Application

2015-03-31

2015-04664 Edfors, Ove NT-14

Information about applicant

Name: Ove Edfors
Doctorial degree: 1996-11-14
Birthdate: 19660909
Academic title: Professor
Gender: Male
Employer: Lunds universitet
Administrating organisation: Lunds universitet
Project site: Elektro- och informationsteknik 107201

Information about application

Call name: Forskningsbidrag Stora utlysningen 2015 (Naturvetenskap och teknikvetenskap)
Type of grant: Projektbidrag
Focus: Fri
Subject area:

Project title (english): Wireless channel models with high spatial resolution
Project start: 2016-01-01
Project end: 2019-12-31
Review panel applied for: NT-14
Classification code: 20204. Telekommunikation, 20203. Kommunikationssystem
Keywords: Kanalmodeller, Stora antennarrayer, Massiv MIMO

Funds applied for

Year:	2016	2017	2018	2019
Amount:	1,310,634	1,418,572	1,308,559	1,345,626

Participants

Name: Fredrik Tufvesson
Doctorial degree: 2000-09-22
Birthdate: 19700314
Academic title: Professor
Gender: Male
Employer: Lunds universitet

Descriptive data

Project info

Project title (Swedish)*

Trådlösa kanalmodeller med hög spatiell upplösning

Project title (English)*

Wireless channel models with high spatial resolution

Abstract (English)*

We develop much needed channel models with high spatial resolution, suitable for evaluation of massive MIMO and other systems using large antenna arrays. Today there are no suitable channel models for the purpose, which slows down development of very promising and highly energy and spectrally efficient systems, such as massive MIMO. Reliable system evaluations can only be made using measured channels or over-the-air real-time testbeds, very expensive resources not available in most research environments. The team pursuing the research in this proposal has access to these resources and will make channel models for this class of systems available to the research community.

The developed models are based on the same concept as the well known COST 2100 model for traditional MIMO systems. The COST 2100 model will be modified, allowing the new models to correctly emulate channels experienced by massive MIMO systems. Long channel measurements and modelling traditions in Lund, together with large amounts of massive MIMO channel data available from several measurement campaigns, forms the basis for the project. Developed models will be verified against over-the-air real-time massive MIMO communication tests in the same environments as the original channel data was collected.

The project spans over four years and is divided into three overlapping work packages (WPs):
WP1: Channel measurements and analysis (2.5 yrs)
WP2: Channel model development (3 yrs)
WP3: Model validation (2.5 yrs)

The most important outcome of the project is channel simulation models for massive MIMO systems, based on our experience and developed using the world-unique equipment available in Lund. The models will be made available to the research community, allowing researchers to develop and perform realistic evaluations of massive MIMO systems without the need for very expensive channel sounders and/or over-the-air real-time test beds. The availability of these models will greatly accelerate the development of massive MIMO systems.

Popular scientific description (Swedish)*

Massiv MIMO är en ny paradigm inom trådlös kommunikation. Under ideala förhållanden och realistiska antaganden om systemets uppbyggnad kan man uppnå mer än tiofaldig ökning av datahastigheten, samtidigt som utstrålad effekt från basstationen kan miskas med något eller några hundratal gånger. Detta uppnås genom att använda ett massivt antal antenner på varje basstation -- många fler än antalet terminaler som är uppkopplade till den. Terminalerna kan, å andra sidan, fungera ungefär som i dag med endast en eller ett fåtal antenner. Denna metod föreslogs så sent som för fem år sedan av en forskare från Alcatel-Lucent Bell Laboratories i USA, Dr Tom Marzetta. I Lund har vi haft möjlighet att arbeta med massiv MIMO under hela denna tid och har skaffat oss stor erfarenhet i området. Särskilt vad gäller mätning och karaktärisering av de radiokanaler man upplever med massiva MIMO-system, samt utveckling av testsystem för att kunna köra och testa massiv MIMO i realtid under verkliga förhållanden. Dessa erfarenheter använder vi oss nu av för att utveckla simuleringsmodeller för de radiokanaler vi mätt upp. På detta sätt gör vi våra erfarenheter tillgängliga för andra forskare och kanalmodellerna kan användas i simuleringar för att testa och utveckla massiv MIMO utan att nehöva ha tillgång till den mycket dyra utrustning som krävs för att själv mäta kanalerna eller köra realtidstester i riktiga miljöer.

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 > 20204. Telekommunikation 2. Teknik > 202. Elektroteknik och elektronik > 20203. Kommunikationssystem

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

Keyword 1*

Kanalmodeller

Keyword 2*

Stora antennarrayer

Keyword 3*

Massiv MIMO

Keyword 4

Keyword 5

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*

Projektet är av rent teknisk natur och inbegriper inga direkta etiska spörsmål.

The project includes handling of personal data

No

The project includes animal experiments

No

Account of experiments on humans

No

Research plan

Research plan (Appendix A): Wireless channel models with high spatial resolution

Ove Edfors

1 Purpose and aims

Mobile data traffic is growing exponentially and the 3.2 ExaBytes/month in 2014 are expected to grow by a factor of eight in the period until 2020 [1]. Providing technology sustaining such a growth at reasonable cost is extremely important and a formidable challenge. Conceptually straightforward solutions include the use of more electromagnetic spectrum, at higher frequencies, and/or densification of existing networks, with more base stations per area unit. Both these solutions have their respective drawbacks, such as limited communication ranges and expensive electronics at high frequencies or huge investment needed to densify networks with many more base stations than today. For these reasons it is of great interest to explore other solutions, less conceptually straightforward but providing new means to support the rapid increase of mobile data traffic. Wireless communications is currently going through such a major paradigm change and one of the most important tools in the development of this technology is addressed in this proposal.

The new paradigm is to use massive numbers of antenna elements at base stations to perform very efficient spatial multiplex of many users in the same time/frequency resource. It was initiated some five years ago by Thomas L. Marzetta at Alacatel-Lucent Bell Labs [2] under the name large-scale antenna systems and is now mostly known as massive MIMO (multiple-in/multiple-out) [3].

A major obstacle in the development of this new technology is the lack of appropriate channel models. None of the conventional and widely used channel models incorporate the rich spatial properties needed to realistically evaluate this new class of systems through simulations and very few research groups in the world have the necessary equipment and experience to successfully develop such models. At Lund University we have everything required and in the proposed project we will develop new channel models suitable for simulation-based evaluation of wireless systems using physically large antenna arrays and heavily relying on spatial properties of propagation channels.

2 Survey of the field

As mentioned above, massive MIMO was introduced some five years ago by Thomas L. Marzetta [2]. Spatial multiplex of users has been done before, but with much fewer antenna elements exploiting only a small fraction of the spatial richness available in typical propagation environments. Using simple theoretical channel models, such as independent and identically distributed (IID) channel coefficients, it has been shown that massive MIMO has the potential to deliver orders-of-magnitude improvements in both spectral and energy efficiency [4].

Channel data from measurement campaigns, with large antenna arrays, give strong indications that a large fraction of the theoretically predicted gains can be harvested also in real propagation environments [5–7]. This has made massive MIMO one of the prime candidates for improving both fifth-generation (5G) mobile systems and wireless local-area networks (WLANs).

Theoretical analysis of massive MIMO performance under more realistic channel correlation assumptions, aiming at finding how many antenna elements are required to obtain a certain fraction of the asymptotic performance, as been done in e.g. [8]. While this type of analysis gives important insights into the properties of massive MIMO, numerical examples or simulation studies often resort to IID channels or theoretical constructions of channel correlation by, e.g., limiting the channel available rank [9]. The reason for this is that there are no channel models available today, where the specific characteristics of massive MIMO channels have been included.

The most promising class of models, giving tractable parameterizations of realistic scenarios, are the geometry-based stochastic channel models (GSCMs) where the model is based on geometrical properties mimicking a real propagation environment. One such family of models [10] is provided by the WINNER project and another [11] by the European Cooperation in Science and Technology (COST). These two models are both GSCMs, but differ in the details of how they approach the channel modeling (for details we refer the reader to [10, 11]). As a consequence of modeling the physical location of scatterers explicitly, the COST family of models provide a better foundation for introducing the specific effects observed when using physically large arrays, in e.g. massive MIMO, such as varying large-scale fading over the array, significant non-planar wave-fronts across the array, and three-dimensional environments. In this work we use the COST 2100 MIMO channel model [11] as a basis and work our way towards simulation models adapted to the requirements of massive MIMO system evaluations.

3 Project description

The project focus is realistic modeling of massive MIMO channels for time-division duplex (TDD) operation in the sub 6 GHz range of frequencies. While frequency-division duplex (FDD) operation of massive MIMO is possible in principle, its practicality is largely debated and, to the applicant's best knowledge, no such systems have been tested successfully. Channel models for FDD operation of massive MIMO, with appropriate correlation between up- and down-link channels at different carriers, is not in the scope of this proposal. Model parameters will be extracted for the frequency range below 6 GHz, but we expect the general modeling approach to be applicable at higher frequencies. Channel models beyond the 6 GHz frequency range are, however, not in the scope of this proposal.

Based on high-resolution massive MIMO channel measurements, we will develop a new class of channel models by extending the COST-family of MIMO models. In particular, we use the COST 2100 model [11] as a basis and increase its capability to accurately model channel variations encountered when using physically large antenna arrays with many elements. In more detail, this implies the following changes:

- Interaction between the near environment and a physically large array requires modeling of large-scale channel variations along, or across, the array.
- A physically large array, with many antenna elements, can resolve the propagation environment with higher accuracy than traditional arrays and the spatial granularity of the environment part of the model has to be increased (more clusters introduced).
- Two or three dimensional structures, such as rectangular and cylindrical, are beneficial when designing compact antenna arrays with many elements. This implies a need to model the environment in three dimensions, similar to models for full-dimension (FD) MIMO [12], where both azimuth and elevation properties of multipath components (MPCs) are included.

The entire modeling process can be summarized in three separate, but overlapping and highly interconnected, steps:

1. Aquire channel data and analyze channel behavior.
2. Based on experience from Step 1, adapt channel models accordingly and test their statistical properties against measured data.
3. Verify behavior of channel models from Step 2 by comparing massive MIMO simulations against real-time over-the-air communication tests.

For each of these, we form a project work package (WP).

3.1 Work packages

WP1 - Channel measurements and analysis: Channel measurements, using powerful channel sounding equipment, is one of the corner stones of the project. This is a monumental task, but fortunately large data collections appropriate for the project are already available from measurement campaigns preformed in other projects, such as MAMMOET [13] and ELLIIT [14]. Complementary measurements will be done as the analysis reveal that more, or different, data is needed to quantify necessary spatial channel properties. Channel data is analyzed using directional

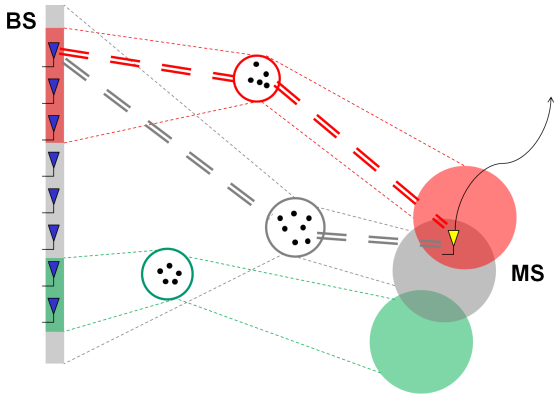

Figure 1: Initial extension of the COST 2100 model where cluster visibility regions are included on the base-station (BS) side, with appropriate large-scale fading properties (not shown explicitly) inside visibility regions. The original COST 2100 model only contains cluster visibility regions on the terminal/mobile station (MS) side, shown as colored disks.

methods where MPC clusters are tracked in the spatial dimension, along the lines of what is presented in [15]. In this context we need to work with physical clusters[1], where common clusters shared between links to different users can have a significant impact on the model's ability to correctly capture spatial orthogonality between users [16]. Statistical properties of direction (azimuth and elevation), distance, and strength of individual clusters, in combination with the total number of MPC clusters visible from each location across the array, will be estimated for a number of characteristic propagation scenarios. The scenarios will be selected with a focus on areas where conventional MIMO systems are known to have trouble to separate users spatially or provide enough capacity. These include, e.g., crowd scenarios (stadium, outdoor concert) and indoor coverage from an outdoor base station.

WP2 - Channel model development: As mentioned above, we will use the COST 2100 channel model as a structural basis for the new models developed in this project. Using statistical properties from WP1, for different propagation scenarios, appropriate modifications of the COST 2100 model will be proposed and simulation parameters for different scenarios established. The one-dimensional visibility regions proposed in [17], and illustrated in Fig. 1, will be extended to higher dimensions, making it possible to model channel variations over two and three dimensional antenna arrays. This is a non-trivial, but important, modeling step since it opens up for the use of more practical and compact massive arrays, such as rectangular and cylindrical ones. Implicit in this change is that the entire COST 2100 model will have to be upgraded to model a three-dimensional environment. While conceptually simple in a model of the COST 2100 type, this upgrade has to be done with great care and will consume a large portion of resources in WP2. Another important investigation that we will perform is the role of so called dense MPCs (DMCs) in massive MIMO. DMCs are typically seen as the part of the channel that cannot

[1] As opposed to parametric clusters.

readily be described by specular MPCs, but originating from the same objects/area as the specular MPCs. Hence, the DMCs constitute a non-white process with specific angular properties that may be efficient when it comes to making user signals spatially orthogonal.

Before new models are used in WP3 for validations against real-time communication tests, this WP will also perform simulation-based tests of the models. By model implementation and simulation in, e.g., MATLAB their behaviour will be compared against the channel data used to extract statistical properties and model parameters. These simulations will also reveal the dynamic properties of these channels, brought about by introducing user movements, and we can observe how spatial orthogonality between user channels develop over time. Unexpected deviations from the behavior observed in measured channels will be corrected accordingly.

Depending on the model validation outcome in WP3, additional changes of the modeling approach may be required.

WP3 - Model validation: Exploiting the fact that we have a massive MIMO testbed at hand, we will validate the models developed in WP2 against real massive MIMO communication. By performing real-time communication in the environments used as a basis for modeling, we can verify that the corresponding massive MIMO simulations result in performance and system behavior in accordance. This is especially important for validation of dynamic properties, since channel measurements from WP1, used in the modeling in WP2, only cover a fairly limited user mobility. With the testbed we can verify that they are correctly modeled over a much larger range of mobility. Any significant deviations and unexpected behavior will be fed back to the channel development work-package (WP2).

Initially, channel models will be verified against real propagation in terms of the performance of individual communication links and number of terminals spatially multiplexed in the same time/frequency resource. These tests will be done for the modeled environments/scenarios using different precoding/detection techniques, such as conjugate beamforming, zero-forcing and regularized zero-forcing, to ensure that the models behave well for a wide range of use.

An integrated part of this WP is also to evolve the validation process from the one proposed above, as new experiences and performance measures become available. In particular, we expect that the rapidly evolving precoding techniques and baseband processing strategies for massive MIMO to influence the validation process. Results and experiences will also bring about strong synergy effects between modeling activities in this project and development of massive MIMO technology in other projects in Lund.

3.2 Project execution

The project will be undertaken mainly by a doctoral student under leadership of the PI, and co-PI. After project completion the doctoral student is expected to defend a thesis on the project topic.

The project will be highly integrated with other related projects, such as the MAMMOET project [13] and the ongoing development of the massive MIMO real-

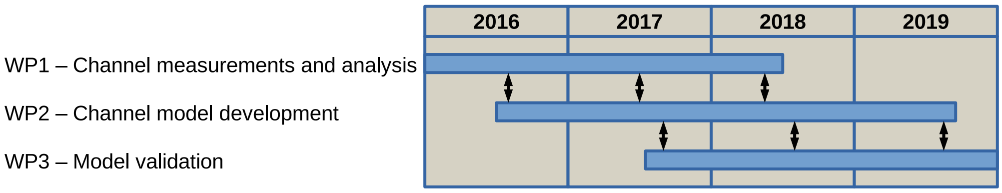

Figure 2: Work package time extensions and indicated interactions over the four project years.

time testbed [18]. Additional project resources in terms of staff and equipment for WP1 and WP3 will be made available through this cooperation. This creates strong synergy effects among projects using channel sounding and massive MIMO real-time testbed equipment, maximizing utilization of major hardware investments. Estimated WP time extensions and interactions are illustrated in Fig. 2.

4 Significance

A new class of channel models, with much more detailed modeling of spatial channel properties, will be made available. This class of models makes it possible to accelerate development of wireless communication systems relying on high-resolution spatial properties of propagation channels, such as massive MIMO. This is achieved since realistic system evaluations can be done in simulations without access to expensive channel sounding equipment or real-time over-the-air testbeds.

In addition, we foresee secondary effects in terms of greater understanding of spatial processing, parameter tracking and general statistical modeling for a range of applications where high-resolution spatial information processing is at the core, well beyond the limits of wireless communication at radio frequencies. One example would be acoustic models for arrays of microphones or speakers operating in "acoustic multipath" environments, sensing or controlling sound at specific spatial locations.

5 Preliminary results

The team in Lund has performed extensive massive MIMO measurement campaigns and used these measurements both as a tool to directly assess achievable sum-rates in real propagation environments [7, 19, 20] and to investigate in what way observed properties of MIMO channels are different from those assumed in existing channel models [21, 22]. An illstration of the findings is shown in Fig. 3, where we can see that the angular power spectrum changes significantly with position along the array, with signal components showing variations both in angle of arrival and strength (appearing and disappearing). None of the existing MIMO channel models can capture these important effects, which have potential to greatly influence both system performance [7] and how we should design and use antenna arrays efficiently [20, 22, 23].

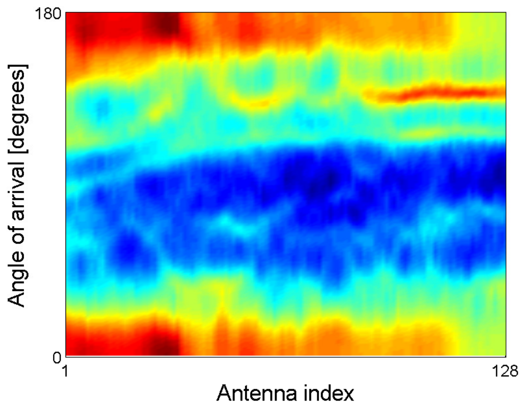

Figure 3: Measured angular power spectrum along a 7.3 meter linear array with 128 $\lambda/2$-spaced antenna elements (virtual array) at 2.6 GHz carrier, with five closely spaced user terminals in line-of-sight conditions.

Based on these investigations, we have made a first attempt at extending the COST 2100 channel model to include some observed properties [17]. This extension only covers linear/one-dimensional arrays in one type of base-station environment and it will be extended in this project, along the lines described in Section 3.

6 Equipment

The group undertaking this project has two world-unique, and for WP1 and WP3 of this project essential, pieces of equipment:

- **Channel Sounder:** The RUSK Lund channel sounder is one of the most powerful sounders available for MIMO measurements. It consists of a transmitter and a receiver, each capable of handling up to 128 antenna element arrays, with oven controlled rubidium clocks for untethered operation. Dynamic channel measurements can be performed over 240 MHz bandwidth with calibrated antenna arrays. This system allows us to collect channel data for massive MIMO systems with up to nine simultaneous users and perform detailed delay and directional (azimuth/elevation) analysis of propagation environments.
- **Massive MIMO testbed:** The Lund University Massive MIMO (LuMaMi) testbed [18] is a highly flexible 100-antenna programmable testbed capable of real-time TDD-based communication with spatial multiplexing of ten simultaneous users. In its current setting it is operating with 3GPP LTE-like parameters, such as 20 MHz system bandwidth using 1200 OFDM subcarriers (of 2048) with 0.5 ms resource blocks consisting of seven OFDM symbols each. Currently, this is the largest and only real-time massive MIMO testbed publicly available. It has been developed by our research group at Lund University together with the Advanced Wireless Research Team at National Instruments in Austin, TX. With this testbed we can perform real-time massive MIMO

communication tests and compare achieved performance with that predicted by our channel models in simulations. It can also be used for complementary channel measurements where a truly parallel architecture is desirable.

In addition to the above, the Department of Electrical and Information Technology has a fully equipped laboratory with all necessary instruments and facilities that may be needed during the project. This includes powerful network analyzers and positioning devices for virtual array measurements and shielded/anechoic chambers providing highly controlled environments for calibration measurements. Through collaboration with local industry we have access additional advanced measurement facilities, if needed, such as a SATIMO StarGate [24] for antenna characterization.

7 International and national collaboration

The team at Lund University has a very strong collaboration base in the area, covering all aspects of massive MIMO from communication theory to hardware implementation. Cooperation partners include Linköping University - Sweden (communication theory and algorithm development), KU Leuven (efficient transceivers), IMEC - Belgium (baseband processing, algorithm development, system simulation), Infineon AG - Austria (efficient transceivers), Ericsson AB - Sweden (system design and standardization), Telefonica - Spain (system design and standardization), Sony Mobile AB - Sweden (terminals and terminal antennas), National Instruments - USA (testbed development), University of Southern California - USA (channel measurements), Xilinx - USA (baseband processing), and Alcatel Lucent - USA (system design and communication theory). Much of this collaboration takes place in large projects or strategic research organizations, such as the EU 7th framework project MAMMOET [13] or the Swedish strategic research area ELLIIT [14], while some collaborations are more of a bilateral type. All above collaboration partners are among the world leaders in their specific areas related to massive MIMO.

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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

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	Ove Edfors	20
2	Participating researcher	Fredrik Tufvesson	10
3	Other personnel without doctoral degree	Ny doktorand	85

Salaries including social fees

	Role in the project	Name	Percent of salary	2016	2017	2018	2019	Total
1	Applicant	Ove Edfors	20	237,706	244,837	252,182	259,747	994,472
2	Participating researcher	Fredrik Tufvesson	10	115,168	118,623	122,181	125,847	481,819
3	Other personnel without doctoral degree	Ny doktorand	85	444,821	458,165	471,910	486,067	1,860,963
	Total			797,695	821,625	846,273	871,661	3,337,254

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	Arbetsrum	109,608	118,635	109,435	112,535	450,213
	Total	109,608	118,635	109,435	112,535	450,213

Running Costs

	Running Cost	Description	2016	2017	2018	2019	Total
1	Resor		50,000	50,000	50,000	50,000	200,000
2	Teknisk utrustning		50,000	100,000	0	0	150,000
	Total		100,000	150,000	50,000	50,000	350,000

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	797,695	821,625	846,273	871,661	3,337,254		3,337,254
Running costs	100,000	150,000	50,000	50,000	350,000		350,000
Depreciation costs					0		0
Premises	109,608	118,635	109,435	112,535	450,213		450,213
Subtotal	1,007,303	1,090,260	1,005,708	1,034,196	4,137,467	0	4,137,467
Indirect costs	303,331	328,312	302,851	311,430	1,245,924		1,245,924
Total project cost	1,310,634	1,418,572	1,308,559	1,345,626	5,383,391	0	5,383,391

Explanation of the proposed budget

Briefly justify each proposed cost in the stated budget.

Explanation of the proposed budget*

Lönekostnader baseras direkt på de olika deltagarnas engagemang i projektet, kompenserad med en förväntad löneökning på 3% per år.

Lokalkostander baseras på institutionens lokalkostnader för deltagarna, viktade med deltagarnas engagemang i projektet.

Resekostnader baseras på förväntade kostnader för konferensresor och andra resor direkt kopplade till projektet.

Teknisk utrustning består av beräknad kostnad för extra utrustning till kanal-sounder och masiv MIMO-testbädd, direkt relaterade till projektets genomförande.

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 and publications

CV

Name: **Ove Edfors**
Date of birth: **September 9, 1966**
Citizenship: **Swedish**

Present position: **Professor (50% research)**
Dept. of EIT
Lund University, Sweden

Higher education degree

M.Sc. in Computer Science and Electrical Engineering, Luleå University of Technology, Sweden, 1990.

Doctoral degree

Ph.D. degree in Signal Processing from Luelå University of Technology, 1996.

Postdoctoral positions

Postdoctoral Fellow at the Dept. of Applied Electronics, Lund University, Sweden. **1997 - 1999**

Qualification required for appointments as a docent

Appointed full professor in 2002.

Current position

Professor of Radio Systems, since 2002, and leader of the Communications Engineering Lab, since 2008, both at the Department of Electrical and Information Technology, Lund University, Sweden.

Previous positions and periods of appointment

University

- Vice head of department at Lund University, Sweden. **2002–2008**
- Director of External Training at the Dept. of Electroscience, Lund University, Sweden. **2000–2007**
- Associate Professor at Lund University, Sweden. **1999–2002**
- Postdoctoral Fellow at the Dept. of Applied Electronics, Lund University, Lund, Sweden. **1997–1999**
- Assistant Professor at Luleå University of Technology, Sweden. **1996–1997**
- Ph.D. candidate at Luleå University of Technology, Sweden. **1991–1995**
- Part-time lecturer in Mathematics at Luleå University of Technology, Sweden. **1988–1990**

Industry and other organizations

- Member of the Socware Research and Education Committee. **2001–2005**
- Board member and Tresurer, IEEE Sweden Section, VT/COM Chapter. **2000–2007**
- Lecturer and course developer for Ericsson's Radio School. **1997–2003**
- Part time lecturer at SFT Ingenjörsutbildningar, Stockholm. **1999–2006**
- Military service, Boden. **1987–1988**
- Founder and owner of HB Aragorn, a company that developed and marketed the leading

software in Sweden for analysis of overhead cranes. **1986–1996**

- Engineer/programmer at Berencsy Linbane AB, Örnsköldsvik, Sweden. **1986**

Interruption in research

During the last eight years there are three activities that have had a significant impact on the time I have been spending on research:

- Between 2002 and 2008 I spent almost 300 days on parental leave.
- In the period 2002–2008 I acted as Deputy Head at two departments. First at the Department of Electroscience and later, after a department merge, at the Department of Electrical and Information Technology.
- In the period since 2008 I have been group leader of the Communications Engineering Lab at the Department of Electrical and Information Technology.

Supervision

Ove Edfors has been main supervisor (or acting main supervisor) for 8 Ph.D. studenths through to their respective degrees (seven Ph.D degrees and four Lic.Eng. degrees). Currently main supervisor of four Ph.D. students.

- Main supervisor of current students
  - M. Sarajlic. Research area: Control of performance vs power consumption in flexible digital receivers. Expected Ph.D degree: Autumn 2018.
  - H. Prabhu. Research area: Centralized processing for distributed antenna systems. Expected Ph.D degree: June 2016.
  - X. Gao. Research area: Performance issues for very-large MIMO systems. Expected Ph.D degree: September 2015.
  - N. Mazloum. Research area: Medium access techniques for ultra-low power communications. Expected Ph.D degree: June 2014.
- Main supervisor of graduated students
  - Ph.D. degrees: P. Hammarberg (2012), J. Chen (2008 at DTU, Denmark), A. Stranne (2005), and F. Florén (2005)
  - Lic.Eng degrees: F. Foroughi (2011) and A. Stranne (2003).
- Acting main supervisor
  When Torleiv Maseng left his position at Lund University for the Norwegian Defence Research Establishment in Oslo in 1997, he continued as the formal main supervisor of his Ph.D. students in Lund. I took over the daily supervision, acting as on-site main supervisor.
  - Ph.D. degrees: C.F. Leanderson (2002), J. Hokfelt (2000), and F. Tufvesson (2000).
  - Lic.Eng degrees: C.F. Leanderson (2000), and P. Malm (1999).

CV for Fredrik Tufvesson

1. Higher education qualification(s)

Master of Science M.Sc. in Electrical Engineering from Lund University, Lund, Sweden. Thesis title: On Harmonic Penetration in Urban Low- and Medium-Voltage Networks (in Swedish). June 1994
Licentiate in Engineering in Applied Electronics from Lund University, Lund, Sweden. Thesis title: Channel Related Optimization of Wireless Communication Systems. February 1998

2. Doctoral degree

PhD in Applied electronics / Radio systems, Department of Applied Electronics, Lund University. Thesis title: Design of Wireless Communication Systems - Issues on Synchronization, Channel Estimation and Multi-Carrier Systems. September 2000. Advisor: Prof. Torleiv Maseng

3. Postdoctoral positions

System specialist, Fiberless society/Branoc Networks, September 2000 – January 2002.

4. Qualification required for appointments as a docent

Docent in Radio systems August 2007.

5. Current position

Professor of Radio Systems, May 2014 – present, Dept. of Electrical and Information Technology, Lund University. Approximately 60 % time for research.

6. Previous positions and periods of appointment

- Associate Professor of Radio systems, Dept. of Electrical and Information Technology, Lund University, June 2003-May 2014
- CTO/founder, Hepkie/ResQU AB, startup developing equipment for location of disaster victims and missing people. 2009-2014
- Researcher at the Department of Electroscience, Lund University. February 2002 - June 2003
- Co-founder and system specialist, Branoc Networks, Lund, Sweden. September 2001 - January 2002
- System specialist, Fiberless Society, Lund, Sweden. October 2000 - August 2001
- Ph.D. candidate at the Department Applied Electronics, Lund University. January 1995 -September 2000

7. Interruption in research

Parental leave June-September 2002, June-September 2004, May-September 2008.

8. Supervision

As main advisor for the following students finishing with a PhD:

- Carl Gustafson, “60 GHz Wireless Propagation Channels: Characterization, Modeling and Evaluation”, Dec. 2014;
- Meifang Zhu, “Geometry-based Radio Channel Characterization and Modeling: Parameterization, Implementation and Validation”, Sept. 2014;
- Taimoor Abbas, “Measurement Based Channel Characterization and Modeling for Vehicle-to-Vehicle Communications, February 2014.
- Rohit Chandra “Antennas, Wave Propagation, and Localization in Wireless Body Area Networks” March 2014. Anders J Johansson was active (co-)advisor
- Palmi Thorbergsson, “Signal Modeling and Data Reduction for Wireless Brain Machine Interfaces” in Nov. 2012, Anders J Johansson was active (co-)advisor
- Fredrik Harrysson, “Multiple Antenna Terminals in Realistic Environments - A Composite Channel Modeling Approach”, May 2012.

As co-advisor for students that defended PhD thesis, where I took an active role as advisor: Anders Bernland (May 2012), Andres Alayon Glazunov (March 2009), Shurjeel Wyne (March 2009), Johan Kåredal (Feb. 2009), Peter Almers (May 2007). For the last four I took a major role as advisor

Main advisor for the following Ph.D. students: Jose Flordelis, expected PhD in 2015; Muhammad Atif Yaqoob expected PhD in 2016; Mikael Nilsson, expected PhD in 2016; Dimitrios Vlastaras, expected PhD in 2017; Joao Vieira, expected PhD in 2017; Xuhong Li, expected PhD in 2019.

Post-doctoral supervision: Peter Almers, June 2007-Sept 2008. Multi-link channel characterization; Shurjeel Wyne, April 2009-April 2010, mm wave systems; Johan Kåredal, March 2009-August 2011, Vehicular communication; Ghassan Dahman, Aug 2011-present, Distributed antenna systems

9. Other information of relevance to the application

Awards: Co-author of 4 papers that were granted best paper/student paper awards. Awards in Ventrue Cup 2006, 2011, 2013. Stipend to realize and commercialize a cell phone based search and rescue system, which was the foundation for our startup ResQU AB.

Management experience: Deputy head of the department of electrical- and information technology (Jan 2015-present) board member (2007-2014); deputy head of the Lund part of the strategic research area ELLIIT, board member (2012-present); PI of a larger SSF project on distributed antenna systems (26 MSEK/5 years, 2012-2016); Director for SSF High Speed Wireless Center (2011-2012), board member (2009-2010); National Swedish delegate in COST 2100 and IC 1004; CTO and founder Hepkie AB (2009-2012).

Publications: 7 book chapters, 54 journal papers, 115 conference papers, 4 patent applications. H-index 34 (Google scholar March. 2015). See www.eit.lth.se/staff/fredrik.tufvesson for a full list of publications.

Editorship and review assignments: Associate editor for IEEE Transactions on Wireless Communications, 2009 -- 2013. Reviewer for a number of journals such as IEEE Trans. Comm., IEEE Trans. Wireless Comm., IEEE Trans. Vehicular Techn., IEEE Sel. Areas in Comm., IEEE Trans. Ant. and Prop., IEEE Trans. Sig. Proc.

Conference chairing and technical program committee memberships: Co-chair of Wireless Communication Symposium at IEEE International Conference on Communications 2013. In total we managed 462 submitted papers and 260 Technical Program Committee members. 175 papers were presented at the conference held in Budapest, Hungary, June 2013. Co-chair of Dependable Vehicular Communications (DVC), ICC workshop 2015, London, U.K., June 2015. Member of the organizing committee and financial officer for SWE-CTW, Swedish Communication Technologies Workshop, 2012.

Technical Program Committee member for IEEE Vehicular Technology Conference (2013, 2011, 2010, 2005), IEEE ICC Workshop on Advances in Network Localization and Navigation (2015, 2014, 2013), IEEE International Conference on Communication (2014, 2013, 2010), IEEE IEEE Globecom (2013, 2014, 2007), IEEE International Conference on Ultra-Wideband, ICUWB (2009, 2006), International Conference on Localization and GNSS (2015)

International collaboration: Strong network with other universities and research institutes, with well-established collaboration in terms of joint projects, publications or applications, examples include: University of Southern California, US (A. Molisch), TU Vienna, Austria, (C. Mecklenbräuker), FTW Forschungszentrum Telekommunikation Wien/Austrian Institute of Technology, Austria (T. Zemen), Alcatel-Lucent Bell labs, USA (T. Marzetta), Aalto University, Finland (K. Haneda), UCL Belgium (C. Oestges). More than 50% of the papers are written jointly with international collaborators.

Selected invited talks and tutorials:
Tutorial at ICC 2015, ``Massive MIMO for 5G: From Theory to Practice", London, U.K., June 2015.
Invited talk at International Solid State Circuit Conference, ISSCC 2015, "More Bits via the Same Spectrum - Massive MIMO Opportunities", San Francisco, USA, Feb. 2015
Tutorial at ICC 2013, ``Massive MIMO systems", Budapest, Hungary, June 2013.
Tutorial at ICASSP 2012, ``Very Large MIMO", Kyoto, Japan, March 2012.
Globecom Industry Forum 2011, ``Know thy channel -– considerations for reliable and scalable ITS technologies", Houston, USA, Nov. 2011.
``60 GHz impulse radio for short range wireless communication –- something for the future?", Vienna University of Technology, Oct. 2010.

Major research grants and project experience:
2013-2016 “Wireless Communication in Automotive Environment", FFI/ Vinnova, 71 MSEK, co-applicant
2012-2016 “Distributed Antenna Systems for Highly Efficient Wireless systems", Swedish Foundation for Strategic Research (SSF), 27 200 kSEK, PI
2011-2014 “mmWave-pulses above 10 Gbps", VR multi project grant, 9 600 kSEK, co-applicant
2011-2014 “Scaling up MIMO: Challenges and Opportunities with Very Large Arrays", VR multi project grant, 12 800 kSEK, co-applicant
2011-2013 “Chanel modelling for multi user MIMO with multiple base stations", VR, 2 400 kSEK, main applicant
2008-2010 “Channel modelling for cooperative and interfering MIMO systems", VR project grant, 2 250 kSEK, main applicant
2007-2010 ”WILATI+", NORDITE/Vinnova, 4 638 kSEK, project leader
2004 “MIMO channel sounder", KAW, 4 400 kSEK equipment grant, co-applicant
Participant and WP leader in EU projects MAMMOET, MAGNET, MANGET beyond

Publication list

Number of citations from Google Scholar

Five most cited publications (all times)

1. O Edfors, M Sandell, JJ Van de Beek, SK Wilson, PO Borjesson. OFDM channel estimation by singular value decomposition. IEEE Transactions on Communications, 46 (7), 931-939, 1998.
   Number of citations: **1533**
2. JJ Van de Beek, O Edfors, M Sandell, SK Wilson, PO Borjesson. On channel estimation in OFDM systems. Vehicular Technology Conference, 1995 IEEE 45th 2, 815-819 vol. 2, 1995.
   Number of citations: **1303**
3. F. Rusek, D. Persson, B. K. Lau, E. G. Larsson, O. Edfors, F. Tufvesson, T. L. Marzetta. Scaling up MIMO: Opportunities and challenges with very large arrays. IEEE Signal Processing Magazine, No. 1, 2013.
   Number of citations: 7**91**
4. E. G. Larsson, O. Edfors, F. Tufvesson, T. L. Marzetta. Massive MIMO for Next Generation Wireless Systems. IEEE Communications Magazine, Vol. 52, No. 2, pp. 186-195, 2014.
   Number of citations: **284**
5. F Tufvesson, O Edfors, M Faulkner. Time and frequency synchronization for OFDM using PN-sequence preambles. IEEE Vehicular Technology Conference, 2203-2207, 1999.
   Number of citations: **278**

Peer reviewed original articles

1. ***** X. Gao, O. Edfors, F. Rusek, and F. Tufvesson, Massive MIMO performance evaluation based on measured propagation data, IEEE Trans. Wireless Commun., 2015 (In press)
   Number of citations: **0**
2. I. Diaz, L. Wilhelmsson, P. Sofotasios, Y. Miao, S. Tan, O. Edfors, V. Öwall. A New Approach to Sign-Bit Based Parameter Estimation in OFDM Receivers, Circuits, Systems, and Signal Processing, 2015. (In press)
   Number of citations: **0**
3. C. Zhang, H. Prabhu, Y. Liu, L. Liu, O. Edfors, V. Öwall. Energy Efficient Group-Sort QRD Processor with On-line Update for MIMO Channel Pre-processing, IEEE Transactions on Circuits and Systems-I: Regular Papers, 2015 (In press)
   Number of citations: **0**
4. N. Seyed Mazloum, O. Edfors. Performance Analysis and Energy Optimization of Wake-Up Receiver Schemes for Wireless Low-Power Applications, IEEE Transactions on Wireless Communications, Vol. 13, No. 12, pp. 7050-7061, 2014.
   Number of citations: **0**
5. J. Löfgren, L. Liu, O. Edfors, P. Nilsson. Improved Matching-Pursuit Implementation for LTE Channel Estimation. IEEE Transactions on Circuits and Systems I (TCAS-1), Vol. 61, No. 1, pp. 226-237, 2014.
   Number of citations: **1**
6. ***** E. G. Larsson, O. Edfors, F. Tufvesson, T. L. Marzetta. Massive MIMO for Next Generation Wireless Systems. IEEE Communications Magazine, Vol. 52, No. 2, pp. 186-195, 2014.
   Number of citations: **284**
7. ***** F. Rusek, D. Persson, B. K. Lau, E. G. Larsson, O. Edfors, F. Tufvesson, T. L. Marzetta.

Scaling up MIMO: opportunities and challenges with very large arrays. IEEE Signal Processing Magazine, No. 1, 2013.
Number of citations: **791**

8. P. Hammarberg, F. Rusek, O. Edfors. Iterative receivers with channel estimation for multi-user MIMO-OFDM: complexity and performance. EURASIP Journal on Wireless Communications and Networking, Vol. 11, No. 5, pp. 1722-1732, 2012.
Number of citations: **13**
9. P. Hammarberg, F. Rusek, O. Edfors. Channel estimation algorithms for OFDM-IDMA: complexity and performance. IEEE Transactions on Wireless Communications, Vol. 11, No. 5, pp. 1722-1732, 2012.
Number of citations: **22**
10. H. Sjöland, J. B. Anderson, C. Bryant, R. Chandra, O. Edfors, A. Johansson, N. Seyed Mazloum, R. Meraji, P. Nilsson, D. Radjen, J. Rodrigues, Y. Sherazi, V. Öwall. A receiver architecture for devices in wireless body area networks. Journal on Emerging and Selected Topics in Circuits and Systems (JETCAS), Vol. 2, pp. 82-95, 2012.
Number of citations: **18**
11. O. Edfors, A. J. Johansson. Is orbital angular momentum (OAM) based radio communication an unexploited area? IEEE Transactions on Antennas and Propagation, Vol. 60, No. 2, pp. 1126-1131, 2012.
Number of citations: **41**
12. P. Salvo Rossi, R. R. Müller, O. Edfors. Linear MMSE estimation of time-frequency variant channels for MIMO-OFDM systems. Signal Processing, Vol. 91, No. 5, pp. 1157-1167, 2011.
Number of citations: **15**
13. J. González-Bayón, C. Carreras, O. Edfors. A multistandard frequency offset synchronization scheme for 802.11n, 802.16d, LTE, and DVB-T/H systems. Journal of Computer Systems, Networks, and Communications, Vol. 2010, 2010.
Number of citations: **6**

Peer reviewed conference contributions

1. I. Diaz, S. Tan, Y. Miao, L. Wilhelmsson, O. Edfors, V. Öwall. A 350 uW Sign-Bit Architecture for Multi-parameter Estimation During OFDM Acquisition in 65nm CMOS, International Symposium on Circuits and Systems (ISCAS), Lisbon, Portugal, 2015 (To appear)
Number of citations: **0**
2. H. Prabhu, F. Rusek, J. Rodrigues, O. Edfors. High Throughput Constant Envelope Pre-coder for Massive MIMO Systems, IEEE International Symposium on Circuits and Systems (ISCAS), Lisbon, Portugal, 2015. (To appear)
Number of citations: **0**
3. J. Vieira, S. Malkowsky, K. Nieman, Z. Miers, N. Kundargi, L. Liu, I. Wong, V. Öwall, O. Edfors, F. Tufvesson. A flexible 100-antenna testbed for Massive MIMO, IEEE Globecom 2014 Workshop - Massive MIMO: From Theory to Practice, Austin, Texas, USA, 2014-12-08.
Number of citations: **1**
4. ***** X. Gao, M. Zhu, F. Rusek, F. Tufvesson, O. Edfors. Large antenna array and propagation environment interaction, The 48th Annual Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, California, U.S.A., 2014-11-02/2014-11-05.
Number of citations: **0**
5. M. Stala, O. Edfors, V. Öwall. Implementation of a Novel Architecture for DFT-based

Channel Estimators in OFDM Systems, SIPS 2014, Belfast, 2014-10-20
Number of citations: **0**

6. M. Sarajlic, L. Liu, O. Edfors. Reducing the Complexity of LDPC Decoding Algorithms: An Optimization-Oriented Approach, IEEE 25th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC), Washington, D.C., USA, 2014-09-02/2014-09-06.
   Number of citations: **0**
7. C. Zhang, H. Prabhu, L. Liu, O. Edfors, V. Öwall. Energy Efficient SQRD Processor for LTE-A using a Group-sort Update Scheme. IEEE International Symposium on Circuits and Systems (ISCAS), 2014, Melbourne, Australia, 2014-06-01/2014-06-05.
   Number of citations: **0**
8. H. Prabhu, O. Edfors, J. Rodrigues, L. Liu, F. Rusek. Hardware Efficient Approximative Matrix Inversion for Linear Pre-Coding in Massive MIMO. IEEE International Symposium on Circuits and Systems (ISCAS), Melbourne, Australia, 2014-06-01.
   Number of citations: **0**
9. H. Prabhu, O. Edfors, J. Rodrigues, L. Liu, F. Rusek. A low-complex peak-to-average power reduction scheme for OFDM based massive MIMO systems. IEEE, International Symposium on communications, control and signal processing, Athens, Greece, 2014-05-21.
   Number of citations: **2**
10. H. Sjöland, J. B. Anderson, C. Bryant, R. Chandra, O. Edfors, A. Johansson, N. Seyed Mazloum, R. Meraji, P. Nilsson, D. Radjen, J. Rodrigues, Y. Sherazi, V. Öwall. Ultra low power transceivers for wireless sensors and body area networks, 8th International Symposium on Medical Information and Communication Technology (ISMICT), Firenze, Italy, 2014-04-02.
    Number of citations: **0**
11. X. Gao, O. Edfors, J. Liu, F. Tufvesson. Antenna selection in measured massive MIMO channels using convex optimization. IEEE GLOBECOM 2013 Workshop on Emerging Technologies for LTE-Advanced and Beyond-4G, Atlanta, Georgia, U.S.A., 2013-12-13.
    Number of citations: **2**
12. M. Stala, R. Gangarajaiah, O. Edfors, V. Öwall. Area and Power Reduction in DFT Based Channel Estimators for OFDM Systems. NORCHIP, 2013.
    Number of citations: **0**
13. ***** X. Gao, F. Tufvesson, O. Edfors. Massive MIMO channels - measurements and models. The 47th Annual Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, California, U.S.A., 2013-11-03/2013-11-06.
    Number of citations: **6**
14. R. Gangarajaiah, L. Liu, M. Stala, P. Nilsson, O. Edfors. A High-Speed QR Decomposition Processor for Carrier-Aggregated LTE-A Downlink Systems. European Conference on Circuit Theory and Design (ECCTD 2013), Dresden, Germany, 2013-09-08/2013-09-12.
    Number of citations: **0**
15. H. Prabhu, J. Rodrigues, O. Edfors, and F. Rusek. Approximative Matrix Inverse Computations for Very-large MIMO and Applications to Linear Pre-coding Systems. IEEE Wireless Communications and Networking Conference (WCNC), Shanghai, China, April 2013.
    Number of citations: **7**
16. C. Zhang, L. Liu, Y. Wang, M. Zhu, O. Edfors, and V. Öwall. A Highly Parallelized MIMO Detector for Vector-Based Reconfigurable Architectures. IEEE Wireless Communications and Networking Conference (WCNC), Shanghai, China, April 2013.
    Number of citations: **3**

17. ***** X. Gao, F. Tufvesson, O. Edfors, and F. Rusek. Measured propagation characteristics for very-large MIMO at 2.6 GHz. The 46th Annual Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, California, USA, November 2012.
    Number of citations: **31**
18. C. Zhang, H. Prabhu, L. Liu, O. Edfors, and V. Öwall. Energy Efficient MIMO Channel Pre-processor Using a Low Complexity On-Line Update Scheme. IEEE NORCHIP, Copenhagen, Denmark, November 2012.
    Number of citations: **1**
19. N. Seyed Mazloum, J. Rodrigues, and O. Edfors. Sub-VT Design of a Wake-up Receiver Back-end in 65 nm CMOS. IEEE Subthreshold Microelectronics Conference, Waltham, Massachusetts, USA, October 2012.
    Number of citations: **0**
20. F. Rusek, O. Edfors, F. Tufvesson. Indoor Multi-User MIMO: Measured User Orthogonality and Its Impact on the Choice of Coding. European Conference on Antennas and Propagation (EuCAP), Prague, March 2012.
    Number of citations: **0**
21. J. Löfgren, O. Edfors, P. Nilsson. Improved matching pursuit algorithm and architecture for LTE channel estimation. In Proc 2011 IEEE International Symposium on Circuits and Systems (ISCAS 2011), Rio de Janeiro, Brazil, 2011-05-15.
    Number of citations: **3**
22. F. Karimdady Sharifabad, F. Foroughi, O. Edfors. Low complexity channel estimation for low-mobility LTE using 4×4 MIMO. In Proc 6th IEEE Conference on Industrial Electronics and Applications (ICIEA), Beijing, China, pp. 1893-1897, 2011-06-21/2011-06-23.
    Number of citations: **0**
23. F. Foroughi, F. Rusek, O. Edfors. On coefficient memory co-optimization for channel estimation in a multi-standard environment (LTE and DVB-H). In Proc 8th International Workshop on Multi-Carrier Systems & Solutions (MC-SS), Herrsching, Germany, 2011-05-03 /2011-05-04.
    Number of citations: **0**
24. J. Löfgren, O. Edfors, P. Nilsson. Improved matching pursuit algorithm and architecture for LTE channel estimation. In Proc Swedish System-on-Chip Conference 2011 (SSoCC 2011), Varberg, Sweden, 2011-05-02.
    Number of citations: **0**
25. N. Seyed Mazloum, O. Edfors. DCW-MAC: An energy efficient medium access scheme using duty-cycled low-power wake-up receivers. In Proc 74th IEEE Vehicular Technology Conference, The 74th IEEE Vehicular Technology Conference, San Francisco, U.S.A., 2011-09-05/2011-09-08.
    Number of citations: **7**
26. X. Gao, O. Edfors, F. Rusek, F. Tufvesson. Linear pre-coding performance in measured very-large MIMO channels. In Proc 74th IEEE Vehicular Technology Conference, The 74th IEEE Vehicular Technology Conference, San Francisco, U.S.A., 2011-09-05/2011-09-08.
    Number of citations: **65**
27. P. Hammarberg, S. Wu, X. Chen, J. Wang, O. Edfors. Coded IDMA system performance with parallel interleavers. In Proc 6th Conference on Wireless Advanced (WiAD), London, pp. 1-4, 2010-06-27/2010-06-29.
    Number of citations: **0**
28. F. Foroughi, F. Karimdady Sharifabad, O. Edfors. Low complexity channel estimation for LTE in fast fading environments for implementation on multi-standard platforms. In Proc IEEE 72nd Vehicular Technology Conference Fall 2010, IEEE 72nd Vehicular Technology

Conference: VTC2010-Fall, Ottawa, Canada, 2010-09-06/2010-09-09.
Number of citations: **3**

29. J. Löfgren, P. Nilsson, O. Edfors. Hardware architecture of an SVD based MIMO OFDM channel estimator. . In Proc 2009 International Symposium on Circuits and Systems (ISCAS?09), Taipei, Taiwan, 2009-05-24/27.
Number of citations: **1**
30. F. Foroughi, J. Löfgren, O. Edfors. Channel estimation for a Mobile Terminal in a Multi-Standard Environment (LTE and DVB-H). In Proc 3rd International Conference on Signal Processing and Communication Systems, 2009. ICSPCS 2009., Omaha, NE, pp. 67-75, September 28-30, 2009.
Number of citations: **15**
31. P. Salvo Rossi, R. Müller, O. Edfors. Slepian-based serial estimation of time-frequency variant channels for MIMO-OFDM systems. In Proc IEEE Global Telecommunications Conference (GLOBECOM) 2009, Honolulu, HI, 2009-11-30—2009-12-04.
Number of citations: **1**
32. P. Hammarberg, F. Rusek, P. Salvo Rossi, O. Edfors. EXIT chart evaluation of a receiver structure for multi-user multi-antenna OFDM systems. In Proc IEEE Global Telecommunications Conference (GLOBECOM) 2009, Honolulu, HI, 2009-11-30--2009-12-04. Number of citations: **2**
33. A. Richter, F. Tufvesson, P. S. Rossi, K. Haneda, J. Koivunen, V. M. Kolmonen, J. Salmi, P. Almers, P. Hammarberg, K. Pölönen, P. Suvikunnas, A. Molisch, O. Edfors, V. Koivunen, P. Vainikainen, R. R. Muller. Wireless LANs with high throughput in interference-limited environments - project summary and outcomes. In Proc COST 2100, 2008.
Number of citations: **3**
34. P. Hammarberg, P. Salvo Rossi, F. Tufvesson, O. Edfors, V. M. Kolmonen, P. Almers, R. Muller, A. Molisch. On the performance of iterative receivers for interfering MIMO-OFDM systems in measured channels. In Proc 42nd Asilomar Conference on Signals, Systems and Computers, Pacific Grove, California, pp. 141-145, 2008-10-26/2008-10-29.
Number of citations: **2**
35. P. Salvo Rossi, P. Hammarberg, F. Tufvesson, O. Edfors, P. Almers, V. M. Kolmonen, J. Koivunen, H. Haneda, R. Muller. Performance of an Iterative Multi-User Receiver for MIMO-OFDM Systems in a Real Indoor Scenario. In Proc IEEE GLOBECOM 2008 - 2008 IEEE Global Telecommunications Conference, New Orleans, USA, 2008-11-30/2008-12-04.
Number of citations: **5**
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An updated publication list, and many full text papers, can found at http://www.eit.lth.se/staff/fredrik.tufvesson

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5. Open access computer programs

Administrator of, and one of the main contributors to, the open source implementation of the COST2100 channel model. Specific contributions to the multi-link concept, parameterization of indoor as well as outdoor scenarios, massive MIMO extension.

Five most cited publications

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CV

Name: Ove Edfors	**Doctorial degree:** 1996-11-14
Birthdate: 19660909	**Academic title:** Professor
Gender: Male	**Employer:** Lunds universitet

Research education

Dissertation title (swe)
Lågkomplexa algoritmer i digitala mottagare

Dissertation title (en)
Low-complexity algorithms in digital receivers

Organisation	Unit	Supervisor
Luleå Tekniska Universitet, Sweden Sweden - Higher education Institutes	Inst för Systemteknik - Avd. för Signalbehandling	Per Ola Börjesson

Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
20205. Signalbehandling	0348-8373	1996-11-14

CV

Name: Fredrik Tufvesson	**Doctorial degree:** 2000-09-22
Birthdate: 19700314	**Academic title:** Professor
Gender: Male	**Employer:** Lunds universitet

Research education

Dissertation title (swe)

Dissertation title (en)

Design of Wireless Communication Systems -- Issues on Synchronization, Channel Estimation and Multi-Carrier Systems

Organisation	Unit	Supervisor
Lunds universitet, Sweden Sweden - Higher education Institutes	Elektro- och informationsteknik 107201	Torleiv Maseng

Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
20203. Kommunikationssystem	1402-8662	2000-09-22

Publications

Name: Ove Edfors	**Doctorial degree:** 1996-11-14
Birthdate: 19660909	**Academic title:** Professor
Gender: Male	**Employer:** Lunds universitet

Edfors, Ove has not added any publications to the application.

Publications

Name: Fredrik Tufvesson	**Doctorial degree:** 2000-09-22
Birthdate: 19700314	**Academic title:** Professor
Gender: Male	**Employer:** Lunds universitet

Tufvesson, Fredrik 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.