Vetenskapsrådet

Application

2015-03-31

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Descriptive data

Project info

Project title (Swedish)*

PRESIDIUM - Distribuerad optimering med certifierade Sekretess Garantier

Project title (English)*

PRESIDIUM - PRivacy prEServIng DIstribUted OptiMization

Abstract (English)*

Sovereign state governments, national and international banks and companies in a free market, hospitals, social network members, electors, electrical distribution companies and local electrical producers, wireless devices, are all typical networked parties that have to collaborate by distributed computations for huge mutual benefit while the transactions among them must be private. For example, wireless devices may cooperatively compute the best routing path for downloading some multimedia content, or send sensitive data to the cloud to receive services without disclosing private information. Hospitals could merge their patient data sets, which contain private information, to better classify, derive patient state correlations, and make risk predictions, which is currently not allowed in many European and North American countries due to privacy restrictions.

The classical protocols to preserve privacy among parties that need to perform joint computations are given by cryptography and secure multi-party computation theory (a subfield of cryptography). However, cryptography can be used only in some special cases of the applications mentioned above. Even when it can be used, cryptography may introduce substantial overhead among the parties. Performing a computation using cryptography is still order of magnitudes slower than performing it with no privacy guarantee. The party may need to share anyhow private control information to set-up the cryptographic primitives. Cryptography is prone to attack by third parties who may inadvertently own or recover the cryptographic keys. For large networks, it might be prohibitive or simply impossible to use cryptography. Thus, new solutions must be established where computations are solved without sharing private data and without engaging a trusted third-party.

Any collaboration among parties for distributed computations is ultimately based on mathematical distributed optimization problems, the solution of which requires data sharing among these parties. Unfortunately, collaboration may be substantially hindered or prevented due to privacy concerns. Actually, this is the case when merging medical data sets of different hospitals for inference purposes, which is currently not allowed in Sweden and many other European and North American countries due to privacy reasons. Yet such a collaboration would entail great benefits for society if conducted properly. The fundamental question is how to quickly solve distributed optimization problems among parties that are unwilling or cannot share their sensitive data and that yet would receive much benefit by a collaboration.

In this research project, we plan to establish a new fundamental theory for privacy preserving distributed optimization. The growing size, complexity, and heterogeneity of networks make it simply essential the availability of fast and private distributed solution methods. In the near future, it is expected that the role of optimization will be even more important, when billions of wireless devices will have to optimally interconnect people, things, and machines. The development of such a theory would posses many appealing aspects, e.g., efficiency, scalability, natural geographical distribution of problem data. It would offer highly desirable privacy-preserving properties without requiring the huge extra coordination or overhead required by cryptography. Several application scenarios can benefit from our theoretical investigations: from communication networks, to smart grids, intelligent transportation systems, and industrial automation.

The development of a new theory of privacy preserving optimization would have a huge impact in the scientific community as well as in the society. We believe our results would enable many applications that are currently not allowed by cryptography, with exceptional benefits in the society: for example, medical data could be privately shared among hospitals to perform inference (which is not allowed today due to privacy concerns), thus leading to better medical

Popular scientific description (Swedish)*

Regeringar, nationella och internationella banker, företag på den fria marknaden, sjukhus, sociala nätverk, väljare, elleverantörer och lokala elektriska producenter, och trådlösa enheter är alla typiska nätverksanslutna parter som har mycket att tjäna på att samarbeta, förutsatt att de inte behöver lämna ut känslig data. Trådlösa enheter kan tillsammans beräkna den bästa routing-vägen under nedladdningar, eller skicka känsliga data till molnet för att använda tjänster utan att avslöja privat information. Sjukhus kan slå ihop sina patientdatabaser, som innehåller privat information, för att bättre diagnostisera patienter och göra riskbedömningar. För närvarande är detta inte tillåtet i många europeiska och nordamerikanska länder på grund av integritetslagstiftning.

Den klassiska metoden för att bevara integriteten hos parter som behöver utföra gemensamma beräkningar är kryptografi och ”secure multi-party computation” (ett delområde av kryptografi). Kryptografi kan endast användas i vissa särskilda fall av de tillämpningar som nämns ovan. I de fall där kryptografi är tillämpbart, kan det införa betydande overhead mellan parterna. Att utföra en beräkning med hjälp av kryptering är fortfarande tiotals gånger långsammare än att genomföra det utan krav på bevarad integritet. Parterna kan ändå behöva ge ut privat information för att ställa upp de kryptografiska beräkningarna. Kryptering kan också utsättas för angrepp från en tredje part som har funnit de kryptografiska nycklarna. För stora nätverk, kan det vara opraktiskt eller helt enkelt omöjligt att använda kryptografi. Därför behöver nya metoder upprättas, där beräkningar genomförs utan att privata uppgifter delas och utan att använda en betrodd tredje part.

Alla samarbeten mellan parterna för distribuerade beräkningar bygger ytterst på matematiska optimeringsproblem, vars lösning kräver delning av data mellan dessa parter. Tyvärr kan samarbetet hindras väsentligt, eller helt förhindras, på grund av integritetsfrågor, trots att sådant samarbete skulle innebära stora fördelar för samhället om det utförs på rätt sätt. Den grundläggande frågan är hur man snabbt kan lösa distribuerade optimeringsproblem mellan parter som är ovilliga eller inkapabla att dela sina känsliga uppgifter, trots att de skulle få mycket nytta av ett samarbete.

I detta forskningsprojekt planerar vi att etablera en ny grundläggande teori för integritetsbevarande distribuerad optimering. Den växande storleken, komplexiteten och mångfalden av nätverk gör det nödvändigt att dessa metoder är snabba och distribuerade. Inom en snar framtid kan det förväntas att denna form av optimering kommer bli ännu viktigare, då miljarder nya trådlösa enheter på ett optimalt sätt måste sammankoppla människor, saker och maskiner. Den utvecklade teorin skulle ha många tilltalande egenskaper inom effektivitet, skalbarhet och naturlig geografisk fördelning av problemens datamänger. Det skulle ge mycket önskvärda sekretessbevarande egenskaper utan att kräva den enorma extra samordningen och overheaden som krävs av kryptografi. Våra teoretiska undersökningar kan var till nytta i många tillämpningar, t.ex. kommunikationsnät, smarta elnät, intelligenta transportsystem och industriell automation.

Utvecklingen av en ny teori om integritetsbevarande optimering skulle ha en enorm inverkan såväl i vetenskapliga kretsar som i samhället. Vi tror att våra resultat skulle möjliggöra många lösningar som för närvarande inte stöds av kryptografi, med exceptionella fördelar i samhället. Exempel på detta är datadelning mellan sjukhus under diagnostisering (vilket på grund av integritetsskäl inte kan göras idag), som leder till bättre medicinska behandlingar och kan rädda många liv. Försäkringsbolagen skulle kunna använda varandras datamänger (utan att ge ifrån sig känslig data) för att minska riskerna och därmed erbjuda lägre premier, vilket skulle ge stora kostnadsbesparingar. Även framtida heterogena trådlösa nätverk måste drivas av distribuerade optimala algoritmer som upprätthåller användarnas integritet och personuppgifter.

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 > 20205. Signalbehandling 2. Teknik > 202. Elektroteknik och elektronik > 20202. Reglerteknik 2. Teknik > 202. Elektroteknik och elektronik > 20204. Telekommunikation

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

Keyword 1*

privacy

Keyword 2*

optimisation

Keyword 3*

data analysis

Keyword 4

networking

Keyword 5

network operations

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*

No specific ethical issues are concerned. The project deals with mathematical optimisation theory and its application to domains for which emulations of sensitive data such as personal data is enough. No real personal data will be needed.

The project includes handling of personal data

No

The project includes animal experiments

No

Account of experiments on humans

No

Research plan

1 Purpose and aims

Privacy is an essential concern for today's networked world. Internet of Things, Cyber Physical Systems, and Tactile Internet [1], are making it possible to interconnect people, things, and machines by billions of connected devices for real-time communication, control, and monitoring purposes. Wireless devices, member of social networks, smart grids with electrical distribution companies and local electrical producers, intelligent transportation systems, are all examples of networked nodes that have to interact for mutual benefits while the **operations among them must be private**. Analogously, personal health and lifestyle measurements, personal purchases, personal movements, or home energy consumptions will produce huge quantity of **data whose processing and analysis demands privacy**. The constant development of these technology has rapidly outpaced the ability to protect operations and data exchange in networked systems [1]. There is a fundamental need to develop innovative theoretical methods capable to ensure privacy.

Operations among nodes of a network are often based or simply governed by optimisation problems, the solution of which has to be achieved by keeping private the problem's input and/or the decision variables. This is an extremely relevant issue because mathematical optimisation theory is of pervasive application in networking, control, and signal processing. A relevant example is efficient resource allocation in wireless networks or smart grids by auction mechanisms (i.e., network optimisation mechanisms), where a major concern for the nodes participating to the auctions is their unwillingness to reveal their utilities or consumer profile [2]. Yet, the distributed optimisation underlying the auctions has to be carried out so to maximise the network utility without disclosing the individual nodes's utilities. Another relevant example is the case of statistical analysis of health-related data collected by wearable wireless sensors. Here, data sets belonging to different persons could be merged to better classify, derive person's state correlations, and make risk predictions while keeping private the person's data sets [3]. More in general, the utility of privacy optimisation methods has been noted in the communities of signal processing [4], machine learning literature [3, 5], and networking [2, 6]. In fact, although these optimisation problems arise in diverse engineering domains, they share some key mathematical characteristics. **The fundamental question is how to solve distributed optimisation problems among networked nodes that are unwilling or cannot share their private data and that yet would receive much benefit by the problem's solution?**

Unfortunately, there is not an adequate theory for privacy preserving distributed optimisation. Privacy has not been the concern of traditional optimisation methods. The capability of optimisation to ensure privacy has been known or casually noted here and there in various application domains. However, no systematic approach to pose a general framework can be found. The classic approach to preserve privacy, cryptography (and in particular its sub-field secure multi-party computation theory) [7], introduces formidable overheads and heavy coordinations in optimisation, which substantially prevents or makes it impossible the use of current optimisation solvers. The alternative methods to cryptography, namely, Information-theoretic secrecy [8], Differential privacy [9], k-anonymity [10], and Signal Processing security methods [4], cannot be applied to optimisation over networks either. Information-theoretic secrecy, similar to cryptography, prevents that an eavesdropper learns information among two communicating nodes taking advantage of encoding or channels. However, once data has been encoded, transmitted, and placed into a database of the receiver, it loses the privacy provided by the secure communication. By contrast, the **application domains of optimisation mentioned above contemplate that private information be never disclosed to any other party**. Differential privacy, k-anonymity and Signal processing methods perturb the original data to make data analysis, whereas optimisation methods either are of more general application (e.g., for resource allocation, consensus protocols, cloud computing) or when used for statistical data analysis, they may not require any source data perturbation and thus can be more accurate.

In this research project, we propose to undertake a systematic study of a new fundamental theory for privacy preserving distributed optimisation. We emphasise the distributed nature, because the agents are distributed nodes interacting by a network. We are particularly interested at three aspects 1) How to quantify or measure privacy, 2) How to design optimisation-based privacy preserving mechanisms of provable privacy measure, 3) How to apply the new methods to relevant application domains and further investigate the tradeoff between privacy techniques and potential optimality losses for the problems at hand. The development of such a theory would posses many appealing aspects, e.g., efficiency, scalability, natural geographical distribution of problem data. It would offer highly desirable privacy-preserving properties without requiring the huge extra coordination or overhead required by cryptography. Similar to cryptography, Differential privacy, k-anonimity and Signal processing security methods, we are concerned with privacy because it is the essential component of trust. How to protect the optimisation from misbehaviour of network nodes is an orthogonal question that will deserve another future project in its own right.

We have already started to lay the initial foundations of such a theory in [11, 12]. Specifically [11] was presented to the invited session on "Systems and Control Methods for Cybersecurity" organized by Profs. J. Baras, T. Basar, C. Cassandras, and I. Paschalidis at the IEEE Conference on Decision and Control 2013. Given the broad application nature of the planned fundamental research, it will be carried out in collaboration with well-known scholars at our institution KTH Royal Institute of Technology, but also at MIT Massachusetts Institute of Technology (where we are currently on Sabbatical for the overall 2015), Harvard University (where a PhD student of our will be visiting researcher), and other collaborators specified in the related section below. This project springs as a natural continuation of the VR research projects "In-network computation in wireless sensor networks" (Junior Researcher, 2007) and "In-network optimization in wireless sensor networks" (Projectbidrag) we were awarded in 2011. None of these projects dealt with privacy.

Finally, the name PRESIDIUM is an acronym as PRivacy prEServIng DIstribUted optiMization, and evokes the ancient Roman institutions or buildings that guarded for trust and security.

2 Survey of the Field

In this section, we focus on the state-of-the-art of distributed optimisation and methods to ensure privacy.

The theory of distributed optimisation is grounded on parallel and distributed computation, which was developed for networks of processors [13]. This is a topic that has attracted much attention in the recent years [3, 14–16], especially for what concerns convex solution methods. Convex optimisation, given the availability of interior point methods and Lagrangian duality [17], has been very popular for applications such as cross-layer adaptation, network utility maximisation, and distributed statistical learning. These studies have advanced the classic methods, such as decomposition methods [13] to state-of-the-art distributed optimization methods, such as consensus-based distributed optimization [14] and alternating direction method of multipliers (ADMM) [3]. ADMM methods in particular are having a prominent role in statistical data analysis and machine learning. Interestingly, ADMM methods are casually known to possess privacy guarantees, however this characteristic has never been formally investigated with respect to neither which adversary model nor which privacy measure.

Optimisation solution methods and non-convexity are challenging for privacy. The solution methods to distributed optimisations from the literature above are commonly based on decomposition techniques or on intermediate consensus iterations, where an iterate-and-broadcast procedure among the nodes injects huge amounts of messages over the network. This causes high vulnerability to privacy attacks given that the many message-passings can be eavesdropped by an adversary. How to adopt faster methods that are less privacy vulnerable is an open problem. In addition, many network optimisation problems, such as distributed nodes localisation, medium access control scheduling, and even radio power control, are non convex. Recent non-convex methods include the iterative contraction mappings of the interference function theory and monotonic optimisation [18]. A promising behaviour of ADMM on non convex problems is discussed in some recent papers [19], where the ADMM can be viewed (at state-of-the-art) as a mere heuristic. The privacy guarantees of these non-convex methods or how to make them sufficiently private has never been investigated.

The classical protocols to preserve privacy among parties that need to perform joint computations, such as solving distributed optimisation problems, are given by cryptography theory [7] and secure multi-party computation theory [20, 21] (which is a subfield of cryptography). Cryptography-based methods for optimisation are well investigated [7]. There, cryptographic tools are used to privately perform iterations of the well known simplex and interior-point algorithms so that sensitive data is not disclosed during the solution iterations [22]. However, cryptographic methods are unfavorable in terms of computational complexity and efficiency [7, 22], which greatly limits their applicability to networked systems. Cryptography introduces substantial overhead among the parties due to the exchange of security information and coordination. Performing a computation using cryptographic protocols is still order of magnitudes slower than performing the computation with no privacy guarantee [7]. For future networks, which will have to carry already huge amount of data, or large data sets, it might be prohibitive or simply impossible to use cryptography. Consequently, non-cryptographic methods for optimisation have recently attracted the interest of the research community [6, 23]. The key idea is to use algebraic manipulations to disguise the original problem. However, these works consider very simple optimisation problems (for example, only special cases of linear optimization problems). No attempts have been made to establish a systematic general theory.

In addition to cryptographic methods, there are other methods to ensure privacy in context such as in physical layer communications (Information secrecy), statistical data analysis (Differential privacy) [9], data mining (k-anonimity) [10], and more recently Signal Processing methods [4]. Information secrecy, initiated by Shannon, aims at protecting communication networks from eavesdroppers without using cryptography, but exploiting the randomness of the channels [8]. However, Information theoretic secrecy makes assumptions on channels, such as channel state information or channel advantage over the eavesdropper or broadcast nature of the channel, computation and latency advantages, jamming/noise adding capabilities, as well as intelligent code design. These protocols have a drawback compared to optimisation, since they “disclose data to legitimate users, which provides informational utility while enabling possible loss of privacy. In the course of a legitimate transaction, a user can learn some public information, which is allowed and needs to be supported and at the same time also learn/infer private information, which needs to be prevented. Thus every user is (potentially) also an adversary” [4].

Differential privacy is a concept defined for statistical databases [9]. In these data bases, sensitive information of the users (e.g. medical records, voter registration information, email usage) has to be guaranteed. How to learn useful information about data set without learning anything about individual users can be accomplished by statistical data perturbations of Differential privacy methods. Differential privacy is a measure of how any sequence of outputs (responses to queries) is essentially equally likely to occur. Optimisation methods have a wider scope than just dealing with statistical data sets, moreover optimisation methods are more appealing because may not introduce any perturbation. However, when optimisation based methods are used for inference from statistical data sets, such as by ADMM methods, a completely open question is what is the relation between the privacy measure of the optimisation methods and Differential privacy? When using optimisation for tasks other than statistical data analyses (e.g., resource allocation, consensus, localisation), the continuous message exchange of iterative solution methods could benefit from differential Privacy approaches. Such a bridge between Differential privacy and optimisation is completely unexplored.

K-anonymity privacy concept has bene proposed for data mining to deal with this problem: "Given person-specific field-structured data, produce a release of the data with scientific guarantees that the individuals who are the subjects of the data cannot be re-identified while the data remain practically useful” [10]. Privacy in the k-anonymity sense means that the information for each person contained in the data release cannot be distinguished from at least k-1 individuals whose information also appear in the release. Thus, k-anonymity deals with different problems with respect to optimisation based methods. Because k-anonymisation does not include any randomisation, attackers can still make inferences about data sets [9].

Signal Processing methods for privacy are now being investigated [4]. The underlying idea involves processing the data (also called sanitation process), by perturbing data, altering data precision, suppressing or subsuming data, or aggregating data, prior to sharing them with a data collector who could make inferences on personal habits. Give then sanitation may reduce the data utility, a central question is the trade-off between privacy and utility. Thus Signal processing methods are concerned with the following three ingredients: 1) a (statistical) model for the data, 2) measures for privacy and utility, and 3) a method to formalise the mappings from private data to distorted data to be disclosed. Since optimisation based method do not need necessarily a statistical data analysis, they have the potentiality of being of broader interest than Signal processing methods. Interestingly, this was also noted in [4]. However, the relation between the two remains largely unexplored and will be the object of this research project.

Moving from the central existing scientific approaches and open issues we have surveyed, the research methodology will be further discussed in the section of the programme description, where we present a detailed overview of each activity and potential results to establish a new theory of fast distributed optimisation with privacy guarantees.

3 Programme Description

Our research programme is specifically formalised as follows: **We would like establish a general theory to solve in a manner that preserves nodes’s privacy, the general n-nodes network optimisation problems having the form:**

$$\inf_{\mathbf{x}\in\{\mathbf{x}|\mathbf{g}(\mathbf{x},\mathbf{A}_1,\ldots,\mathbf{A}_n)\preceq\mathbf{0}\}} f_0(\mathbf{x}_1,\ldots,\mathbf{x}_n,\mathbf{A}_1,\ldots,\mathbf{A}_n)\,, \tag{1}$$

where $\mathbf{A}_i$ is the private data belonging to node i, $\mathbf{x} = (\mathbf{x}_1,\ldots,\mathbf{x}_n)$ are the decision variables of which node i wants to know the optimal $\mathbf{x}_i$, $f_0(\cdot)$ is the network global objective function, $\mathbf{g}(\cdot)$ is the vector-valued constraint function. **This seemingly simple optimisation problem is instead very general and models all the applications mentioned in the previous**

sections. In wireless networks, $f_0(\cdot)$ is, e.g., the network utility, $\mathbf{A}_i$ represent the parameters owned by the node, such as the available storage, or energy budget, or traffic profile, and $\mathbf{x}_i$ are the protocol decision variables describing how to allocate the resources, whereas the constraint $\mathbf{g}(\cdot)$ is for example due to delay or quality of service [2, 4]. In statistical data analysis, $f_0(\cdot)$ is a classification or estimation error, the nodes own data sets $\mathbf{A}_i$ to merge for operations such as estimation, classification, or inference, and $\mathbf{x}_i$ is the individual classifier, and $\mathbf{g}(\cdot)$ defines the boundary of the classification [3, 5]. Many more examples include the consensus problem for multi-agent systems [14], game-theoretic approaches (namely, sub-optimal optimisations) in smart grids data pricing [24], distributed positioning of network nodes [12, 25], cloud-computing outsourcing [6]. The fundamental theory we would like to establish concerns how to solve the distributed optimisation problem (1) with privacy guaranties, namely without that the nodes give out information such as $\mathbf{A}_i$ or individual decision variables $\mathbf{x}_i$ and nevertheless are able to compute the optimal solution $\mathbf{x}_i^*$?

To establish this exciting theory, we will follow three main activities each corresponding to a work-package. The first activity considers the investigation of the measures to quantify the privacy characteristics of the optimisation problems. The results of the first activity will be used to establish the methods capable to ensure measurable privacy in the second activity. Finally, the results of the first and second activities will be put together to investigate fundamental performance in relevant application domains. The activities are structured in such a way that, roughly, two PhD students could develop the planned tasks: every activity has at least two tasks, each corresponding to a PhD student. As a contingency plan, in case the project is approved and the requested funding would be reduced, the project can still be carried out by a PhD student, clearly developing only selected tasks per activity.

3.1 Privacy measures in Optimisation (Months 1-18)

In this activity, the fundamental question is the quantification of universal indexes that quantify privacy for problem (1). This activity will demand considerable research efforts, since many standard privacy/security conventional definitions are already adopted in cryptographic, Signal Processing and Information theory literature. However, cryptographic definitions, Differential privacy measures, k-anonymity measures, and Signal Processing measures cannot be directly applied for optimisation based approaches since optimisation has more application domains.

The first thrust in this activity will consist in investigating a privacy measure that have the following properties: 1) easy to compute, 2) capable to allow unequivocally comparisons of privacy among different optimisation problems or different solution methods to the optimisation, 3) when optimisation based methods apply and also alternative statistical data analysis approaches apply (i.e., data bases with Differential privacy methods, data mining with k-anonymity methods, statistical data based with Signal processing methods), the privacy index should allow to unequivocally tell whether optimisation methods are better or worse compared to the alternative approaches. We will make the important distinction between the capability to ensure privacy by using optimisation problems (**extrinsic privacy**) and the capability of the optimisation solution method to maintain privacy in the solution process (**intrinsic privacy**). The challenging part of this thrust is that no formal definition or quantification of attack models as well as of privacy can be found in the papers from the literature where optimisation has been noted to possess privacy properties, including the celebrated optimisation paper on ADMM for statistical data analysis [3]. We will perform a through literature investigation of the metrics used in the contexts of cryptography and statistical data analysis. We have already started to investigate a preliminary privacy indexes for optimisation in [11, 12], however the definition is restricted to the case 2) above and to extrinsic privacy.

The second thrust of this activity will consists in formalising the concept of attack models, such as passive or active eavesdroppers, and will have to give a theoretical base to specify what is the eavesdropper knowledge and what are the sensitive parts of the problems that must be private, such as problem's input constants, output values, functions, and variables. The specification of eavesdropper knowledge will have to take into account the two essential different aspects: optimisation problem (1) can ensure privacy for operations that are not optimisation problems by themselves, but can be posed as an optimisation (extrinsic privacy). For example, consensus protocols or outsourcing computations to cloud computing are not an optimisation problem, but can be equivalently formulated by an optimisation. The second aspect concerns with privacy within the solution procedure of optimisation problems (intrinsic privacy). Since there are different classed of parallel and distributed solution methods, where specific information has to be exchanged among the nodes of the network, each class will deserve its own attention with respect to the attack model.

3.2 Privacy-preserving Optimisation Methods (Months 12-30)

The second activity will build on the result of the previous one to establish a general theoretical framework of optimisation methods that are provably privacy preserving. A unified privacy protecting framework, where all existing approaches can be included, developed, and other could be added, would allows us to establish standard proof techniques for proving the privacy properties (measures) of optimisation methods. These mechanisms will be grouped into two categories: the theoretical mechanisms that we can apply to disguise the problem (1) data and variables so they remain protected against an active or passive eavesdropper (extrinsic privacy), and the theoretical mechanisms that make the solution methods of problem (1) private (intrinsic privacy).

In the first thrust of this activity, the theoretical mechanisms to disguise the optimisation problem data and variables will be investigated (extrinsic privacy). The key idea of existing methods is to use deterministic algebraic manipulations to disguise $f_0(\cdot)$, $\mathbf{g}(\cdot)$, and $\mathbf{x}_i$ into an equivalent problem so that the private data is hidden while the optimal solution is unchanged. However, given that transformation methods have been studied only for specific optimisation problems and no attempts have been made to establish a systematic approach, we aim at proposing a general framework that capitalises on more general techniques, such as change of variables and transformation of objective and constraint functions, not only deterministic but also stochastic. An interesting issue that has never been considered in the optimisation literature is that there are problem structures for which simple deterministic algebraic transformation will not by sufficient for privacy. In such a case, we will re-consider Differential privacy mechanisms and of Signal Processing mechanism, such as perturbing the problem's data or objective or constraints by deterministic or probabilistic manipulations. This will naturally rise the issue of quantifying the trade off between the resulting sub optimality of the solution and the privacy index. A unified framework to encapsulate both existing algebraic transformations to disguise sensitive problem data, and the new ones will be developed. We have already started to work in this direction in [11], where, however, we have not considered any deterministic or stochastic perturbation.

In the second thrust of this activity, we will focus on the privacy of the solution mechanism for problem (1) (intrinsic privacy). First, the privacy preserving mechanisms that are inherent in the classical decomposition techniques such as primal decomposition, dual decomposition, ADMM methods will be reviewed. We intend to clearly identify the existing privacy preserving solution methods that have been noted in the literature. Recently developed non-convex methods, such as the promising Fast-Lipschitz optimisation or ADPM, will be considered, as we have already planned in [12]. Af for the case of extrinsic privacy methods, we plan to investigate when the nature of the solution method cannot per-se ensure privacy or is subject to high privacy vulnerability. In such cases, which have never been considered in the literature, we will take inspiration from Differential privacy and Signal Processing methods by perturbing the problem structure, variables or functions in such way that the privacy indexes are of adequate value while the resulting sub optimality of the solution is still acceptable.

3.3 Application to Selected Relevant Domains (Months 28-48)

The importance of our theoretical results of the first and second work packages will be highlighted in three relevant categories: 1) competitive privacy, which occurs when competing agents unwilling to disclose private information have to share a common resource; 2) statistical data privacy among distributed data sets, and 3) consumer privacy, which is related to guaranteeing privacy for users of smart devices. Within these application domains, whose relevance has been already recognised in [4], the new optimisation theory will allow to quantify privacy in terms of efficiency, scalability, and complexity.

In the first thrust of this activity we will consider the case of competitive privacy. This occurs for example in wireless cellular and/or heterogenous networks, smart power grids, financial systems, water distribution networks [2]. Here, a number of competing agents typically perform measurements on a common system (e.g., the wireless spectrum, or the individual smart phones traffic distribution, or the power distribution buses, etc.). The measurements enable estimating the underlying state vector. Each agent wishes to minimise the estimation state error to gain some own utility (the sum of the utilities is $f_0(\cdot)$) and allocate some resource (i.e., the $\mathbf{x}_i$'s) within some constraints $\mathbf{g}(\cdot)$ (resources are not unlimited). Collaboration among the agents by measurements exchange would allow a better individual estimation, but the agents are unwilling to collaborate since they generally consider their measures as confidential information. The competitive privacy problem consists in the distributed solution of a minimisation problem with private variables $\mathbf{x}_i$ and datasets $\mathbf{A}_i$. We will investigate what is the privacy of these competitive systems and what are the tradeoff in terms of privacy and optimality.

In the second thrust, we will consider scalable, privacy-preserving algorithm for distributed data analysis. This happens when merging the datasets of different hospitals or insurance or banks, where we encounter advanced machine learning tasks such as average/sum computation, distributed estimation, inference, and feature selection [3, 5]. Here, recall that the nodes own data sets $\mathbf{A}_i$, $\mathbf{x}_i$ is the individual classifier, and $\mathbf{g}(\cdot)$ defines the boundary of the classification. Our goal will be understanding fundamental tradeoffs between maintaining privacy while still providing a useful output (the optimisation result) from the statistical analysis procedure. Given that this application domain has been the focus of traditional methods such as Differential privacy and Signal Processing security, one important question will be the quantification of the efficiency, complexity and scalability of these traditional methods and our new methods. Working under the proposed models of privacy, we will study the fundamental tradeoff between privacy guarantees and optimality.

In the third thrust we will consider the case of consumer privacy, which deals with problems of data analysis to allocate a common resource among the users who then, in turn, may consume or contribute to the production of the resource [26]. As opposed to the competitive privacy of the first thrust, here the users are not competing, and as opposed to statistical data analysis of the second thrust, users also need to take decisions based on the data analysis. This is the typical case of the optimal power flow problem in smart grids, where a finegrained monitoring of power consumption by smart meters would enables better load balancing and reliability analysis in the electric grid. Clearly the consumers would like to preserve privacy of their profiles, while receiving a more reliable service (e.g., power loss minimisation) from the network operator. Once again, the relevant question is how to achieve such minimisation under privacy guarantees.

4 Preliminary Results

We have obtained encouraging preliminary results in all the planned activities. Our research has been characterised by the development or usage of theoretical optimisation results and their application in networking (protocol optimisation), signal processing (information processing and localisation), and control theory (networked control) domains. This research history will allow us to first propose the general theoretical results of the first two work packages, and then to apply them to the relevant domains as described in the third work package. In fact, we have recently proposed an initial foundation of privacy preserving optimisation in [J-1,C-69] (see Appendix C for the bibliography of this section), where, however, only simple deterministic variable transformation methods were initially formalised for intrinsic privacy, and an intrinsic privacy measure was suggested. We have been already active researchers in each application domain of this project.

We have been investigating optimisations in [B-1, J-22, J-23, J-24], where we proposed novel methods for network utility maximisation. Our research activity then focused on the mathematical modelling of medium access control and routing of wireless sensor networks as a preliminary step for their optimisation. Subsequently, new general methods to cross-layer protocol optimisation were proposed in [J-14, J-15, J-17, J-18, J-21, J-23, J-27, BC-3]. Important attempts to distributed optimisation solvers for sensor networks in industrial and automation domains were proposed in [J-27, C-7,C-40]. The emerging mmwaves wireless networks and resource allocation was studied in [J-2, J-7].

The joint optimisation of network protocols and operations, such as estimation and control, was considered in [J-2, J-6, J-16, J-19, BC-2, BC-3]. The distributed and fast optimisation of estimators, even in the presence of packet losses induced by the network, were proposed in [J-2, J-25, C-33]. In [J-19, C-35, C-44], the optimisation of rate allocation problems with radio power constraints for closed loop control and estimation over wireless networks was investigated. Algorithms to ensure the stability of a control loop and dynamic estimation by quickly optimising the network parameters were designed in [J-16, J-19, BC-3, BC-2, C-53, C-56].

While facing the research challenges about joint optimisation of network protocols, control, and estimation, the fundamental question of how to formalise a general optimisation approach of convex and non convex low computational and communication complexity arose naturally. This was investigated in a series of contributions [J-1,J-25, C-33, C-50], and notably in [J-25] where we established Fast-Lipschitz optimisation. In [J-3, J-7] we extended ADMM methods to non convex cases. Remarkably, the stability analysis of our networking problems is similar to the Optimal Power Flow network optimisation problem by non-convex ADMM we have studied in [J-9, J-12].

5 International and National Collaborations

The research project will be carried out in collaboration with well known leading experts both in academia, research centers, and industries. Current university international collaborations include, among others, Prof. E. Modiano, MIT Massachusetts Institute of Technology, Prof. V. Tarok at Harvard University, Prof. A. Sangiovanni Vincentelli, University of California at

Berkeley; Prof. J. Baras and Prof. T. Ephremides, University of Maryland, College Park, United States; Prof. L. Tassiulas, University of Thessaly, Greece; Prof. M. Rabbat, McGill University, Montreal, Canada; Prof. M. Di Benedetto and Prof. F. Santucci, University of L'Aquila, Italy; Prof. S. Coleri-Ergen, Koç University, Turkey. Current industrial collaborations include ABB Corporate Research, Sweden and Norway; Ericsson Research, Sweden; United Technology Research Center, East Hartford, CT, USA. In Sweden, we have several ongoing research collaborations with different groups at KTH Royal Institute of Technology, as well as with the Swedish Institute of Computer Sciences.

We are having also a leading role in the following European projects: The Swedish-Italian collaborative VR project Chromous (Cultural heritage monitoring by sensor networks) (2015-2017), NoE HYCON2 (Highly-complex and networked control systems), Network of Excellence, European Commission, FP7, 2010–2015; STREP HYDROBIONET (Autonomous Control of large-scale Water Treatment Plants based on Self-Organized Wireless BioMEM Sensor and Actuator Networks), European Commission, FP7 (2011-2015); several EIT ICT Labs projects on Wireless Sensor Networks, Smart Cities and Smart Grids (2011-2015).

6 Significance

The development of a new theory of privacy preserving optimisation would have a huge impact in the scientific community as well as in the society. Privacy and distributed optimisation are currently regarded (separately) as some of the most relevant research topics in signal processing, wireless networking, control and computer sciences. Between privacy and optimisation there is an evident fundamental research gap. Universities and academic research centre would benefit by the introduction of new courses both at the Master level and PhD level based on the theoretical explorations we propose to undertake.

A wide variety of real world problems can benefit by our research project, as we argued in the past sections. Our results would enable many applications that are currently not allowed by existing methods, with exceptional benefits in the society: future heterogeneous wireless networks will be able to operate by fast distributed optimal algorithms that maintain the privacy of the users and personal data; medical data could be safely shared without disclosing individual's information among hospitals to perform inference (a distributed optimisation problem) which is not allowed today due to privacy concerns, thus leading to better medical treatments and potentially saving of many lives; insurance companies would be able to merge their data sets to optimise the risks and thus offering cheaper premium with huge cost savings.

Our research has received appreciations both from academia and industry. Our work on distributed optimisation for sensor network has received the best paper award of the IEEE Transaction on Industrial Informatics in 2007 and IEEE Mobile Ad-Hoc and Sensor Systems 2005 and 2009. We have been already active in promoting the commercial use of our theoretical results. We received the best business idea award of Venture Cup for East Sweden in 2011 and recently the best business idea award for distributed localisation with privacy guarantees by Stockholm Innovation and Growth (STING) in 2014. We own an international patent on distributed optimisation algorithms for wireless networking, and have filed a patent on "Distributed Estimation of the Position of Network Nodes with Privacy Guarantees", which is the main asset of our start-up company that has recently received substantial support from the prominent Swedish innovation agency Vinnova, by the VFT2 Innovation Program, and from BGI-MIT international Innovation Program sponsored by the MIT Sloan School of Business, Cambridge MA.

The exciting and promising results we have so far obtained let us hope that our investigations may have relevant impacts in the society, with potentially many benefits for the scientific, technology, social, and industrial development in Sweden, Europe, and at a global scale.

References

[1] ITU-T Technology Watch Report. The Tactile Internet. Technical report, ITU, 2014.

[2] G. Iosifidis and I. Koutsopoulos. Challenges in auction theory driven spectrum management. *IEEE Communication Magazine*, pages 128–135, August 2011.

[3] S. Boyd, N. Parikh, E. Chu, B. Peleato, and J. Eckstein. Distributed optimization and statistical learning via the alternating direction method of multipliers. *Foundations and Trends in Machine Learning*, 3(1):1–122, 2011.

[4] L Sankar, W. Trappe, K. Ramchandran, H. V. Poor, and M. Debbah. The role of signal processing in meeting privacy challenges. *IEEE Signal Processing Magazine*, pages 95–106, September 2013.

[5] J. C. Duchi, M. I. Jordan, and M. J. Wainwright. Privacy aware learning. *J. ACM*, 61(6):38:1–38:57, December 2014.

[6] C. Wang, K. Ren, and J. Wang. Secure and practical outsourcing of linear programming in cloud computing. In *Proc. IEEE INFOCOM*, pages 820–828, Shanghai, China, April 2011.

[7] O. Goldreich. *The Foundations of Cryptography*, volume 2. Cambridge University Press, Cambridge, UK, 2004.

[8] M. R. Bloch S. W. McLaughlin W. K. Harrison, J. Almeida and J. Barros. Coding for secrecy. *IEEE Signal Processing Magazine*, pages 41–50, September 2013.

[9] C. Dwork and A. Roth. *The Algorithmic Foundations of Differential Privacy*, volume 9. NOW Foundations and Trends in Theoretical Computer Science, 2014.

[10] P. Samarati and L. Sweeney. K-anonymity: a model for protecting privacy. In *IEEE Symposium on Research in Security and Privacy*, May 1998.

[11] P. C. Weeraddana, G. Athanasiou, C. Fischione, and J. Baras. Per-se privacy preserving solution methods based on optimization. In *IEEE Conference on Decision and Control*, December 2013.

[12] P. C. Weeraddana, G. Athanasiou, C. Fischione, and J. Baras. On the privacy of optimisation methods. *IEEE Transactions on Automatic Control*, 2014. Provisionally Accepted. [Online]. Available: `http://arxiv.org/abs/1210.3283`.

[13] D.P. Bertsekas and J.N. Tsitsiklis. *Parallel and Distributed Computation: Numerical Methods*. Athena Scientific, Belmont, Massachusetts, USA, 2nd edition, 1997.

[14] A. Nedic, A. Ozdaglar, and P. A. Parrilo. Constrained consensus and optimization in multi-agent networks. *IEEE Transactions on Automatic Control*, 55(4):128–135, August 2010.

[15] L. Xiaojun, N.B. Shroff, and R. Srikant. A tutorial on cross-layer optimization in wireless networks. *IEEE Journal on Selected Areas on Communications*, pages 1452 – 1463, August 2006.

[16] C. Fischione. Fast-lipschitz optimization with wireless sensor networks applications. *IEEE Transactions on Automatic Control*, 56(10):2319–2331, October 2011.

[17] D. P. Bertsekas. *Nonlinear Programming.* Athena Scientific, Belmont, MA, 2nd edition, 1999.

[18] E.A. Jorswieck and E.G. Larsson. Monotonic optimization framework for the two-user MISO interference channel. *IEEE Transactions on Communications*, 58(7):2159–2168, 2010.

[19] R. Chartrand. Nonconvex splitting for regularized low-rank + sparse decomposition. *IEEE Transactions on Signal Processing*, 60(11):5810–5819, 2012.

[20] A. C. Yao. Protocols for secure computations. In *Proc. IEEE Symp. Found. of Comp. Science*, pages 160–164, Chicago, USA, November 1982.

[21] W. Du and Z. Zhan. A practical approach to solve secure multi-party computation problems. In *Proc. New Security Paradigms Works.*, pages 127–135, Virginia beach, Virginia, USA, September 23–26 2002.

[22] T. Toft. Solving linear programs using multiparty computation. *Financial Cryptography and Data Security. LNCS*, pages 90–107, 2009.

[23] O. L. Mangasarian. Privacy-preserving linear programming. *Opt. Letters*, 5(1):165–172, February 2011.

[24] L. Sankar E.V. Belmega and H. V. Poor. Enabling data exchange in interactive state estimation with privacy constraints. *IEEE Journal of Selected Topics in Signal Processing, Special Issue on Signal and Information Processing for Privacy*, January 2015.

[25] G. Rahmatollahi, G. Abreu, and S. Severi. Cooperative multihop localization with privacy. In *Decision and Control (CDC), 2012 IEEE 51st Annual Conference on*, pages 1524 – 1529, Nov.

[26] P. C. Weeraddana S. Magnusson and C. Fischione. A distributed approach for the optimal power flow problem based on admm and sequential convex approximations. *IEEE Transactions on Control of Network Systems*, 2015. To Appear. [Online]. Available: `http://arxiv.org/abs/1401.4621`.

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	Carlo Fischione	20
2	Other personnel without doctoral degree	PhD student	80
3	Other personnel without doctoral degree	PhD student	80

Salaries including social fees

	Role in the project	Name	Percent of salary	2016	2017	2018	2019	Total
1	Applicant	Carlo Fischione	20	300,000	300,000	300,000	300,000	1,200,000
2	Other personnel with doctoral degree	PhD student	80	400,000	400,000	400,000	400,000	1,600,000
3	Other personnel without doctoral degree	PhD Student	80	400,000	400,000	400,000	400,000	1,600,000
	Total			1,100,000	1,100,000	1,100,000	1,100,000	4,400,000

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	office space	100,000	100,000	100,000	100,000	400,000
2	Laboratory running costs	100,000	100,000	100,000	100,000	400,000
	Total	200,000	200,000	200,000	200,000	800,000

Running Costs

	Running Cost	Description	2016	2017	2018	2019	Total
1	Travel	Travel and Conference registration	50,000	50,000	50,000	50,000	200,000
2	Computers	Costs and maintenance	50,000	50,000	50,000	50,000	200,000
	Total		100,000	100,000	100,000	100,000	400,000

Depreciation costs

	Depreciation cost	Description	2016	2017	2018	2019	Total
1	PhD students salary increases	Doktorandsteg	0	50,000	70,000	100,000	220,000
	Total		0	50,000	70,000	100,000	220,000

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	1,100,000	1,100,000	1,100,000	1,100,000	4,400,000		4,400,000
Running costs	100,000	100,000	100,000	100,000	400,000		400,000
Depreciation costs	0	50,000	70,000	100,000	220,000		220,000
Premises	200,000	200,000	200,000	200,000	800,000		800,000
Subtotal	1,400,000	1,450,000	1,470,000	1,500,000	5,820,000	0	5,820,000
Indirect costs					0		0
Total project cost	1,400,000	1,450,000	1,470,000	1,500,000	5,820,000	0	5,820,000

Explanation of the proposed budget

Briefly justify each proposed cost in the stated budget.

Explanation of the proposed budget*

Cost Specification

The salary of the Principal Investigator and PhD students follows standard KTH Electrical Engineering rates.

The office space includes the common expenses at the Laboratory of Automatic Control plus those for the School of Electrical Engineering.

The laboratory running costs include the salaries for the administrative assistants and ofice supplies.

The travels specifies two trips per year per PhD student, including conference registration (approx. 2*10000SEK per student) plus 10000 for the PI.

The computer maintainance specifies the costs of buying computers and software support for two PhD students.

The depreciation summarises the salary increased of the PhD students depending on their level of seniority.

Contingency Plan

In the case the project is approved, and the full amount is not given, one PhD student might not be hired. The work specified in the workpackages can still be conducted since each workpackage consists of at least two separate thrusts. Thus, one thrust per work package could be removed in case of project approval with budget reduction so to hire only on PhD student.

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

Contact Information

Name	Carlo Fischione
Work address	School of Electrical Engineering, KTH Royal Institute of Technology, Stockholm, Sweden
Home page	`http://www.ee.kth.se/~carlofi`

Present and Previous Positions

- Visiting Associate Professor, MIT Massachusetts Institute of Technology, Laboratory of Information and Decision Systems (LIDS), Cambridge, MA, USA, January 2015-December 2015.
- Associate Professor with Tenure, KTH, July 2011–. 80% research, 20% teaching.
- Assistant Professor (VR funded), KTH, May 2008–June 2011.
- Visiting Scholar, University of California at Berkeley, Department of Electrical Engineering and Computer Sciences, Berkeley, CA, US, October-December 2006 and September 2004 - April 2005.

Postdoctoral positions

- Post Doc at University of California at Berkeley, Berkeley, CA, US, Department of Electrical Engineering and Computer Sciences, with Prof. Alberto Sangiovanni Vincentelli, May 2007–September 2008.
- Post Doc at KTH with Prof. Karl Henrik Johansson, May 2005–April 2007.

Doctoral Degrees

- PhD Degree, Electrical and Information Engineering (3/3 years), University of L'Aquila, L'Aquila, Italy, May 4 2005; thesis title: "*Performance Analysis of Control Algorithms and Protocols for Wireless Communications*".

Higher Education Degree

- Laurea Degree in Electronic Engineering (Summa cum Laude, 5/5 years), University of L'Aquila, L'Aquila, Italy, April 2001; Thesis: "*Analysis of Space-Time Codes for Wireless Communications*".

Docent

- Docent in Automatic Control, KTH Royal Institute of Technology, Stockholm, Sweden, February 2011.

Doctoral supervision (Main Supervisor)

- Junior Mairton Barroso da Silva, KTH, from March 2015, "Fundamental Analysis and Optimisation of Full-Duplex Wireless Networking", in progress.
- Sindri Magnússon, KTH, from March 2014, in progress, "Non Convex Distributed Optimisation with Signal Processing Applications".
- Rong Du, KTH, from March 2014, in progress, "Mixed Integer Real Distributed Network Optimisation in Cyber Physical Systems".
- Hossein Shokri, KTH, from September 2013, in progress, "Fundamental Performance Analysis and Optimization of MillimiterWaves Wireless Networking".
- Yuzhe Xu, KTH, from September 2011, in progress, "Distributed Network Optimization", September 2011.
- Martin Jakobsson, KTH, September 2011-September 2014 (Licentiate), "Extensions of Fast Lipschitz Optimization".
- De-facto main supervisor of Dr. Piergiuseppe Di Marco, KTH. PhD thesis "Modeling and Design of Wireless Protocols for Networked Control Applications". Graduation: January 2013.
- De-facto main supervisor of Dr. Pangun Park, KTH. PhD thesis "Modeling, Analysis, and Design of Wireless Sensor Network Protocols". Graduation: March 2011.

Post Doctoral supervision

- Lazaros Gkatzikis (2014-2015), Ph.D. with Prof. Leandros Tassiulas at University of Thessaly, Greece.
- George Athanasiou (2012-2013), Ph.D. with Prof. Leandros Tassiulas at University of Thessaly, Greece.
- Marco Levorato (2013). Ph.D. with Prof. Michele Zorzi, University of Padova, Italy. Now Assistant Professor (tenure track) at University of California Irvine, USA.
- Pradeep Chathuranga Weeraddana (2012-2014). Ph.D. with Prof. Antony Ephremides, and Prof. Matti Latva-aho at University of Oulu, Finland. Now Assistant Professor (tenure track) at Sri Lankan Institute of Information Technology, Malabe, Sri lanka.

Distinctions

- Best Paper Award of the "IEEE Sweden VT-COM-IT Chapter" for the paper "Effect of Rayleigh-Lognormal Fading on IEEE 802.15.4 Networks", P. Di Marco, C. Fischione, F. Santucci, K. H. Johansson, in Proc. of *IEEE International Conference on Communications 2013 (IEEE ICC 13)*, Budapest, Hungary, June 2013.
- Best Business Idea Award of the Venture Cup Sweden East, 2010/2011.
- Best Paper Award at "IEEE International Conference on Mobile Ad-hoc and Sensor Systems 2009 (IEEE MASS 09)" (18% acceptance rate).
- Best Paper Award for the IEEE Transactions on Industrial Informatics of the year 2007 (2.35 Impact Factor in 2009).
- Best Paper Award at "IEEE International Conference on Mobile Ad-hoc and Sensor Systems 2005 (IEEE MASS 05)" (18% acceptance rate).

Main ongoing or recent research projects

- Chromous - Cultural Heritage Monitoring via Wireless Sensor Networks, Italian Ministry of Research and Swedish Research Council, January 2015 - December 2017, principal investigator.
- In-Network Optimization over Wireless Sensor Networks, Swedish Research Council, Projektbidrag, January 2012 - December 2014, principal investigator.
- Vinnova-Wireless@KTH Develop LTE for Smart Energy Systems, June 2013 - May 2015.
- Vinnova-Wireless@KTH LTE for Water, June 2014 - May 2015.
- EIT ICT Labs Projects (I3C14-15, Car2X13, DevelopLTE4Grids12-14, VirtualSmartEnergyLab11), January 2012 - December 2015.
- Hydrobionets (Autonomous Control of large-scale Water Treatment Plants based on Self-Organized Wireless BioMEM Sensor and Actuator Networks, STREP Project, European Commission, FP7), 2011–2015, work–package leader, KTH co-principal investigator.
- HYCON2 (HYbrid CONtrol: Taming Heterogeneity and Complexity of Networked Embedded Systems, Network of Excellence, European Commission, FP7), 2010 – 2014, task leader, co-applicant.

Professional services

- Associated Editor of *Elsevir Automatica*, 2014–
- Guest Editor of the *IEEE Transactions on Industrial Informatics.*
- Co-organizer of the ACM CyberPhysicalSystems Water 2015, CPS Week. Signal Processing and Information Theory Track Chair, *IEEE International Conference on Distributed Computing in Sensor Systems (IEEE DCOSS '12)*, Hangzhou, China, May 2012; Student Activities Chair of *Cyber Physical Systems Week Conferences*, Stockholm, Sweden, 2010.
- Member of the Technical Program Committees of IEEE Int. Conference on Sensing Communication and Networking (SECON) 2015, IEEE European Conference on Control (ECC) 2013, 2014, 2015, IEEE Int. Conference on Distributed Computing in Sensor Systems (DCOSS) 2010, 2011, 2013, 2014, 2015; European Conference on Wireless Sensor Networks (EWSN), 2007, 2008, 2011, 2014; IEEE Int. Conference on Communications (ICC), 2011, 2013, 2015; IEEE Global Telecommunications Conference (Globecom), 2007, 2008, 2009, 2010, 2013; IEEE Real-Time Systems Symposium (RTAS) 2013, 2014, 2015; ACM/IEEE Int. Conference on Information Processing in Sensor Networks (IPSN) 2010, 2011; IEEE Int. Workshop on Wireless Sensor, Actuator and Robot Networks (WiSARN) 2012; IFAC Congress on Telematic Applications, 2013; IEEE Int. Conference on Automation Science and Engineering (CASE) 2012.

Teaching

- PhD level course EL3250 "Network Optimization", 7.0hp, 2014, KTH Royal Institute of Technology, course responsible and developer.
- Master level course EL2745 "Principles of Wireless Sensor Networks", 7.5hp, 2012, 2013, 2014, 2015, KTH Royal Institute of Technology, course responsible and course developer.
- Bachelor level course EL111X "Degree Project in Automatic Control", 15hp, Spring 2010, 2011, 2012, 2013, and 2014, KTH Royal Institute of Technology, course responsible and course developer.
- PhD level course EL3700 "Principles of Wireless Sensor Networks", 7.0hp, Fall 2009, 2011, 2015, KTH Royal Institute of Technology, course responsible.
- EL2420 Project Course in Automatic Control, Spring 2009, KTH Royal Institute of Technology, course responsible.
- Master level Course EL2450 Hybrid and Embedded Control Systems, Spring 2009 and 2010, 7.5hp, KTH Royal Institute of Technology, Sweden, course responsible.

Publication list

Books

[B-1] P. C. Weeraddana, M. Codreanu, M. Latva-aho, A. Ephremides and C. Fischione, “A Review of Weighted Sum-Rate Maximization in Wireless Networks”, NOW Foundations and Trends in Networking, Vol. 6, No 1-2, pp. 1–163, 2012.

Peer-reviewed original articles

[J-1] C. Weeraddana, G. Athanasiou, M. Jakobsson, C. Fischione, J. S. Baras, “Per-se Privacy Preserving Distributed Optimisation”, *IEEE Transactions on Automatic Control*, Provisionally Accepted for Publication, 2015.

[J-2] Y. Xu, C. Fischione, A. Speranzon, “A Model-Based Peer-to-Peer Estimator over Wireless Sensor Networks”, *Automatica*, Provisionally Accepted for Publication, 2015.

[J-3] S. Magnússon, C. Weeraddana, M. G. Rabbat, C. Fischione, “On the Convergence of Alternating Direction Lagrangian Methods for Nonconvex Structured Optimisation Problems”, *IEEE Transactions on Control of Network Systems*, Provisionally Accepted for Publication, 2015.

[J-4] M. Jakobsson, C. Fischione, C. Weeraddana, “Extensions of Fast-Lipschitz Optimisation”, *IEEE Transactions on Automatic Control*, Provisionally Accepted for Publication, 2015.

[J-5] P. Di Marco, G. Athanasiou, P. V. Mekikis, C. Fischione, “MAC-aware Routing Metrics for the Internet of Things”, *Elsevir Computer Networks*, Accepted for Publication, to Appear, 2015.

[J-6] A. De Angelis, C. Fischione, “Mobile Node Localization via Pareto Optimisation: Algorithm and Fundamental Performance Limitations”, *IEEE Journal on Selected Areas on Communications*, Accepted for Publication, to Appear, 2015.

[J-7] S. Magnússon, C. Weeraddana, C. Fischione, “A Distributed Approach for the Optimal Power Flow Problem Based on ADMM and Sequential Convex Approximations”, *IEEE Transactions on Control of Network Systems*, Accepted for Publication, To Appear, 2015.

[J-8] H. Shokri-Ghadikolaei, C. Fischione, “Analysis and Optimisation of Distributed Random Sensing Oder in Cognitive Radio Networks”, *IEEE Journal on Selected Areas on Communications*, Accepted for Publication, to Appear, 2015.

[J-9] G. Athanasiou, C. Weeraddana, C. Fischione, L. Tassiulas, “Optimizing Client Association in 60GHz Wireless Access Networks”, *IEEE/ACM Transactions on Networking*, Accepted for Publication, to Appear, 2015.

[J-10] P. Di Marco, C. Fischione, F. Santucci, K. H. Johansson, “Modeling IEEE 802.15.4 Networks over Fading Channels”, *IEEE Transactions on Wireless Communications*, Vol. 13, No. 10, pp. 5366–5381, August 2014.

[J-11] C. Fischione, G. Athanasiou, F. Santucci, “Dynamic Optimisation of Generalized Least Squares Handover Algorithms”, *IEEE Transactions on Wireless Communications*, Vol. 13, No. 3, pp. 1235–1249, March 2014.

[J-12 G. Athanasiou, C. Weeraddana, C. Fischione, “Auction-based Resource Allocation in Millimeter-Wave Wireless Access Networks”, *IEEE Communications Letters*, Vol. 17, No. 11, pp. 2108–2111, November 2013.

[J-13] P. Park, S. Coleri Ergen, C. Fischione, A. Sangiovanni-Vincentelli, “Duty-Cycle Optimisation for IEEE 802.15.4 Wireless Sensor Networks”, *ACM Transactions on Sensor Networks*, Vol. 10, No. 1, November 2013.

[J-14] C. Fischione, P. Park, S. Coleri Ergen, “Duty-cycle Analytical Modelling and Optimisation in Unslotted IEEE 802.15.4 Wireless Sensor Networks”, *Springer Wireless Networks*, Vol. 19, Issue 7, pp. 1691–1707, October 2013.

[J-15] P. Park, C. Fischione, K. H. Johansson, “Modelling and Stability Analysis of Hybrid Multiple Access in IEEE 802.15.4 Protocol”, *ACM Transactions on Sensor Networks*, Vol. 9, No. 2, pp. 13:1–13:55, April 2013.

[J-16] U. Tiberi, C. Fischione, M. Di Benedetto, K. H. Johansson, “Energy-efficient Sampling of Networked Control Systems over IEEE 802.15.4 Wireless Networks”, *Automatica*, Vol. 49, No. 3, pp. 712–724, March 2013.

[J-17] P. Park, P. Di Marco, C. Fischione, K. H. Johansson, “Modelling and Optimisation of the IEEE 802.15.4 for Timely and Reliable Communications", *IEEE Transactions on Parallel and Distributed Systems*, Vol. 24, No. 3, pp. 550–564, March 2013.

[J-18] P. Di Marco, P. Park, C. Fischione, K. H. Johansson, “Analytical Modeling of Multi-hop IEEE 802.15.4 Networks”, *IEEE Transactions on Vehicular Technology*, Vol. 61, No. 7, pp. 3191–3208, September 2012.

[J-19] L. Bao, M. Skoglund, C. Fischione, K. H. Johansson, “Rate Allocation with Power Constraints for Quantized Control over Binary Symmetric Channels”, *IEEE Transactions on Signal Processing*, Vol. 60, No. 6, pp. 3188–3202, June 2012.

[J-20] C. Fischione, “Fast-Lipschitz Optimisation with Wireless Sensor Networks Applications”, *IEEE Transactions on Automatic Control*, Vol. 56, No. 10, pp. 2319–2331, October 2011.

[J-21] P. Park, C. Fischione, A. Bonivento, K. H. Johansson, A. Sangiovanni-Vincentelli, “Breath: a Self-Adapting Protocol for Industrial Control Applications Using Wireless Sensor Networks”, *IEEE Transactions on Mobile Computing*, Vol. 6. N. 6, pp. 821–838, June 2011.

[J-22] C. Fischione, M. D’Angelo, M. Butussi, “Utility Maximization via Power and Rate Allocation with Outage Constraints in Nakagami-Lognormal Channels”, *IEEE Transactions on Wireless Communications*, Vol. 10, N. 4, pp. 1108–1120, April 2011.

[J-23] C. Fischione, M. Butussi, K. H. Johansson, M. D’Angelo, “Power and Rate Control with Outage Constraints in CDMA Wireless Networks”, *IEEE Transactions on Communications*, Vol. 57, N. 8, pp. 225–229, August 2009.

[J-24] C. Fischione, K. H. Johansson, A. Sangiovanni-Vincentelli, B. Zurita Ares “Energy Consumption of Minimum Energy Coding in CDMA Wireless Sensor Networks”, *IEEE Transactions on Wireless Communications*, Vol. 8, N. 2, pp. 985–994, February 2009.

[J-25] A. Speranzon, C. Fischione, K. H. Johansson, A. Sangiovanni-Vincentelli, “A Distributed Minimum Variance Estimator for Sensor Networks”, *IEEE Journal on Selected Areas in Communications, special issue on Control and Communications*, Vol. 26, N. 4, pp. 609–621, May 2008.

[J-26] C. Fischione, F. Graziosi, F. Santucci, "Approximation for a Sum of On-Off Log-Normal Processes with Wireless Applications", *IEEE Transactions on Communications*, Vol. 55, pp. 1984–1993, October 2007.

[J-27] A. Bonivento, C. Fischione, L. Necchi, F. Pianegiani, A. Sangiovanni-Vincentelli, "System Level Design for Clustered Wireless Sensor Networks", *IEEE Transactions on Industrial Informatics*, Vol. 3, No. 3, pp. 202–214, August 2007. **Best Paper Award of the IEEE Transactions on Industrial Informatics of the year 2007**.

[J-28] C. Fischione, F. Graziosi, F. Santucci, "Outage Performance of Power Controlled DS CDMA Wireless Systems with Heterogeneous Traffic Sources", *Wireless Personal Communications*, Vol. 24, pp. 171–187, 2003.

[J-29] F. Santucci, G. Durastante, F. Graziosi, C. Fischione, "Power Allocation and Control in Multimedia CDMA Wireless Systems", *Telecommunications Systems*, Vol. 23, pp. 69–94, 2003.

Under review

[J-30] M. Gerami, M. Xiao, J. Li, C. Fischione, X. Li, "Repair for Distributed Storage Systems in Erasure Networks", Submitted to *IEEE Transactions on Parallel and Distributed Systems*, 2014.

[J-31] C. Fischione, "An Holistic Approach to Wireless Sensor Networks Teaching", Submitted to *IEEE Transactions on Education*, 2014.

[J-32] H. Shokri-Ghadikolaei, I. Glaropoulos, V. Fodor, C. Fischione, T. Ephremides, "Green Sensing and Access: Energy-Throughput Tradeoffs in Cognitive Networking", Submitted to *IEEE Communication Magazine*, 2014.

[J-33] E. Alfonsettti, C. Weeraddana, C. Fischione, "A Semi Distributed Approach for Min-Max Fair Car-Parking Slot Assignment Problem", Submitted to *Elsevir Transportation Research: Part B*, 2014.

[J-34] Y. Xu, L. Wang, C. Fischione, V. Fodor, "Distributed Spectrum Leasing via Vertical Cooperation in Spectrum Sharing Networks", Submitted to *IEEE Transactions on Wireless Communications*, 2014.

[J-35] A. R Pavankumar, A. Bertoldi, G. Athanasiou, M. Nilsson, C. Fischione, "Water bio-nets: Real-time wireless biosensor networks for the surveillance of bacterial pathogens in drinking water supply lines", Submitted to *Elsevir Journal of Water Research*, 2014.

[J-36] Y. Xu, C. Fischione, "Distributed Association Control and Relaying in MillimeterWave Wireless Access Networks", Submitted to *IEEE Transactions on Signal Processing*, 2015.

[J-37] M. Jakobsson, C. Fischione, "Optimality of Radio Power Control Algorithms via Fast-Lipschitz Optimisation ", Submitted *IEEE Transactions on Communications*, 2015.

[J-38] L. Gkatzikis, I. Koutsopouos, C. Fischione, "Task Migration and Consolidation Policies for Cloud Computing Systems", Submitted to *IEEE Transactions on Cloud Computing*, 2015.

[J-39] H. Shokri, C. Fischione, G. Fodor, P. Popovski, M. Zorzi,"Millimeter Wave Cellular Networks: A MAC Layer Perspective", Invited Paper, Submitted to *IEEE Transactions on Communications*, 2015.

[J-40] C. Kalalas, L. Gkatzikis, C. Fischione, F. Williams, "Feasibility Study of IEC 61850 Communication Services over Public LTE Infrastructure", Submitted to *IEEE Transactions on Smart Grids*, 2015.

[J-41] R. Du, L. Gkatzikis, C. Fischione, M. Xiao, “An Energy Efficient Sensor Activation Scheme for Water Distribution Netowrks based on Compressive Sensing”, Submitted to *IEEE Journal on Selected Areas on Communications, Special Issue on Green Communication and Networking*, 2015.

[J-42] M. Levorato, C. Weeraddana, C. Fischione, “Distributed Optimisation of Transmission Strategies in Reactive Cognitive Networks”, Submitted to *IEEE Transactions on Cognitive Communications and Networking*, 2015.

[J-43] L. Gkatzikis, V. Sourlas, C. Fischione, I. Koutsopouos, L. Tassiulas, “In time Content Replication via Clustering in Content-Delivery Networks”, Submitted to *IEEE Transactions on Communications*, 2015.

Peer-reviewed conference contributions

[C-98] S. Magnússon, C. Weeraddana, C. Fischione, “A Distributed Optimisation Approach Based on ADMM and Sequential Convex Approximations”, Submitted to *IEEE Conference on Decision and Control, (IEEE CDC 15)*, Osaka, Japan, December 2015.

[C-97] H. Shokri-Ghadikolaei, C. Fischione, “Millimeter Wave Ad-Hoc Networks: Noise-limited or Interference-Limited?”, Submitted *IEEE Global Telecommunications Conference 2015, (IEEE Globecom 15)*, San Diego, CA, USA, December 2015.

[C-96] S. Zhuo, H. Shokri-Ghadikolaei, C. Fischione, and Z. Wang, “Adaptive Congestion Control in Cognitive Industrial Wireless Sensor Networks”, Submitted to *IEEE International Conference on Industrial Informatics (IEEE INDIN 2015)*, Cambridge, UK, July 2015.

[C-95] E. Alfonsettti, C. Weeraddana, C. Fischione, “A Semi Distributed Approach for Min-Max Fair Car-Parking Slot Assignment Problem”, Submitted to *IEEE Workshop on Smart Vehicles (IEEE SmartVehicles 15)*, Boston, MA, USA, June 2015.

[C-94] A. De Angelis, C. Fischione, “Performance Limitations of Localization Based on Ranging, Speed, and Orientation”, Submitted to *IEEE International Workshop on Signal Processing Advances in Wireless Communications (SPAWC 15)*, Stockholm, Sweden, June 2015.

[C-93] F. Boem, Y. Xu, C. Fischione, T. Parisini, “A Distributed Pareto-Optimal Dynamic Estimation Method”, in Proc. of *IFAC European Control Conference 2015, (ECC 15)*, Linz, Austria, July 2015.

[C-92] R. Du, L. Gkatzikis, C. Fischione, M. Xiao, “Energy Efficient Monitoring of Water Distribution Networks via Compressive Sensing”, in Proc. of *IEEE International Conference on Communications 2015 (IEEE ICC 15)*, London, UK, June 2015.

[C-91] H. Shokri-Ghadikolaei, L. Gkatzikis, C. Fischione, “Beam-searching and Transmission Scheduling in Millimeter Wave Communications”, in Proc. of *IEEE International Conference on Communications 2015 (IEEE ICC 15)*, London, UK, June 2015.

[C-90] L. Gkatzikis, V. Sourlas, I. Koutsopouos, C. Fischione, G. Dan, “Clustered Content Replication for Hierarchical Content Delivery Networks”, in Proc. of *IEEE International Conference on Communications 2015 (IEEE ICC 15)*, London, UK, June 2015.

[C-89] R. Valentini, M. Levorato, C. Fischione, “Performance Analysis of IEEE 802.15.3c-Based mmW Wireless Networks”, in Proc. of *IEEE 49th Annual Conference on Information Systems and Sciences (IEEE CISS 15)*, Baltimore, Maryland, March 2015.

[C-88] M. Levorato, C. Weeraddana, C. Fischione, "Distributed Optimisation of Transmission Strategies in Reactive Cognitive Networks", in Proc. of *IEEE Global Telecommunications Conference 2014, (IEEE Globecom 14)*, Austin, TX, USA, December 2014.

[C-87] S. Magnússon, C. Weeraddana, M. G. Rabbat, C. Fischione, "On the Convergence of Alternating Direction Penalty Method for Nonconvex Problems", *IEEE Asilomar Conference on Signals, Systems and Computers (IEEE Asilomar 2014)*, Pacific Grove, CA, USA, November 2014.

[C-86] G. Athanasiou, C. Weeraddana, C. Fischione,"Association Control in MillimeterWave Wireless Access Networks", in Proc. of *IEEE 19th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (IEEE CAMAD 14)*, Athens, Greece, October 2014.

[C-85] H. El-Sayed, G. Athanasiou, C. Fischione,"Evaluation of Localization Methods in Millimeter-Wave Wireless Systems", in Proc. of *IEEE 19th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (IEEE CAMAD 14)*, Athens, Greece, October 2014.

[C-84] C. Fischione, G. Athanasiou, F. Santucci, "Dynamic Optimisation of Generalized Least Squares Handover Algorithms", *IEEE International Conference on Network Games, Control and Optimisation (IEEE NETGCOOP 14)*, Trento, Italy, October 2014,

[C-83] P. Di Marco, R. Alesii, F. Santucci, C. Fischione, "An UWB-enhanced Identification Procedure for Large-scale Passive RFID Systems", in Proc. of *IEEE International Conference on Ultra-Wideband (IEEE ICUWB 14)*, Paris, France, September 2014.

[C-82] Y. Xu, L. Wang, C. Fischione, V. Fodor, "Distributed Spectrum Leasing via Vertical Cooperation in Spectrum Sharing Networks", in Proc. of *9-th International Conference on Cognitive Radio Oriented Wireless Networks (IEEE CrownComm 14)*, Oulu, Finland, July 2014 (invited paper).

[C-81] R. Alesii, R. Congiu, F. Santucci, P. Di Marco, C. Fischione, "Architectures and Protocols for Fast Identification in Large-scale RFID Systems", in Proc. of *IEEE International Conference on Communications 2014 (IEEE ICC 14)*, Sidney, Australia, June 2014.

[C-80] H. Shokri-Ghadikolaei, C. Fischione, "Distributed Random Sensing Order Analysis and Optimisation in Cognitive Radio Networks", in Proc. of *IEEE International Conference on Communications 2014 (IEEE ICC 14)*, Sidney, Australia, June 2014.

[C-79] H. Shokri-Ghadikolaei, C. Fischione, "Random Sensing Order in Cognitive Radio Systems: Performance Evaluation and Optimisation ", Student Poster Paper in Proc. of *IEEE Conference on Computer Communications 2014, (IEEE Infocom 14)*, Toronto, ON, Canada, May 2014.

[C-78] R. Alesii, R. Congiu, F. Santucci, P. Di Marco, C. Fischione, "Architectures and protocols for fast identification in large-scale RFID systems", in Proc. of *IEEE 5-th International Symposium on Control, Communication and Signal Processing 2012 (IEEE ISCCSP 14)*, Athens, Greece, May 2014 (invited paper).

[C-77] A. Bertoldi, C. Fischione, G. Athanasiou, "Optimal Sensor Placement for Bacteria Detection in Water Distribution Networks", in Proc. of *IEEE 5-th International Symposium on Control, Communication and Signal Processing 2012 (IEEE ISCCSP 14)*, Athens, Greece, May 2014 (invited paper).

[C-76] H. Shokri-Ghadikolaei, F. Yaghoubi, C. Fischione, "Analysis and optimisation of Centralized Sequential Channel Sensing in Cognitive Radio Networks", in Proc. of *IEEE European Wireless 2014 (IEEE EW 14)*, Barcelona, Spain, May 2014 (invited paper).

[C-75] P. Di Marco, G. Athanasiou, C. Fischione, "Harmonizing MAC and Routing in Low Power and Lossy Networks", in Proc. of *IEEE Global Telecommunications Conference 2013, (IEEE Globecom 13)*, Atlanta, GA, USA, December 2013.

[C-74 C. Weeraddana, G. Athanasiou, C. Fischione, J. Baras, "Per-se Privacy Preserving Solution Methods Based on Optimisation ", in Proc. of *IEEE 52nd Conference on Decision and Control 2012 (IEEE CDC 13)*, Florence, Italy, December 2013.

[C-73] G. Loianno, G. Lippiello, C. Fischione, "Visual/Inertial Data Fusion via Pareto Optimisation for Motion Estimation", in Proc. of *2013 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2013)*, Tokyo, Japan, November 2013.

[C-72] G. Athanasiou, C. Weeraddana, C. Fischione, P. Orten, "Communication Infrastructures in Industrial Automation: The Case of 60 GHz MillimeterWave Communications", in Proc. of *IEEE 18-th International Conference on Emerging Technology and Factory Automation (IEEE IETFA 2013)*, Cagliari, Italy, September 2013.

[C-71] F. Boem, Y. Xu, C. Fischione, T. Parisini, "Distributed Fault Detection using Sensor Networks and Pareto Estimation", in Proc. of *IFAC European Control Conference 2013, (ECC 13)*, Zurich, Switzerland, July 2013.

[C-70] D. Katselis, C. Fischione, H. Hjalmarsson,'Efficient OOK/DS-CDMA Detection Thresholds Selection", in Proc. of *IFAC European Control Conference 2013, (ECC 13)*, Zurich, Switzerland, July 2013.

[C-69] H. Farhadi, A. A. Zaidi, C. Fischione, C. Wang, M. Skoglund, "Distributed Interference Alignment and Power Control for Wireless MIMO Interference Networks with Noisy Channel State Information", in Proc. of *IEEE First International Black Sea Conference on Communications and Networking (IEEE BlackSeaComm 13)*, Batumi, Georgia, July 2013.

[C-68] D. Katselis, C. Fischione, H. Hjalmarsson,"OOK/DS-CDMA Bit Error Probability over Rayleigh Fading Channels", in Proc. of *IEEE International Conference on Communications 2013 (IEEE ICC 13)*, Budapest, Hungary, June 2013.

[C-67] M. Gerami, M. Xiao, C. Fischione, M. Skoglund, "Decentralized Minimum-Cost Repair for Distributed Storage Systems", in Proc. of *IEEE International Conference on Communications 2013 (IEEE ICC 13)*, Budapest, Hungary, June 2013.

[J-66] P. Di Marco, C. Fischione, F. Santucci, K. H. Johansson, "Effect of Rayleigh-Lognormal Fading on IEEE 802.15.4 Networks", in Proc. of *IEEE International Conference on Communications 2013 (IEEE ICC 13)*, Budapest, Hungary, June 2013.

[J-65] P. V. Mekikis, G. Athanasiou, C. Fischione, "A Wireless Sensor Network Testbed for Event Detection in Smart Homes", in Proc. of *IEEE International Conference on Distributed Computing in Sensor Systems (IEEE DCOSS 2013)*, Poster Session, May 2013.

[J-64] P. Di Marco, C. Fischione, G. Athanasiou, P. V. Mekikis, "MAC-aware Routing Metrics for Low Power and Lossy Networks", in Proc. of *IEEE International Conference on Computer Communications (IEEE Infocom 2013)*, Poster Sessions, Turin, Italy, April 2013.

[C-63] M. Jakobsson, C. Fischione, "A Comparative Analysis of the Fast-Lipschitz Convergence Speed", in Proc. of *IEEE 51st Conference on Decision and Control 2012 (IEEE CDC 12)*, Maui, Hawaii, December 2012.

[C-62] F. Boem, Y. Xu, C. Fischione, T. Parisini, “A Distributed Estimator Method for Sensor Networks Based on Pareto Optimisation ”, in Proc. of *IEEE 51st Conference on Decision and Control 2012 (IEEE CDC 12)*, Maui, Hawaii, December 2012.

[C-61] P. Park, P. Di Marco, C. Fischione, K. H. Johansson, “Delay Distribution Analysis of Personal Area Networks”, in Proc. of *IEEE 51st Conference on Decision and Control 2012 (IEEE CDC 12)*, Maui, Hawaii, December 2012.

[C-60] J. Weimer, Y. Xu, C. Fischione, K. H. Johansson, P. Ljungberg, C. Donovan, A. Sutor, L. Fahlen, “A Virtual Laboratory for Micro-Grid Information and Communication Infrastructures”, in Proc. of *IEEE PES Innovative Smart Grid Technologies Europe Conference (IEEE ISGT)*, Berlin, Germany, October 2012.

[C-59] G. Athanasiou, C. Fischione, “Green Traffic Engineering for Future Core Networks”, in Proc. of *20th IEEE International Conference on Software, Telecommunications and Computer Networks (SoftCOM) 2012*, Split, Croatia, September 2012.

[C-58] M. Jakobsson, C. Fischione, “On Some Extension of Fast-Lipschitz Optimisation for Convex and Nonconvex Problems”, in Proc. of *IFAC Workshop on Distributed Estimation and Control in Networked Systems (IFAC NecSys)*, Santa Barbara, CA, USA, September 2012.

[C-57] Y. Xu, C. Fischione, A. Speranzon, “Model Based Peer-to-peer Estimation on Wireless Sensor Netowrks”, in Proc. of *IFAC Workshop on Distributed Estimation and Control in Networked Systems (IFAC NecSys)*, Santa Barbara, CA, USA, September 2012.

[C-56] L. Bao, C. Fischione, M. Skoglund, “On Rate Allocation for Multiple Plants in a Networked Control System”, in Proc. of *American Control Conference (ACC 12)*, Montréal, Canada, June 2012.

[C-55] Y. Xu, C. Fischione, “Real Time Scheduling in LTE for Smart Grids”, in Proc. of *IEEE 5-th International Symposium on Control, Communication and Signal Processing 2012 (IEEE ISCCSP 12)*, Rome, Italy, May 2012.

[C-54] M. Khaksari, C. Fischione, “Performance Analysis and Optimisation of the Joining Protocol for a Platoon of Vehicles”, in Proc. of *IEEE 5-th International Symposium on Control, Communication and Signal Processing 2012 (IEEE ISCCSP 12)*, Rome, Italy, May 2012.

[C-53] U. Tiberi, C. Fischione, K. H. Johansson, M. D. Di Benedetto, “System Level Design of Self-triggered IEEE 802.15.4 Networked Control Loops Increases the Network Capacity”, in Proc. of *IFAC World Congress*, Milan, Italy, August 2011.

[C-52] A. De Angelis, C. Fischione, P. Händel, “A Sensor Fusion Algorithm for Cooperative Localization”, in Proc. of *IFAC World Congress*, Milan, Italy, August 2011.

[C-51] A. De Angelis, C. Fischione, “A Distributed Information Fusion Method for Localization Based on Pareto Optimisation ”, in Proc. of *IEEE International Conference on Distributed Computing in Sensor Systems (IEEE DCOSS ’11)*, Barcelona, Spain, June 2011.

[C-50] C. Fischione, U. Jönsson, “F- Lipschitz Optimisation with Wireless Sensor Networks Applications”, in Proc. of *ACM/IEEE International Conference on Information Processing in Sensor Networks 2011 (ACM/IEEE IPSN 11)*, Chicago, IL, US, April 2011.

[C-49] U. Tiberi, C. Fischione, K. H. Johansson, M. D. Di Benedetto, "Adaptive Self-triggered Control over IEEE 802.15.4 Networks", in Proc. of *IEEE 49th Conference on Decision and Control 2010 (IEEE CDC 10)*, Atlanta, Georgia, December 2010.

[C-48] P. Di Marco, P. Park, C. Fischione, K. H. Johansson, "Analytical Modelling of IEEE 802.15.4 for Multi-hop Networks with Heterogeneous Traffic and Hidden Terminals", in Proc. of *IEEE Global Telecommunications Conference 2010, (IEEE Globecom 10)*, Miami, Florida, USA, December 2010.

[C-47] C. Fischione, M. D'Angelo, "A Generalized Utility Maximization Problem with Outage Constraints in CDMA Networks", in Proc. of *IFAC Workshop on Distributed Estimation and Control in Networked Systems (IFAC NecSys)*, Annecy, France, September 2010.

[C-46] P. Di Marco, P. Park, C. Fischione, K. H. Johansson, "TREnD: a Timely, Reliable, Energy efficient, and Dynamic WSN Protocol for Control Applications", in Proc. of *IEEE International Conference on Communications 2010 (IEEE ICC 10)*, Cape Town, South Africa, June 2010.

[C-45] P. Park, C. Fischione, K. H. Johansson, "Adaptive IEEE 802.15.4 Protocol for Energy Efficient, Reliable, and Timely Communications", in Proc. of *ACM/IEEE International Conference on Information Processing in Sensor Networks 2010 (ACM/IEEE IPSN 10)*, Stockholm, Sweden, April 2010.

[C-44] L. Bao, M. Skoglund, C. Fischione, K. H. Johansson, "Rate Allocation for Quantized Control over Noisy Channels", in Proc. of *IEEE 48th Conference on Decision and Control 2009 (IEEE CDC 09)*, Shanghai, China, December 2009.

[C-43] D. Pacifico, M. Pacifico, C. Fischione, H. Hjalmarsson, K. H. Johansson, "Improving TCP Performance during the LTE Handover", in Proc. of *IEEE Global Telecommunications Conference 2008, (IEEE Globecom 09)*, Honolulu, Hawaii, USA, November 2009.

[C-42] P. Park, P. Di Marco, C. Fischione, K. H. Johansson, "Delay Analysis of Slotted IEEE 802.15.4 with a Finite Retry Limit and Unsaturated Traffic", in Proc. of *IEEE Global Telecommunications Conference 2008, (IEEE Globecom 09)*, Honolulu, Hawaii, USA, November 2009.

[C-41] S. Coleri-Ergen, P. Di Marco, C. Fischione, "MAC Protocol Engine for Sensor Networks", in Proc. of *IEEE Global Telecommunications Conference 2008, (IEEE Globecom 09)*, Honolulu, Hawaii, USA, November 2009.

[C-40] P. Park, P. Di Marco, P. Soldati, C. Fischione, K. H. Johansson, "A Generalized Markov Model for an Effective Analysis of Slotted IEEE 802.15.4", in Proc. of *IEEE International Conference on Mobile Ad-hoc and Sensor Systems 2009 (IEEE MASS 09)*, Macau SAR, P.R.C., October 2009. **Best Paper Award.**

[C-39] C. Fischione, S. Coleri Ergen, P. Park, K. H. Johansson, A. Sangiovanni-Vincentelli, "Medium Access Control Analytical Modelling and Optimisation in Unslotted IEEE 802.15.4 Wireless Sensor Networks", in Proc. of *Sixth Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON 09)*, Rome, Italy, June 2009.

[C-38] P. Di Marco, P. Park, C. Fischione, K. H. Johansson, "SERAN++: a Cross-Layer Protocol for Wireless Sensor Networks in Control and Automation", in Proc. of *Sixth Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON 09)*, Rome, Italy, June 2009.

[C-37] P. Park, C. Fischione, K. H. Johansson, “Performance Analysis of GTS Allocation in Beacon Enabled IEEE 802.15.4”, in Proc. of *Sixth Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON 09)*, Rome, Italy, June 2009.

[C-36] L. Bao, M. Skoglund, C. Fischione, K. H. Johansson, “Rate Allocation for State-Feedback Control over Noisy Channels”, in Proc. of *IEEE Control and Communication workshop 2009 (IEEE ConCom 09)*, Seoul, Korea, July 2009.

[C-35] L. Bao, M. Skoglund, C. Fischione, K. H. Johansson, “Rate Allocation for Closed-Loop Control over Noisy Channels”, in Proc. of *IEEE International Symposium on Information Theory 2009 (IEEE ISIT 09)*, Seoul, Korea, July 2009.

[C-34] C. Fischione, S. Tennina, F. Santucci, F. Graziosi, “Reliability and Efficiency Analysis of Distributed Source Coding in Wireless Sensor Networks”, in Proc. of *IEEE International Conference on Communications 2009 (IEEE ICC 09)*, Dresden, Germany, June 2009.

[C-33] C. Fischione, A. Speranzon, K. H. Johansson, A. Sangiovanni-Vincentelli, “Peer-to-Peer Estimation over Wireless Sensor Networks via Lipschitz Optimisation ”, in Proc. of *ACM/IEEE International Conference on Information Processing in Sensor Networks 2009, (ACM/IEEE IPSN 09)*, San Francisco, CA, USA, April 2009.

[C-32] M. D’Angelo, C. Fischione, “How to Select the OOK Modulation Detection Threshold in Wireless Ad Hoc and Sensor Networks”, in Proc. of *IEEE 67th Vehicular Technology Conference - Spring 2009 (IEEE VTC Spring 09)*, Barcelona, Spain, April 2009.

[C-31] S. Coleri Ergen, C. Fischione, D. Marandin, A. Sangiovanni-Vincentelli, “Duty-Cycle Optimisation in Unslotted 802.15.4 Wireless Sensor Networks”, in Proc. of *IEEE Global Telecommunications Conference 2008, (IEEE Globecom 08)*, New Orleans, LA, USA, December 2008.

[C-30] M. D’Angelo, C. Fischione, M. Butussi, A. Pinto, A. Sangiovanni-Vincentelli, “Outage-Based Rate Maximization in CDMA Wireless Networks”, in Proc. of *IEEE Global Telecommunications Conference 2008, (IEEE Globecom 08)*, New Orleans, LA, USA, December 2008.

[C-29] C. Fischione, L. Pomante, F. Santucci, C. Rinaldi, S. Tennina, “Mining Ventilation Control: Wireless Sensing, Communication Architecture and Advanced Services”, in Proc. of *IEEE Conference on Automation Science and Engineering (CASE 08)*, Washington, DC, USA, August 2008.

[C-28] P. G. Park, C. Fischione, K. H. Johansson, “Experimental Evaluation of Power Control Algorithms for Wireless Sensor Networks”, in Proc. of *IFAC world Congress*, Seoul, Korea, July 2008.

[C-27] P. G. Park, C. Fischione, A. Bonivento, K. H. Johansson, A. Sangiovanni-Vincentelli, “Breath: a Self-Adapting Protocol for Wireless Sensor Networks in Control and Automation”, in Proc. of *Fifth Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (IEEE SECON 08)*, San Francisco, CA, USA, June 2008.

[C-26] A. Pinto, M. D’Angelo, C. Fischione, E. Scholte, A. Sangiovanni-Vincentelli, “Synthesis of Embedded Networks for Building Automation and Control”, in Proc. of *American Control Conference*, Seattle, Washington, June 2008.

[C-25] A. Speranzon, C. Fischione, B. Johansson, K. H. Johansson, “Adaptive Distributed Estimation over Wireless Sensor Networks with Packet Losses”, in Proc. of *IEEE 46th Conference on Decision and Control 2007 (IEEE CDC 07)*, New Orleans, LA, USA, December 2007.

[C-24] M. Fiorenzi, D. Girella, N. Möller, C. Fischione, K. H. Johansson, “Enhancing TCP over HSDPA by Cross-Layer Signalling”, in Proc. of *IEEE 50th Global Telecommunications Conference 2007, (IEEE Globecom 07)*, Washington, DC, USA, November 2007.

[C-23] E. Witrant, P. G. Park, C. Fischione, K. H. Johansson, M. Johansson, “Control over Wireless Multi-Hop Networks”, in Proc. of *IEEE 16th Conference on Control Applications 2007 (IEEE CCA 07)*, Singapore, October 2007.

[C-22] B. Zurita Ares, P. G. Park, C. Fischione, A. Speranzon, K. H. Johansson, “On Power Control for Wireless Sensor Networks: System Model, Middleware Components and Experimental Evaluation”, in Proc. of *IFAC European Control Conference 2007, (ECC 07)*, Kos, Greece, July 2007.

[C-21] C. Fischione, M. Butussi, “Power and Rate Control Outage Based in CDMA Wireless Networks under MAI and Heterogeneous Traffic Sources”, in Proc. of *IEEE International Conference on Communications 2007 (IEEE ICC 07)*, Glasgow, UK, June 2007.

[C-20] A. Speranzon, C. Fischione, K. H. Johansson, “A Distributed Estimation Algorithm for Tracking over Wireless Sensor Networks”, in Proc. of *IEEE International Conference on Communications 2007 (IEEE ICC 07)*, Glasgow, UK, June 2007.

[C-19] C. Rinaldi, C. Fischione, F. Santucci, K. H. Johansson, “Hybrid Model of Least Squares Handover Algorithms in Wireless Networks”, poster in Proc. of *IEEE 65th Vehicular Technology Conference - Spring 2007 (IEEE VTC Spring 07)*, Dublin, Ireland, April 2007.

[C-18] O. Flärdh, C. Fischione, K. H. Johansson, M. Johansson, “Analysis and Evaluation of an Adaptive FEC Scheme”, in Proc. of *IEEE International Conference on Networking, Sensing and Control 2007 (IEEE ICNSC 07)*, London, UK, April 2007 (Best Student Paper Finalist).

[C-17] N. Möller, Å. Arvidsson, J. Petersson, C. Fischione, R. Skog, P. Karlsson, K. H. Johansson, “Supporting End-to-End Applications over HSDPA by Cross-Layer Signalling”, in Proc. of *IEEE Wireless Communication and Networking Conference 2007 (IEEE WCNC 07)*, Hong Kong, March 2007.

[C-16] B. Zurita Ares, C. Fischione, K. H. Johansson, “Energy Consumption of Minimum Energy Coding in CDMA Wireless Sensor Networks”, in Proc. of *4th European Conference on Sensor Networks 2007 (EWSN 07)*, Delft, The Netherlands, January 2007.

[C-15] A. Speranzon, C. Fischione, K. H. Johansson, “Distributed and Collaborative Estimation over Wireless Sensor Networks”, in Proc. of *IEEE 45th Conference on Decision and Control 2006 (IEEE CDC 06)*, San Diego, USA, December 2006.

[C-14] L. Di Paolo, C. Fischione, F. Graziosi, F. Santucci, S. Tennina, “Performance Evaluation of Distributed Source Coding and Packet Aggregation for Wireless Sensor Networks”, in Proc. of *IEEE 49th Global Telecommunications Conference 2006 (IEEE Globecom 06)*, San Francisco, USA, November 2006.

[C-13] L. Di Paolo, C. Fischione, F. Graziosi, F. Santucci, S. Tennina, “Loss Factor of Distributed Source Coding with Packet Aggregation in Wireless Sensor Networks”, in Proc. of *14th International Conference on Telecommunication Systems - Modelling and Analysis 2006 (ICTSM 06)*, Penn State Berks Campus, Reading, PA, USA, October 2006.

[C-12] C. Fischione, F. Graziosi, K. H. Johansson, F. Santucci, “Distributed Cooperative Processing and Control over Wireless Sensor Networks”, in Proc. of *ACM International Wireless Communication and Mobile Computing Conference 2006 (ACM IWCMC 06)*, Vancouver, Canada, July 2006.

[C-11] C. Fischione, A. Bonivento, A. Sangiovanni-Vincentelli, K. H. Johansson, "Cooperative Diversity with Disconnection Constraints and Sleep Discipline for Power Control in Wireless Sensor Networks", in Proc. of *IEEE 64th Semiannual Vehicular Technology Conference - Spring 2006 (IEEE VTC Spring 06)*, Melbourne, Australia, May 2006.

[C-10] O. Flärdh, C. Fischione, K. H. Johansson, M. Johansson, "A Control Framework for Online Error Control Adaptation in Networked Applications", in Proc. of *IEEE 2nd International Symposium on Control, Communication and Signal Processing 2006 (ISCCSP 06)*, Marrakech, Morocco, March 2006.

[C-9] C. Fischione, A. Bonivento, A. Sangiovanni-Vincentelli, F. Santucci, K. H. Johansson, "Performance Analysis of Collaborative Spatio-Temporal Processing for Wireless Sensor Networks", in Proc. of *IEEE 3rd Consumer Communications and Networking Conference 2006 (IEEE CCNC 06)*, January 2006.

[C-8] A. Bonivento, C. Fischione, A. Sangiovanni-Vincentelli, "Randomized Protocol Stack for Ubiquitous Networks in Indoor Environment", in Proc. of *IEEE 3rd Consumer Communications and Networking Conference 2006 (IEEE CCNC 06)*, January 2006.

[C-7] A. Bonivento, C. Fischione, A. Sangiovanni-Vincentelli, F. Graziosi, F. Santucci "SERAN: A Semi Random Protocol Solution for Clustered Wireless Sensor Networks", in Proc. of *IEEE 2nd International Conference on Mobile Ad-hoc and Sensor Systems 2005 (IEEE MASS 05)*, November 2005. **Best Paper Award in the category "Applications"**.

[C-6] N. Möller, C. Fischione, K. H. Johansson, F. Santucci, and F. Graziosi , "Modelling and Control of IP Transport in Cellular Radio Links", in Proc. of *IFAC World Congress 2005*, Prague, Czech Republic, July 2005.

[C-5] C. Fischione, N. Möller, F. Graziosi, K. H. Johansson, F. Santucci, H. Hjalmarsson, "Analysis of TCP over WCDMA Wireless Systems under Power Control, MAI and Link Level Error Recovery", in Proc. of *International Workshop on Convergent Technologies 2005 (IWCT 05)*, University of Oulu, Centre for Wireless Communications, Finland, June 2005.

[C-4] C. Fischione, F. Graziosi, F. Santucci, "Approximation of a Sum of OnOff LogNormal Processes with Wireless Applications", in Proc. of *IEEE International Conference on Communications 2004 (IEEE ICC 04)*, Paris, France, June 2004.

[C-3] C. Fischione, F. Graziosi, F. Santucci, F. De Angelis, "A Simulation Framework for WCDMA Wireless Systems", in Proc. of *World Wireless Congress 2004 (WWC 04)*, San Francisco, USA, May 2004.

[C-2] C. Fischione, F. Graziosi, F. Santucci, A. Tresca, "Link Level Simulation Environment for the Radio Interface of Third Generation Mobile Radio Systems", poster in Proc. of *Design, Automation and Test in Europe Conference 2003 (DATE 03)*, Munich, Germany, March 2003.

[C-1] C. Fischione, F. Graziosi, F. Santucci, "Outage Performance of Power Controlled DSCDMA Wireless Systems with Heterogeneous Traffic Sources", in Proc. of *IEEE 4th International Symposium on Wireless Personal Multimedia Communication 2001 (IEEE WPMC 01)*, Aalborg, Denmark, September 2001.

Book Chapters

[BC-4] Y. Xu, V. Gupta, C. Fischione, “Distributed Estimation”, Book Chapter in *E-Reference Signal Processing*, R. Chellappa and S. Theodoridis Eds., Elzevir, 2013.

[BC-3] C. Fischione, P. Park, P. Di Marco and K. H. Johansson, “Design Principles of Wireless Sensor Networks Protocols for Control Applications”, Book Chapter in *Wireless Network Based Control*, Springer, 2011.

[BC-2] P. Park, C. Fischione, and K. H. Johansson, “Adaptive IEEE 802.15.4 Communication Protocol for Control and Monitoring Applications”, Book Chapter in *Wireless Network Based Control*, Springer, 2011.

[BC-1] B. Zurita Ares, C. Fischione, K. H. Johansson, “Energy Consumption of Minimum Energy Coding in CDMA Wireless Sensor Networks”, in *Wireless Sensor Networks*, Springer-Verlag Lecture Notes in Computer Science, Vol. 4373, pp. 212–227, 2007, also presented to *4th European Conference on Sensor Networks 2007 (EWSN 07)*, Delft, The Netherlands, January 2007.

Patents

[P-1] C. Fischione, S. C. Ergen and C. Borean, “Method for Setting the Optimal Operation of a Routing Node of an Asynchronous Wireless Communication Network, Network Node and Communication Network Implementing the Method”, International Patent PCT/EP2008/008925.

[P-2] C. Fischione, “Method for Finding the Position of a Network Node”, Under Filing Process, March 2015.

[P-3] M. Benincaso, L. Turchet, S. Zambon, C. Fischione, “Method for Real-time Control of the Timbre of a Stringed Instrument”, Under Filing Process, April 2015.

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Performance Analysis of Control Algorithms and Protocols for Wireless Networks

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Subject doctors degree	**ISSN/ISBN-number**	**Date doctoral exam**
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Fischione, Carlo 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.