Application

2015-03-31

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Project site: 3204 - Kommunikationssystem

Information about application

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

Type of grant: Projektbidrag

Focus: Fri

Subject area:

Project title (english): Constrained-envelope Coded-modulation Multiple-access Schemes for Energy Efficient Communications

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Project end: 2019-12-31

Review panel applied for: NT-14

Classification code: 20203. Kommunikationssystem, 20205. Signalbehandling, 20204. Telekommunikation

Keywords: Energy efficiency, Coded modulation, Multiple access, Constrained envelope, Communication systems

Funds applied for

Year:	2016	2017	2018	2019
Amount:	1,784,000	1,829,000	1,906,000	1,954,000

Descriptive data

Project info

Project title (Swedish)*

Kodad modulation för fleranvändar-system med begränsning av signal-envelopp-variation för energi-effektiv kommunikation

Project title (English)*

Constrained-envelope Coded-modulation Multiple-access Schemes for Energy Efficient Communications

Abstract (English)*

For both environmental and economical reasons, the power consumption in communication systems should be as low as possible. Constant envelope signals offer the possibility to use non-linear cost-effective and power efficient High Power Amplifier (HPA) at the transmitter, since then the HPA can be operating close to saturation without distorting the transmit signal.

The need for increasing spectral efficiency has however made signaling formats like Orthogonal Frequency Division Multiplexing (OFDM) popular in recent spectrally efficient wireless systems, such as the 4th generation wireless access, at the cost of large signal envelope variations. However, new requirements are emerging for future generation wireless access coming from both envisioned new applications and new high carrier frequency bands, calling for constrained envelope multiple access solutions.

The aim of this research project is to design, analyze and optimize end-to-end energy efficient constrained envelope coded modulation multiple access schemes for SISO, MIMO and Massive MIMO scenarios in Additive White Gaussian Noise (AWGN) and frequency selective fading channels, taking HPA properties into account to meet a target on end-to-end energy efficiency. We will also develop performance bounds and seek to evaluate the true end-to-end energy efficiency taking also baseband energy consumption into account.

Popular scientific description (Swedish)*

Energieffektiva signaler för framtida tillämpningar av mobila kommunikationssystem

Energi- och kostnadseffektiv trådlös kommunikation är av stor betydelse för vårt moderna trådlösa informationssamhälle. För att kunna möta dagens efterfrågan på mobilt bredband har dagens system tvingats att sänka kraven på energieffektivitet i sändarna, genom att tillåta signaler som kan bära mer information, men som därigenom är svåra att sända energieffektivt. Nya applikationer för mobil-system såsom maskin-kommunikation, bilar som kommunicerar med varandra, och olika sensorer som behöver vara energieffektiva skulle vara avhjälpta av kommunikationssignaler som möjliggör sändarna att agera mer energieffektivt. Tillämpning finns också för att kostnadseffektivt kunna ansluta enskilda hushåll till det fasta internet med optiska fiber-system, samt för kommunikationssystem som använder mycket höga bärfrekvenser, då nuvaramde kommunikationshårdvara är ytterligare begränsad vid sådana bärfrekvenser.

Detta projekt kommer att undersöka hur sådana signaler kan definieras, både för enskilda kommunikationslänkar, och för system som delar frekvensutrymmet med många användare. Projektet kommer att bygga på lovande initiala resultat av ett nytt signal-schema, och målen är dels att förbättra dessa existerande lösningar genom att göra dem än mer energi-effektiva, mer robusta för tillämpning vid hög mobilitet, samt undersöka hur de kan anpassas för användning i system med många sändar- och mottagarantenner. Projektet kommer även att undersöka de fundamentala gränserna för hur hög datatakt det går att åstadkommer med denna typ av signal-scheman under begränsing av energi-effektivitet hos sändarna, samt försöka undersöka total energi-åtgång inklusive basbandsprocessning.

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 > 20205. Signalbehandling
	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*

Energy efficiency

Keyword 2*

Coded modulation

Keyword 3*

Multiple access

Keyword 4

Constrained envelope

Keyword 5

Communication systems

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*

We here list potential dual use and misuse, followed by argumentation that ethical issues arising in the proposed research are the same as those in any use of wireless communications systems. Finally, we propose concrete measures to mitigate these ethical issues within this research project.

Potential dual use
The analysis techniques and algorithms targeted for the project are of general use and value, independent of the purpose of the wireless communication system. As such, the analysis techniques and algorithms can be used for both public, private and military wireless communication networks.

Potential misuse
The techniques targeted in the project aim to the benefit of society, with applications to end-users, companies, and governments. As any wireless (and wireline) communication network, the information conveyed can potentially be eavesdropped, collected and used for other purposes than intended by the eligible users, such as for commercial or illegal activities. With dense wireless networks, the connectivity will be higher, which might increase the privacy threat even further (from an already high level on the Internet), due to more eavesdropping and collection of data points, but also increased possibility for collecting meta data, such as location and usage context information. The increased connectivity can on the other hand also enable robustified communications by using path diversity and network coding approaches to mitigate eavesdropping and hacker attacks.

Proposed measures within the project
• Privacy: The research within the project will be based on analytical, numerical and simulation based methods, based on open
data and models. I.e., the project will not collect any such data. In case we receive such data for use in this project from external related projects, the data will be handled with full attention to privacy laws in all applicable countries. During potential utilization of our research findings upon completion of the research, we will recommend any system using our solutions to also use security measures (e.g. cryptography, hardware-based security).
• Dual use: The research will deal exclusively with non-military applications. Researchers involved in the project will be made aware of dual use potential. We plan on an open research dissemination strategy, where the public and research community have full open access to our research findings (in accordance with the policy at Chalmers University of Technology). The focus of the research is on open access to our results.

The project includes handling of personal data

No

The project includes animal experiments

No

Account of experiments on humans

No

Research plan

Upload your research plan, designed in accordance with the instructions in the call text, in PDF-format below. Click the folder-button to locate the file on your computer, then click the Plus-button to upload the file. You can only upload one file, and it can be a maximum of 10 mb in size.

Research plan*

See following page for attachment

Constrained-envelope Coded-modulation Multiple-access Schemes for Energy Efficient Communications

Research Programme

1 Purpose and Aims

For both environmental and economical reasons, the power consumption in communication systems must be as low as possible. Constant envelope signals offer the possibility to use non-linear cost-effective and power-efficient High-Power Amplifier (HPA) at the transmitter, because the HPA can be operated close to saturation without distorting the transmit signal. For this reason, constant envelope coded-modulation systems have found extensive use in e.g. satellite links, early wireless standards like the 2nd generation Global System for Mobile Communications (GSM), and low rate microwave radio links for cellular backhauling.

Starting with the evolution of GSM, the Enhanced Data Rates for GSM Evolution (EDGE), and continuing with 3rd and 4th generation wireless standards, envelope properties have been sacrificed in favor of higher spectral efficiency. This is because of the dramatic increase in demand of mobile broadband wireless access and the scarcity of spectrum. High spectral efficiency calls for the use of high-order constellations; for high spectral efficiency, constant-envelope coded-modulation is not competitive. Still, for the uplink of the 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) standard, a precoded orthogonal frequency multiple access (OFDMA) scheme was adopted to somewhat alleviate the burden of envelope variations at the uplink transmitter.

Currently, we are actively taking part in the research efforts aimed at the definition of the 5th Generation wireless access system, and, for this system, we see a strong need to revisit the potential of constrained-envelope coded-modulation multiple-access schemes. The reason is that, for this new system, providing unprecedented spectral efficiency is just one among many challenges. Among them is the need for greener wireless communications: it is expected that next generation wireless systems must offer up to a 1000-fold capacity increase while maintaining the same levels of energy consumption as today’s systems. New challenges also come from new applications for wireless access systems [FT+13], such as

- Machine-to-Machine (M2M),
- Vehicular-to-Vehicular (V2V) communications, as well as when using
- mm-wave carrier frequencies for access networks.

For these applications, other metrics, such as terminal energy efficiency for long battery life and coverage, are more important than spectral efficiency. The cellular wireless access system may also incorporate user terminals to assist the infrastructure nodes by providing Device-to-Device (D2D) communication, in order to improve the spectral efficiency per unit area and increase coverage though multi-hop user terminal relaying and mesh networking. Such heterogeneous networks require more robust control channels and pilot signals, which employ modulated signals that enable the HPA to operate close to its saturation, and, hence, provide high generated RF power, which is important to detect user activity. All these applications call for a renewed focus on energy efficiency, which make constrained-envelope multiple-access solutions attractive.

As mentioned above, constrained-envelope signals are also of interest for systems deployed in the multi-GHz carrier (mmWave) frequency bands, such as 60 GHz and the 71-76 and 81-86 GHz bands (known as the E-band). These bands may be used soon for both wireless access and for wireless backhauling as well as for wireless links in home networks for consumer electronics. The hardware is less mature at these frequencies with amplifiers suffering from low peak power and poor linearity. At the same time, there is plenty of bandwidth available at these frequencies, so spectral efficiency is not an issue. Similar considerations apply to fiber optical links aimed at the last mile fixed subscriber access. For all these new applications and scenarios, as well as for the traditional application area of satellite links, a constrained-envelope coded-multiple access scheme may be the preferred solution.

Motivated by these considerations, the goal of this research project is also to understand the fundamental performance limits of constrained-envelope communication. Specifically, the aim of this research project is as follows.

- Design, analyze and optimize *end-to-end* energy-efficient constrained-envelope coded-modulation for SISO, MIMO and Massive MIMO scenarios in additive white Gaussian noise (AWGN) and frequency selective channels fading channels, taking HPA properties into account to meet a target on *end-to-end* energy efficiency. The schemes will have controlled *continuous time* envelope variations and support *multiple-access* with frequency diversity against frequency selective small scale fading and uncoordinated interference for robust and low latency communication, thus avoiding retransmissions.

The methodology we will use for designing the constrained-envelope multiple access schemes will be based on *continuous-time* basis function sets. In particular, we will define constrained-envelope *coded modulation* signals that can be properly sampled and used as pre-coders for various generalized multi-carrier waveforms to enable frequency-domain multiple access.

At Chalmers, we have a strong track record on coded modulation and hardware-constrained communications. The main applicant has a PhD on constrained-envelope coded modulation, has worked on various constrained-envelope techniques for uplink multiple access within the European WINNER projects towards the LTE standard, which has become the basis for the most wide-spread 4th Generation wireless access system.

2 Survey of the Field

2.1 Constrained envelope schemes for HPA efficiency and multiple access

Continuous Phase Modulation (CPM) [AAS86] has been the technique of choice in the field of *constant* envelope digital communications, due to its good spectral properties, well-studied receiver structures, and its ability to support advanced channel coding schemes via concatenated coding and turbo receivers [MA01]. With partial response CPM, using frequency pulses of several symbol durations, CPM becomes a coded modulation scheme.

The envelope properties of the serially modulated signals after digital to analog (D/A) conversion depends on the employed pulse-shaping filter. Even a constant envelope signal constellation such as *M*-ary Phase Shift Keying (MPSK) has typically substantial envelope variations after the pulse-shaping filter (cf. Fig. 5 upper left). Only continuously modulated phase signals such as CPM have a true constant envelope in the analog domain.

However, starting with the Enhanced Data Rates for GSM Evolution (EDGE), envelope properties needed to be sacrificed in favor of higher spectral efficiency. This is because CPM becomes cumbersome to implement and difficult to synchronize as the spectral efficiency increases, even though CPM can provide twice as high spectral efficiency [S02] compared to the Gaussian Minimum Shift Keying (GMSK) originally used in GSM. The EDGE modulation scheme is based on offset M-ary Phase Shift Keying (MPSK), which is an example of *constrained envelope* modulation. This offset MPSK avoids zero crossing in the in-phase versus quadrature-phase (I/Q) diagram, but yields significant envelope variations, although still smaller than for filtered MPSK (see [S02, ch 8], for further references and discussion).

The envelope property of the modulated signal after D/A conversion is typically characterized by means of the peak-to-average power ratio (PAPR) [FKH08, eq. (15)], [NP00], or the Raw Cubic Metric (RCM) as defined in [FKH08, eq. (16)], which is closely related to the 3GPP Cubic Metric (CM) defined in [3GPPR4040367]. The rationale behind CM and RCM is the fact that the primary cause of transmit-signal distortion is the third order nonlinearity of the amplifier gain characteristic.

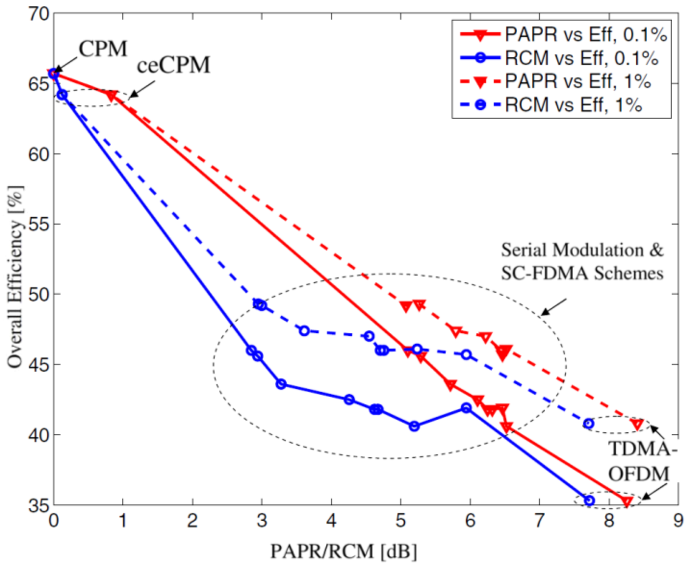

*Fig. 1: Maximum overall HPA efficiency versus mean PAPR and RCM of various modulated signals with 1% and 0.1% clipping level [*SE10*].*

In Fig. 1, we show how these metrics relate to the overall efficiency of a typical HPA for a set of signals having different envelope properties [SE10]. Here, the HPA overall efficiency is defined as $\eta_A=P_{out}/(P_{DC}-P_{IN})$, where P_{In} is the RF power at the input of the HPA; P_{Out}: resulting RF output power and P_{DC} is the power at the Direct Current (DC) input of the amplifier.

For signals with a large PAPR, the average input power must be reduced (this is known as input power backoff) in order to keep the peak power of the input signal less than or equal to the saturation input level of the HPA. If the input power is not backed off then signal distortion occurs, the most serious consequence of which is out-of-band spectral regrowth. The amount of backoff must be at least equal to the PAPR (unless some kind of pre-distorsion technique is applied).

As shown in Fig. 1, HPAs are most efficient when they are driven into saturation. Therefore, input power backoff reduces the efficiency of the HPA and is detrimental to battery-powered devices, which have limited power resources. Because of this, PAPR reduction has been the subject of numerous studies and various schemes have been developed to address this issue - such as coding and tone reservation [DJ99], [KJ04], [JA04], predistortion schemes [ALR01], and clipping [A02]. An alternate approach involves the transformation of Orthogonal Frequency Division Multiplexing (OFDM) signals into constant envelope waveforms by phase modulating the OFDM waveform. In [TAP+08], an OFDM waveform is used to phase-modulate a single carrier, and the result is a constant envelope waveform (i.e., the resulting signal has 0 dB PAPR). In [TS02], a similar approach is taken whereby the encoded data is first applied to a DCT (discrete cosine transform) and then passed through a continuous phase modulation (CPM) unit. Although both approaches are novel and result in a constant envelope waveform, neither approach retains the orthogonality of the subcarriers. This implies that some of the advantages of using OFDM---such as low complexity frequency domain equalization and frequency multiplexing of user data on the uplink---are lost.

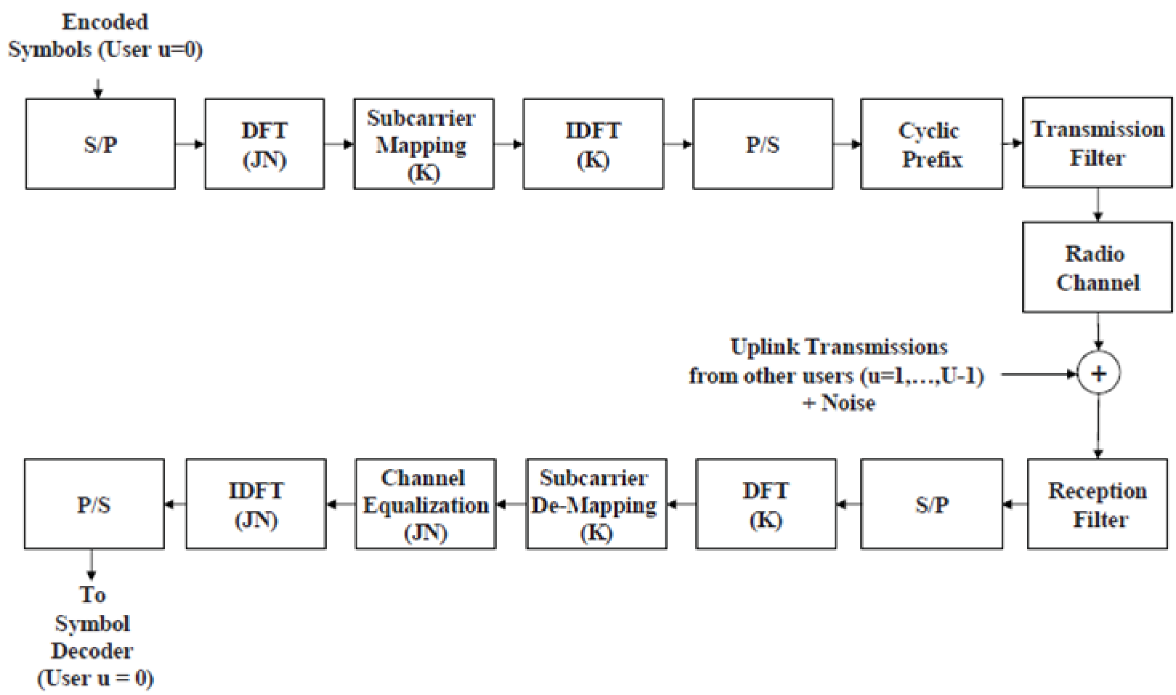

Fig. 2: SC-FDMA transceiver.

The state-of-the-art approach sofar in constrained envelope coded multiple access involves the use of Single Carrier Frequency Division Multiple Access (SC-FDMA). A block diagram of a generic SC-FDMA system is shown in Fig. 2. SC-FDMA is a variant of OFDM multiple access (OFDMA) in which the encoded data symbols of each user are first modulated in the time domain and then spread across the data subcarriers by using a Discrete Fourier Transform (DFT). In OFDMA, the data symbols corresponding to each user are generated in the frequency domain and then mapped to a distinct set of subcarriers for transmission over the radio channel. In OFDMA, each symbol occupies one subcarrier. However, SC-FDMA maps information from each data symbol onto each subcarrier allocated to a given user to offer an advantageous gain in frequency diversity.

SC-FDMA generally exhibits a rather low PAPR because of its inherent single carrier nature [MLG06a] and is therefore seen as an attractive alternative to OFDMA. Two original variants of SC-FDMA have emerged, which differ in the way the subcarriers are mapped to a particular user. These are: (1) interleaved-FDMA (I-FDMA) [SBS97], which assigns equidistant subcarriers to each user, and (2) localized-FDMA (L-FDMA) [MLG06b], whereby groups of contiguous subcarriers are assigned to a particular user. Recently, a generalized version of these two schemes has been proposed, called block-interleaved-FDMA (B-IFDMA) [SFE+09]. The LFDMA variant has been adopted for the uplink multiple access scheme of LTE.

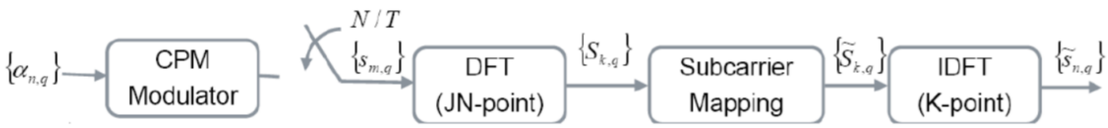

Fig. 3: CPM-SC-FDMA precoder

In [WPS11], we investigated the performance of a scheme employing a sub-sampled CPM encoder as precoder of SC-FDMA with I-FDMA subcarrier mapping, as illustrated in Fig. 3. As we shall explain in Section 5, this so-called CPM-SC-FDMA scheme can outperform convolutionally encoded Quadrature Phase Shift Keying (QPSK) by up to 4 dB in end-to-end power efficiency, taking HPA power backoff into account. An important property of CPM-SC-FDMA is that it yields very good envelope properties while at the same time maintaining the OFDMA structure. This allows for a simple multiple access scheme through frequency division and permit the reuse of the OFDMA transceiver structure currently in use in OFDMA-based systems.

2.2 Information-theoretic limits on the performance of constrained-envelope signals

Information-theoretic analyses aimed at determining channel capacity are typically limited to the situation where the transmit signals are subject to an average-power constraint. Capacity analyses accounting for the presence of *power-amplifier-oriented* constraints (such as PAPR, RCM, and CM) on the transmit signals are scarce. One notable exception is the case of peak-amplitude-constrained input signals, which has been analyzed in [S71], [SB95]. There, it is established that the input distribution that achieves the capacity of an additive Gaussian noise channel in the presence of a peak-amplitude constraint is discrete with a finite number of mass points. By contrasting this with the average-power limited case, where the optimal input distribution is Gaussian and capacity is given by the well-known log(1 + *SNR*) formula, we see that the specific form of the constraint imposed on the transmit signal has a severe impact on both the channel capacity and the structure of the capacity-achieving signaling scheme.

PAPR is the traditional metric used by information theorists to assess the suitability of a certain signaling scheme to transmission over a HPA. The performance of different signaling schemes under a PAPR constraint has been studied intensively, especially within the context of multicarrier transmissions (see [WFB+12] and references therein), although no capacity results are available to date. Moving to the non-asymptotic regime of finite block length, Polyanskiy and Wu [PW13] have recently shown that signaling schemes achieving the first two terms in the asymptotic expansion of the maximum rate achievable for a given block length and frame error probability in the limit of large block length must have a PAPR that grows logarithmically with the block length.

Capacity or finite block length results for signaling schemes subject to more practically relevant power-amplifier-oriented constraints than PAPR, such as RCM and CM are not available in the literature.

3 Project Description

The following tasks have been identified for the project.

1. **Mth 1-12: Optimize sampled CPM precoding schemes for SC-FDMA**
   As a first step we plan to build on our previous work on CPM-SC-FDMA published in [WPS11]. These schemes proposed in [WPS11] were derived without performing any kind of optimization. The goal there was to demonstrate performance gains over a convolutionally encoded QPSK SC-FDMA scheme. The sampled CPM precoding schemes have similar minimum Euclidean distance as the original CPM schemes, but since these subsampled schemes introduce a controlled envelope variation, there is a potential to improve the minimum Euclidean distance by intelligently utilizing the amplitude domain. In [S02] we showed that it is possible to design constrained envelope coded modulation schemes based on the extended Laurent decomposition of CPM [MM95] in such a way that the allowed envelope variations can be linearly translated to a corresponding increase in the minimum Euclidean distance with the so-called Constrained Envelope Continuous Phase Modulation (ceCPM) scheme [SS03]. We will investigate if this property can be utilized with SC-FDMA mapping. We will also seek to explore other waveforms as basis for designing the constrained-envelope precoders, such as wavelets.
2. **Mth 13-24: Investigate alternative multi-carrier schemes**
   In this task we will investigate alternative multi-carrier schemes to explore the possibility to obtain constrained envelope multiple access schemes with better robustness to carrier frequency offset, phase noise, and Doppler spread for scenarios where user mobility is high. In particular, we intend to design constrained envelope precoders using the extended Laurent decomposition of CPM [MM95] to obtain constrained envelope multi-carrier schemes based on generalized multi-carrier schemes such as Universal Filtered Multicarrier (UFMC) [VWS+13], Filterbank Multicarrier (FBMC) [PWK+13], as well as compare with B-IFDMA subcarrier mapping [SFE+09].
3. **Mth 25-36: Investigate MIMO and Massive MIMO transceiver structures with the constrained envelope multi-carrier schemes**
   Massive MIMO and MIMO for high carrier frequencies may suffer from low power non-linear HPAs. We will investigate how well our schemes developed and analyzed in tasks 1-2 can be integrated with (massive) MIMO, taking HPA arrays and also antenna characteristics into account.
4. **Mth 37-48: Derive ultimate limit on the rates achievable over continuous-time channels in the presence of power-amplifier-oriented constraints**

In this task we seek to derive performance limits for constrained envelope schemes to assess their optimality. Our approach to address the continuous-time case will be as follows: for a given map between discrete-time codewords and continuous-time waveforms, we will impose our amplifier-oriented constraints to the discrete-time signal obtained by suitably oversampling the continuous-time waveform. This approach exploits the fundamental property that some of the characteristics of a continuous-time waveform, among which its peak value, can be predicted (with firm guarantees on the prediction accuracy) from the analysis of its samples taken at rate higher than the critical sampling (Nyquist) rate [WB03].

5. **Mth 25-48: Investigate baseband energy efficiency of the considered constrained envelope multiple access schemes**
   Sofar we have focused on end-to-end energy efficiency w.r.t. the radio frequency (RF) chain. In this task, we plan to work in parallel with the work in task 4-5 to explore the possibility to quantify also the baseband energy consumption of the various schemes in task 1-2. This is a very open research area with very few results. As such, this task has a high risk, but is still very important to explore since baseband energy consumption might be of similar level as RF energy in future dense networks. We will build our work on [HSI06]. If successful, the methodology will be used to revisit also the results in task 3 if time permits.

All these studies will be carried out on AWGN and frequency selective fading channels taking HPA properties into account. If time permits, we will also look into serially concatenated codes with turbo decoding [MA01] of the best schemes identified in task 1-2. Here, the recent work in [MCA+15] might be useful.

The applicant, a PhD student and a post doc will perform the research in tasks 1-5. The post doc will have a special focus during mth 1-24 to aid with optimization techniques and during mth 25-48 to develop techniques to assess baseband energy efficiency of the investigated techniques. We will have this in focus when recruiting the post doc for the two respective project periods (mth 1-24 and mth 25-48, respectively).

4 Significance

The best frequency-division multiple access scheme in use in today’s mobile wireless access systems is SC-FDMA in LTE, which has a *continuous-time-domain* PAPR of about 7.5 dB for a spectral efficiency of 1 bit/s/Hz. With constrained envelope precoded OFDMA in the form of CPM-SC-FDMA, we have already shown that we can lower the PAPR down to 0.5 dB while maintaining a spectral similar efficiency of 1 bit/s/Hz and similar error rate performance at the receiver side, and we can find schemes with end-to-end RF energy gains on 4 dB.

With this research project, we make a more general approach to constrained envelope coded multiple access by exploring other multi-carrier schemes than OFDM and seek to optimize the constrained envelope pre-coding to cope with new challenging application scenarios. At the same time, we will unveil the fundamental limits of envelope-constrained communications by means of an information-theoretic analysis and seek to optimize the true end-to-end energy efficiency taking baseband energy consumption into account. As discussed in Section 1, constrained-envelope coded multiple-access schemes are attractive for future wireless access, wireless backhaul, satellite, and optical fiber last mile communications. The most significant near-term application scenarios may be for efficient M2M communications in 5G wireless access and for wireless access and wireless backhauling communications at mm-wave frequency bands.

5 Preliminary results

In Fig. 4 and Fig. 5 we summarize our most recent results on the CPM-SC-FDMA scheme, as published in [WPS11].

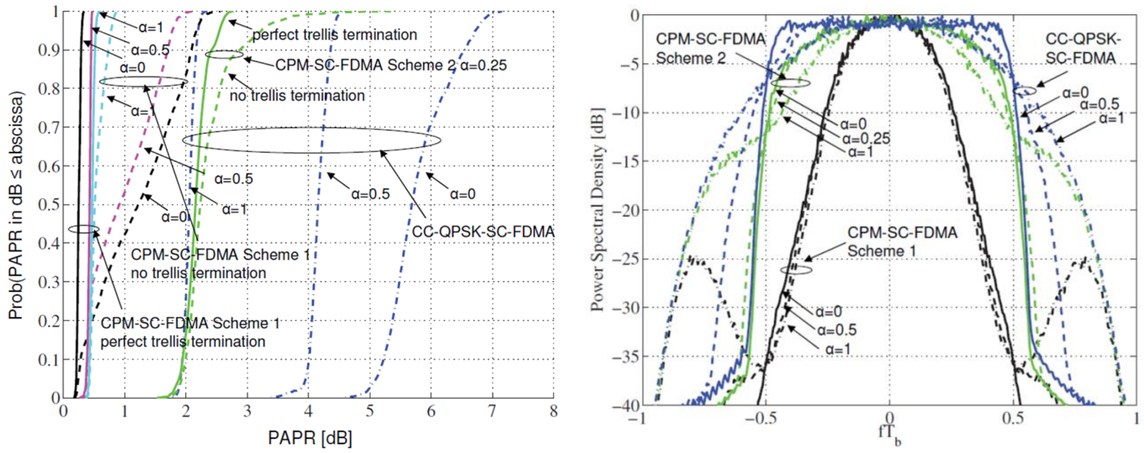

Fig. 4: Performance overview of CPM-SC-FDMA. Left: The PAPR cumulative density function shows that CPM-SC-FDMA can be 7 dB better than convolutionally encoded QPSK modulated SC-FDMA (CC-QPSK-SC-FDMA). Right: spectrum is well confined and with equal data rate and spectrum efficiency as CC-QPSK-SC-FDMA.

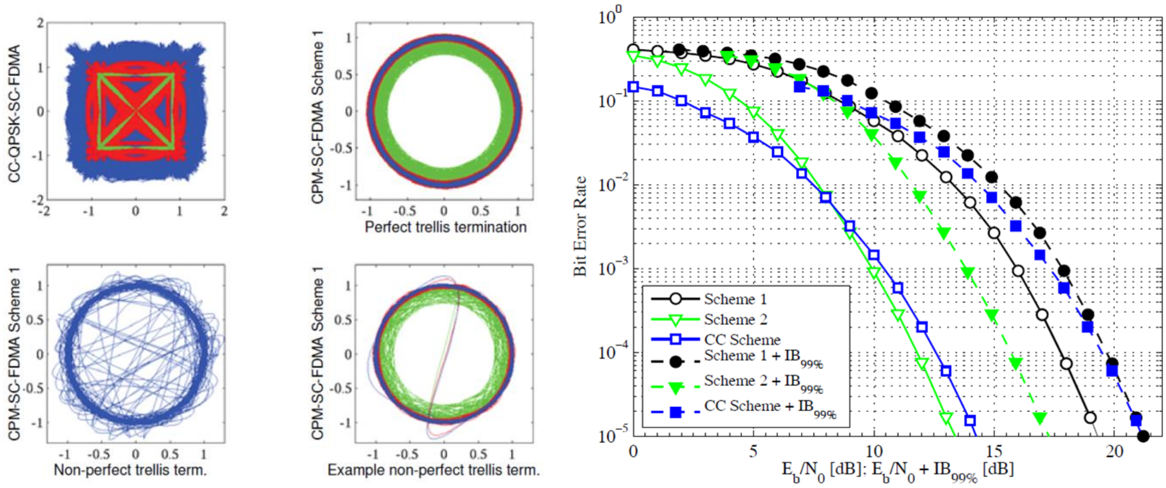

Fig. 5: Performance overview of CPM-SC-FDMA. Left: CPM-SC-FDMA I/Q diagram shows that the signal is confined within two concentric rings. Right: The CPM-SC-FDMA schemes show equal or better Bit Error Rate (BER) versus energy per bit (E_b) over AWGN power spectral density (N_0) than CC-QPSK-SC-FDMA including HPA backoff requirements.

6 National and International Collaborations

The applicant has a strong track record in European research aimed at the definition of next generation wireless access standards in collaboration with industrial partners. For this project, we intend to collaborate with and impact the EU Horizon2020 mmMAGIC project, which the applicant will be heavily involved in. mmMAGIC aims at the definition of a 5G wireless access system using mmWaves. We will also build on system assumptions from the EU FP7 METIS project (www.metis2020.com) that the applicant has been heavily involved in.

Important collaboration partners at Chalmers will be Prof. Thomas Eriksson at Chalmers on HPA modeling and efficiency evaluation, and Assoc. Prof. Giuseppe Durusi on performance limits. Both Thomas and Giuseppe will be involved as co-supervisors of the participating students. We will also collaborate with Assist. Prof. Kin Cheong Sou (applied optimization expert). Kin is sharing his time between the Math and the Signals and Systems departments at Chalmers. If time permits, as mentioned in the research plan, we will also explore serially concatenated schemes, and there we plan to collaborate with Assoc. Prof. Alexandre Graell i Amat at Chalmers. In addition to the funded researchers in the project, we will involve several MSc thesis students.

7 Other Grants

This project has no relation to research carried out within ongoing projects sponsored by VR. The main applicant is co-applicant of a VR project with Prof. Thomas Eriksson at Chalmers. That project has a different focus and will complement the research in this project very well.

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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	Tommy Svensson	25
2	Other personnel with doctoral degree	Post doc	50
3	Other personnel without doctoral degree	PhD student	100

Salaries including social fees

	Role in the project	Name	Percent of salary	2016	2017	2018	2019	Total
1	Applicant	Tommy Svensson	25	286,000	296,000	307,000	317,000	1,206,000
2	Other personnel with doctoral degree	Post doc	50	340,000	352,000	364,000	377,000	1,433,000
3	Other personnel without doctoral degree	PhD student	100	544,000	563,000	582,000	603,000	2,292,000
	Total			1,170,000	1,211,000	1,253,000	1,297,000	4,931,000

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	Kontor	84,000	87,000	90,000	93,000	354,000
	Total	84,000	87,000	90,000	93,000	354,000

Running Costs

	Running Cost	Description	2016	2017	2018	2019	Total
1	Datorer		15,000		15,000		30,000
2	Konferensresor		60,000	60,000	60,000	60,000	240,000
3	IT-kostnader		26,000	27,000	28,000	29,000	110,000
	Total		101,000	87,000	103,000	89,000	380,000

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	1,170,000	1,211,000	1,253,000	1,297,000	4,931,000		4,931,000
Running costs	101,000	87,000	103,000	89,000	380,000		380,000
Depreciation costs					0		0
Premises	84,000	87,000	90,000	93,000	354,000		354,000
Subtotal	1,355,000	1,385,000	1,446,000	1,479,000	5,665,000	0	5,665,000
Indirect costs	429,000	444,000	460,000	475,000	1,808,000		1,808,000
Total project cost	1,784,000	1,829,000	1,906,000	1,954,000	7,473,000	0	7,473,000

Explanation of the proposed budget

Briefly justify each proposed cost in the stated budget.

Explanation of the proposed budget*

Project Budget

The proposed budget for the project is for four years, with 1.79-1.96 kSEK/year.

The main budget items are (excluding indirect costs)

- PhD student at Chalmers, 80% (to be recruited): 544-603 kSEK/year
- Post doctoral researcher at Chalmers, 50% (to be recruited) 340-377 kSEK/year
- Senior researcher at Chalmers, 25% applicant Tommy Svensson: 286-317 kSEK/year

In addition, travel costs of 60 kSEK/year are included, mainly for traveling to conferences and workshops, and 15 kSEK year 2016 and 2018 for computers. The remaining costs are related to office costs and IT support.

The goal is that the PhD student will perform research on all the defined tasks 1-5 in the project description, but with close collaboration with the applicant and a post doc. The post doc will have a special focus during mth 1-24 to aid with optimization techniques and during mth 25-48 to develop techniques to assess baseband energy efficiency of the investigated techniques. We will have this in focus when recruiting the post doc for the two respective project periods (mth 1-24 and mth 25-48, respectively).

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

CV for Tommy Svensson (http://www.chalmers.se/en/staff/Pages/tommy-svensson.aspx)

Tommy Svensson is Associate Professor in Communication Systems at Chalmers University of Technology ("Chalmers"), Gothenburg, Sweden, where he is leading the research on air interface and microwave backhauling network technologies for future wireless systems.

His main expertise is in design and analysis of physical layer algorithms, multiple access schemes, coordinated multipoint schemes, as well as moving relays/cells/networks for wireless access and wireless backhaul networks, and recently satellite networks. He also has industrial experience of higher layers and system design for wireless communication systems. He has co-authored two books and more than 110 journal and conference papers. IEEE Senior member.

1. Higher education qualification(s):

MSc ("Civilingenjör"), Engineering Physics, Chalmers, Dec 1994.

2. Doctoral degree

Ph.D. in Information Theory from Chalmers, March 2003. Ph.D. Thesis defended Jan 2003, "Spectrally Efficient Continuous Phase Modulation". Thesis supervisor: Arne Svensson, Chalmers.

3. Postdoctoral positions

- Coordinator Chalmers Master Program on Communication Engineering Jan. 2012-present.
- Own research and coordinator of Chalmers involvement together with Third party Uppsala University in the EU FP7 METIS project https://www.metis2020.com, and EU FP7 ARTIST4G project https://ict-artist4g.eu.
- Own research and coordinator of Chalmers involvement in the emerging EU Horizon2020 5GPPP mmMAGIC project focusing on mmWave for access and backhauling, starting mid 2015.
- Initiator, project leader and own research within the VINNOVA project on Microwave backhauling for IMT advanced and beyond (MAGIC).
- Project preparation and project leading of "Mobility management, control and routing technology for IMT-Advanced and beyond" project with Beijing University of Post and Telecommunications (BUPT) within the VINNOVA-MOST (Ministry of Science and Technology in China) program on IMT Advanced and Beyond.
- Coordination with budget, legal contracts, cost claims, reporting and work planning responsibilities, for Chalmers and our Third parties Uppsala and Karlstad university in the EU FP6 IST-2003-507581 WINNER (2004-2005), IST-4-027756 WINNER II (2006-2007) and CELTIC CP5-035 WINNER+ projects. http://projects.celtic-initiative.org/winner+/
- Own research within the WINNER, WINNER II and WINNER+ projects. In WINNER II also task leader of the multiple access task with extensive contributions to the WINNER II system concept. The WINNER projects have been acknowledged by the EU commission: http://europa.eu/rapid/pressReleasesAction.do?reference=IP/09/1238
- Attracted external funding from VINNOVA, ESA, EU and VR accumulated until present to 40 MSEK.
- Reviewer of conference papers and journal papers such as IEEE Globecom, VTC, ICC, PIMRC, IEEE WCNC, Milcom, and COST289; IEEE Trans. Wireless Comm., Communications, Communications Letters, Wireless Communications Letters, Journal on Selected Areas in Communications, Trans. Vehicular Technology, Proc. of the IEEE, Wireless Communications Magazine, EURASIP Journal on Wireless Communications and Networking, Wiley Wireless Communications and Mobile Computing, China Communications, IET Communications
- TPC member: EUSIPCO 2011/2012, EW2011, VTC2012-Fall/2013Spring, ISWCS2010, PIMRC2010/2012/2014, WEMIC 2006, ICC2014, WCNC2013/2014, Globecom BWA workshop 2013, SweCTW2011/2012/2013, ICCVE2013/2014, ICC2014/2015, 5GU2014
- Workshop steering committee member of SweCTW 2011, 2012, 2013, 2014.
- Organizing committee member at SNOW workshop 2014, Åre, Sweden.
- Tutorial on "Coordinated Multi-Point in Cellular Networks" at ICC'2013, June 2013, Budapest, Hungary, SweCTW'2013, Aug 2013, Gothenburg, Sweden, ISWCS'2013, Aug 2013, Ilmenau, Germany.
- Track chair VTC2013-Spring, Track co-chair VTC2012-Spring.
- Research Evaluator for Research Council of Norway, 2004, Italian Research and University Evaluation Agency, ANVUR&PRIN, 2013, Cyprus Research Promotion Foundation 2014.

- Co-organizer of "International Workshop on Emerging Technologies for LTE-Advanced and Beyond-4G" 2012, in conjunction with IEEE Globecom 2012, 2013, 2014 and 2015(to appear).
- Evaluation committee member of PhD candidates Daniel Calabuig Soler, Universidad Politécnica de Valencia (UPV), Dec 2009; Emil Björnsson, KTH Nov 2011; Tania Villa Trapala, EURECOM, France, Sep 2013; pre-eval&opponent Xiaojia Lu, Oulu University, Finland, Sep.&Dec. 2013; Johannes Lindblom, Linköping University, Sweden, Jan 2014; Sara Modarres Razavi, LiU Norrköping campus, May 2014; Lei Shi, KTH, June 2014; Miltiades FILIPPOU, EURECOM, July 2014; Hamed Farhadi, KTH, Dec 2014.
- Invited speaker at the WWI Innovation Day, Brussels, Nov 2007, European Commission FP7 Consultation Meeting: Future Mobile and Wireless Radio Systems, Feb 6, 2008.
- Technical Reviewer of 4 STREP project in EU FP7 and FP6 within Information and Communication Technologies (ICT), Objective ”The Network of the Future”, 2009 and 2010.
- Invited as Horizon2020 project applications evaluator.
- Expert member of EU H2020 5GPP-related Networld2020 European Technology Platform (ETP).
- Development and teaching of the ESS165/ESS166 Communication Systems course in the undergraduate Electrical Engineering program E3 during 2003, 2004, 2005 and 2007.
- Guest lecturer in Communication Engineering Master Program course SSY135 Wireless communications, 2009, and SSY145 Wireless Networks, 2009-2014, Beijing University of Posts and Telecommunications (BUPT), Beijing, China, 2010.
- June 2006 - Aug 2007: Board member, Sep 2007 - Dec 2009: Vice Chairman, and Jan 2010 to Present: Chairman of IEEE Sweden VT/COM/IT Chapter. Received the IEEE Comsoc Chapter Achievement Award 2011, 2012 and 2013, and IEEE Information Theory Society Chapter of the Year Award 2013, as well as the IEEE Comsoc Special recognition award "For long-time achievements in chapter activities and ongoing excellence serving its members", 2013.
- Best paper award at IEEE International Conference on Connected Vehicles & Expo (ICCVE’2013), Las Vegas, USA, Dec 2013.

4. Qualification required for appointment as a docent

June 23, 2010, at Chalmers. Docent seminar: “Research Towards IMT Advanced and Beyond”.

5. Present position, period of appointment

- 2010/07, Present, Chalmers, Associate Professor. Time for research in the position: about 40%.

6. Previous positions and periods of appointment

2008/01-2010/07, Chalmers, Project Manager & Project applications and coordination, Research towards Associate Professor competence. **2004/01-2008/01**, Chalmers, Assistant Professor, Research, teaching and project management. **2003/02-2004/01**, Ericsson AB, Mölndal, System Designer, System design of Point-to-point Microwave Radio Links. Then, leave of absence until 2005-12-31. **2003/01-2003/05**, Chalmers, Lecturer. **1997/09-2003/01**, Chalmers and part time employment at Ericsson Microwave Systems AB, Mölndal, Ph.D. student, Ph.D. studies on coded modulation. **1994/12-1997/08**, Ericsson Mobile Data Design AB, Gothenburg, Software Engineer and System Designer, project leader, design and implementation of software systems for mobile packet data switches in Mobitex, PPDC and GPRS.

7. Deductible time

2003/02-2004/01 Ericsson AB, Mölndal, Sweden, System Designer, Ericsson MINI-LINK.

8. Supervision

- Main supervisor of 3 PhD students, Jingya Li, Yutao Sui and Tilak Rajesh Lakshmana. All three obtained their Licentiate degrees in early 2013. The defense of Jingya Li is scheduled for April 29, 2015, and the other two are expected to graduate their PhD during autumn 2015.
- I am/have been co-supervisor of 6 PhD students, whereof Nima Jamaly and Behrooz Makki defended their PhD thesis April and Nov. resp. 2013, Wei Wang defended her Licentiate degree Jan. 2006. Currently I’m co-supervising 3 PhD students, Rajet Krishnan, Rahul Devassy, and Srikar Muppirisetty. Srikar defended his Licentiate Dec. 2014, and Rajet will defend his PhD April 10, 2015.
- Postdoctoral researchers under my guidance: Carmen Botella Mascarell Jan 2009-Jan 2011; Hani Mehrpouyan Sep 2010 - April 2012; Agisilaos Papadogiannis Aug 2011 - Feb 2013. Nima Seifi April 2013-Sep 2013. Behrooz Makki Nov 2013 - present.
- Supervision of external/internal MSc theses, leading to several conference and journal publications.

Publication list

Publication List 2007-present for Tommy Svensson

Citation database: Google Scholar. h-index: 17
Complete publication list at:
http://publications.lib.chalmers.se/lists/publications/people/html/index.xsql?ids=340&lyear=1900&hyear=2020

Five most cited publications

- M. Sternad, T. Svensson, T. Ottosson, A. Ahlen, A. Svensson, A. Brunström, "Towards Systems Beyond 3G Based on Adaptive OFDMA Transmission," Proceedings of the IEEE, 95 (12) pp. 2432 - 2455, Dec 2007. Number of citations: **118**.
- P. S. Kildal, A. Hussain, X. Chen, C. Orlenius, A. Skårbratt, J. Åsberg, T. Svensson, T. Eriksson, "Threshold Receiver Model for Throughput of Wireless Devices with MIMO and Frequency Diversity Measured in Reverberation Chamber," IEEE Antennas and Propagation Wireless Letters, pp. 1201-1204, 2011. Number of citations: **47**.
- T. Svensson, T. Frank, D. Falconer, M. Sternad, E. Costa, A. Klein, "BIFDMA - A Power Efficient Multiple Access Scheme for Non-frequency-adaptive Transmission," IST Mobile Summit 2007, Budapest, July 2007. Number of citations: **46**.
- H. Mehrpouyan, A. Nasir, S. D. Blostein, T. Eriksson, G. K. Karagiannidis, T. Svensson, "Joint Estimation of Channel and Oscillator Phase Noise in MIMO Systems," IEEE Transactions on Signal Processing. 60 (9) s. 4790-4807, 2012. Number of citations: **44**.
- A. Osseiran, E. Hardouin, M. Boldi, I. Cosovic, K. Gosse, A. Gouraud, J. Luo, J. Monserrat, T. Svensson, A. Tölli, A. Mihovska, S. Redana, M. Werner, W. Mohr, "The Road to IMT-Advanced Communication Systems: State-of-the-Art and Innovation Areas Addressed by the WINNER+ Project", IEEE Communications Magazine, June 2009. Number of citations: **34**.

1. Peer-reviewed original articles

1. B. Makki, T. Eriksson, T. Svensson, "On the Performance of the Relay-ARQ Networks," IEEE Transactions on Vehicular Technology, To appear. Number of citations: **0.**
2. D.T. Phan-Huy, M. Sternad, T. Svensson, "Making 5G adaptive antennas work for very fast moving vehicles," IEEE Transactions on Intelligent Transportation Systems and Intelligent Transportation Systems Magazine, To appear. Number of citations: **0.**
3. L. Wang, F. Tian, T. Svensson, D. Feng, M. Song, and S. Li, "Exploiting Full Duplex for Device-to-Device Communications in Heterogeneous Networks," IEEE Communications Magazine, To appear. Number of citations: **0.**
4. Y. Sui, I. Guvenc, T. Svensson "Interference Management for Moving Networks in Ultra-Dense Urban Scenarios," EURASIP Journal on Wireless Communications and Networking, 2015. To appear. Number of citations: **0.**
5. B. Makki, T. Svensson, T. Eriksson, M. Debbah, "On Feedback Resource Allocation in Multiple-Input-Single-Output Systems using Partial CSI Feedback," IEEE Transactions on Communications. Communications, IEEE Transactions on, vol.63, no.3, pp.816,825, March 2015. Number of citations: **0.**
6. B. Makki, T. Svensson, T. Eriksson, M. S. Alouini, "Adaptive Space-Time Coding using ARQ," IEEE Transactions on Vehicular Technology, vol.PP, no.99, pp.1,1., Oct 2014. Number of citations: **0.**
7. B. Makki, T. Svensson, T. Eriksson, M. S. Alouini, "Coordinated Hybrid Automatic Repeat Request," IEEE Communications Letters, vol.18, no.11, pp.1975,1978, Nov. 2014. Number of citations: **3.**
8. B. Makki, T. Svensson, M. Zorzi, "Finite Block-length Analysis of the Incremental Redundancy HARQ", IEEE Wireless Communications Letters, vol.3, no.5, pp.529,532, Oct. 2014. Number of citations: **1.**
9. N. Seifi, J. Zhang, R.W. Heath., T. Svensson, M. Coldrey, "Coordinated 3D Beamforming for Interference Management in Cellular Networks", IEEE Transactions on Wireless Communications, vol.13, no.10, pp.5396,5410, Oct. 2014. Number of citations: **1.**

10. R.D. Taranto, L.S. Muppirisetty, R. Raulefs, D. Slock, T. Svensson, H. Wymeersch "Location-aware Communications for 5G Networks", IEEE Signal processing magazine, vol.31, no.6, pp.102,112, Nov. 2014. Number of citations: **3.**
11. J. Li, M. Matthaiou, T. Svensson "I/Q Imbalance in Two-Way AF Relaying", IEEE Transactions on Communications. vol., no., pp.5042, 5048, 10-14 June 2014. Number of citations: **2.**
12. V. Jungnickel, K. Manolakis, W. Zirwas, V. Braun, M. Lossow, M. Sternad, R. Apelfrojd, T. Svensson, "The Role of Small Cells, Coordinated Multi-Point and Massive MIMO in 5G", IEEE Communications Magazine. vol.52, no.5, pp.44,51, May 2014. Number of citations: **28.**
13. A. Papadogiannis, M. Färber, A. Saadani, M. D. Nisar, P. Weitkemper, T. Martins de Moraes, J. Gora, N. Cassiau, D. Ktenas, J. Vihriälä, M. Khanfouci, T. Svensson "Advanced Relaying Concepts and Challenges for Networks beyond 4G", IEEE Vehicular Technology Magazine, vol.9, no.2, pp.29,37, June 2014. Number of citations: **0.**
14. R. Chai, H. Zhang, X. Dong, Q. Chen, T. Svensson, "Optimal joint utility based load balancing algorithm for heterogeneous wireless networks", Springer, Wireless Networks, 1-15, Jan 2014. Online: http://link.springer.com/article/10.1007/s11276-014-0695-0#. Number of citations: **0.**
15. Z. Mayer, J. Li, A. Papadogiannis, T. Svensson, "On the Impact of Control Channel Reliability on Coordinated Multi-Point Transmission", EURASIP Journal on Wireless Communications and Networking, Feb 2014. Online: http://jwcn.eurasipjournals.com/content/2014/1/28/abstract. Number of citations: **0.**
16. J. Li, M. Matthaiou, T. Svensson, "I/Q Imbalance in AF Dual-Hop Relaying: Performance Analysis in Nakagami-m Fading", IEEE Transactions on Communications, March 2014. Number of citations: **5**.
17. Y. Sui, A. Papadogiannis, J. Vihriälä, M. Sternad, W. Yang, T. Svensson, "Moving Cells: A promising solution to boost performance for vehicular users", Special Issue IEEE Communications Magazine, 51, (6), 2013. Number of citations: **24**.
18. R. Krishnan, M. R. Khanzadi, T. Eriksson, T. Svensson, "Soft metrics and their Performance Analysis for Optimal Data Detection in the Presence of Strong Oscillator Phase Noise", IEEE Transactions on Communications, 2013. Number of citations: **8**.
19. B. Makki, T. Eriksson, T. Svensson, "On an HARQ-based coordinated multi-point network using dynamic point selection", EURASIP Journal on Wireless Communications and Networking 2013, 209. Number of citations: **3**.
20. X. Xu, D. Wang, X. Tao T. Svensson, "Resource pooling for frameless network architecture with adaptive resource allocation", SCI. CHINA Inf. Sci. 2013, Vol. 56 Issue: 022314(12) DOI: 10.1007/s11432-013-4788-7, Online: http://info.scichina.com:8083/sciFe/EN/abstract/abstract509836.shtml Number of citations: **5**.
21. R. Chai, X. Wang, Q. Chen, T. Svensson, "Utility-based bandwidth allocation algorithm for heterogeneous wireless networks", SCI. CHINA Inf. Sci. 2013, Vol. 56 Issue: 022313(13) DOI: 10.1007/s11432-013-4789-6, Online: http://info.scichina.com:8083/sciFe/EN/abstract/abstract509835.shtml. Number of citations: **8**.
22. J. Li, T. Eriksson, T. Svensson, C. Botella, "Power Allocation for Two-Cell Two-User Joint Transmission", IEEE Communication Letters. 16 (19) s. 1474-1477, 2012. Number of citations: **5**.
23. J. Li, C. Botella, T. Svensson, "Resource allocation for clustered network MIMO OFDMA systems", EURASIP Journal on Wireless Communications and Networking. 2012. Number of citations: **11**.
24. H. Mehrpouyan, A. A. Nasir, S. D. Blostein, T. Eriksson, G. K. Karagiannidis, T. Svensson, "Joint Estimation of Channel and Oscillator Phase Noise in MIMO Systems", IEEE Transactions on Signal Processing. 60 (9) s. 4790-4807. 2012. Number of citations: **44**.
25. T. R. Lakshmana, C. Botella, T. Svensson, "Partial joint processing with efficient backhauling using particle swarm optimization", EURASIP Journal on Wireless Communications and Networking, 2012, Number of citations: **6**.
26. X. Chen, X. Xu, H. Li, X. Tao, T. Svensson, C. Botella, "Improved resource allocation strategy in SU-CoMP network", The Journal of China Universities of Posts and Telecommunications, (4) pp. 7-12, 2011. Number of citations: **3**.

27. P. S. Kildal, A. Hussain, X. Chen, C. Orlenius, A. Skårbratt, J. Åsberg, T. Svensson, T. Eriksson, " Threshold Receiver Model for Throughput of Wireless Devices with MIMO and Frequency Diversity Measured in Reverberation Chamber", IEEE Antennas and Propagation Wireless Letters, pp. 1201-1204, 2011. Number of citations: **47**.
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29. J. Li, X. Xu, X. Chen, X. Tao, H. Zhang, T. Svensson, C. Botella, "Downlink Radio Resource Allocation for Coordinated Cellular OFDMA Networks", IEICE Transactions on Communications, (12) pp. 3480-3488, 2010. Number of citations: **10**.
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EU Project deliverables

METIS projects deliverables (https://www.metis2020.com/documents/deliverables/):

1. F. Schaich, ..., T. Svensson, et al. EU FP7 INFSO-ICT-317669 METIS, D2.3 “Components of a new air interface - building blocks and performance”, April 2014.
2. R. Fantini, ..., T. Svensson, et al. EU FP7 INFSO-ICT-317669 METIS, D3.2 “First performance results for multi-node/multi-antenna transmission technologies”, April 2014.
3. E. Pollakis, ..., T. Svensson, et al. EU FP7 INFSO-ICT-317669 METIS, D4.2 “Final report on trade-off investigations”, Sep 2014
4. P. Weitkemper, ..., T. Svensson, et al. EU FP7 INFSO-ICT-317669 METIS, D2.2 “Novel radio link concepts and state of the art analysis”, Oct 2013.
5. N. Brahmi, V. Venkatasubramanian, ..., T. Svensson, et al. EU FP7 INFSO-ICT-317669 METIS, D4.1 “Summary on preliminary trade-off investigations and first set of potential network-level solutions”, Sep 2013.
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42. Khanfouci, Mourad; Redana, Simone; Bonneville, Hervé; Braun, Volker; Brück, Stefan; Cesar, Bozo; Fantini, Roberto; Färber, Michael; Gora, Jacek; He, Xiaoben; Kténas, Dimitri; Liebl, Guenther; de Moraes, Thiago Martins; Saadani, Ahmed; Seidel, Eiko; Svensson, Tommy; Pietsch, Christian; Weitkemper, Petra; Zirwas, Wolfgang: EU FP7 INFSO-ICT-247223 ARTIST4G, D3.1 Definitions and Architecture requirements for supporting Advanced Relay concepts, 2010.

WINNER projects deliverables (http://projects.celtic-initiative.org/winner+/):

43. Osseiran, Afif; Auer, Gunther; Mehdi, Bennis; Boldi, Mauro; Gouraud, Alexandre; Jungnickel, Volker; Mayrargue, Sylvie; Mihovska, Albena; Monserrat, Jose; Sroka, Pawel; Svensson, Tommy; Tölli, Antti; Vihriälä, Jaakko; Thiele, Lars; Zinovieff, Eric: CELTIC CP5-026 WINNER+, D2.2 Enabling Techniques for LTE-A and beyond, 2010.
44. Svensson, Tommy; Zinovieff, Eric; Auer, Gunther; Bennis, Mehdi; Boldi, Mauro; Botella, Carmen; Brunel, Loic; Calvanese, Emilio; D'Amico, Valeria; Duchesne, Amelie; Greco, Paulo; Jungnickel, Volker; Komulainen, Petri; Ktenas, Dimitri; Liu, Yang; Mayrargue, Sylvie; Melis, Bruno; Mihovska, Albena; Monserrat, Jose; Olsson, Magnus; Osseiran, Afif; Pennanen, Harri; Rasmussen, Lars; Roemer, Florian; Rost, Peter; Savin, Valentin; Schoenen, Rainer; Sezginer, Serdar; Sroka, Pawel; Thiele, Lars; Tölli, Antti; Vihriälä, Jaakko; Vivier, Guillaume; Wesolowski, Krzysztof; Xiao, Ming: CELTIC CP5-026 WINNER+, D1.9 Final Innovation Report, 2010.
45. Auer, Gunther; Cabrejas, Jorge; Calvanese, Emilio; Clessienne, Thierry; Greco, Paulo; Wylie-Green, Marilynn P.; Ktenas, Dimitri; Martín-Sacristán, David; Mihovska, Albena; Monserrat, Jose; Otyakmaz, Arif; Rossi, Roberto; Saul, Andreas; Sroka, Pawel; Svensson, Tommy: CELTIC CP5-026 WINNER+, D1.5 Intermediate Report on System Aspect of Advanced RRM, 2009.
46. Boldi, Mauro; Botella, Carmen; Boccardi, Federico; D'Amico, Valeria; Hardouin, Eric; Olsson, Magnus; Pennanen, Harri; Rost, Peter; Savin, Valentin; Svensson, Tommy; Tölli, Antti: CELTIC CP5-026 WINNER+, D1.8 Intermediate Report on CoMP (Coordinated Multi-Point) and Relaying in the Framework of CoMP, 2009.
47. Osseiran, Afif; Gouraud, Alexandre; Svensson, Tommy; Boldi, Mauro; D'Amico, Valeria; Hardouin, Eric; Monserrat, Jose; Otyakmaz, Arif; Saul, Andreas; Tölli, Antti; Vihriälä, Jaakko; Bennis, Mehdi; Mihovska, Albena: CELTIC CP5-026 WINNER+, D2.1 Preliminary WINNER+ System Concept, 2009.
48. Bengtsson, Mats; Shankar, Bhavani; Björnson, Emil; Boccardi, Federico; Boldi, Mauro; D'Amico, Valeria; Fehske, Albrecht; Fuchs, Martin; Hardouin, Eric; Komulainen, Petri; Melis, Bruno; Olsson, Magnus; Papadogiannis, Agisilaos; Pennanen, Harri; Rost, Peter; Saadani, Ahmed; Schellmann,

Malte; Svensson, Tommy; Thiele, Lars; Tölli, Antti; Wild, Thorsten: CELTIC CP5-026 WINNER+, D1.4 Initial Report on Advanced Multiple Antenna Systems, Dec 2008.

49. Aronsson, Daniel; Auer, Gunther; Svensson, Tommy; et., al: EU FP6 IST-4-027756 WINNER II, D2.3.3 Link level procedures for the WINNER System, Nov 2007.
50. Auer, Gunther; Döttling, Martin; Svensson, Tommy; et., al: EU FP6 IST-4-027756 WINNER II, D6.13.14 WINNER II System Concept Description, Dec 2007.
51. Irmer, Ralf; Döttling, Martin; Svensson, Tommy; et., al: EU FP6 IST-4-027756 WINNER II, D6.13.10 Final CG wide area description for integration into overall System Concept and assessment of key technologies, Nov 2007.
52. Lestable, Thierry; Ma, Yi; Svensson, Tommy; et., al: EU FP6 IST-4-027756 WINNER II, D2.2.3 Modulation and Coding schemes for the WINNER II System, Nov 2007.
53. Rouquette-Lveil, Stephanie; Auer, Gunther; Svensson, Tommy; et., al: EU FP6 IST-4-027756 WINNER II, D6.13.12 Final CG local area description for integration into overall System Concept and assessment of key technologies, Oct 2007.

3. Monographs

1. * T. Svensson, ”Spectrally Efficient Continuous Phase Modulation”, Gothenburg, Chalmers University of Technology. Ph.D. thesis, Technical report 435, Dec. 2002. Number of citations: **5.**
2. T. Svensson, “On Spectrally Efficient Continuous Phase Modulation”, Gothenburg, Chalmers University of Technology, Licentiate thesis, Technical report 363L, Nov. 2000. Number of citations: **7.**

4. Research review articles

None.

5. Books and book chapters

1. Book chapter in: A. Osseiran, W. Mohr, J. Monserrat, …, T. Svensson, et, al., “Mobile and wireless communications for IMT-A and beyond”, ISBN/ISSN: 978-1-1199-9321-6, 2011. Number of citations: **33**.
2. Book chapter in: W. Mohr, M. Döttling, A. Osseiran, …, T. Svensson, et, al., “Radio Technologies and Concepts for IMT-Advanced”. Wiley Nov. 2009. ISBN/ISSN: 978-0-470-74763-6. Number of citations: **4**.

6. Patents

No patent granted, but one submitted. IPR rights are sold to Ericsson AB, Dec 2014.

7. Open access computer programs or databases you have developed

None.

8. Popular-scientific articles/presentations

1. Numerous invited talks at Ericsson AB in Sweden/ Italy/ China, 2005-present
2. Numerous technical presentations within EU projects (WINNER, ARTIST4G, METIS), 2004-present
3. Invited speaker with three talks related to Heterogeneous networks, Moving networks, and Radio link enablers at METIS 5G Global Summit, Berlin, Oct 2014.
4. Invited speaker “Challenges and research towards 5G” at EURECOM, Sep 2013, and University of Oulu, Dec 2013.
5. Invited guest lecturer in Communication Engineering Master Program course SSY145 “Wireless Networks” on Future wireless systems technologies, Department of Signals and Systems, Chalmers University of Technology, Sweden, 2009-2014.
6. Invited speaker at Huawei 5G@Europe, Munich, Feb 2014.
7. Invited speaker at Huawei Research Shanghai R&D center, April 2013.
8. Invited speaker at Orange Labs, Oct 2012.

9. Tutorial on “Coordinated Multi-Point in Cellular Networks” at ICC’2013, June 2013, Hungary, SweCTW’2013, Aug 2013, Sweden, ISWCS’2013, Aug 2013, Germany.
10. Invited speaker at Chongqing University of Posts and Telecommunications, 2012.
11. Invited speaker at Beijing University of Posts and Telecommunications, 2010.
12. Invited speaker at Ericsson AB Göteborg, Ericsson AB Mölndal, Ericsson AB Milano, Ericsson Research Stockholm, Ericsson Research Beijing at several occasions during 2005-2013.
13. Invited speaker with title ”Visions and technologies for IMT Advanced and Beyond” at the CHASE workshop Oct 22-23, 2008.
14. Invited speaker with titles ”Technologies and impacts on spectrum management” and ”Visions of IMT Advanced and Beyond” at the Future Spectrum Management workshops at Chalmers with the National Telecommunications Commission, Thailand during Jan 31-Feb 1 and April 15-16, respectively, 2008.
15. Invited speaker at the European Commission FP7 Consultation Meeting: Future Mobile and Wireless Radio Systems, Feb 6, 2008, with the aim to influence coming FP7 call profiles.
16. Haardt, Martin; Stuckmann, Peter; Zimmermann, Rainer; Svensson, Tommy; et., al: Report on the FP7 Consultation Meeting, Future Mobile and Wireless Radio Systems: Challenges in European Research., Feb 2008. ftp://ftp.cordis.europa.eu/pub/fp7/ict/docs/future-networks/20080206-future-mobile-and-wireless-radio-systems-report en.pdf
17. Invited speaker at the Wireless World Initiative (WWI) Innovation Day, Brussels, Nov 2007, describing our main innovations within the WINNER II system concept.
18. Guest lecturer on future wireless networks in the course ITS031, Computers, Communication, and Social Networks, 2006, within the undergraduate school at Chalmers Technology Management and Economics.

Pedagogical science publication:

1. Svensson, Tommy: Retrospective Analysis of ESS166 Kommunikationssystem E3. Pedagogical Papers Series, vol.3, Winter 2009,

Articles in IEEE Communications Magazine describing the Swedish IEEE VT/COM Section activities:

1. Hernandez, Juan; Nilsson, Jan; Svensson, Tommy; Timus, Bogdan; Wilhelmsson, Leif R., ”Age vs. Time Speed at Sweden ComSoc”, IEEE Communications Magazine, March 2009.
2. Hernandez, Juan; Nilsson, Jan; Svensson, Tommy; Timus, Bogdan; Wilhelmsson, Leif R., ”A White Green Scenario for Communications”, IEEE Communications Magazine, June 2008.

CV

Name: Tommy Svensson	**Doctorial degree:** 2003-03-25
Birthdate: 19700120	**Academic title:** Docent
Gender: Male	**Employer:** Chalmers tekniska högskola

Research education

Dissertation title (swe)		
Spektral-effektiv kontinuerlig fasmodulation		
Dissertation title (en)		
Spectrally Efficient Continuous Phase Modulation		
Organisation	**Unit**	**Supervisor**
Chalmers tekniska högskola, Sweden Sweden - Higher education Institutes	3204 - Kommunikationssystem	Arne Svensson
Subject doctors degree	**ISSN/ISBN-number**	**Date doctoral exam**
20203. Kommunikationssystem	91-7291-244-8	2003-03-25

Publications

Name: Tommy Svensson	**Doctorial degree:** 2003-03-25
Birthdate: 19700120	**Academic title:** Docent
Gender: Male	**Employer:** Chalmers tekniska högskola

Svensson, Tommy 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.