Vetenskapsrådet

Application

2015-03-31

2015-05358	Sung, Ki Won	NT-14

Information about applicant

Name: Ki Won Sung

Doctorial degree: 2005-02-18

Birthdate: 19760330

Academic title: Doktor

Gender: Male

Employer: Kungliga Tekniska högskolan

Administrating organisation: Kungliga Tekniska högskolan

Project site: Avdelningen för Kommunikationssystem

Information about application

Call name: Forskningsbidrag Stora utlysningen 2015 (Naturvetenskap och teknikvetenskap)

Type of grant: Projektbidrag

Focus: Fri

Subject area:

Project title (english): Spectrum sharing in wireless systems with receiver-based regulation

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Classification code: 20203. Kommunikationssystem, 20204. Telekommunikation

Keywords: spectrum sharing, receiver-based regulation, performance evaluation, optimal design, wireless access system

Funds applied for

Year:	2016	2017	2018	2019
Amount:	930,000	969,000	994,000	1,060,000

Participants

Name: Jens Zander

Doctorial degree: 1985-01-28

Birthdate: 19550706

Academic title: Professor

Gender: Male

Employer: No current employer

Descriptive data

Project info

Project title (Swedish)*

Samutnyttjande av spektrum i trådlösa system med mottagarbaserade störningsregler

Project title (English)*

Spectrum sharing in wireless systems with receiver-based regulation

Abstract (English)*

Increased availability and explosive growth of mobile Internet traffic combined with emerging machine-type applications is driving the need for fifth-generation (5G) wireless systems. Despite much time and effort on developing this technology, the majority of the studies have neglected an important issue: changing landscape in spectrum authorization and novel spectrum usage principles. Spectrum sharing, with the novel principle of receiver-based regulation, will play a key role in the future 5G systems due to the serious lack of spectrum available for today's exclusive licensing regime. It requires a rethinking of the design and evaluation of 5G systems because interference characteristics of a wireless access system under the shared spectrum will be significantly different from that of the present systems built for exclusively licensed spectrum. Proposals for 5G techniques and architecture must be examined carefully whether they are still functioning well in spectrum sharing environments. We also need a new theoretical framework to analyze the inter-system interference problems with the principle of receiver-based regulation.

In the light of the emerging requirements, this project is aimed to design, evaluate, and optimize future wireless access systems with the spectrum sharing. We have three specific objectives to achieve the aim of the project. First, we will propose a mathematical framework for analysis of spectrum sharing schemes and systems with the receiver-based regulation principle. Second, we will identify 5G technologies suitable for the envisaged spectrum sharing scenarios. Finally, after having achieved the above objectives, we will design and optimize the spectrum sharing system. This project is planned for four years, and will be implemented as a PhD study with sequential investigation of the objectives. The applicant will serve as the primary supervisor of the PhD student who will be selected for this project. A senior scientist will also be involved as the co-supervisor, providing a high-level guidance to the direction of the project. International collaboration will be an integral of this project.

Exclusive spectrum of today is expected to account for only marginal portion of available spectrum in the future. It means that any technology developed under the assumption of exclusive spectrum will have only limited impact to the performance of the 5G systems. Spectrum sharing will be a game changer for the design of future wireless systems. This project will provide the necessary input for the wireless industry to tackle a profound challenge in the design of future wireless systems. Also, this project will steer the research community to the studies related to the spectrum sharing by offering the fundamental tools of performance evaluation and optimization underpinning the follow-up studies.

Popular scientific description (Swedish)*

Bättre tillgänglighet och kraftigt ökad användning av mobilt bredband tillsammans med utbredningen av maskin-till-maskin-liknande applikationer har på senare tid drivit på behovet av femte generationens mobilsystem (5G). Trots mycket tid och resurser på att utveckla tekniken är det en omständighet som ofta glöms bort – det allt mer föränderliga landskapet kring licensiering och användning av befintligt radiospektrum.

Dagens mobilsystem drivs nästan uteslutande i dedikerade (exklusiva) frekvensband. Följaktligen förutsätter de flesta teknikstudier av framtidens radionät samma typ av licensieringsförhållande, trots att detta spektrum redan idag är stundtals överbelastat. Nya frekvensband i det licensierade bandet anses både svåråtkomligt och dyrt. Samtidigt beräknas 5G-näten kräva mer bandbredd, inte mindre. I samägt spektrum kan istället operatörer gemensamt bruka samma frekvensband. Samägt spektrum blir därför en nyckeldel i förverkligandet av 5G. I USA och delar av Europa pågår försök från myndighetshåll att på olika sätt uppmuntra samägt spektrum i syfte att förbättra nyttjandegraden av befintliga frekvensband samt minska trösklarna för nya aktörer att slå sig in på mobilmarknaden.

Samägt spektrum kräver helt klart ett omtänk av teknisk design och utvärdering då typen av radiostörningar i sådana nätverk skiljer sig markant från det i dedikerat spektrum. Existerande förslag till arkitektur och teknik för 5G behövs också omvärderas inom ramen för samägt spektrum, inklusive mekanismer för att lösa störningsproblem mellan nätverk. Hur man bäst bygger radiosystem samt utvärderar dess prestanda inom ramen för samägt spektrum är en nyckelfråga och teknisk utmaning för ett effektivt framtida mobilsystem.
Syftet med detta projekt är att designa, analysera och optimera framtida mobila accessystem inom ramen för samägt spektrum. För detta har vi identifierat fyra specifika mål: 1) identifiera lämpliga radiotekniker för samägt spektrum, 2) designa en passande systemarkitektur, 3) föreslå ett matematiskt ramverk för analys av spektrumdelningsstrategier, och 4) optimera det övergripande systemet byggt på föregående målpunkter.

Exklusivt spektrum väntas svara för endast en bråkdel av allt tillgängligt spektrum i framtiden. Teknik utvecklad för exklusiva radiofrekvenser kommer därför ha begränsad påverkan på 5G-nätens prestanda. Samägt spektrum tros kunna förändra synen på hur framtidens trådlösa bredbandssystem utformas. 5G:s framgång avgörs i mångt och mycket av hur man tacklar frågor och problem kring samägt spektrum. Det här projektet kommer tillföra ett nödvändigt bidrag för mobilindustrin att lösa dessa utmaningar. Utöver det kommer den förse verktyg för att analysera och optimera mobilnätens prestanda nu och i framtida uppföljningsstudier.

Det råder bred konsensus inom mobilindustrin att börja rulla ut 5G mellan 2020-2030. Av denna anledning bör mestadelen av den grundläggande forskningen kring 5G avslutas år 2020, vilket överensstämmer väl med tidsmålet för detta projekt.

Project period

Number of project years*

4

Calculated project time*

2016-01-01 - 2019-12-31

Classifications

Select a minimum of one and a maximum of three SCB-codes in order of priority.

Select the SCB-code in three levels and then click the lower plus-button to save your selection.

SCB-codes*

2. Teknik > 202. Elektroteknik och elektronik > 20203. Kommunikationssystem

2. Teknik > 202. Elektroteknik och elektronik > 20204. Telekommunikation

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Enter a minimum of three, and up to five, short keywords that describe your project.

Keyword 1*

spectrum sharing

Keyword 2*

receiver-based regulation

Keyword 3*

performance evaluation

Keyword 4

optimal design

Keyword 5

wireless access system

Research plan

Ethical considerations

Specify any ethical issues that the project (or equivalent) raises, and describe how they will be addressed in your research. Also indicate the specific considerations that might be relevant to your application.

Reporting of ethical considerations*

The research in this project does not raise any ethical issues.

The project includes handling of personal data

No

The project includes animal experiments

No

Account of experiments on humans

No

Research plan

Spectrum sharing in wireless systems with receiver-based regulation

1 Purpose and aims

1.1 Background and motivation

Increased availability and explosive growth of mobile Internet traffic combined with emerging machine-type applications is driving the need for fifth-generation (5G) wireless systems. Despite much time and effort on developing this technology, the majority of the studies have neglected an important issue: **changing landscape in spectrum authorization and novel spectrum usage principles**.

Spectrum sharing will play a key role in the future 5G systems due to the serious lack of spectrum chunks available for the exclusive licensing. In fact, policy makers in Europe and the USA are vigorously pushing spectrum sharing in order to improve the spectrum utilization and to lower the entry barrier in the wireless service market. A report to European Commission suggested that the spectrum sharing would provide a great value to European society [1]. In [2], the council of advisors on science and technology (PCAST) reported to the president of the USA that the shared use of government-held spectrum is necessary to spur economic growth.

We expect that the spectrum sharing will come with a new interference regulation principle. Since the beginning of radio communications, transmitter emission control has been the tool of regulating interference. However, it imposes excess restriction on the transmitters, and thus prevents an efficient use of spectrum. A new principle, namely **receiver-based regulation**, is considered a remedy [3]. It can potentially make a disruptive change on how different wireless systems can utilize the spectrum together, but its impact has not been investigated yet.

Arguably, the spectrum sharing with the receiver-based regulation requires a rethinking of the design and evaluation of 5G systems. With the spectrum sharing, multiple wireless networks may use the same frequency band. Thus, interference characteristics of a wireless access system

under the shared spectrum will be significantly different from that of the present systems built for exclusively licensed spectrum. Proposals for 5G techniques and architecture must be examined carefully whether they are still functioning well in spectrum sharing environments. We also need a new theoretical framework to analyze the inter-system interference problems with the principle of receiver-based regulation. **Therefore, how to design wireless systems under the novel spectrum sharing principle and how to evaluate the performances of such systems will be among the most important challenges for wireless systems of long-term future.**

1.2 Objectives

This project is aimed to design, evaluate, and optimize future wireless access systems for the spectrum sharing with the receiver-based regulation. For this, we have three specific objectives.

Objective 1: to propose mathematical framework for analysis of spectrum sharing schemes and systems

A scalable and tractable mathematical framework of performance analysis is a profound stepping stone to the system design. Our approach is to make a major revision of the tools available today (e.g. stochastic geometry) to take into account the effect of the receiver-based regulation in practical spectrum sharing scenarios. A measurable goal of objective 1 is a mathematical framework that can be used for the analysis of spectrum sharing systems of the project scope.

Objective 2: to identify technology components suitable for spectrum sharing

Most studies on 5G technology components, particularly multi-antenna techniques, implicitly assumed exclusively licensed spectrum. Therefore, it is important to examine the suitability of the technologies under the spectrum sharing environments. A measurable goal of objective 2 is a list of promising technologies for spectrum sharing systems.

Objective 3: to provide design guidelines for efficient spectrum sharing

Having achieved the above objectives, the final objective is to design spectrum sharing systems. Because receiver-based spectrum sharing creates a new interference management problem, the system architecture has to include new functionalities for resolving inter-system interference. Mathematical optimization is considered a promising design approach. A measurable goal of

objective 3 is a proposal of system architecture and a set of guidelines on how to optimize the set of parameters for various sharing scenarios.

2 Survey of the field

Policy makers currently consider spectrum sharing a promising means to fulfill the tremendous need for radio spectrum for future wireless systems [1, 2]. Various modes of shared spectrum usage, such as vertical sharing with TV and radar [4, 5] and licensed shared access (LSA) [6], are currently under discussion. Of particular interest to our project is co-primary sharing between local service providers [7]. Here, the envisaged scenario is that geographically non-overlapping small operators utilize the same frequency band for high capacity services in dense areas.

Interference regulation is one of the key issues in spectrum sharing because inevitably occurring interference between the systems has to be addressed. Since the beginning of the radio regulation, the burden has been on the transmitter side by means of emission control. However, it tends to impose excess restriction on the transmitters, and thus prevents an efficient use of spectrum. Recently, a new principle of receiver-based regulation has been considered as a remedy. This means that the receivers declare harm claim threshold that the interferers should abide by [3]. We expect that the receiver-based regulation, combined with the emerging co-primary sharing scenario, will require a disruptive change in the design of wireless access systems.

The progress made in the regulatory domain, however, has not been fully reflected in the studies on the 5G technologies and system design. Ample researches have been performed to develop the future wireless systems. These include massive MIMO [8], millimeter-wave transmission [9], D2D communications [10], wideband carrier aggregation [11], full duplex transceiver [12], and ultra-dense deployment of small cells [13]. However, the majority of studies implicitly assumed the exclusive spectrum licensing which has been the norm of frequency allocation in conventional cellular systems (up to fourth generation). It is not certain whether these technology components are adequate for spectrum sharing environments or not. Some exceptions are the studies of cognitive radio network where a vertical spectrum sharing takes place between a primary and cognitive systems [14, 15]. However, they are not readily applicable to co-primary sharing scenarios. Furthermore, they remain in the legacy regime of transmitter emission control. To my best knowledge, there has been no attempt to design a system and to develop an analysis framework under the novel co-primary spectrum sharing scenarios with receiver-based regulation.

To sum up, the literature review leads us to the finding that important questions have not been

answered yet:

- What is mathematical framework for analyzing wireless systems in the co-primary spectrum sharing with receiver-based regulation?
- What are 5G technology components suitable for the new principle and environment of spectrum sharing?
- How should we design and optimize the spectrum sharing systems and what is envisaged gain?

3 Project description

3.1 Methodology

This project will be built upon realistic scenarios of spectrum sharing with plausible business cases and user requirements in order to ensure the practical relevance of the work [1]. However, the research tasks will deal with fundamental problems in wireless systems so that the outcome of the project can serve as a basis for the wide range of researchers in this field. The tasks in this project are divided into three thematic areas.

Area 1: mathematical framework of performance evaluation

An accurate and efficient performance evaluation framework is a prerequisite for optimal system design. While simulation-based evaluation provides a quite accurate estimation of the system performance, it is terribly time-consuming particularly when the network size grows large. Also, it is difficult to reproduce and validate the results. Therefore, a mathematical framework is preferred in terms of tractability, computational efficiency, and scalability.

Performance evaluation of wireless systems has been studied quite extensively. However, the new requirements of this project call for a novel methodology of performance evaluation.

- Users in a spectrum sharing network will be affected by two types of interference: the conventional interference from the inside of the network and a new interference from other networks. The interference among multiple networks creates a complicated interference footprint, and makes the analysis of interference management schemes difficult.

[1] The importance of practical scenario making in the study of spectrum sharing was discussed in my previous work [15]

- Realistic propagation conditions should be taken into account. The need for spectrum sharing is highest in dense urban areas. Thus, an accurate modeling of radio propagation in and between three-dimensional buildings is a key requirement for the analysis of spectrum sharing systems. Currently, three-dimensional propagation modeling relies on computationally demanding ray tracing methods. An efficient way of handling walls and floors is a challenge even when we ignore the spectrum sharing aspect.

- The performance evaluation framework should include the new principle of receiver-based regulation, e.g. harm claim threshold [3]. The new regulatory initiative defines how the spectrum sharing systems should coexist with each other. However, the system performance under the receiver-based regulation has not been investigated.

We will start by upgrading the tools available today. Stochastic geometry has gained a popularity due to the mathematical tractability coming from the properties of point Poisson process [16]. However, it is not readily expandable for realistic propagation environments. Another framework widely accepted for numerical evaluation is aggregation of variables with feasible load concept [17, 18]. It is easier to manipulate the topology of the network, but it does not yield a closed-form solution. Therefore, the advantages and disadvantages of existing tools should be closely examined. Both were developed for traditional cellular systems, Thus, the extension of the tools for fulfilling aforementioned requirements will be the main challenges in this area.

Area 2: incorporation of advanced 5G technologies to the framework

Various advanced technologies, such as massive MIMO, D2D, and full duplex communications, have been proposed for 5G systems. So far, most of studies have focused on the performance of individual technology component. The effect of combined components in a single system is yet to be identified. Furthermore, an important question is whether they would be useful for spectrum sharing environments. Multiple antenna techniques are of particular interest because the metamorphosis of interference footprint may significantly affect the performance, and even the feasibility, of the techniques.

In order to answer the question, the technology components should be incorporated into the performance evaluation framework developed in the area 1. In my recent publication, we examined the interaction between two prominent technologies, namely massive MIMO and D2D [19]. The next steps will be to add more components into the picture and to consider the spectrum sharing aspect. However, this is far from straightforward. We observed that the combination of two technologies is already very complicated. A systematic investigation on the various tech-

nologies under the spectrum sharing requires a more efficient method of adding/removing the technologies to/from the evaluation framework. It is the major research challenge in the area 2.

Area 3: system design and optimization

After having developed the necessary tools for the performance evaluation, the final research area of the project is the design and optimization of wireless access systems in spectrum sharing environments. The first step in this area is to establish the guidelines of the system design. There is a fundamental design choice in the inter-system interference management: cooperation vs. non-cooperation [7]. It also involves the comparison of a coordinated vs. uncoordinated system and centralized vs. distributed interference management. We expect that different recommendations would be applied to different situations, e.g. user demand, inter-network separation, and availability of backhaul. Therefore, we will pursue the identification of operating conditions of each design principle rather than seeking a universal solution. Then, for each regime, we will extract the key parameters, formulate an optimization problem, and solve it. The nature of the problem will determine the optimization technique to be employed. Convex optimization [20] and nature-inspired algorithms [21] are the first candidates. These can be evolved during the lifetime of the project.

3.2 Implementation and time plan

This project consists of three research areas which need a long-term incremental knowledge. In other words, the latter research areas should be built upon the findings obtained in former areas. Therefore, parallel investigation of the areas is not practical. Instead, this project is best suited as a doctoral study where a PhD student continues exploring the three research areas one by one. The project is planned for four years. Sequential studies of the areas will be implemented with a partial overlap to allow for smooth transition between the areas. Figure 1 illustrates the time plan of the project.

Each area addresses a profound research question. Thus, the primary output of this project will be publications to prestigious journals which can be utilized as the foundation for the wireless research community.

The project budget is designed to support a full-time doctoral student who will be selected for this project. I will serve as his or her main supervisor. In addition, Professor Jens Zander at KTH Royal Institute of Technology will be involved in the project as a participating researcher. He will serve as the co-supervisor of the student, and mainly provide a high-level guidance to the

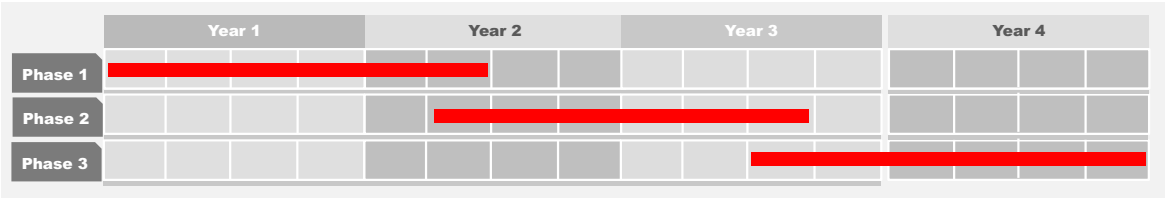

Figure 1: Project time plan.

direction of the project.

International collaboration will play an important role in this project. Such a collaboration will be achieved by cooperation with other research projects and frequent interaction with colleague researchers around the globe. More details are available in Section 6.

4 Significance

Today's cellular wireless systems operate on exclusively licensed spectrum. Hence, it is not surprising that the majority of studies for the future wireless systems have implicitly assumed the same licensing regime. However, it is obvious that the currently available spectrum is severely overloaded, and the additional frequency band is hard to come by, if we only look for the exclusive spectrum. 5G systems will require substantially larger system bandwidth. Moreover, regulators strongly advocate the shared use of spectrum. Combining these two facts clearly indicates that the spectrum sharing will be one of the key enablers for 5G. Exclusive spectrum of today is expected to account for only marginal portion of available spectrum in the future. It means that any technology developed under the assumption of exclusive spectrum will have very limited impact to the performance of the 5G systems.

Spectrum sharing will be a game changer for the design of future wireless systems. It is arguable that the success of 5G depends on how effectively the system addresses the spectrum sharing issues. This project will provide the necessary input for the wireless industry to tackle the challenge. Also, this project will steer the research community to the studies related to the spectrum sharing by offering the tools of performance evaluation and optimization underpinning the follow-up studies.

The timeliness of the project should also be emphasized. There is a broad consensus in the wireless community that 5G systems will roll out in the time frame of year 2020-2030. Fundamental research on 5G systems design should therefore be finished by the year 2020, which has a perfect alignment with the period of this project.

5 Preliminary results

This project aims to build the bridge between two almost orthogonal research realms: spectrum sharing policy and 5G systems and technologies. Therefore, one should have expertise in both areas in order to conduct the project successfully.

I have investigated the efficient use of spectrum via spectrum sharing over the past years. Most of the studies have been performed within the framework of FP7 projects QUASAR and METIS. My earlier work focused on vertical sharing of the spectrum. In [15], principles of spectrum sharing between primary and secondary systems were discussed. Then, technical feasibility of secondary access was investigated in [5, 22–24]. Indoor and hotspot mobile broadband was considered as the secondary system, while various primary systems were paired: TV broadcasting [22], aeronautical navigation [23], and radar [5, 24]. Aggregate interference model was also developed as a fundamental building block of the feasibility studies [25]. The results of the research is summarized with suggestions for business and regulatory perspectives in [14]. The later study, which is closest to this project, addressed an important issue of the co-primary sharing [7]. Here, we discussed the decision criteria of whether to cooperate or not between the spectrum sharing networks.

Another pillar of this project is wireless systems design and performance evaluation. I have contributed to a method of analyzing performance of indoor wireless networks in [26]. Also, I have utilized various methodologies for evaluation of wireless systems of different settings: system-level simulations [27], feasible load concept [28], and stochastic geometry [19]. My recent studies are closely related to 5G technology components: massive MIMO [19], D2D [19], and ultra-dense deployment of wireless networks [27, 28]. But, these did not take into account spectrum sharing.

Integration of the two realms is essential for the design of the future wireless systems. It will be a challenging task, and I believe that my previous work will lay a foundation to it.

6 International and national collaboration

This project will take a substantial advantage of other international research projects that will be ongoing at the same time. In European level, I will participate in Horizon 2020 project, METIS-II, between July 2015 and June 2017, where I lead the research activities of KTH and will advise two PhD students. METIS-II is the successor of METIS, the flagship FP7 project about 5G concepts and technologies, and therefore it will play a leading role in European 5G research. This project and METIS-II will mutually benefit each other. This project will strengthen the spectrum

sharing aspect of METIS-II, and thus will make the system proposal of METIS-II more relevant and of higher impact. METIS-II will provide realistic 5G use cases and up-to-date knowledge of 5G technologies for this project. METIS-II can also be utilized as a fast and effective path for disseminating the outcome of the project.

In the international level, I will be the principal investigator of a small collaboration project with Korea from June 2015 to May 2019, namely ”Agile Radio Resource Management for 5G Wireless Systems in Shared Spectrum.” It is funded by STINT, and it supports the exchange of PhD students between KTH and Yonsei University, Korea. Therefore, the main research person of this project (a to-be-hired PhD student) will be the prime candidate for the exchange scheme. It will encourage the international collaboration on the theme of this project. Thus, this project will have a higher chance of making a global impact.

References

[1] S. Forge, R. Horvitz, and C. Blackman, “Perspectives on the value of shared spectrum access,” Final Report for the European Commission, Feb. 2012, http://ec.europa.eu/digital-agenda/sites/digital-agenda/files/scf_study_shared_spectrum_access_20120210.pdf.

[2] Presidents Council of Advisors on Science and Technology, “Realizing the full potential of government-held spectrum to spur economic growth,” Report to the President, Jul. 2012, http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_july_20_2012.pdf.

[3] J. P. de Vries, “Optimizing receiver performance using harm claim thresholds,” *Telecommunications Policy*, vol. 37, no. 9, pp. 757 – 771, 2013.

[4] J. van de Beek, J. Riihijarvi, A. Achtzehn, and P. Mahonen, “TV White Space in Europe,” *IEEE Transactions on Mobile Computing*, vol. 11, no. 2, pp. 178–188, 2012.

[5] E. Obregon, K. W. Sung, and J. Zander, “On the sharing opportunities for ultra-dense networks in the radar bands,” in *Proc. IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN)*, Apr. 2014, pp. 215–223.

[6] ECC, “Licensed Shared Access (LSA),” ECC Report 205, Feb. 2014.

[7] D. H. Kang, K. W. Sung, and J. Zander, “High Capacity Indoor & Hotspot Wireless System in Shared Spectrum - A Techno-Economic Analysis,” *IEEE Communications Magazine*, vol. 51, no. 12, pp. 102–109, Dec. 2013.

[8] E. G. Larsson, F. Tufvesson, O. Edfors, and T. L. Marzetta, “Massive MIMO for next generation wireless systems,” *IEEE Communications Magazine*, vol. 52, no. 2, pp. 186–195, Feb. 2014.

[9] T. Rappaport, S. Sun, R. Mayzus, H. Zhao, Y. Azar, K. Wang, G. Wong, J. Schulz, M. Samimi, and F. Gutierrez, “Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!” *IEEE Access*, vol. 1, pp. 335–349, 2013.

[10] K. Doppler, M. Rinne, C. Wijting, C. Ribeiro, and K. Hugl, “Device-to-device communication as an underlay to LTE-advanced networks,” *IEEE Communications Magazine*, vol. 47, no. 12, pp. 42–49, Dec. 2009.

[11] Z. Shen, A. Papasakellariou, J. Montojo, D. Gerstenberger, and F. Xu, "Overview of 3GPP LTE-advanced carrier aggregation for 4G wireless communications," *IEEE Communications Magazine*, vol. 50, no. 2, pp. 122–130, Feb. 2012.

[12] X. Xie and X. Zhang, "Does full-duplex double the capacity of wireless networks?" in *Proc. IEEE INFOCOM*, Apr. 2014, pp. 253–261.

[13] S. Yunas, M. Valkama, and J. Niemela, "Spectral and energy efficiency of ultra-dense networks under different deployment strategies," *IEEE Communications Magazine*, vol. 53, no. 1, pp. 90–100, Jan. 2015.

[14] J. Zander, L. K. Rasmussen, K. W. Sung, P. Mähönen, M. Petrova, R. Jäntti, and J. Kronander, "On the Scalability of cognitive radio: assessing the commercial viability of secondary spectrum access," *IEEE Wireless Communications*, vol. 20, no. 2, Apr. 2013.

[15] Y. Hwang, S.-L. Kim, K. W. Sung, and J. Zander, "Scenario making for assessment of secondary spectrum access," *IEEE Wireless Communications*, vol. 19, no. 4, pp. 25–31, Aug. 2012.

[16] J. G. Andrews, F. Baccelli, and R. K. Ganti, "A Tractable Approach to Coverage and Rate in Cellular Networks," *IEEE Transactions on Communications*, vol. 59, no. 11, 2011.

[17] I. Siomina and D. Yuan, "Analysis of Cell Load Coupling for LTE Network Planning and Optimization," *IEEE Transactions on Wireless Communications*, vol. 11, no. 6, 2012.

[18] A. J. Fehske and G. P. Fettweis, "Aggregation of Variables in Load Models for Interference-Coupled Cellular Data Networks," in *Proc. IEEE ICC*, 2012.

[19] S. Shalmashi, E. Bjornson, M. Kountouris, K. W. Sung, and M. Debbah, "Energy Efficiency and Sum Rate when Massive MIMO meets Device-to-Device Communication," in *Proc. IEEE ICC*, 2015.

[20] S. Boyd and L. Vandenberghe, *Convex Optimization*, 1st ed. Cambridge Univ. Press, 2004.

[21] X.-S. Yang, *Nature-Inspired Optimization Algorithms*. Elsevier, 2014.

[22] L. Shi, K. W. Sung, and J. Zander, "Secondary spectrum access in TV-bands with combined co-channel and adjacent channel interference constraints," in *IEEE International Symposium on Dynamic Spectrum Access Networks (DYSPAN)*, Bellevue, USA, Oct. 16–19 2012, pp. 452–460.

[23] K. W. Sung, E. Obregon, and J. Zander, "On the requirements of secondary access to 960-1215 MHz aeronautical spectrum," in *Proc. of IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN)*, Aachen, Germany, 2011, pp. 371–379.

[24] M. Tercero, K. W. Sung, and J. Zander, "Exploiting Temporal Secondary Access Opportunities in Radar Spectrum," *Wireless Personal Communications*, 2013, published online, DOI: 10.1007/s11277-013-1127-7.

[25] K. W. Sung, M. Tercero, and J. Zander, "Aggregate Interference in Secondary Access with Interference Protection," *IEEE Communications Letters*, vol. 15, no. 6, pp. 629–631, Jun. 2011.

[26] K. W. Sung, H. Haas, and S. McLaughlin, "A Semianalytical PDF of Downlink SINR for Femtocell Networks," *EURASIP Journal on Wireless Communications and Networking*, vol. 2010, 2010, article ID 256370.

[27] H. Celik and K. W. Sung, "On the Feasibility of Blind Dynamic TDD in Ultra-Dense Wireless Networks," in *Proc. IEEE VTC Spring*, 2015.

[28] Y. Yang and K. W. Sung, "Tradeoff Between Spectrum and Densification for Achieving Target User Throughput," in *Proc. IEEE VTC Spring*, 2015.

Interdisciplinarity

My application is interdisciplinary

☐

An interdisciplinary research project is defined in this call for proposals as a project that can not be completed without knowledge, methods, terminology, data and researchers from more than one of the Swedish Research Councils subject areas; Medicine and health, Natural and engineering sciences, Humanities and social sciences and Educational sciences. If your research project is interdisciplinary according to this definition, you indicate and explain this here.

Click here for more information

Scientific report

Scientific report/Account for scientific activities of previous project

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Budget and research resources

Project staff

Describe the staff that will be working in the project and the salary that is applied for in the project budget. Enter the full amount, not in thousands SEK.

Participating researchers that accept an invitation to participate in the application will be displayed automatically under Dedicated time for this project. Note that it will take a few minutes before the information is updated, and that it might be necessary for the project leader to close and reopen the form.

Dedicated time for this project

	Role in the project	Name	Percent of full time
1	Applicant	Ki Won Sung	20
2	Participating researcher	Jens Zander	5
3	Other personnel without doctoral degree	PhD Student	65
4	Participating researcher	Jens Zander	

Salaries including social fees

	Role in the project	Name	Percent of salary	2016	2017	2018	2019	Total
1	Applicant	Ki Won Sung	20	153,000	156,000	160,000	164,000	633,000
2	Participating researcher	Jens Zander	5	71,000	72,000	74,000	76,000	293,000
3	Other personnel without doctoral degree	PhD Student	65	315,000	335,000	344,000	379,000	1,373,000
	Total			539,000	563,000	578,000	619,000	2,299,000

Other costs

Describe the other project costs for which you apply from the Swedish Research Council. Enter the full amount, not in thousands SEK.

Premises

	Type of premises	2016	2017	2018	2019	Total
1	Offices	70,000	73,000	75,000	80,000	298,000
	Total	70,000	73,000	75,000	80,000	298,000

Running Costs

	Running Cost	Description	2016	2017	2018	2019	Total
1	Travel	attendance to conferences	40,000	40,000	40,000	40,000	160,000
2	Publication	fee for open access pubication	10,000	10,000	10,000	10,000	40,000
	Total		50,000	50,000	50,000	50,000	200,000

Depreciation costs

	Depreciation cost	Description	2016	2017	2018	2019

Total project cost

Below you can see a summary of the costs in your budget, which are the costs that you apply for from the Swedish Research Council. Indirect costs are entered separately into the table.

Under Other costs you can enter which costs, aside from the ones you apply for from the Swedish Research Council, that the project includes. Add the full amounts, not in thousands of SEK.

The subtotal plus indirect costs are the total per year that you apply for.

Total budget

Specified costs	2016	2017	2018	2019	Total, applied	Other costs	Total cost
Salaries including social fees	539,000	563,000	578,000	619,000	2,299,000		2,299,000
Running costs	50,000	50,000	50,000	50,000	200,000		200,000
Depreciation costs					0		0
Premises	70,000	73,000	75,000	80,000	298,000		298,000
Subtotal	659,000	686,000	703,000	749,000	2,797,000	0	2,797,000
Indirect costs	271,000	283,000	291,000	311,000	1,156,000		1,156,000
Total project cost	930,000	969,000	994,000	1,060,000	3,953,000	0	3,953,000

Explanation of the proposed budget

Briefly justify each proposed cost in the stated budget.

Explanation of the proposed budget*

This project consists of three research areas which need a long-term incremental knowledge. In other words, the latter research areas should be built upon the findings obtained in former areas. Therefore, parallel investigation of the areas is not practical. Instead, this project is best suited as a doctoral study where a PhD student continues exploring the three research areas one by one.

The project is planned for four years. A PhD student will be newly hired for this project. The student will devote 65% of his or her time to this project. I will spend 20% of time on it, which mainly accounts for the supervision of the student. In addition, Professor Jens Zander at KTH Royal Institute of Technology will be involved in the project as a participating researcher. He will spend 5% of his time. He will serve as the co-supervisor of the student, and mainly provide a high-level guidance to the direction of the project.

A reasonable amount of travel and publication cost is also included in the budget to support the publication in open access journals, the presentation in conferences, and travel inside Sweden for national collaboration. This project does not claim any equipment cost. Required IT equipment (e.g. computer) will be procured by the other budget.

Other funding

Describe your other project funding for the project period (applied for or granted) aside from that which you apply for from the Swedish Research Council. Write the whole sum, not thousands of SEK.

Other funding for this project

Funder	Applicant/project leader	Type of grant	Reg no or equiv.	2016	2017	2018	2019

CV

Curriculum vitae of Ki Won Sung

1. Higher education degrees

M.S. in Industrial Engineering

- Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Korea
- Period: Mar. 1998 ~ Feb. 2000
- Thesis: *Approximate Analysis on Retrial Queues with Fixed Number of Retrials*

Bachelor of Industrial Management

- Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Korea
- Period: Mar. 1994 ~ Feb. 1998

2. Doctoral degree

Ph.D. in Industrial Engineering

- Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Korea
- Period: Mar. 2000 ~ Feb. 2005
- Thesis: *Resource Allocation and Call Admission Control for Mobile Communication systems*
- Advisor: Prof. Chae Y. Lee

3. Post-doctoral positions

KTH Royal Institute of Technology, Kista, Stockholm, Sweden

- Affiliation: Communication Systems Department (CoS)
- Period: Apr. 2009 – Dec. 2009

University of Edinburgh, Edinburgh, UK

- Affiliation: Institute for Digital Communications (IDCOM)
- Period: Jan. 2008 – Dec. 2008

4. Docent level

- Docent at KTH since September 2013.

5. Current position

KTH Royal Institute of Technology, Kista, Stockholm, Sweden

- Title: Docent Researcher (with permanent employment)
- Affiliation: Communication Systems Department (CoS)
- Period: Sep. 2013 – present

6. Previous positions and periods of appointment

KTH Royal Institute of Technology, Kista, Stockholm, Sweden

- Researcher (Jan. 2010 – Aug. 2013)

KTH Royal Institute of Technology, Kista, Stockholm, Sweden

- Post-doc (Apr. 2009 – Dec. 2009)

University of Edinburgh, Edinburgh, UK

- Post-doc (Jan. 2008 – Dec. 2008)

Samsung Electronics, Suwon, Korea

- Senior Engineer (Mar. 2005 – Dec. 2007)
- Professional area: Mobile WiMAX system research, development, and commercialization

7. Interruption in research: N/A

8. Supervision of doctoral students

Current students: 3 students as primary supervisor and 1 student as secondary supervisor

- Serveh Shalmashi (Licentiate in June 2014)
- Yanpeng Yang (since Nov. 2013)
- Haris Celik (since Jan. 2014)
- Ashraf Widaa (as secondary supervisor)

Former students: 5 PhD graduates as secondary supervisor

- Du Ho Kang (graduated in May 2014)
- Sibel Tombaz (graduated in May 2014)
- Lei Shi (graduated in June 2014)
- Evanny Obregon (graduated in June 2014)
- Ali Ö zyagci (graduated in Oct. 2014)

9. Other merits of relevance

Experience in European projects

- FP7 QUASAR, FP7 METIS, H2020 METIS-II

Project as primary investigator (PI)

- Agile Radio Resource Management for 5G Wireless Systems in Shared Spectrum, STINT project for cooperation with Korea, (June 2015 – May 2019)

Academic activities

- Tutorial chair of IEEE DySPAN 2015
- Track program chair of CROWNCOM 2012

CV : Jens Zander

Personal Details

- Jens Zander
- July 6, 1955 in Lütjenburg, Germany
- Naturalized Swedish Citizen since 1968

Academic Degrees

1979 M.Sc. Linköping University EE (civ ing Y)
1985 Ph.D. Linköping University EE (Tekn Dr, Datatransmission)

Post-Doctoral positions: None

Qualification as Docent:

Appointed as full professor at KTH 1989

Current position:

Full professor in Radio Communication Systems since 1989
Dean, School of ICT, KTH (50%) since 2013
Scientific Director, KTH Center for Wireless Systems (Wireless@KTH) since 2003

Previous positions and appointments:

1979 - 1984 Research Assistant, Linköping University
1985 - 1989 Co-founder and Vice president of SECTRA AB
1992 - Senior Scientific Advisor, Swedish Defense Research Establishment (FOI)
2001- 2005 PI: Affordable Wireless Services and Infrastructures, National Strategic Research program
2010-2012 PI: ICT The Next Generation (TNG) Strategic Research Area
2010 -2012 Project Manager/PI – FP7 QUASAR project

Interruption in Research: None

Graduate Supervision

Recent PhD Graduates as main advisor (Current affiliation):

2007 Klas Johansson, Ericsson AB, Sweden
2008 Marvin Sanchez, Enitel, Nicaragua
2008 Johan Hultell, Ericsson AB, Sweden
2009 Aurelian Bria, Ericsson AB, Sweden
2009 Bogdan Timus, Ericsson AB, Sweden
2010 Pietro Lungaro, KTH
2010 Luca Stabellini, McKinsey, Sweden
2011 Jan Markendahl, KTH
2014 Du Ho Kang, Ericsson AB, Sweden
2014 Sibel Tombaz, Ericsson AB, Sweden
2014 Evanny Obregon, Ericsson AB, Sweden
2014 Lei Shi, Northstream AB, Sweden
2014 Ali Özyagci, KTH,

In total (1994-2011): Main advisor to **35 Ph.D graduates**, Secondary adv to 4 Ph.D graduates

Other information of relevance:

Awards:

2014 Honorary Doctor, Aalto University, Finland

Knowledge Exchange and Entrepreneurial Achievements

2006- Board member of PTS (Swedish National Telecom Regulator)
2002 - 2005 Board member of Åkerströms AB
2001 - 2003 Board member of Affärsstrategerna AB
2000 - 2005 Chairman IEEE VT/COM Swedish Chapter
1999 - 2011 Board member of Possio AB
1998 - 2000 Chairman of Factum Electronik AB
1994 - 1999 Board Member of Teracom Components AB, Hörby
1992 - 2000 Board member of Teracom AB
1985 - 1991 Board member and VP of SECTRA AB (http://www.sectra.com)

Publication list

Publication list of Ki Won Sung

Source of citation information: Google Scholar

Peer-reviewed articles

1. S. Tombaz, K. W. Sung, and J. Zander, "On Metrics and Models for Energy Efficient Design of Wireless Access Networks," *IEEE Wireless Communications Letters*, vol. 3, no. 6, pp.649-652, 2014.
   Number of citations: 0

2. Y. Yang, K. W. Sung, L. Wosinska, and J. Chen, "Hybrid Fiber and Microwave Protection for Mobile Backhauling," *IEEE/OSA Journal of Optical Communications and Networking*, vol. 6, no. 10, pp.869-878, 2014.
   Number of citations: 0

3. S. Tombaz, S.-w. Han, K. W. Sung, and Jens Zander, "Energy Efficient Network Deployment with Cell DTX," *IEEE Communications Letters*, vol. 18, no. 6, pp.977-980, June 2014.
   Number of citations: 1

4. L. Shi, E. Obregon, K. W. Sung, J. Zander, and J. Bostrom, "CellTV - On the Benefit of TV Distribution over Cellular Networks: A Case Study," *IEEE Transactions on Broadcasting*, vol. 60, no. 1, pp. 73-84, 2014.
   Number of citations: 7

5. **(*)** D. H. Kang, K. W. Sung, and J. Zander, "High Capacity Indoor & Hotspot Wireless System in Shared Spectrum - A Techno-Economic Analysis," *IEEE Communications Magazine*, vol. 51, no. 12, pp. 102-109, December 2013.
   Number of citations: 3

6. E. Obregon, K. W. Sung, and J. Zander, "On the Feasibility of Indoor Broadband Secondary Access to 960-1215 MHz Aeronautical Spectrum," *Transactions on Emerging Telecommunications Technologies*, vol. 24, no.7-8, pp. 724-733, 2013.
   Number of citations: 6

7. **(*)** J. Zander, L. K. Rasmussen, K. W. Sung, P. Mähönen, M. Petrova, R. Jäntti, and J. Kronander, "On the Scalability of Cognitive Radio: Assessing the Commercial Viability of Secondary Spectrum Access," *IEEE Wireless Communications*, vol. 20, no. 2, pp. 28-35, April 2013.
   Number of citations: 12

8. M. Tercero, K. W. Sung, and J. Zander, "Exploiting Temporal Secondary Access Opportunities in Radar Spectrum," *Wireless Personal Communications*, vol. 72, no. 3, pp. 1663-1674, 2013.
   Number of citations: 13

9. **(*)** Y. Hwang, K. W. Sung, S.-L. Kim, and J. Zander, "Scenario Making for Assessment of Secondary Spectrum Access," *IEEE Wireless Communications*, vol. 19, no. 4, 2012.
   Number of citations: 11

10. J. Zander and K. W. Sung, "Opportunistic Secondary Spectrum Access: Opportunities and Limitations," *Radio Science Bulletin*, No. 340, March 2012, pp.29-33.
    Number of citations: 8

11. K. W. Sung, M. Tercero, and J. Zander, "Aggregate Interference in Secondary Access with Interference Protection," *IEEE Communications Letters*, vol. 15, no. 6, pp. 629-631, June, 2011 (*).
    Number of citations: **22 (five most cited papers)**

12. K. W. Sung, S.-L. Kim, and J. Zander, "Temporal Spectrum Sharing based on Primary User Activity Prediction," *IEEE Transactions on Wireless Communications*, vol. 9, no. 12, pp. 3848-3855, Dec. 2010.
    Number of citations: **40 (five most cited papers)**

13. **(*)** K. W. Sung, H. Haas, and S. McLaughlin, "A Semianalytical PDF of Downlink SINR for Femtocell Networks," *EURASIP Journal on Wireless Communications and Networking*, vol. 2010, Article ID 256370, 9 pages, doi:10.1155/2010/256370, 2010.
    Number of citations: **35 (five most cited papers)**

14. K. W. Sung and C. Y. Lee, "Distributed Timeslot Allocation with Crossed Slots in CDMA-TDD Systems," *Wireless Communications and Mobile Computing*, vol. 10, no. 3, pp. 337–348, Mar. 2010.
    Number of citations: 2

15. A. Mudesir, M. Bode, K. W. Sung, and H. Haas, "Analytical SIR for Self-Organizing Wireless Networks," *EURASIP Journal on Wireless Communications and Networking*, vol. 2009, Article ID 912018, 8 pages, doi:10.1155/2009/912018, 2009.
    Number of citations: 4

16. K. W. Sung, C. Y. Lee, K. H. Yim, and A. Gravrand, "Downlink Capacity Analysis of Collaborative Crossed Timeslots in CDMA TDD Systems," *Wireless Personal Communications*, vol. 50, no. 4, pp. 469–481, 2009.
    Number of citations: 0

Peer-reviewed conference contributions

17. **(*)** S. Shalmashi, E. Björnson, M. Kountouris, K. W. Sung, and M. Debbah, "Energy Efficiency and Sum Rate when Massive MIMO meets Device-to-Device Communication," to be presented at *IEEE ICC Workshop*, London, 8th June 2015.
    Number of citations: 0

18. Y. Yang and K. W. Sung, "Tradeoff between Spectrum and Densification for Achieving Target User Throughput," to be presented at *IEEE VTC Spring*, Glasgow, Scotland, May 11-14 2015.
    Number of citations: 0

19. H. Celik and K. W. Sung, "On the Feasibility of Blind Dynamic TDD in Ultra-Dense Wireless Networks," to be presented at *IEEE VTC Spring Workshop (MWC2020)*, Glasgow, Scotland, May 11-14 2015.
    Number of citations: 0

20. L. Shi and K. W. Sung, "Spectrum Requirement for Vehicle-to-Vehicle Communication for Traffic Safety," in *Proc. IEEE VTC Spring*, Seoul, Korea, May 18-21 2014.
    Number of citations: 1

21. A. Ozyagci, K. W. Sung, and J. Zander, "Association and deployment considerations in dense wireless LANs," in *Proc. IEEE VTC Spring*, Seoul, Korea, May 18-21 2014.
    Number of citations: 1

22. L. Shi, K. W. Sung, and J. Zander, "Spectrum Requirement for Cellular TV distribution in UHF Band from Urban to Rural Environment," in *Proc. IEEE DySPAN*, McLean, VA, USA, Apr. 1-4 2014. [Best Poster Award]
    Number of citations: 1

23. E. Obregon, K. W. Sung, and J. Zander, "On the Sharing Opportunities of Ultra-Dense Networks in the Radar Bands," in *Proc. IEEE DySPAN*, McLean, VA, USA, Apr. 1-4 2014.
    Number of citations: 1

24. A. Ozyagci, K. W. Sung, and J. Zander, "Effect of propagation environment on area throughput of dense WLAN deployments," in *Proc. 9th BWA Workshop in conjuction with IEEE GLOBECOM*, Atlanta, USA, Dec. 9, 2013.
    Number of citations: 3

25. C. Dahlberg, Z. Liu, A. Pradini, and K. W. Sung, "A Techno-Economic Framework of Spectrum Combining for Indoor Capacity Provisioning," in *Proc. IEEE PIMRC*, London, UK, Sep. 8-11, 2013.
    Number of citations: 1

26. D. H. Kang, K. W. Sung, and J. Zander, "Attainable User Throughput by Dense Wi-Fi Deployment at 5 GHz," in *Proc. IEEE PIMRC*, London, UK, Sep. 8-11, 2013.
    Number of citations: 1

27. E. Obregon, K. W. Sung, and J. Zander, "Availability Assessment of Secondary Usage in Aeronautical Spectrum," in *Proc. IEEE WCNC*, Shanghai, China, Apr. 7-10, 2013.
    Number of citations: 3

28. S. Tombaz, K. W. Sung, and J. Zander, "Impact of Densification on Energy Efficiency in Wireless Access Networks," in *Proc. 8th BWA Workshop in conjuction with IEEE GLOBECOM*, Anaheim, USA, Dec. 3 2012.
    Number of citations: 8

29. D. H. Kang, K. W. Sung, and J. Zander, "Is Multicell Interference Coordination Worthwhile in Indoor Wireless Broadband Systems?," in *Proc. IEEE GLOBECOM*, Anaheim, USA, Dec. 3-7 2012.
    Number of citations: 9

30. L. Shi, K. W. Sung, and J. Zander, "'Secondary Spectrum Access in TV-Bands with Combined Co-Channel and Adjacent Channel Interference Constraints," in *Proc. IEEE DySPAN*, Bellevue, USA Oct. 16-19 2012.
    Number of citations: 10

31. S. Tombaz, K. W. Sung, and J. Zander, "Energy and Throughput Tradeoff in Temporal Spectrum Sharing," in *Proc. CROWNCOM*, Stockholm, Sweden, Jun. 18-20 2012.
    Number of citations: 2

32. L. Shi, K. W. Sung, and J. Zander, "Controlling Aggregate Interference under Adjacent Channel Interference Constraint in TV White Space," in *Proc. CROWNCOM*, Stockholm, Sweden, Jun. 18-20 2012.
    Number of citations: 10

33. L. Shi, K. W. Sung, and J. Zander, "On the Permissible Transmit Power for Secondary User in TV White Spaces," in *Proc. CROWNCOM*, Stockholm, Sweden, Jun. 18-20 2012.
    Number of citations: 4

34. D. H. Kang, K. W. Sung, and J. Zander, "Operator Competition with Asymmetric Strategies in Shared Spectrum," in *Proc. IEEE WCNC*, Paris, France, Apr. 1-4 2012.
    Number of citations: 3

35. M. Tercero, K. W. Sung, and J. Zander, “Temporal Secondary Access Opportunities for WLAN in Radar Bands,” in *Proc. WPMC*, Brest, France, Oct. 3-7 2011.
    Number of citations: 9

36. D. H. Kang, K. W. Sung, and J. Zander, “Cost and Feasibility Analysis of Self-deployed Cellular Network,” in *Proc. IEEE PIMRC*, Toronto, Canada, Sep. 11-14 2011.
    Number of citations: 4

37. D. H. Kang, K. W. Sung, and J. Zander, “Cooperation and Competition between Wireless Networks in Shared Spectrum,” in *Proc. IEEE PIMRC*, Toronto, Canada, Sep. 11-14 2011.
    Number of citations: 11

38. M. Tercero, K. W. Sung, and J. Zander, “Aggregate Interference from Secondary Users with Heterogeneous Density,” in *Proc. IEEE PIMRC*, Toronto, Canada, Sep. 11-14 2011.
    Number of citations: 9

39. J. Zander and K. W. Sung, “Opportunistic Secondary Spectrum Access: opportunities and limitations,” in Proc. *The XXX General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS 2011)*, Istanbul, Turkey, Aug. 13-20 2011. [invited paper]
    Number of citations: 8

40. K. W. Sung and J. Zander, “Coordination of Clusters for Inter-cell Scheduling,” in Proc. *IEEE VTC Spring*, Budapest, Hungary, May 15-18 2011.
    Number of citations: 3

41. K. W. Sung and J. Zander, "Aeronautical Communication Systems as Potential Primary Users in Secondary Spectrum Access," in *Proc. 10th Scandinavian Workshop on Wireless Ad-hoc Networks (ADHOC ´11)*, Stockholm, Sweden, May 10-11 2011.
    Number of citations: 2

42. K. W. Sung, E. Obregon, and J. Zander, "On the Requirements of Secondary Access to 960-1215 MHz Aeronautical Spectrum," in *Proc. IEEE DySPAN*, Aachen, Germany, May 3-6 2011.
    Number of citations: **20 (five most cited papers)**

43. M. Tercero, K. W. Sung, and J. Zander, “Impact of Aggregate Interference on Meteorological Radar from Secondary Users,” in *Proc. IEEE WCNC*, Cancun, Mexico, Mar. 28-31 2011.
    Number of citations: 13

44. K. W. Sung, L. Shi, and J. Zander, “Coexistence of LTE Femtocells with GSM Cellular Network,” in *Proc. IEEE PIMRC*, Istanbul, Turkey, Sep. 26-29 2010.
    Number of citations: 8

45. J. Zander, J. Kronander, A. Achtzehn, M. Nekovee, K. W. Sung, and S.-L. Kim, “QUASAR Scenarios for White Space Assessments and Exploitation,” in *Proc. EMC Europe 2010*, Wroclaw, Poland, Sep. 13-16 2010. [invited paper]
    Number of citations: **16 (five most cited papers)**

Registered patents

46. K. W. Sung, "Method and apparatus for scanning signals of neighboring base station in broadband wireless communication system," patent of Samsung Electronics, registered in USA, US patent, 8837378, Sep 2014.

47. K. W. Sung and S. Y. Oh, "Apparatus and Method for Preamble Pseudo Noise Code Allocation in Broadband Wireless Communication System," patent of Samsung Electronics, registered in USA, US patent, 8189520, May 2012.

48. K. W. Sung, C. Y. Lee, S. Y. Ham, H. D. Kim, and S. H. Oh, "Apparatus and Method for Allocating Segments in Broadband Wireless communication System," patent of Samsung Electronics and KAIST, registered in USA, US patent 8160597, Apr. 2012.

49. K. W. Sung, C. Y. Lee, H. D. Kim, and S. H. Oh, “Apparatus and Method for Reallocating Segments in Broadband Wireless Communication System,” patent of Samsung Electronics and KAIST, registered in USA, US patent 8041357, Oct. 2011.

50. K. W. Sung, C. Y. Lee, S. Y. Ham, H. D. Kim, and S. H. Oh, “Apparatus and Method for IDcell Allocation in a Broadband Wireless Communication System,” patent of Samsung Electronics and KAIST, registered in USA, US patent 7945268, May 2011.

51. K. W. Sung, S. Y. Oh, “Apparatus and Method for Preamble Pseudo Noise Code Allocation in Broadband Wireless Communication System,” patent of Samsung Electronics, registered in Korea, 1010179700000, Feb. 2011.

52. K. W. Sung, “Method and Apparatus for Scanning Signal of Neighboring Base Station in Broadband Wireless Communication System,” patent of Samsung Electronics, registered in Korea, 1010120070000, Jan. 2011.

53. K. W. Sung, “Apparatus and Method for Operatting of Broadcasting Message in Broadband Wireless Communication System,” patent of Samsung Electronics, registered in Korea, 1009806480000, Sep. 2010.

54. K. W. Sung, C. Y. Lee, S. Y. Ham, H. D. Kim, and S. H. Oh, “Apparatus and Method for IDcell Allocation in Broadband Wireless Communication System,” patent of Samsung Electronics and KAIST, registered in Korea, 1009593300000, May 2010.

55. K. W. Sung, C. Y. Lee, S. Y. Ham, H. D. Kim, and S. H. Oh, “Apparatus and Method for Allocating Segments in Broadband Wireless Communication System,” patent of Samsung Electronics and KAIST, registered in Korea, 1009593310000, May 2010.

56. K. W. Sung, C. Y. Lee, H. D. Kim, and S. H. Oh, “Apparatus and Method for Re-Allocating Segments in Broadband Wireless Communication System,” patent of Samsung Electronics and KAIST, registered in Korea, 1009590390000, May 2010.

Publications 2007-2014 Jens Zander

Google Scholar

	Peer-reviewed original articles	
	Title	**Citations**
1	L Shi, K W Sung, J. Zander, "CellTV - On the Benefit of TV Distribution Over Cellular Networks: A Case Study", IEEE Trans Broadcasting, vol 6 Issue 1, 2014	7
2	S Tombaz, K W Sung, J. Zander,"On Metrics and Models for Energy Efficient Design of Wireless Access Networks", IEEE Wireless Communications Letters 08/2014	
3	S Tombaz, K W Sung, J. Zander,"Energy Efficient Network Deployment with Cell DTX", IEEE Communications Letters, vol 18, Issue 6, 2014	1
4	D H Kang, K W Sung, J. Zander, "High Capacity Indoor and Hotspot Wireless Systems in Shared Spectrum: A Techno-Economic Analysis", IEEE Communications Magazine, December 2013	3
5	E. Obregon, K W Sung, J. Zander, On the Feasibility of Indoor Broadband Secondary Access to the 960-1215 MHz Aeronautical Spectrum, Transactions on Emerging Telecommunications Technologies, ISSN 2161-3915, 2013	6
6	J.Zander, et.al.,"On the Scalability of Cognitive Radio: Assessing The Commercial Viability of Secondary Spectrum Access", IEEE Wireless Communcations, April 2013	12
7	J. Zander, P. Mähönen, "Riding the Data Tsunami in the Cloud - Myths and Challenges in Future Wireless Access", IEEE Communications Magazine, March 2013	39
8	¨M. Tercero, K. W. Sung, and J. Zander, "Exploiting Temporal Secondary Access Opportunities in Radar Spectrum", Wireless Personal Communications, March 2013	13
9	Youngju Hwang, Seong-Lyun Kim, Ki Won Sung, Jens Zander, "Scenario Making for Assessment of Secondary Spectrum Access", IEEE Wireless Communications, Vol. 19, no. 4, August 2012	11
10	J. Zander and K. W. Sung, ""Opportunistic Secondary Spectrum Access -opportunities and limitations", URSI Radio Science Bulletin, No 340, March 2012, p 29-33.	
11	S. Tombaz, A. Västberg, J. Zander, Energy- and Cost-Efficient Ultra-High-Capacity Wireless Access , (Invited Article), IEEE Wireless Communications, October 2011.	63
12	K. W. Sung, M. Tercero, and J. Zander, “Aggregate Interference in Secondary Access with Interference Protection,” IEEE Communications Letters, vol. 15, no. 6, pp. 629-631, June 2011.	22
13	B. Timus, P. Soldati, D W Kim, J Zander, "Cross-Layer Resource Allocation Model for Cellular-Relaying Network Performance Evaluation", IEEE Trans Veh Tech, July 2011	9
14	Mehdi Rasti, Ahmad R. Sharafat, Jens Zander, "Pareto and Energy-Efficient Distributed Power Control With Feasibility Check in Wireless Networks", IEEE Transactions on Information Theory, Jan 2011	20
15	K. W. Sung, S.-L. Kim, and J. Zander, "Temporal Spectrum Sharing Based on Primary User Activity Prediction ", IEEE Transactions on Wireless Communications, Dec 2010.	40
16	Y.-K. Song, D. Kim, and J. Zander, "Pilot power adjustment for saving transmit power in pilot channel assisted DS-CDMA mobile systems", IEEE Transactions on Wireless Communications, vol. 9, no. 2, 488-493, 2010.	6
17	Hultell, J, Ileri, O, Zander J, "Selfish Users in Energy Constrained ALOHA Systems with Power Capture", Wireless Information Networks, WINET, Sept 2010.	3
18	Rasti, M., Sharafat, A.R., and Zander, J., "A Distributed Dynamic Target-SIR-Tracking Power Control Algorithm for Wireless Cellular Networks", IEEE Transactions on Vehicular Technology, vol. 59, no. 2, 906-916, 2010.	10
19	Stabellini L, . Zander J, "Energy Efficient Detection of Intermittent Interference in Wireless Sensor Networks", International Journal on Sensor Networks, IJSNET, Vol 8 No 1/2010	23
20	Tercero, M González P, Ileri O, Zander, J "Distributed Spectrum Access with Energy Constraint for Heterogeneous Channels". IEE Proceedings-I, June 2010	
21	E.-H. Shin, D. Kim, and J. Zander, "Impact of open-loop power controlled feedback on multiuser capacity in Rayleigh fading channels", IEEE Communications Letters, vol. 13, no. 12, 932-934, 2009.	
22	Klas Johansson, Anders Furuskär, Jens Zander, "Modelling the cost of heterogeneous wireless access networks", Int. J. Mobile Network Design and Innovation, Special Issue on Planning and Optimisation of Wireless Networks, May 2007	27
23	David Gomez-Barquero, Aurelian Bria, Jens Zander, Narcis CardonaAffordable Mobile TV Services in Hybrid Cellular and DVB-H Systems", IEEE Network, April 2007 .	37

	Peer-reviewed conference contributions	
	Title	**Citations**
1	J Park, SL Kim, J Zander, "Asymptotic Behavior of Ultra-Dense Cellular Networks and Its Economic Impact", IEEE Global Communications Conference (GLOBECOM) 2014, Austin, TX, USA, Dec 2014	4
2	A Özyagci, K W Sung, J Zander," Association and deployment considerations in dense wireless LANs", 79th IEEE Veh Tech Conference, VTC-Spring, Seoul, Korea, May 2014.	1
3	S Tombaz, P Monti, F Farias, M Fiorani, L Wosinska, J. Zander, "Is Backhaul Becoming a Bottleneck for Green Wireless Access Networks?", IEEE ICC 2014, Sydney, June 2014	9
4	E Obregon, K W Sung, J. Zander, "On the Sharing Opportunities for Ultra-Dense Networks in the Radar Bands", IEEE DySPAN 2014, McLean, VA, April 2014	1
5	L Shi, K W Sung, J. Zander, "Spectrum Requirement for Cellular TV distribution in UHF Band from Urban to Rural Environment", IEEE DySPAN 2014, McLean, VA, April 2014	1
6	A Özyagci, K W Sung, J Zander, Effect of propagation environment on area throughput of dense WLAN deployments, 9th IEEE Broadband wireless access workshop (BWA 2013) (Globecom 2014), Atlanta, GA, December 2013	3
7	S-W. Han, Y. Kim, J. Cioffi, V.C.M. Leung, J. Zander, An asynchronous distributed power allocation scheme for sum-rate maximization on cognitive GMACs, 6th Joint IFIP Wireless and Mobile Networking Conference, WMNC 2013, Dubai UAE 2013	
8	S-W. Han, Y. Kim, J. Cioffi, J. Zander, V.C.M. Leung, Distributed power allocation for cooperative access in cognitive radios to guarantee QoS for cell edge primary users, 6th Joint IFIP Wireless and Mobile Networking Conference, WMNC 2013, Dubai UAE 2013	2
9	D H Kang, K W Sung, J. Zander, The Validity of Unlicensed Spectrum for Future Local High Capacity Services, 24th European Regional Conference of the International Telecommunications Society, Florence, Italy, 20 - 23 October 2013	
10	E. Obregon, K W Sung, J. Zander, Secondary Access to the Radar Spectrum Bands: Regulatory and Business Implications, 24th European Regional Conference of the International Telecommunications Society, Florence, Italy, 20 - 23 October 2013	
11	D H Kang, K W Sung, J. Zander, Attainable User Throughput by Dense Wi-Fi Deployment at 5 GHz, IEEE PIMRC 2013, London Sept 2013.	1
12	S. Tombaz, Z. Zheng, J.Zander, Energy Efficiency Assessment of Wireless AccessNetworks Utilizing Indoor Base Stations, IEEE PIMRC 2013, London, Sept 2013	4
13	Y Yang, L Shi, J Zander, "On the Capacity of Wi-Fi System in TV White Space with Aggregate Interference Constraint" , 2013 8th International Conference on Cognitive Radio Oriented Wireless Networks and Communications, CROWNCOM 2013	5
14	E Obregon, K W Sung, J. Zander, "Availability Assessment of Secondary Usage in Aeronautical Spectrum", IEEE WCNC 2013, Shanghai, China, April 2013	3
15	S. Tombaz, K. W. Sung, and J. Zander, "'Impact of Densification on Energy Efficiency in Wireless Access Networks", 8th BWA Workshop in conjuction with IEEE GLOBECOM, Anaheim, USA, Dec. 3 2012.	8
16	D. H. Kang, K. W. Sung, and J. Zander, "Is Multicell Interference Coordination Worthwhile in Indoor Wireless Broadband Systems?," IEEE GLOBECOM, Anaheim, USA, Dec. 3-7 2012.	9
17	L. Shi, K. W. Sung, and J. Zander, "'Secondary Spectrum Access in TV-Bands with Combined Co-Channel and Adjacent Channel Interference Constraints," IEEE DySPAN, Bellevue, USA Oct. 16-19 2012.	10
18	D. H. Kang, Z. Li, Q. Luo, F. Fathali, A. Vizcaino, and J. Zander, “Impact of Asymmetric Transmission Power on Operator Competition in Shared Spectrum", in Proc. IEEE Swedish Communication Technologies Workshop (SWE-CTW), Lund, Sweden, Oct. 2012.	
19	Monti, P, Tombaz, S., Wosinska, L., Zander, J., "Mobile backhaul in heterogeneous network deployments: Technology options and power consumption, 14th Int Conference on Transparent Optical Networks (ICTON), Conventry, UK, July 2012	28
20	Lei Shi, Ki Won Sung, Jens Zander, "Controlling Aggregate Interference under Adjacent Channel Interference Constraint in TV White Space", Crowncom 2012, Stockholm, Sweden, June 2012	10
21	Lei Shi, Ki Won Sung, Jens Zander, "On the Permissible Transmit Power for Secondary User in TV White Spaces", Crowncom 2012, Stockholm, Sweden, June 2012	4
22	Sibel Tombaz, Ki Won Sung, Jens Zander, "Energy and Throughput Tradeoff in Temporal Spectrum Sharing", Crowncom 2012, Stockholm, Sweden, June 2012	2
23	Kang, Du Ho; Sung, Ki Won; Zander, Jens, "Operator competition with asymmetric strategies in shared spectrum", IEEE Wireless Communications and Networking Conference (WCNC), Paris, France, April 2012	3
24	S. Tombaz, P. Monti, K. Wang, A. Vastberg, M. Forzati, J Zander, "Impact of Backhauling Power Consumption on the Deployment of Heterogeneous Mobile Networks", IEEE Globecom' 11, Houston, TX, Dec 2011	49

	Peer-reviewed conference contributions	
	Title	**Citations**
25	M. Tercero, K. W. Sung and J. Zander, "Temporal secondary access opportunities for WLAN in radar bands", Wireless Personal Multimedia Communications (WPMC), Brest France, Oct 2011	9
26	Gonzalez-Sanchez, P., Khamit, S M., Zander, J, "Competitive pricing with demand heterogeneity in open wireless access market", 2011 3rd International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT), Budapest October 2011	2
27	D. H. Kang, K. W. Sung, and J. Zander, "Cost and Feasibility Analysis of Self-deployed Cellular Network ," IEEE PIMRC, Toronto, Sep. 2011.	4
28	D. H. Kang, K. W. Sung, and J. Zander, "Cooperation and Competition between Wireless Networks in Shared Spectrum ," IEEE PIMRC, Toronto, Sep. 2011.	
29	M. Tercero, K. W. Sung, and J. Zander, "Aggregate Interference from Secondary Users with Heterogeneous Density," in Proc. IEEE PIMRC 2011. Toronto, September 2011	9
30	S. Tombaz, M. Usman, and J. Zander, " Energy Efficiency Improvements Through Heterogeneous Networks in Diverse Traffic Distribution Scenarios," 6th International ICST Conference on Communications and Networking in China(Chinacom11), Harbin, China, August 2011.	30
31	J. Zander and K. W. Sung, ""Opportunistic Secondary Spectrum Access -opportunities and limitations", (Invited paper) URSI General Assembly 2011, Istanbul, Turkey, August 2011.	
32	K. W. Sung and J. Zander, "Coordination of Clusters for Inter-cell Scheduling ," IEEE VTC 2011 Spring, Budapest, Hungary, May 2011	3
33	Obregon,E. and Shi,L. Ferrer,J. and Zander,J., "A Model for Aggregate Adjacent Channel Interference in TV White Space", Vehicular Technology Conference (VTC 2011-Spring), 2011 IEEE 73rd , 15-18 May 2011	18
34	K. W. Sung and J. Zander, "Aeronautical Communication Systems as Potential Primary Users in Secondary Spectrum Access ," 10th Scandinavian Workshop on Wireless Ad-hoc Networks (ADHOC 11), Stockholm, Sweden, May 2011.	
35	K. W. Sung, E. Obregon, and J. Zander, "On the Requirements of Secondary Access to 960-1215 MHz Aeronautical Spectrum ," IEEE DySPAN 2011, Aachen, Germany, May 2011.	20
36	Khamit, S M, Zander, J, "Competitive Spectrum Allocation in Heterogeneous Coverage Areas", 11th European Wireless Conference 2011, April 27-29, 2011, Vienna, Austria	3
37	Pamela González Sánchez, Jens Zander, "Deployment Strategies in Competitive Wireless Access Networks", COCORA 2011, Budapest, April 2011 [Received best paper award]	1
38	M. Tercero, K. W. Sung, and J. Zander, "Impact of Aggregate Interference on Meteorological Radar from Secondary Users", IEEE WCNC 2011, Mar. 28-31, Cancun, Mexico	13
39	Sung K W, Shi L, Zander J, "Coexistence of LTE Femtocells with GSM Cellular Network",IEEE Personal, Indoor and Mobile Radio Conference (PIMRC), September 2010	8
40	Kronander, J, Nekovee M, Sung K W, Zander J, Kim, S-L, Achtzehn, A, "QUASAR scenarios for white space assessments and exploitation", URSI EMC conference, Wroclaw, Poland, September 2010	7
41	P. Lungaro, Z. Segall and J. Zander, "ActiveCast - a network and user aware mobile content delivery system", 2nd International Conference onUbiquitous and Future Networks (ICUFN), Jeju Island, South Korea, June 2010	10
42	P. Lungaro, Z. Segall and J. Zander, "Context-aware RRM for Opportunistic Content Delivery in Cellular Networks", in Proceedings of the third international conference on Communication Theory, Reliability and Quality of service (CTRQ), Athens, June 2010. [**Received Best Paper Award**]	12
43	Obregon E, Zander J, "Short range white space utilization in broadcast systems for indoor environments", DySPAN 2010, April 2010,	20
44	Ozyagci A, Ileri O, Zander J "Distributed Multichannel Random Access Networks with Selfish Users", Crowncom 2010, June 2010,	3
45	Ozyagci A, Zander J., "Distributed Dynamic Spectrum Access in Multichannel Random Access Networks with Selfish Users", WNCN 2010, Sydney, April 18-20, 2010	9
46	Lungaro, P., Segall, Z., and Zander, J., ContextShift: A Model for Efficient Delivery of Content in Mobile Networks. WNCN 2010, Sydney, April 18-20, 2010	10
47	Lungaro, P., Segall, Z., and Zander, J., "Predictive and Context-Aware Multimedia Content Delivery for Future Cellular Networks", IEEE VTC 2010 Spring, Taipei, 2010.	19
48	Ileri, O, Zander J, "Broker Coordination in Demand Responsive DSA Settings", ICC 2009, June 2009,	1
49	Somarriba, O. and Zander, J., "Robust STDMA scheduling in Multi-hop Wireless Networks for single-node position perturbations", IEEE PIMRC, Tokyo, 2009.	
50	Zander, J, "Can we Find (and Use) Spectrum Holes? - Spectrum Sensing and Spatial Reuse Opportunities in Cognitive Radio Systems", (Invited paper), VTC 2009, Barcelona, April 2009	6
51	Timus, B., Soldati, P., and Zander, J., "Implications of Fairness Criteria on the Techno-Economic Viability of Relaying Networks", IEEE VTC Spring 2009, Barcelona, 2009	10

	Peer-reviewed conference contributions	
	Title	**Citations**
52	Timus, B. and Zander, J., "Incremental Deployment with Self-Backhauling Base Stations in Urban Environment", IEEE ICC Workshops, 2009	4
53	Mehdi Rasti, Ahmad R. Sharafat, Jens Zander, A Distributed and Efficient Power Control Algorithm for Wireless Networks, IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, September 2008	6
54	Obregon E, Shi l, Ferrer J, Zander J "Experimental Verification of Indoor TV White Space Opportunity Prediction Model", Proceedings CrownCom, June 2010	17
55	Stabellini, Luca; Zander, Jens, "Interference Aware Self-Organization for Wireless Sensor Networks: a Reinforcement Learning Approach", IEEE International Conference on Automation Science and Engineering Arlington, VA, AUG 23-26, 2008	6
56	Västberg, A, Johansson,K, Zander, J, Nilson, M, ""Green Radio" in Heterogeneous Wireless Wideband Networks", RadioVetenskap och Kommunikation (RVK). Växjö, SWE. 9 - 11 june 2008	
57	Mehdi Rasti, Ahmad R. Sharafat, Jens Zander, Improved Distributed Power Control Algorithms with Gradual Removal in Wireless Networks, European Wireless 2008 (EW2008) , June 2008	5
58	Sanchez, Marvin; Zander, Jens; Hagerman, Bo, "A reuse-greedy algorithm for STDMA multihop networks with advanced antennas & rate control", 3rd International Symposium on Wireless Pervasive Computing Location: Santorini, Greece Date: May 07-09, 2008	1
59	Marvin Sanchez, Jens Zander, Bo Hagerman, "On the Performance of Power and Rate Control in STDMA Multihop Networks With Advanced Antennas", 7th International Conference on Networking (ICN 2008), Cancun, MEXICO, April 13-18, 2008	4
60	Marvin Sanchez Bo Hagerman Jens Zander, Radio Resource Allocation in Spatial TDMA Multihop Networks with Advanced Antennas, Wireless Rural and Emergency Communications WRECOM 2007 , October 2007	5
61	Oscar Sommariba, Jens Zander, "Evaluation of Heuristic Strategies for Scheduling, and Power Allocation in STDMA Wireless Networks" , International Symposium on Signals, Systems, and Electronics, August 2007	1
62	Klas Johansson, Anders Furuskär, Jens Zander, "Cost Efficient Deployment of Heterogeneous Wireless Access Networks", Proceedings IEEE Vehicular Technology Conference, Spring.April 2007 - Received best paper award	16
	Books and book chapters	
	Title	**Citations**
	Johan Hultell Jens Zander, Jan Markendahl, Competition and Cooperation in Wireless Multi-Access Networks, Book chapter in “Cognitive Wireless Networks “ , September 2007	2
	Niebert N Schieder A Zander J Hancock R (ed.s), "Ambient Networks - cooperative mobile networking for the wireless world", Wiley, April 2007	49

CV

Name: Ki Won Sung	**Doctorial degree:** 2005-02-18
Birthdate: 19760330	**Academic title:** Doktor
Gender: Male	**Employer:** Kungliga Tekniska högskolan

Research education

Dissertation title (swe)

Dissertation title (en)

Resource Allocation and Call Admission Control for Mobile Communication systems

Organisation	Unit	Supervisor
Korea Advanced Institute of Science and Technology, Korea , South Not Sweden - Higher Education institutes	Industrial Engineering	Chae Young Lee

Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
20203. Kommunikationssystem		2005-02-18

CV

Name: Jens Zander	**Doctorial degree:** 1985-01-28
Birthdate: 19550706	**Academic title:** Professor
Gender: Male	**Employer:** No current employer

Research education

Dissertation title (swe)

Dissertation title (en)

Distributed Access Algorithms for a Class of Random Access Channel

Organisation	Unit	Supervisor
Linköpings universitet, Sweden Sweden - Higher education Institutes	Institutionen för systemteknik (ISY)	Thomas Ericson

Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
20203. Kommunikationssystem		1985-01-28

Publications

Name: Ki Won Sung	**Doctorial degree:** 2005-02-18
Birthdate: 19760330	**Academic title:** Doktor
Gender: Male	**Employer:** Kungliga Tekniska högskolan

Sung, Ki Won has not added any publications to the application.

Publications

Name: Jens Zander	**Doctorial degree:** 1985-01-28
Birthdate: 19550706	**Academic title:** Professor
Gender: Male	**Employer:** No current employer

Zander, Jens has not added any publications to the application.

Register

Terms and conditions

The application must be signed by the applicant as well as the authorised representative of the administrating organisation. The representative is normally the department head of the institution where the research is to be conducted, but may in some instances be e.g. the vice-chancellor. This is specified in the call for proposals.

The signature*from the applicant*confirms that:

- the information in the application is correct and according to the instructions form the Swedish Research Council
- any additional professional activities or commercial ties have been reported to the administrating organisation, and that no conflicts have arisen that would conflict with good research practice
- that the necessary permits and approvals are in place at the start of the project e.g. regarding ethical review.

The signature *from the administrating organisation* confirms that:

- the research, employment and equipment indicated will be accommodated in the institution during the time, and to the extent, described in the application
- the institution approves the cost-estimate in the application
- the research is conducted according to Swedish legislation.

The above-mentioned points must have been discussed between the parties before the representative of the administrating organisation approves and signs the application.

Project out lines are not signed by the administrating organisation. The administrating organisation only sign the application if the project outline is accepted for step two.

Applications with an organisation as applicant is automatically signed when the application is registered.