below.

TUD

TUD will exploit the results of SAPHYRE in various activities. Besides publications which are mainly intended for the scientific community and integration into modern teaching courses on master and PhD level (see Section 3.10), the results will be integrated in the Communications Laboratory by providing input to the BMBF project EASY-C (http://www.easy-c.de/index_en.html) and to the cluster of excellence CoolSilicon (http://www.cool-silicon.de) [13]. TUD will be supported by its special unit, the European Project Center (EPC). The Chair of Communications Theory has experience in organising special sessions at flagship conferences [103] and giving tutorials [138]. Therefore, TUD plans to organise a special session at upcoming main conferences of the IEEE communications and signal processing society, such as ICC or ICASSP. All the activities are seen as strategic efforts expected to result in the increase of partnerships at national and international levels.

ALUD

As the original inventors of the BLAST MIMO concept, Bell Labs Wireless Access Research continue to investigate advanced space-time and cross-layer PHY/MAC technologies and is actively involved in their incorporation into 3rd and 4th generation wireless systems and products. Alcatel-Lucent is also highly motivated to explore novel wireless architectures and paradigms and to incorporate the findings within the company's long-term business strategy. Alcatel-Lucent will use the project to investigate advanced technologies and their efficient adoption in future systems.

CFR

The outcome of the SAPHYRE project will be used by CFR to strengthen its research competence in the topic areas covered by the project, as well as its connections with relevant European research groups in both academia and industry. More specifically, the research activities carried out by the SAPHYRE consortium will provide inspiration for relevant topic of PhD dissertations of students at the University of Padova, as well as Masters projects and class materials for design classes and hands-on activities.

CTU

CTU is the largest technical university in the Czech Republic. It has numerous bilateral contacts to the Czech industry and telecommunication operators and support companies. CTU is the primer research related contact point for industry and naturally serves as dissemination point of new progressive research results. The research teams frequently directly participate on the development of the new product. Thus, the results from this research project have a very direct way to practical application in the industry. The communications industry in the Czech Republic, due to typically small size of companies,

mainly concentrates on flexibly filling the gaps in the communications devices markets. Typical are custom solutions for customers with special demands. Those solutions can quite benefit from the cutting edge research results.

ECM

EURECOM is a consortium of industrial and academic partners with primary interest in both applied research and fundamental research and teaching. Additionally, it is present in standardisation groups. Therefore, its marketing strategies are threefold: industrial, academic and regulatory. They span from direct application of SAPHYRE results to innovative industrial projects with EURECOM industrial partners to the enhanced international visibility by publications in esteemed journals and conferences. In the following we detail the threefold EURECOM strategy:

Academic direction: by co-operation between researchers with complementary expertise and exchanging of know-how and scientific results EURECOM will strengthen its competencies and experiences in cutting edge research topics, will increase its international reputation, extend its international network of the partners, its presence and impact on the telecommunications arena. This will imply as well an amelioration of master and PhD programs and the education of young researchers in innovative applications of fundamental analytical tools to wireless communications. Primary interest of EURECOM is also the publication of joint results in prestigious journals and in proceedings of highly refereed international conferences.

Industrial direction: The innovative concepts motivating SAPHYRE will be disseminated among EURECOM industrial partners. Thus, SAPHYRE will be a breeding ground to set up new applied projects. This can enable the implementation of project results in commercial equipment. Additionally, SAPHYRE will create possibilities and opportunities of establishing and promoting EU projects.

Regulatory direction: As a member of ETSI, EURECOM will promote in standardisation and regulatory authorities innovative concepts and visions on frequency, spectrum and infrastructure sharing.

FhG

FhG planed to organise two “open house events” at the end of the second and third project year to demonstrate the key results of SAPHYRE on the FhG-HHI testbed to European wireless communications companies and operators. The open-house events (1 day each) will consist of a workshop with tutorial and in-depth presentations by SAPHYRE partners and 2–3 additional invited talks by experts from industry and academia, a panel discussion and a demonstration of the FhG-HHI testbed. The events will be broadly announced in industry and academia in Europe with up to 50 participants. These events constitute a good opportunity to invite the SAPHYRE project evaluators and demonstrate the SAPHYRE project results.

Relevant discoveries will be patented by FhG-HHI. Subject to a mutually acceptable agreement thereon between the SAPHYRE partners, the patents may be licensed to both established and emerging companies so that they can benefit from the SAPHYRE research.

The close connections to the Technical University of Berlin (Prof. Holger Boche, Chair of Mobile Communications) guarantee the dissemination of SAPHYRE results in the form of student education (PhD and masters).

LiU

At LiU, the outcome from the SAPHYRE project will continue to be disseminated to scientific peers and other national and international academic research projects, mainly by presentations to workshops and meetings. The research results will be further disseminated in the form of overview or tutorial publications in international peer-reviewed journals or magazines and book chapters. Additionally, some results may also be included in ongoing theses done by PhD students the Department of Electrical Engineering, Division of Communication Systems that worked in SAPHYRE. Moreover, the project results fuel a continuously ongoing revision of the graduate curriculum in communications. The topics and results of the project are of significant interest for the industry, and it is envisioned that they will help strengthening collaboration with the local industry and research institutes, in the context of follow-up research activities. Finally, the project results will also provide a basis for strengthening the already ongoing co-operation between the Division of Communication Systems and other laboratories within the EE Department at LiU.

TI

Telecom Italia S.p.A. stopped all its activities in SAPHYRE and left the consortium as of 1st November 2010.

TNO

TNO will increase the awareness of the project results in multiple ways, as outlined below:

Advising our customers: TNO will use the outcomes of the SAPHYRE project on spectrum regulation and policy to advice governmental organisations, regulators, mobile network operators and other customers on issues related to spectrum regulation (where appropriate). Likewise, the outcomes on business modelling and cost analysis will be used to advice mobile operators and other parties on their roles in the future economical landscape of wireless communications and to advice governmental bodies and competition authorities on issues related to business models and cost analysis. Furthermore, results related to simulation and performance evaluation will be incorporated in TNO's own system level simulators. With this we can handle a wider set of questions as expected to be raised by customers and in other research projects.

Publications: TNO has a long tradition of publishing and presenting its work in prestigious journals and at conferences in order to reach a wider public (both scientific and commercial). We intend to continue this by presenting SAPHYRE results in international publications and at global conferences, e.g. organised by IEEE. We will also seek interaction with other projects within the ICT framework to achieve a European level for the SAPHYRE results. The results will also form input to white-papers published by TNO.

External Advisory Board: The EAB will be used extensively for communicating project findings, especially those related to economic and regulatory aspects of resource sharing and for collecting feedback. Since the Advisory Board contain members from a number of European mobile operators and governmental bodies, this will ensure that results are available directly to a large number of parties in the industries and that relevant issues are addressed by the project.

Seminars: TNO organises seminars covering regulation of radio spectrum, which are open to the public. TNO will make use of these opportunities to communicate the findings of the SAPHYRE project to a broader audience.

Future research: Finally, the knowledge built up in the project will, together with the knowledge available at TNO, form the basis for the definition of future research project to be carried out together with other European partners.

TUIL

The research results of the SAPHYRE project have been exploited to graduate Master and PhD students in the Department of Electrical Engineering and Information Technology, Communications Research Laboratory, at TUIL. TUIL will continue and strengthen the exploitation of the SAPHYRE results for the prospective students in our international graduate program of communications and signal processing.

To attract the interests from industry partners, TUIL have also presented our results in WWRF, which aims at bridging the research in the academia and the requirements from the industry [109]. In order to strengthen the collaboration with international research institutes, the dissemination of TUIL has also been performed in the smart antennas research group of Stanford University [110] and the department of electronics of the University of York [111]. An invited presentation has also been given in the wireless research seminar of Bell Labs in Stuttgart [112]. The research results will be further disseminated to TUIL's international partners and industry partners by presentations and workshops. This will further enhance the cooperation between TUIL and its partners.

Finally, the knowledge built up in the project, together with the knowledge available at TUIL, will be integrated into project proposals such as European projects and national projects.

WRC

The role of WRC as independent research entity, is to transfer the knowledge built in the SAPHYRE project to industries within Poland and across the world for further commercialisation of the results. WRC plans to use the results obtained within the SAPHYRE project, for further enhancement of its knowledge and competence in the field of telecommunication networks.

From the academic point of view, WRC will include selected results from the research activities in curricula in order to prepare the next generation of skilled scientist/ engineers. This will be achieved, for example, by updating the material of existing courses (WRC staff lectures at the universities) and by organising short courses for PhD students on specific topics. This is of great importance in order to guarantee continuity

and to foster a long-term, sustainable technological lead and excellence within Poland and the European Union. The close collaboration between the partners of the SAPHYRE project allows training activities within the consortium itself. The knowledge obtained within the project can also be spread to partners' staff that is not directly involved to the project, by organising in-house training sessions, inviting them to internal workshops, making available a project web-site with links and documents as a base for e-training activities.

WRC will leverage on the project deliverables in order to understand the current market requirements and help industries to create a product roadmap for new algorithms and their implementation wireless networks. WRC will also develop algorithms, software and protocols for the technical packages work. WRC will also use the experience and know-how coming from this project to drive the evaluation and study of emerging technologies in the wireless systems field for their future evolution.

5 Conclusions

This paper provides extensive summary of various knowledge dissemination and exploitation actions related to spectrum and infrastructure sharing between operators in cellular wireless networks, which were already completed, as well as those still planned, within SAPHYRE project's coverage. Technical work packages outcomes showed in multiple cases, that inter-operator sharing scenarios have potential, which was not yet addressed by the real world implementations, indicating potential development directions for the future networks evolution not only on the European level, but world-wide.

Based on multiple industry, regulatory and research forums being addressed and contacted during the projects duration, it is felt that SAPHYRE has fulfilled its plans and goals in terms of research outcomes dissemination.

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