Vetenskapsrådet

Application

2015-03-31

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Project info

Project title (Swedish)*

Feltoleranta och säkra optiska molnnätverk

Project title (English)*

Resilient and Secure Optical Cloud Networks

Abstract (English)*

In this project, we will investigate security vulnerabilities of optical cloud networks comprising distributed data centers interconnected by a fiber-optical transport network. Our aim is to develop a framework for optical cloud networks with tailored mechanisms for guaranteeing high security, resilience, and reliability performance whilst minimizing the necessary network resources.

The project is motivated by the growing importance of cloud services (e.g. e-health, e-science, e-commerce or different content distribution networks) which require highly resilient and secure communication infrastructure. The placement of the datacenter network (DCN) nodes, successful provisioning of the cloud services, and choice of physical-layer transmission schemes are among the most important challenges in the design of optical clouds. Due to the ever-increasing traffic volumes, efficient usage of network resources such as optical spectrum is one of the most important criteria of optical network design.

Optical backbone networks which support cloud services are vulnerable to component failures, large-scale disasters and deliberate attacks at the physical layer, typically aimed at disrupting the service or gaining unauthorized access to carried data. Such breaches can induce financial losses or loss of privacy for cloud service users or, in case of network-wide service disruption, lead to huge revenue losses for the cloud operators. Consequently, the purpose of this project is to address resilience and security of the optical cloud networks and propose network design solutions which will reduce the risk of service disruption in the network in a resource-efficient manner.

The project will be organized in two partially overlapping tasks. Task 1 will consider the potential consequences of various physical-layer attacks and perform DCN placement and cloud service provisioning so as to minimize the possible service disruption. By identifying the attacking possibilities between connections and limiting the number of connections that can be affected, the network becomes more robust since in this way both service disruption and the efforts of recovery approaches can be reduced. New optimization criteria considering security will be defined and novel DCN placement and RSA approaches will be developed to combine these criteria with traditional resource-minimizing objectives. The problems will be modeled as integer linear programs (ILPs) to obtain optimal solutions on smaller network instances. Due to intractability of ILPs in larger network instances, heuristic approaches will be developed to obtain sub-optimal solutions in reasonable time.

Task 2 will focus on secure optical cloud protection with the objective to design resiliency schemes which will protect the optical cloud from both component faults and attacks. The problem will be mathematically formulated as an ILP and heuristics will be developed to cover for more realistic network instances. The resource efficiency of protection schemes will be enhanced through the design of novel network coding approaches considering realistic failure models from Task 1, including component faults and damage spreading caused by various types of attacks. The potential of network coding in optical networks with heterogeneous line rates will be additionally examined, providing greater degree of flexibility in network resource usage.

The proposed network design framework will enable network operators to have full control over the achieved degree of the considered resilience since the planning is performed in advance (i.e., before the network is put into operation). We would like to emphasize that the proposed mechanisms of increasing robustness to attacks and failures are expected to be realistic for the practical use by network operators because of their operational simplicity and resource-efficiency.

Popular scientific description (Swedish)*

I projektet kommer sårbarheten i det s.k. ”molnet” att undersökas. Detta består av distribuerade datacentra förbundna med ett fiberoptiskt nätverk. Målet är att utveckla skyddsmekanismer speciellt anpassade för molnnätverk, som möjliggör hög säkerhet och tillförlitlighet.
Projektet motiveras av den ökande betydelsen hos molntjänster inom t.ex. hälsa, vetenskap, handel, datalagring och underhållning, som kräver en mycket tillförlitlig och säker infrastruktur. Viktiga frågeställningar är var datacenternoder placeras, hur molntjänsterna tillhandahålls och vilka transmissionsmetoder som används. Eftersom molnanvändningen hela tiden expanderar och genererar allt större trafikvolymer, är en nyckelfråga hur man hushåller med nätverkets begränsade resurser såsom fibrer, kopplingspunkter och bandbredd.
Det fiberoptiska nätverk som levererar molntjänsterna är sårbart för komponentfel, katastrofer och avsiktliga attacker i fibrer och kopplingspunkter, som syftar till att störa kommunikationen eller få tillgång till känslig information. Sådana störningar kan orsaka kunder såväl ekonomisk skada som intrång i den personliga integriteten. Storskaliga störningar är en mardröm för molnoperatörerna, vars marknadspositioner är helt beroende av just förmågan att leverera tillförlitliga och säkra tjänster. Projektets syfte är att finna metoder för att undvika sådana störningar eller minska deras skadliga effekter.
Projektet organiseras i två delvis överlappande etapper. I den första etappen studeras konsekvenserna av olika fysiska attacker. Datacentrens placering och funktion optimeras för att minimera skadeverkningarna. Genom att identifiera möjliga typer av attacker och begränsa antalet förbindelser som påverkas, blir nätverket mer robust, eftersom både serviceavbrotten och ansträngningarna för att återställa nätet efter avbrott minskar. Säkerhetskriterier kommer att formuleras matematiskt och utgöra basen för optimering av nätverkens design och funktion, för maximal tillförlitlighet och feltolerans samt minimal resursanvändning.
I den andra etappen fokuseras på mekanismer för att skydda molnnätet från såväl komponentfel som attacker. Även här formuleras ett matematiskt optimeringsproblem, den här gången för att skydda nätverket och återställa dess funktion efter störningar. Metoder för att skicka redundant datatrafik över flera vägar kommer att studeras, antingen via backup-förbindelser eller genom s.k. nätverkskodning, vilket möjliggör att funktionen bibehålls trots att en eller flera länkar drabbas av störningar.
De nya metoder som tas fram i projektet kommer att hjälpa molnoperatörer att ha full kontroll över tillförlitligheten och säkerheten i sina nätverk, eftersom dessa egenskaper beaktas redan på planeringsstadiet, innan nätverken tas i bruk. Speciell uppmärksamhet kommer att ägnas åt metodernas komplexitet, och vid behov ta fram förenklade, suboptimala metoder som lämpar sig för praktiskt bruk i molnnätverk av realistisk storlek.

Project period

Number of project years*

4

Calculated project time*

2016-01-01 - 2019-12-31

Classifications

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

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

SCB-codes*

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

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

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

Keyword 1*

Optical cloud

Keyword 2*

Datacenter networks

Keyword 3*

Network coding

Keyword 4

Optical network security

Keyword 5

Optical network protection

Research plan

Ethical considerations

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

Reporting of ethical considerations*

No personal data is involved in this research. The applicants will follow the CODEX guidelines, ethics codes and laws related to research process. No animal or human trials are included in the study.

The project includes handling of personal data

No

The project includes animal experiments

No

Account of experiments on humans

No

Research plan

Resilient and Secure Optical Cloud Networks

1. Purpose and aims

The project is motivated by the growing importance of cloud services offered by datacenters in our everyday life. Services such as e-health, e-science, e-commerce or different content distribution networks require a highly reliable and secure communication infrastructure. The tremendous amount of data transferred within datacenter networks (DCNs) requires ultra-high capacity interconnection network, which can only be realized by optical technology. Optical backbone networks which support cloud services can experience component failures, large-scale disasters and also are vulnerable to deliberate attacks at the physical layer, typically aimed at disrupting the service or gaining unauthorized access to carried data. Such breaches can induce financial losses to clients, loss of privacy or cause network-wide service disruption, possibly leading to huge revenue losses and serious problems for the cloud service users, i.e., for all of us. By considering these issues already in the network planning phase, the extent of disturbances and damage to the network could be reduced. In order to support the ever-increasing traffic volumes requiring immense network capacity, efficient usage of resources such as available spectrum is one of the most important criteria of optical network design. Consequently, the purpose of this project is to address resilience and security of the optical interconnection network between distributed datacenters (referred to as optical cloud networks) and propose solutions which will minimize the risk of service disruption in the network in a resource-efficient manner.

In this project, we will investigate security vulnerabilities of optical cloud networks and develop a resilience and physical-layer security framework for data center networks comprising tailored mechanisms for guaranteeing high security and reliability performance whilst minimizing the cost of the necessary resources. Specifically, the project will aim at:

- Developing a model for evaluation of optical cloud network reliability and security.
- Devising a cost-efficient optical cloud network planning approach with content placement policies considering resilience and security concerns.
- Designing a unified routing and spectrum assignment (RSA) approach incorporating awareness of both link-based and node-based faults and attacks in optical cloud networks with standard resource-minimizing optimization criteria.
- Developing novel resilience strategies including network coding and mechanisms for computing pre-planned backup datacenters and paths accounting for protection from faults and attacks.

The combination of the above objectives will result in a fault and attack resilient framework, based on an *a-priori* design technique, capable of substantially increasing inter-datacenter network availability and security without incurring significant extra investments from the operators.

2. Survey of the research field

2.1. Optical clouds

A wide range of cloud-based applications supported by distributed datacenter communication are playing an increasingly prominent role in the scientific (e.g., scientific computing, data-centric computing), business (e.g., financial transactions management, multimedia storage and processing, data mining) and consumer (e.g., personal content processing and storage, gaming, interactive media) domains [1]. In cloud applications, enterprises migrate a lot of their computing and storage resources to distributed datacenters and are interested in connectivity to resources under a stringent set of performance

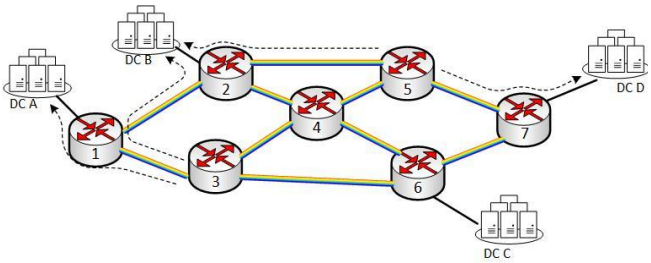

Figure 1. An optical inter-datacenter network.

requirements, rather than connectivity to particular sites [2]. A datacenter is a warehouse-scale and massively parallel computing and storage resource, typically comprising thousands of clustered servers [3]. Cloud services require a transmission infrastructure characterized by ultra-high capacity, low latency, low cost and high availability [3], and optical networking is considered the only viable solution in supporting next-generation cloud services [1].

Optical transmission has been recognized as the enabling technology for inter-datacenter high-capacity communication networks due to the huge bandwidth offered by the optical fiber, low latency, and strong *cost-per-bit* benefits. Over the past decades, optical networks have evolved from non-reconfigurable opaque systems to configurable high-speed networks enabling all-optical, or transparent, transmission over a set of switching nodes. Transparent optical networks overcome the electronic bottleneck by supporting all-optical channels between node pairs. Channels can traverse multiple physical links, essentially creating a virtual/logical topology on top of the physical network topology. Thanks to the new optical component technology the traditional division of optical spectrum into a fixed wavelength grid can be replaced by a flexible grid [4], allowing better adaption to the traffic requirements.

Optical cloud networks introduce changes in the traditional unicast network communication paradigm by placing replicas of content or services in multiple geographical locations and supporting anycast type of communication [2], [5]-[7]. In anycast scenario, a source node can be served by any one from a subset of network nodes which support the desired service. An illustrative example of an optical inter-datacenter network with anycast is shown in Fig. 1. For example, a request originating at node 3 can be served by data center (DC) A or B, while the one from node 5 can be accommodated by DC B or D (shown with dashed lines). DC C could be considered as a backup datacenter for both requests. Establishing an anycast communication request entails selection of the destination node, deciding on the route between the source and destination and reserving spectral resources according to a certain criterion such as geographical distance, latency, load balancing, or cost.

The placement of the DCN nodes and successful solution of the static RSA problem are the most important challenges in the design of optical clouds. Deciding on the DCN node placement under the anycast scenario is important for balancing nework cost and service latency, as well as ensuring cloud service availability [8]. The DCN node placement problem in optical clouds entails deciding on the physical locations of the service replicas by considering the capacities of both the servers and the optical transport network. Since the location of the DCN nodes and the content distribution among the selected nodes impacts the subsequent routing of communication flows under anycast traffic, the decision on the DCN node placement is far more complex than the traditional node placement problem [8], [9].

Given a physical topology and a set of connection requests, the RSA problem consists of finding a feasible route and allocating appropriate spectral resources to each connection request, with the most common optimization objective of minimizing the overall spectrum consumption. RSA is subject to the spectrum continuity and contiguity constraints, which state that each channel must use the same set of contiguous spectrum slots on all physical links included in its path, while there must also be no spectrum overlapping among different channels. The RSA problem in elastic optical networks has been widely studied by formulating the problem as an integer linear program (ILP) to obtain optimal solutions for smaller-sized instances. RSA has been shown to be NP-complete, yielding ILP formulations computationally intractable for larger network instances and requiring heuristic algorithms

such as those in [10], [11]. The above general definition of the RSA problem is referred to as static because it is performed offline for a set of *a priori* known connection requests that do not change over time. In the context of anycast communication in optical clouds, the RSA problem needs to be extended to also entail the selection of the destination node among a subset of candidate nodes supporting the service required by the source node.

2.2. Resilience and security in optical clouds

Due to the transparent nature of transmission in all-optical networks, i.e., the lack of electrical regeneration and the extremely high transmission rates, network robustness to system disruptions such as component failures, large-scale disasters caused by nature, and deliberate attacks becomes crucial. The application of optical networking for cloud services brings forth an additional set of yet unresolved challenges including enhanced support for resource sharing, resilience and security. The goal of this project is to address resilience and security in optical clouds by identifying potential scenarios of physical-layer attacks and developing resource-efficient approaches to *(i)* reduce the potential damage from attacks and *(ii)* guarantee survivability in the presence of component faults and attacks.

Several physical-layer attacks, typically classified into those aimed at service degradation and eavesdropping were identified in [12]-[15]. Numerous occurrences of attacks at the optical layer have been registered, primarily performing industrial espionage in the financial, energy, transport or pharmaceutical sectors, targeting governments, attempting to disable critical infrastructure, or conducting large-scale surveillance [16]-[18]. Commercial tapping devices which can be clamped onto the optical fiber to perform eavesdropping without disturbing communication can be easily found on the market. Countermeasures against eavesdropping typically rely on higher-layer encryption which can be combined with solutions for fiber-intrusion detection [19]. Attacks targeting service degradation typically involve inserting malicious signals into the network which can possibly propagate along configured connections causing wide-spread damage. For example, an inserted signal of excessive power (e.g., 5-20 dB above other, legitimate signals) could degrade co-propagating user channels due to increased crosstalk and nonlinear effects in fibers and in-band crosstalk in optical switches, or cause so-called gain competition in optical amplifiers where the high-power signal robs weaker legitimate signals of gain. The service degradation issue is also compelling in mixed line rate and elastic optical networks [4] where lower-line-rate amplitude-modulated signals may coexist with advanced higher-bit-rate modulation formats, requiring careful RSA to reduce the potential damage from signal insertion attacks inducing strong nonlinear effects [20]. As harmful signals can propagate through parts of transparent optical networks without being discarded by intermediate nodes, they can affect a subset of legitimate channels at multiple physical locations [21]. Furthermore, the damage from attacks can appear sporadically or their effects can accumulate gradually over the network, raising alarms in locations far from the originating points, which complicates attack source localization and attack recovery [15].

Numerous protection strategies have been developed to ensure reliable transmission in optical backbone networks in the presence of single, and possibly multiple, component faults [2]. Protection schemes are typically divided into shared or dedicated schemes providing path or link protection. Path protection implies reserving a physically-disjoint backup path for the primary path of each connection, while link protection implies reserving an alternative route for each link. In shared protection, multiple backup paths can share resources assuming their respective primary paths are disjoint, i.e., do not fail simultaneously. Dedicated protection schemes reserve protection paths without sharing resources, possibly transmitting simultaneously on both primary and backup paths (1+1 protection) or only on the primary path while switching to the backup path in case of failure (1:1 protection). Examples of shared protection approaches can be found in [22], [23], and of dedicated protection approaches in [24], [25].

Although these protection strategies guarantee a certain degree of survivability in the presence of failures, the capacity reserved for sending copies of the data can cause large resource overhead. As an alternative to shared protection schemes, network coding has emerged as a novel and promising strategy of providing protection from failures while reducing the extra resources needed for the same degree of protection. Network coding is a technique to provide robustness against packet and link failures, originally devised for wireless networks [26], whose applicability to all-optical networks is enabled by the recent advances in all-optical logical devices [27]. An analysis of the effectiveness of network coding for optical-layer dedicated protection of multicast traffic can be found in [28], while [29] presents a network-coding based scheme aimed at minimizing the optical spectrum used for protection in elastic optical networks.

Protection schemes in the context of geographically correlated failures which can be a consequence of natural disasters or a physical infrastructure attack (e.g. an Electromagnetic Pulse attack or Weapons of Mass Destruction) have been studied in [5]. Recent studies of disaster-resilient optical inter-datacenter network design can be found in [3], [5], [30]. However, protection in the context of more covert physical-layer attacks that can disrupt multiple connections which do not necessarily all share the same physical components, has not been widely considered yet. Namely, conventional protection schemes (i.e., those which protect from component failures) may fail to provide protection in the presence of attacks because the primary and the backup path, although physically-disjoint, may both be within the reach of the same harmful signal or use parts of the infrastructure whose security has been breached.

Ensuring full protection of transparent optical networks from service-disruption attacks would require a huge number of extra resources or deployment of specialized hardware and, as such, does not represent an economically viable solution for the operators. Since such attacks do not occur often, but can cause major wide-area damage in case they do appear, high resource-efficiency is particularly desirable in resiliency schemes which consider attacks. Therefore, consideration of attacks needs to be incorporated into the network planning procedures as an additional damage-reduction criterion while maintaining standard optimization objectives typically aimed at minimizing resource usage and cost. In the frame of this project, we will study the types and methods of attacks which can be inflicted in optical clouds. We will investigate the properties of such attacks and devise methods for optical cloud planning aimed at reducing the potential damage.

Enhancing optical network security by incorporating attack-awareness into network planning, i.e., the fixed-grid routing and wavelength assignment (RWA) problem was proposed in [31] by performing routing with the objective of limiting the maximum potential damage from high-power jamming attacks. Attack-aware wavelength assignment approaches were designed for reducing the damage from jamming attacks exploiting in-band crosstalk in switches [32], [33]. In [32], theoretical upper bounds were derived on the maximum potential damage from jamming in switches by assuming unlimited attack propagation. In [33], more practical scenarios were investigated with limited attack spreading, and the problem of reducing the damage was modeled using ILPs and heuristics. An RWA algorithm for reducing the compound damage from out-of-band and in-band effects of jamming is proposed in [34].

Although these approaches demonstrated strong reduction of potential damage from high-power jamming in a resource-efficient manner, network survivability in the presence of jamming was not considered. An approach for survivable routing and regenerator placement in the presence of power jamming attacks was proposed in [35] for translucent networks, where the effects of attacks are reduced by adding regeneration points. Preliminary studies of protecting the transparent optical network from jamming attacks by adding attack-awareness to the standard single-link survivability process were proposed in [36], [37].

All of the abovementioned approaches focused on conventional transparent optical networks with unicast traffic. Due to the replication of content in multiple physical locations, cloud networks inherently rely on the anycast routing paradigm, where a source node can connect to *any* one among a subset of candidate destination nodes supporting the required service. Thus, establishing a connection entails an additional step of selecting the destination node which can strongly impact the availability and security of communication. To the best of our knowledge, none of the existing studies addresses the crucial security problem in the distributed optical cloud scenario with anycast traffic.

3. Project description

This section provides a summary of the project structure including theory, method, time schedule and work plan. In our work, we will focus on the DCN node placement and RSA problem in the context of component (i.e., link and node) faults and deliberate service-disruption attacks under static anycast traffic scenario in optical clouds. The goal of establishing a framework for resource-efficient design of resilient and secure optical clouds will be achieved by following the implementation steps of the two tasks highlighted in Fig. 2.

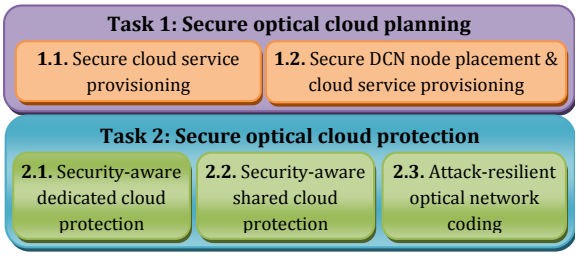

Figure 2. Outline of the project.

Task 1. Secure optical cloud planning [M1 - M30]

The objective of Task 1 will be to perform security-aware DCN node placement and service provisioning (i.e., RSA) in order to reduce the potential damage inflicted by attacks to primary connections. The work of Task 1 will be organized as follows:

- **Designing secure cloud service provisioning approaches.**
- **Designing secure DCN node placement and cloud service provisioning approaches.**

The project will begin with deepening our understanding of security threats and faults in optical clouds. Using this knowledge, we will define a new model of attack spreading in optical clouds and propose new optimization criteria which will quantify the potential damage from attacks to cloud services and connections. To be able to guarantee a certain degree of damage reduction, we will focus on the assessment of the largest potential damage (in terms of, e.g., number of disrupted service requests and/or amount of destroyed data) which can be caused by various types of attacks inflicted at different locations in the cloud. Novel DCN node placement policies and RSA approaches will be designed taking into account the proposed optimization criteria and combining them with the standard resource-efficient objectives. To gain an initial insight into security vulnerabilities of optical clouds we will consider security when provisioning only *primary* connections, i.e., without taking protection from attacks into account.

Two phases of secure optical cloud provisioning will be examined. The first one will assume that the locations of DCN nodes and content are given. Our objective will be to assign DC and network resources to service requests (i.e., solve the RSA problem under anycast traffic) so as to minimize network resource usage as well as the potential disruption of primary paths/services. In the second phase, we will vary the DCN node locations as well as the assignment of routes and spectral resources to service requests in order to further reduce the cost and the damage from attacks. Both phases will adhere to the standard RSA constraints on spectrum continuity, contiguity and overlapping. Furthermore, the usual cloud planning constraint of serving each request by a primary and a backup DC and network resources will also hold in order to protect the services from both DC and network equipment failures. By assessing the performance of our approach with respect to criteria such as DC and

network resource usage, service availability and security, we will investigate the tradoffs between security upgrade and potential overhead in resource usage.

The problems will be modeled as ILPs to obtain optimal solutions for tractable network instances by using, e.g. CPLEX 12.4 solver as the optimization engine [38], and heuristic approaches will be designed to obtain sub-optimal solutions for larger network instances within acceptable running times.

Task 2. Secure optical cloud protection [M7 - M48]

As the approaches of Task 1 strive to reduce the damage from attacks but do not consider *protection* in the presence of attacks, the objective of Task 2 will be to develop protection schemes which will provide survivability of the optical cloud in the presence of both component faults *and* attacks. The work of Task 2 will be organized as follows:

- **Developing security-aware dedicated cloud protection schemes.**
- **Developing security-aware shared cloud protection schemes.**
- **Developing attack-resilient network coding schemes.**

To this end, we will begin by evaluating the shortfalls of conventional protection approaches (i.e., those which only consider component faults) in providing survivability from attacks. We will then develop a framework for enhancing survivability from attacks in the anycast traffic scenario relying on dedicated and shared protection and network coding. The approaches will consider whether attacks disrupting primary paths and destinations can spread to their backup paths and datacenter resources. These properties will be integrated in the DCN node placement and service provisioning problems to minimize the probability that both primary and backup paths and DCs can be disrupted at the same time, leaving the affected service un-protected.

In this task, we will develop three protection schemes. In all of them, our objective will be to minimize cost and maximize the degree of protection in the presence of attacks (in terms of, e.g., number of service requests which are protected from attacks). In all approaches we will vary the placement of DCN nodes and content replicas, the selection of primary and backup DCs for each request, and the routing and spectrum assignment of their primary and backup paths. Again, the standard RSA constraints must hold, and protection from service/link failures must also be provided for all requests. Both ILPs and heuristics will be developed for the described approaches.

In the first approach, i.e., security-aware *dedicated* cloud protection scheme, each service request must have reserved backup DC and network resources and no resource sharing is allowed. Note that security-aware backup DC and path selection are different from conventional, component-fault protection. In this case, the primary and the backup path must not only be physically disjoint, but also need to be out of reach of the same potential attack. In the second approach, i.e., security-aware *shared* cloud protection scheme, sharing of DC and network resources is allowed among backup paths of requests whose respective primary paths do not fall under the risk of simultaneous failure. Note that resource sharing is conditioned not only by concurrent component failures, as is the case for standard component-fault protection, but also has to model the risk of being co-ordinatedly affected by an attack.

In order to enhance resource-efficiency and reduce the overhead required by dedicated and shared protection schemes, we will develop a third approach, i.e., attack-resilient *network coding* scheme. Significant gains are expected, the rationale being that traditional backup paths, in a coding terminology, correspond to repetition codes, which are known to be weak. Previous works on optical network coding schemes for simple single- and multiple-link failure scenarios will be extended to account for more sophisticated failure models, including damage spreading caused by various types of attacks. As an additional challenge, we will investigate the potential of network coding in optical networks with heterogeneous line rates.

Timetable

	Year 2016		Year 2017		Year 2018		Year 2019	
	M1-6	M7-12	M13-18	M19-24	M25-30	M31-36	M37-42	M42-48
T1	←	—	—	—	→			
T2		←	—	—	—	—	—	→

We will employ one Ph.D. student for this project. He/she will be working on cost effective physical layer attack reduction and protection mechanisms. Moreover, the PhD student together with Dr. Marija Furdek will devise protection mechanisms considering component faults and physical layer attacks and will formulate and solve the optimization model for the fundamental damage reduction problem. In addition, the PhD student will spend a part of his/her time at Chalmers and will work on optical cloud protection based on network coding together with Prof. Erik Agrell, tentatively in the third project year after obtaining the licentiate degree. Furthermore, we will involve four Master thesis students who will study optical network coding techniques, as well as help implementing software for simulations and run numerical experiments. The PhD student and Master students will be supervised by Prof. Lena Wosinska and co-supervised by Dr. Marija Furdek and Prof. Erik Agrell.

4. Significance

The rapid proliferation of optical clouds with stringent requirements on network performance makes network robustness of prime concern to network operators. Due to extremely high data rates, even short service interruptions can lead to significant losses of data and related revenues. Furthermore, in the distributed cloud environment, where replicas of user content or services are distributed accross a network of datacenters and share the common country-wide transport infrastructure, it is of utmost importance to identify optical-layer security threats and ensure secure and reliable communication. While most of existing approaches dealing with optical network security address unicast type of communication, we focus on the anycast communication paradigm inherent to the distributed optical clouds.

In the frame of this project, our aim is to identify possible security threats related to the optical layer and try to minimize their damaging effect by developing tailored prevention and reaction mechanisms in the network design process. Our goal is to achieve significant reduction of network vulnerability to faults and attacks through intelligent network design in a cost-effective manner, i.e., without the need for the operators' additional investments into specialized equipment or extra resources. The idea is to consider the potential consequences of various physical-layer attacks and perform DC placement and cloud service provisioning so as to minimize the possible service disruption which can be caused in case of attacks. By identifying the attacking possibilities between connections and limiting the number of connections that can be affected, the network becomes more robust since in this way both service disruption is minimized and the work load of failure detection and localization algorithms can be reduced.

In addition, our objective is to design a protection scheme which will protect the optical cloud from both component faults and attacks. By combining the damage reduction scheme with the attack-aware protection scheme, our proposed approach can both minimize the network disruption in the occurence of an attack and guarantee survivability through judicious selection of protection resources. The resource efficiency will be enhanced through the design of novel network coding approaches considering the particular failure models that may occur in optical cloud networks, including component faults and damage spreading caused by various types of attacks. The potential of network coding in optical networks with heterogeneous line rates will be additionally examined, providing greater degree of flexibility in network resource usage.

From the theoretical viewpoint, the considerations related to the studied optimization problems and network coding schemes will be of interest for the general development of network optimization as they concern a nontrivial problem of minimizing attack spreading together with network resource consumption. This research area requires a *cross-layer* and *cross-disciplinary* approach: A cross-layer design is essential since a successful solution must involve novel network designs based on realistic models for optical transmission and switching technologies, as well as novel transmission and coding schemes tailored to those network designs. The cross-disciplinary nature of the project means that expertise in security, datacenter networks, and coding is needed for successful results, which is exactly the expertise we have in the team behind this proposal.

An additional advantage of the proposed network design framework is that it will help network operators to have full control over the achieved degree of the considered resilience since the planning is performed in advance (i.e., before the network is put into operation). We would like to emphasize again that the proposed mechanisms of increasing robustness to attacks and failures are expected to be realistic for the practical use by network operators because of their operational simplicity and resource efficiency. This area is of strategic interest to Swedish industry, as Sweden and Scandinavia have emerged as promising locations for large-scale datacenters, due to the presence of cold weather, renewable energy, infrastructure, geological and political stability, and technical competences.

5. Preliminary results

Recently we studied network survivability approaches based on attack-aware dedicated path protection (AA-DPP) in optical backbone networks under unicast traffic with fixed-grid spectrum division. We developed an approach for AA-DPP with the objective of minimizing the number of connections in the network whose backup path does not provide protection from attacks disrupting the primary path. Simulation results on the US and European continental reference networks indicate that conventional, resource-minimizing DPP approaches (which protect only from component faults but do not consider attacks) can leave a large number of connections (up to 90%; see Fig. 3) unprotected from attacks. AA-DPP, on the other hand, obtains a strong reduction of network vulnerability, yielding about 6% of attack-unprotected connections on average, while adding no resource overhead compared to DPP.

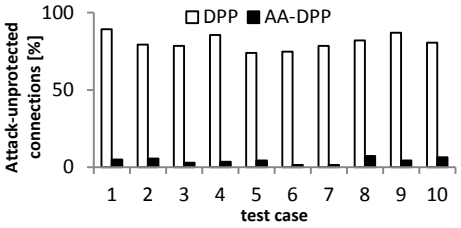

Fig. 3 Portion of connections unprotected from jamming attacks in 14-node US backbone reference network.

Although this preliminary study provides useful insights into attack-protection requirements of unicast-based optical networks utilizing fixed-grid, the research problems targeted in the current proposal require a completely new approach. We will focus on resource-efficient design of resilient and secure optical clouds which bring forth a new set of security vulnerabilities and rely on anycast communication in elastic optical networks, for which we do not have any preliminary results.

6. Equipment

The project is based on analysis and simulations. No experiments are planned, and no equipment is needed, apart from normal computers.

7. National and international cooperation

The proposed project brings together researchers from two Swedish universities to address the interdisciplinary and challenging problems in this proposal. This collaboration is further leveraged by our broad national and international network of contacts. Regarding Swedish col-

laborations, at Chalmers, we are active in the Fiber-Optic Communications Research Center (FORCE), whose expertise in optical hardware for optical interconnects will be a valuable asset in this project, while ONLab at KTH has close research collaborations on different aspects related to optical networking with Ericsson AB in the frame of Kista 5G Transport Lab (Center of Excellence) and with NetInsight AB in the frame of several national projects.

International collaboration is essential for our research. We have well established international collaborations through the participation (and leadership) in many European projects, such as: Large Scale Integrated Projects DISCUS and OASE, European Networks of Excellence (e-Photon, e-Photon+, BONE and TREND), COST actions (COST270, COST291, and COST IC0804), as well as through our personal contacts. For more details we refer to Appendix CV. We often give invited and plenary talks at the major conferences and are represented in their technical program committees (see Appendix CV). We are also frequently hosting visiting professors, researchers and students from leading universities all over the world. The applicants and their students have in the recent years visited the following institutions for at least one week: Stanford University (Prof. J. M. Kahn), Toronto University (Prof. F. R. Kschischang), Technische Universität München, Germany (Prof. G. Kramer and Dr. C. Mas Machuca), University of Parma (Prof. A. Bononi), Bell Labs, NJ (Dr. P. J. Winzer, Dr. R.-J. Essiambre, and Dr. X. Liu), Alcatel–Lucent, Paris (Dr. O. Rival), Jet Propulsion Laboratories, CA (Dr. J. Hamkins and Dr. B. Moision), University of Texas at Dallas (Prof. A. Fumagalli), University of California Davis (Prof. B. Mukherjee), University of Canterbury, NZ (Prof. K. Pawlikowski), Athens Information Technology (Dr. A. Tzanakaki), Warsaw University of Technology (Prof. M. Pioro), and Nagoya University, Japan (Prof. Ken-ichi Sato). Most of the visits have resulted in joint publications (see Appendix Publications). The proposed project will benefit from our international contacts. E.g., the Ph.D. student will spend about 4 months in an internationally recognized research group abroad.

8. Other grants

Prof. Lena Wosinska is a PI of the VR framework grant no. 2014-6230 "Towards flexible and energy-efficient datacentre networks," 2015–2018, which considers highly scalable, flexible and energy-efficient network inside the datacentre. There are synergies with the proposed project, but no overlap. The proposed project, if funded, would greatly complement the VR framework project.

Prof. Erik Agrell is a PI of the VR framework grant no. 2012-5280 "Adaptive optical networks: Theory and algorithms for system optimization," 2013–2016, and the VR project grant no. 2013-5271 "Optical fiber interference is not noise," 2014–2017. The former considers resource allocation in long-distance and metro networks, while the latter introduces new ways to model and mitigate nonlinear interference, also in long-distance optical communications. There are synergies with the proposed project, but no overlap.

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Interdisciplinarity

My application is interdisciplinary

☐

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

Click here for more information

Scientific report

Scientific report/Account for scientific activities of previous project

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Budget and research resources

Project staff

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

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

Dedicated time for this project

	Role in the project	Name	Percent of full time
1	Applicant	Lena Wosinska	25
2	Participating researcher	Erik Agrell	8
3	Other personnel without doctoral degree	doktorand	80
4	Participating researcher	Marija Furdek	

Salaries including social fees

	Role in the project	Name	Percent of salary	2016	2017	2018	2019	Total
1	Applicant	Lena Wosinska	18	249,000	255,000	196,000	201,000	901,000
2	Participating researcher	Erik Agrell	8	65,000	67,000	137,000	140,000	409,000
3	Participating researcher	Marija Furdek	18	264,000	68,000	69,000	71,000	472,000
4	Other personnel without doctoral degree	dkotorand	80	249,000	408,000	418,000	429,000	1,504,000
	Total			827,000	798,000	820,000	841,000	3,286,000

Other costs

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

Premises

	Type of premises	2016	2017	2018	2019	Total
1	kontor	107,000	103,000	106,000	109,000	425,000
	Total	107,000	103,000	106,000	109,000	425,000

Running Costs

	Running Cost	Description	2016	2017	2018	2019	Total
1	Resor	resor till konferenser	80,000	80,000	80,000	80,000	320,000
2	Andra kostnader	publikationer, programlicenser, etc	20,000	20,000	20,000	20,000	80,000
	Total		100,000	100,000	100,000	100,000	400,000

Depreciation costs

Depreciation cost	Description	2016	2017	2018	2019

Total project cost

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

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

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

Total budget

Specified costs	2016	2017	2018	2019	Total, applied	Other costs	Total cost
Salaries including social fees	827,000	798,000	820,000	841,000	3,286,000		3,286,000
Running costs	100,000	100,000	100,000	100,000	400,000		400,000
Depreciation costs					0		0
Premises	107,000	103,000	106,000	109,000	425,000		425,000
Subtotal	1,034,000	1,001,000	1,026,000	1,050,000	4,111,000	0	4,111,000
Indirect costs	416,000	401,000	412,000	423,000	1,652,000		1,652,000
Total project cost	1,450,000	1,402,000	1,438,000	1,473,000	5,763,000	0	5,763,000

Explanation of the proposed budget

Briefly justify each proposed cost in the stated budget.

Explanation of the proposed budget*

1. The applicant, Prof. Lena Wosinska, will work in the project 25% of her time while the project will be charged with 18% of her salary. She will use her faculty funding to cover the difference. She will be responsible for the project management, supervise the PhD student and actively contribute to the technical aspects.
2. The co-applicants, Prof. Erik Agrell and Dr. Marija Furdek, will dedicate to the project in average 8% of time and 20% of time, respectively, while the project will be charged for 8% and 18%, respectively. Prof. Agrell will work 5% of the full time during the first two years of the project and 10% during the last two years. Dr. Furdek will devote 40% of her time during the first year and more than 10% in the remaining three years.
3. We are applying for one PhD student who will be working 80% of time in the project towards his/her PhD degree. The amount of the time in the first year will be lower taking into account a realistic recruitment scenario, i.e., that the student will start two or three months after the project starts. Up to 20% of the PhD student's time will be put on serving as teaching assistant in the courses as well as the other department duty, which will not charge the project.
4. Salaries are calculated with LKP:
5. (Month Salary)×12× (% in the project/100)×1,532
6. Indirect costs include overhead, which is equal to 50,29% of the salary cost.
7. Premises are charged as 12,93% of the salary cost
8. Travel costs include the expenses planned for attending international conferences and project meetings, conference registration fee, accommodation and daily allowance, for participation in conferences with contributions related to the project.
9. Other related costs include software, publication cost, consumables, etc.

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

Lena Wosinska – Curriculum Vitae

1. **University degree: MSc** in Electrical Engineering, 1974, Warsaw Univ. of Technology.
2. **Technical Licentiate:** in Telecommunication systems, 1991, KTH.
3. **Doctoral degree: PhD** in Photonics, 1999, KTH Royal Institute of Technology, "A Study of the Reliability of Optical Switching Nodes for High Capacity Telecommunications Networks". Supervisor: Prof. Lars Thylén.
4. **Docent degree** in Optical Networking, 2008, KTH.
5. **Current degree and position:** Professor in Telecommunication, KTH, School of ICT, since February 2012. Director of Optical Networks Lab. Ca 70% of time spent in research.
6. **Previous positions**

- Associate Professor, KTH, School of ICT, 2001 – 2012.
- Acting Associate Professor, KTH, Dept. of Teleinformatics, 1999 – 2001.
- Assistant Professor, KTH, School of Applied Engineering, 1993 – 1999.
- Researcher, KTH, Dept. of Telecommunication and Computer Systems, 1986 – 1993.
- Researcher, Centre for Research and Development POLAM, Warsaw, Poland, 1975-1983.
- Assistant Professor, Dept. of Physics, Warsaw Univ. of Technology, Poland, 1974-1975.

7. **Interruption in research:** on leave 100% for medical reason, Jan. 2003 – Oct. 2004

8. Supervision

Main supervisor for PhD students:

Jiajia Chen, KTH, completed PhD in 2009
Amornrat Jirattigalachote, KTH, completed PhD in 2012
Mohsan Niaz, KTH, completed Techn. Lic. in 2012
Jawwad Ahmed, KTH, completed PhD in 2013
Mozhgan Mahloo, KTH, completed PhD in 2015
Pawel Wiatr, KTH, currently supervised
Forough Yaghoubi, KTH, currently supervised
Mohammad Rehan Raza, KTH, currently supervised
Kun Wang, KTH, currently supervised

Co-supervisor for PhD students:

Americo Muchanga, KTH, and Antoine B. Bagula, KTH, completed PhD in 2006
Ajmal Muhammad, LiU, currently co-supervised (completed Techn. Lic. in 2012)

Main supervisor for Postdoc fellows:

Jiajia Chen: 2009 – 2012
Marilet de Andrade: 2010 – 2011
Cicek Cavdar: 2010 – 2013
Amornrat Jirattigalachote: 2012 – 2013
Marija Furdek: 2013 – 2014
Matteo Fiorani: 2013 –
Meiqian Wang: 2015 –

Supervision of MSc thesis projects: more than 80 master thesis students. Year 1996 and 1997 two of master students achieved the Swedish best master thesis award.

9. Other merits

9.1. Commission of trust

Natural Sciences and Engineering Research Council of Canada (NSERC) appointment: *Member of the Electrical and Computer Engineering Evaluation Group, 2012-15*

Swedish Research Council (Vetenskapsrådet) appointment: Co-chair of NT-13, *2015*

Reviewer

Books: "*Queuing Systems" by Maria Kihl, Cambridge University Press*

Project proposals:

- *Appointed by Technology Foundation STW, NRC to evaluate Vici project proposals*
- *Appointed by Vinnova to evaluate project proposals*

Scientific journals (selected): *IEEE/OSA JLT, IEEE ToC, IEEE/ACM ToN, IEEE PTL, IEEE JSAC, OSA JON, IEEE/OSA JOCN, Elsevier OSN, Springer TSJ.*

Evaluator of PhD theses:
- Carolina Pinart Gilberga, Universitat Politecnica de Catalunya (UPC), Barcelona, Spain
- Mats Sköld, Photonics Lab., Chalmers University of Technology, Gothenburg, Sweden
- Koen Casier, University of Gent, Belgium
- Clara Kronberger, Munich University of Technology MUT, Germany
- Andreas Kimsås, Norwegian University of Science and Technology NTNU, Norway
- Domenico Siracusa, Politecnico di Milano, Italy
- Fredrik Lindqvist, Lund University, Sweden
- Chamil Jayasundara, University of Melbourne, Australia
- Lida Mollazadeh Sadeghioon, Telecom Bretagne, Brest, France

Membership in journal editorial boards

Member of editorial boards: OSA Journal of Optical Networking (JON), IEEE/OSA Journal of Optical Communications and Networking (JOCN), Springer Photonic Network Communications Journal.
Guest Editor: IEEE Journal on Selected Areas in Communication (JSAC), Elsevier Optical Switching and Networking (OSN), Springer Telecommunication Systems Journal (TSJ)

General Chair and Co-Chair of international conferences
- Chair of IEEE International Conference on Transparent Optical Networks/Workshop on Reliability Issues in Next Generation Optical Networks (ICTON/RONEXT), 2005 – 2011
- Co-Chair of the Technical Sub-committee SC4 of SPIE APOC'2008
- Co-Chair of the Technical Sub-committee SC4 IEEE/OSA/SPIE of ACP'2009 and ACP'2015
- Chair of the Technical Sub-committee SC4 IEEE/OSA/SPIE ACP 2010 - 2012
- Co-Chair of Converged/Optical Track, Future Network & Mobile Summit 2010
- Co-Chair of IEEE ICTON/ Workshop on Green Opt. Comm. (ICTON/GOC), since 2011
- General Chair of 13th IEEE ICTON'2011
- Chair of Optical Networks and Systems Symposium at IEEE ICC'2012
- TPC Chair of IEEE Optical Network Design and Modeling (ONDM) 2013
- TPC Chair of IEEE/OSA/SPIE ACP'2013
- General Chair of IEEE Optical Network Design and Modeling ONDM'14
- Co-General Chair of IEEE/OSA/SPIE ACP'2014

TPC member of many international top-tier IEEE, OSA and SPIE conferences

9.2 Leadership in current and recent Swedish and European research projects
- "Towards flexible and energy-efficient datacentre networks," VR Frame Program, principal investigator (2015–2018)
- Centre of Excellence "Kista 5G Transport Lab", principal investigator (2014 – 16)
- EU EIT ICT Labs "Heterogeneous Networks and Mobile Backhaul", task leader (2013 – 15)
- EU FP7 IP "The DIStributed Core for unlimited bandwidth supply for all Users and Services" (DISCUS), task leader, member of Technical and Management Committees (2012 – 15)
- "Efficient impairments aware optical network technologies for future bandwidth-abundant networks", Vinnova funded project (collaboration with Japan), principal investigator (2012-13).
- EU FP7Large Scale Integr. Proj. "Optical Access Seamless Evolution OASE", WP leader (2010-13)
- Collaborative project "Filterless optical networks", principal investigator (2011-12)
- Focus project "Optical Networking Systems" in the frame The Next Generation (TNG) Strategic Research Area (SRA) initiative, proj. leader and principal investigator (2010-15)
- "Bandwidth Allocation in Future TDM PON", proj. leader and principal investigator (2008-10)
- EU FP7 Network of Excellence BONE, member of advisory board, responsible for implementation of a course on Photonics in Switching in the frame of common Master (2008-11)
- "Security in all-optical networks", project leader and principal investigator (2010-14)
- "All-optical overlay network", project leader and principal investigator (2008-10)
- Eureka/Celtic project "Management Platform for Next Generation of Optical Networks", MANGO, work package leader (2008-11).

9.3 International and national scientific cooperation

Industrial: Different European companies in the frame of EU projects (OASE and DISCUS). In addition: Polish Telecom (Orange), CIENA (Canada).
In Sweden: Ericsson AB, NetInsight, Transmode, Proximion.
Research Institutes: AIT (Greece), ACREO (Sweden), CTTC (Spain), iMind (Belgium)
Universities: LiU (Sweden), SSSUP (Italy), PoliMi (Italy), UniBo (Italy), UPC (Spain), TUM (Germany), UEssex (UK), BME (Hungary), WUT (Poland), AGH (Poland), Uni. Of Zagreb (Croatia), Univ. of Texas at Dallas (USA), Univ. of California Davis (USA), ÉTS (Univ. of Quebec, Canada), Federal Univ. of Para (Brazil), Nagoya Univ. (Japan), Zheijang Univ. (China).

Erik Agrell – Curriculum Vitae

1 Higher education degree

- Master of Science in Electrical Engineering, Chalmers University of Technology, 1989.

2 Doctoral degree

- Doctor of Philosophy in Information Theory, Chalmers, 1997. Dissertation title: "Voronoi-based coding." Supervisor: Prof. Per Hedelin.

3 Postdoctoral positions

- Coordinated Science Laboratory, University of Illinois at Urbana-Champaign (UIUC), 1997–1998 (half time).
- Center for Wireless Communication, University of California, San Diego (UCSD), 1997–1998 (half time), 1998–1999 (full time).

4 Qualifications required for appointment as a docent

- Docent in Communication Systems, Chalmers, 2003.

5 Current position

- Professor in Communication Systems at the Department of Signals and Systems, Chalmers, since 2009. Full Professor since 2013. About 75% research in 2015.
- Visiting Professor at University College London, U.K., since 2014. Honorory position corresponding to about 10 % of full time.

6 Previous positions and periods of appointment

- 2001–2009, Associate Professor, Department of Signals and Systems, Chalmers.
- 1999–2001, Associate Professor, Department of Electrical and Computer Engineering, Chalmers Lindholmen University College, Göteborg.
- 1990–1997, Research Assistant, Department of Information Theory, Chalmers.
- 1988–1990, Systems Analyst, AB Volvo, Technical Development, Göteborg.

7 Interruption in research

- 2005–2008, part-time parental leave and leave of absence, 6 months full-time equivalent.
- 1993–1997, part-time parental leave and sick leave, 11 months full-time equivalent.

8 Supervision

- Ph.D. students: Christian Häger, licentiate 2014, cosupervisor; Tobias Eriksson, licentiate 2014, cosupervisor; Naga V. Irukulapati, licentiate 2014, cosupervisor; Mikhail Ivanov, licentiate 2013, cosupervisor; Krzysztof Szczerba, Ph.D. 2013, cosupervisor; Kasra Haghighi, Ph.D. 2013, cosupervisor; Johnny Karout, Ph.D. 2013, main supervisor; Lotfollah Beygi, Ph.D. 2013, main supervisor; Martin Sjödin, Ph.D. 2012, cosupervisor; Alex Alvarado, Ph.D. 2011, cosupervisor; Hongxia Zhao, Ph.D. 2008, main supervisor; Matts-Ola Wessman, licentiate 2005, cosupervisor; and Johan Lassing, Ph.D. 2005, cosupervisor.
- Postdoctoral researchers: Juzi Zhao, postdoc 2014–present; Debarati Sen, postdoc 2011–2012; A. Serdar Tan, postdoc 2009–2010; and Torsten Wuth, postdoc 2004.

9 Other information of relevance to the application

9.1 Distinctions

- Best poster award, 2013 IEEE Communication Theory Workshop (CTW).
- 2013 Supervisor of the Year, Chalmers University of Technology.
- Best paper award, 2011 IEEE Global Communications Conference (GlobeCom).
- Best poster award, 2009 IEEE Information Theory Workshop (ITW).
- The 1990 John Ericsson medal for "outstanding scholarship for the degree of Master of Science in Engineering."

9.2 Research grants (selected)

- P. Andrekson, M. Karlsson, V. Torres Company, and E. Agrell, "Technologies for spatial-division multiplexing: The next frontier in optical communications," 2015–2018, VR framework grant no. 2014-6138, 12000 kSEK.
- L. Wosinska, J. Chen, E. Agrell, and R. Forchheimer, "Towards flexible and energy-efficient datacentre networks," 2015–2018, VR framework grant no. 2014-6230, 9000 kSEK.
- E. Agrell, G. Durisi, and M. Karlsson, "Optical fiber interference is not noise," 2014–2017, VR no. 2013-5271, 4720 kSEK.
- P. Andrekson, A. Larsson, M. Karlsson, E. Agrell, and P. Larsson-Edefors, "Energy-efficient optical fibre communication," 2014–2018, Knut och Alice Wallenbergs Stiftelse no. 2013.0021, 33894 kSEK.
- E. Agrell, H. Wymeersch, P. Andrekson, and M. Karlsson, "Adaptive optical networks: Theory and algorithms for system optimization," 2013–2016, VR framework grant no. 2012-5280, 12000 kSEK.
- F. Brännström, A. Alvarado, and E. Agrell, "MIMO-BICM: Fundamentals, analysis, and design", 2012–2015, VR no. 2011-5950, 3280 kSEK.
- E. Agrell and M. Karlsson, "Theory and algorithms for fiber-optical intensity channels", 2011–2013, VR no. 2010-5757, 2400 kSEK.
- P. Andrekson, M. Karlsson, E. Agrell, H. Wymeersch, and G.-W. Lu, "Power-efficient terabit/s transmission," 2011–2014, VR framework grant no. 2010-4236, 9600 kSEK.
- P. Andrekson, M. Karlsson, and E. Agrell, "Next generation optical communication systems," 2008–2013, SSF framework grant no. RE07-0026, 20800 kSEK.
- M. Karlsson, P. Andrekson, and E. Agrell, "Advanced optical communication technologies for access and transport networks," 2008–2011, Vinnova no. 2007-02930, 9000 kSEK.
- E. Agrell and M. Karlsson, "Coded modulation for band-limited optical channels," 2008–2010, VR no. 2007-6223, 2250 kSEK.

9.3 Outreach and research community services (selected)

- Invited papers in, e.g., Phil. Trans. Royal Society A 2015, IEEE/OSA J. Lightwave Technol. 2015, Proc. Tyrrhenian Int. Workshop on Dig. Commun. 2015, Proc. OECC 2015, Proc. IEEE SPAWC 2015, Proc. ITW 2015, Proc. OFC 2015, IEEE/OSA J. Lightwave Technol. 2014, Proc. ECOC 2013, Proc. 2013 OFC, Proc. 2012 IEEE IPC, Proc. ITA 2012, Proc. OFC 2012, Proc. IEEE Photonics Soc. Ann. Meeting 2010, Proc. ECOC 2010, and Proc. IWCMC 2009.
- Invited book chapters in *Enabling Technologies for High Spectral-Efficiency Coherent Optical Communication Networks,* Wiley, 2015; *Impact of Nonlinearities on Fiber Optic Communication,* Springer, 2011; and *Experimental Design for Combinatorial and High Throughput Materials Development*, Wiley, 2003.
- TPC member of OFC 2015, ICC 2015, Tyrrhenian Int. Workshop on Dig. Commun. 2015, and GlobeCom 2105.
- Technical Program Co-Chair of the 7th International Symposium on Turbo Codes and Iterative Information Processing, Göteborg, Aug. 2012.
- Associate Editor for *IEEE Transactions on Communications*, 2012–present.
- Publications Editor of *IEEE Transactions on Information Theory*, 1999–2002.
- Cofounder of Fibre-Optic Communications Research Centre (FORCE) at Chalmers, 2010 (chalmers.se/force). The center, currently involving about 35 researchers, originates in interdisciplinary collaboration initiated by E. Agrell and M. Karlsson in 2003.

Curriculum Vitae – Marija Furdek

1 Higher education qualification

- Master of Science in Electrical Engineering, University of Zagreb, Croatia, 2008

2 Doctoral degree

- Doctor of Philosophy in Telecommunications, University of Zagreb, 2012. Dissertation title: "Routing and wavelength assignment for limiting jamming attack propagation in optical networks". Supervisor: Ass. Prof. Nina Skorin-Kapov.

3 Postdoctoral positions

- Optical Networks Laboratory, KTH Royal Institute of Technology, 2013-2014. Host and main research collaborator: Prof. Lena Wosinska.

4 Qualification required for appointment as a docent

5 Current position

- Researcher at the Optical Networks Laboratory, Department of Communication Systems, KTH Royal Institute of Technology. Portion of research 100%.

6 Previous positions and periods of appointment

- 2009-2012: Research and Teaching Assistant, Department of Telecommunications, Faculty of Electrical Engineering and Computing, University of Zagreb, Croatia.
- 2012-2014: Senior Research and Teaching Assistant, Department of Telecommunications, Faculty of Electrical Engineering and Computing, University of Zagreb, Croatia.

7 Interruption in research: none

8 Supervision

Ph. D. student Forough Yaghoubi (KTH), co-supervisor; Ph. D. student Matija Džanko (University of Zagreb), co-supervisor; M. Sc. students Patrik Glavica, Zoran Merki, Filip Dudok, Danko Pavlinović, Mislav Grgić, Darko Lončar, Marko Husnjak (University of Zagreb), co-supervisor; B. Sc. students Luka Babić, Zdravko Ostojić, Neven Mazić (University of Zagreb), co-supervisor.

9 Other merits of relevance to the application

9.1 Distinctions

- 2013 Fabio Neri Best Paper Award for the best paper published in the Optical Switching and Networking journal in 2013.
- The Josip Lončar silver plaque of the Faculty of Electrical Engineering and Computing, University of Zagreb for distinguished doctoral dissertation and research work in the academic year 2012/2013.
- Third place in Best Student Paper Competition at ACP 2011, Shanghai, China.
- Exceptional outstanding paper award at MIPRO 2011, Opatija, Croatia.
- Erasmus scholarship for doctoral students for a 5-month research visit to KTH in 2011.
- The Josip Lončar acknowledgement of the Faculty of Electrical Engineering and Computing, University of Zagreb for excellence in the academic year 2006/2007.
- University of Helsinki, scholarship for one-semester bilateral student exchange in 2007.

- A-type scholarship for excellent students of the Ministry of science, education and sports, Croatia, 2003-2008.

9.2 Outreach and research community services

- Invited papers in Proc. OSA APC Photonics in Switching 2014, Proc. IEEE NOC 2014, Proc. IEEE ICTON 2014, and EUCNC 2014.
- Program Co-Chair of OSA APC Photonic Networks and Devices 2015, Boston, USA.
- Publication Chair of IEEE ONDM 2014, Stockholm, Sweden.
- TPC member of IEEE NOC 2015, OSA APC NETWORKS 2014, IEEE EUROCON 2013.
- Speaker at the KTH Future Friday career day 2014, broadcasted on Kunskapskanalen.
- Co-author of the Croatian Open Access Declaration, Zagreb, Croatia, 2012.
- Co-organizer of the workshop on Open access to scientific information, Zagreb, Croatia, 2012.
- Reviewer for journals: IEEE/OSA Journal of Lightwave Technology, IEEE/OSA Journal of Optical Networking and Communications, OSA Optics Letters, Optical Switching and Networking, Photonic Network Communications, Optical Engineering, Computer Networks, Security and Communication Networks; and for conferences: IEEE ICC, ECOC, IEEE GLOBECOM, IEEE ONDM, IEEE HPSR, IEEE/OSA ACP, IEEE DRCN, IEEE NOC, OSA APC, RNDM, IEEE EUROCON, MIPRO.

Publication list

List of publications, Lena Wosinska (2007 – 2015)

Remark: Number of citations according to Google Scholar, March 2015

1. Peer-reviewed journal articles (published):

1.1. L. Wosinska and T.K. Svensson, "Analysis of Connection Availability in an All-Optical Mesh Network," *Fiber and Integrated Optics*, Volume 26, Issue 2, pages 99 – 110, March 2007. (number of citations: 3)

1.2. W. D. Grover, L. Wosinska and A. Fumagalli, "High Availability in Optical Networks: introduction to the feature issue," *OSA Journal of Optical Networking (JON)*, Vol. 6, No 3, pp. 319 – 321, March 2007. (number of citations: 1)

1.3. J. Chen and L. Wosinska, "Analysis of protection schemes in PON compatible with smooth migration from TDM-PON to hybrid WDM/ TDM-PON," *OSA Journal of Optical Networking (JON)*, Vol. 6, No 5, pp. 514-526, May 2007. (number of citations: 50)

1.4. L. Wosinska and M. Glick, "Photonics in Switching: introduction to the feature issue," *OSA Journal of Optical Networking (JON)*, Vol. 6, No 11, pp. 1244 – 1246, Nov. 2007.

1.5. J. Chen, L. Wosinska, and S. He, "High Utilization of Wavelengths and Simple Interconnection Between Users in a Protection Scheme for Passive Optical Networks," *IEEE Photonics Technology Letters (PTL)*, Vol. 20, No 6, pp: 389 – 391, March 2008. (number of citations: 24)

1.6. C. Raffaelli, K. Vlachos, N. Andriolli, D. Apostolopoulos, J. Buron, R. van Caenegem, G. Danilewicz, J. M. Finochietto, J. Garcia-Haro, D. Klonidis, M. O'Mahony, G. Maier, A. Pattavina, P. Pavon-Marino, S. Ruepp, M. Savi, M. Scaffardi, I. Tomkos, A. Tzanakaki, L. Wosinska, O. Zouraraki, and and F. Neri, "Photonics in Switching: Architectures, Systems and enabling Technologies," *Elsevier Computer Networks*, Vol. 52, Issue 10, Pages 1861-2094, July 2008. (number of citations: 20)

1.7. L. Wosinska, M. Tacca, A. Fumagalli, and A. Autenrieth, "Reliability Issues in Optical Networks: introduction to the feature issue," *OSA Journal of Optical Networking (JON)*, Vol. 7, Issue 10, pp. 834-836, Oct. 2008. (number of citations: 1)

1.8. B. Skubic, J. Chen, J. Ahmed, L. Wosinska, and B. Mukherjee, "A Comparison of Dynamic Bandwidth Allocation for EPON, GPON and Next Generation TDM PON," *IEEE Communications Magazine*, Vol. 47, Issue 3, pp. 40-48, March 2009. (number of citations: 103)

1.9. L. Wosinska, D. Simeonidou, A. Tzanakaki, C. Raffaelli, and Ch. Politi, "Optical Networks for the Future Internet: Introduction," *IEEE/OSA Journal on Optical Communications and Networking (JOCN)*, Vol. 1, Issue. 2, pp: FI1-FI3, July 2009. (number of citations: 13)

1.10. J. Chen, B. Chen and L. Wosinska, "Joint Bandwidth Scheduling to Support Differentiated Services and Multiple Service Providers in 1G and 10G EPONs," *IEEE/OSA Journal on Optical Communications and Networking (JOCN)*, Vol. 1, Issue 4, pp: 343 – 351, Sept. 2009. (number of citations: 26)

1.11. L. Wosinska, J. Chen and C.P. Larsen, "Fiber Access Networks: Reliability Analysis and Swedish Broadband Market," (Invited paper), *IEICE Transaction on Networking (ToN)*, Vol. E92-B, No.10, pp: 3006-3014, Oct. 2009. (number of citations: 6)

1.12. * N. Skorin-Kapov, J. Chen, L. Wosinska, "A New Approach to Optical Networks Security: Attack-Aware Routing and Wavelength Assignment," *IEEE/ACM Transaction on Networking (ToN)*, Vol. 18, Issue 3, pp. 750 – 760, June 2010. (number of citations: 51)

1.13. J. Chen, L. Wosinska, C. Mas Machuca and M. Jaeger, "Cost vs. Reliability Performance Study of Fiber Access Network Architectures," *IEEE Communications Magazine*, Vol. 48, Issue 2, pp: 56 – 65, Feb. 2010. (number of citations: 76)

1.14. B. Skubic, J. Chen, J. Ahmed, B. Chen, L. Wosinska, B. Mukherjee, "Dynamic Bandwidth Allocation for Long-Reach PON: Overcoming Performance Degradation," *IEEE Communications Magazine*, Vol. 48, Issue 11, November 2010. (number of citations: 42)

1.15. A. Jirattigalachote, P. Monti, L. Wosinska, K. Katrinis, A. Tzanakaki, "ICBRDiff: an Impairment Constraint Based Routing Strategy with Quality of Signal Differentiation," *Journal of Networks*, Vol 5, No 11 (2010), 1279-1289, Special Issue on All-Optically Routed Networks, Nov. 2010. (number of citations: 14)

1.16. * A. Tzanakaki, K. Katrinis, T. Politi, A. Stavdas, M. Pikavet, P. Van Daele, D. Simeonidou, M. J. O' Mahony, S. Aleksic, L. Wosinska, P. Monti, "Dimensioning the Future Pan-European Optical Network with Energy Efficiency Considerations," *IEEE/OSA Journal of Optical Communication and Networking (JOCN)*, Vol. 3, No. 4, pp. 272-280, April 2011. (number of citations: 30)

1.17. A. Jirattigalachote, C. Cavdar, P. Monti, L. Wosinska, A. Tzanakaki, "Dynamic Provisioning Strategies for Energy Efficient WDM Networks with Dedicated Path Protection," *Elsevier Optical Switching and Networking (OSN) Journal*, special issue on Green Communication and Networking, Vol. 8, No. 3, pp. 201-213, July 2011. (number of citations: 35)

1.18. M. De Andrade, G. Kramer, L. Wosinska, J. Chen, S. Sallent, and B. Mukherjee, "Evaluating Strategies for Evolution of Passive Optical Networks," *IEEE Communications Magazine*, Vol. 49, Issue 7, pp. 176-184, 2011. (number of citations: 41)

1.19. J. Wu, L. Wosinska, Y. Jin, S. Araki, "Optical Network Architectures and Management," Guest Editorial, Special Issue of *Elsevier Optical Switching and Networking (OSN) Journal*, Vol. 8, Issue. 4, p. 225, Dec. 2011.

1.20. J. Chen, L. Wosinska, M. Niaz Chughtai, and M. Forzati, "Scalable Passive Optical Network Architecture for Reliable Service Delivery," *IEEE/OSA Journal of Optical Communications and Networking (JOCN)*, Vol. 3, Issue 8, pp. 667 – 673, 2011. (number of citations: 19)

1.21. A. Jirattigalachote, N. Skorin-Kapov, M. Furdek, J. Chen, P. Monti, and L. Wosinska, "Sparse Power Equalization Placement for Limiting Jamming Attack Propagation in Transparent Optical Networks," *Elsevier Optical Switching and Networking (OSN) Journal*, special issue on Optical Network Architectures and Management, Vol. 8, Issue 4, pp. 249-258, Dec. 2011. (number of citations: 6)

1.22. L. Velasco, A. Jirattigalachote, M. Ruiz, P. Monti, L. Wosinska, and G. Junyent, "Statistical Approach for Fast Impairment-Aware Provisioning in Dynamic All-Optical Networks," *IEEE/OSA Journal of Optical Communications and Networking (JOCN)*, Vol. 4, Issue 2, pp. 130 – 141, Feb. 2012. (number of citations: 3)

1.23. P. Wiatr, P. Monti and L. Wosinska, "Power savings versus network performance in dynamically provisioned WDM networks," *IEEE Communications Magazine*, Vol. 50, Issue 5, pp. 48 - 55, May 2012. (number of citations: 20)

1.24. J. Ahmed, C. Cavdar, P. Monti, L. Wosinska, "A Dynamic Bulk Provisioning Framework for Concurrent Optimization in PCE-based WDM Networks," *IEEE/OSA Journal of Lightwave Technology (JLT)*, Vol. 30, Issue 14, pp. 2229 – 2239, 2012, July 2012. (number of citations: 8)

1.25. C.Mas Machuca, J. Chen, L. Wosinska, "Cost-Efficient Protection in TDM PONs," *IEEE Communications Magazine*, Vol. 50, Issue 8, pp. 110 – 117, August 2012 (number of citations: 15)

1.26. M. Ruiz, L. Velasco, P. Monti, and L. Wosinska, "A Linearized Statistical XPM Model for Accurate Q-factor Computation," *IEEE Communications Letters*, Vol. 16, Issue 8, pp. 1324 – 1327, Aug. 2012. (number of citations: 2)

1.27. J. Wu, L. Wosinska, G. Shen and S. Spadaro, "Advances in Optical Networks Control and Management", Guest Editorial, Special Issue of *Elsevier Optical Switching and Networking (OSN) Journal*, Vol. 10, Issue 1, pp. 1–2, Jan. 2013.

1.28. M. Mahloo, C. Mas Machuca, J. Chen, L. Wosinska, "Protection cost evaluation of WDM-based next generation optical access networks," Special Issue of *Elsevier Optical Switching and Networking (OSN) Journal*, Vol. 10, Issue 1, pp. 89 – 99, January 2013. (number of citations: 16)

1.29. J. Ahmed, J. Chen, B. Chen, L. Wosinska, and B. Mukherjee "Efficient Inter-Thread Scheduling Scheme for Long-Reach Passive Optical Networks," *IEEE Communications Magazine*, Vol. 51, Issue 2, pp. 35 – 43, Feb. 2013. (number of citations: 12)

1.30. M. De Andrade, J. Chen, B. Skubic, J. Ahmed, and L. Wosinska, "Enhanced IPACT: Solving the Over-Granting Problem in Long-Reach EPON," *Springer Telecommunication Systems Journal, Special Issue on Optical Systems and Access Networks*, Vol. 54, Issue 2, pp. 137-146, 2013. (number of citations: 4)

1.31. A. Mitcsenkov, M. Kantor, K. Casier, B. Lannoo, K. Wajda, J. Chen, L. Wosinska, "Geometric versus Geographic Models for the Estimation of an FTTH Deployment," *Springer Telecommunication Systems Journal, Special Issue on Optical Systems and Access Networks*, Vol. 54, Issue 2, pp. 113-127, 2013. (number of citations: 3)

1.32. C. Mas Machuca, J. Chen, L. Wosinska, "Total Cost Reduction Achieved by Offering Protection in PON Architectures," *Springer Telecommunication Systems Journal, Special Issue on Optical Systems and Access Networks*, Vol. 54, Issue 2, pp. 129-135, 2013.

1.33. J. Wu, L. Wosinska, Y. Jin, S. Araki, "Optical Systems and Access Networks," Guest Editorial, *Special Issue of Springer Telecommunication Systems Journal*, Vol. 54, Issue 2, 11-12, 2013.

1.34. J. Ahmed, C. Cavdar, P. Monti, L. Wosinska, "Hybrid Survivability Schemes Achieving High Connection Availability with Reduced Amount of Backup Resources," [Invited] *IEEE/OSA Journal of Optical Communications and Networking (JOCN)* [OFC2013 Special Issue], Vol. 5, Issue 10, pp. A152 - A161, October 2013. (number of citations: 5)

1.35. A. Muhammad, C. Cavdar, L. Wosinska, R. Forchheimer, "Service Differentiated Provisioning in Dynamic WDM Networks Based on set-up Delay Tolerance," *IEEE/OSA Journal of Optical Communications and Networking (JOCN)*, Vol. 5, Issue 11, pp. 1250 - 1261, November 2013. (number of citations: 1)

1.36. Z. Xu, É. Archambault, C. Tremblay, J. Chen, L. Wosinska, M. P. Béanger, and P. Littlewood, "1+1 Dedicated Optical-Layer Protection Strategy for Filterless Optical Networks," *IEEE Communications Letters, Volume: 18*, No 1, pp. 98 - 101, Jan. 2014. (number of citations: 1)

1.37. M. Mahloo, A. Dixit, J. Chen, C. Mas Machuca, B Lannoo, D. Colle, L. Wosinska, "Towards Reliable Hybrid WDM/TDM Passive Optical Networks," *IEEE Communications Magazine*, Vol. 52 , No 2, pp. S14 - S23, Feb. 2014. (number of citations: 9)

1.38. M. Ruffini, L. Wosinska, M. Achouche, J. Chen, N. Doran, F. Farjady, J. Montalvo, P. Ossieur, B. O'Sullivan, N. Parsons, T. Pfeiffer, X.Z. Qiu, C. Raack, H. Rohde, M. Schiano, P. Townsend, R. Wessaly, X. Yin and D.B. Payne, "DISCUS: An end-to-end solution for ubiquitous broadband optical access," *IEEE Communications Magazine*, Vol. 52, No 2, pp. S24 - S32, February 2014. (number of citations: 20)

1.39. A. Udalcovs, P. Monti, V. Bobrovs, R. Schatz, and L. Wosinska, "Power Efficiency of WDM Networks Using Various Modulation Formats with Spectral Efficiency Limited by Linear Crosstalk," *Elsevier Optics Communications*, Vol. 318, pp. 31-36, May 2014. (number of citations: 3)

1.40. M. Fiorani, S. Aleksic, P. Monti, J. Chen, M. Casoni, L. Wosinska, "Energy Efficiency of an Integrated Intra-Data-Center and Core Network with Edge Caching," *IEEE/OSA Journal of Optical Communication and Networking (JOCN)*, Vol. 6, Issue 4, pp. 421–432, April 2014

1.41. J. Wu, L. Wosinska, G. Shen, S. Spadaro, " Optical Networks Control and Management," Springer Journal of Network and Systems Management, Vol. 22, Issue 3, pp. 434-436, 2014

1.42. J. Wu, L. Wosinska, C. Mas Machuca, A. Tzanakaki, H. Hasegawa, "Guest Editorial ," Elsevier Optical Switching and Networking (OSN) Journal, Vol. 11, Issue 1, pp. 53 - 54, Jan. 2014

1.43. P. Ho, G. Shen, S. Subramaniam, H.T. Mouftah, C. Qiao, L. Wosinska, "Guest Editorial Energy-Efficiency in Optical Networks," IEEE Journal on Selected Areas in Communications (JSAC), Vol. 32, Issue 8, pp. 1521-1523, Aug. 2014

1.44. M. Fiorani, S. Aleksic, M. Casoni, L. Wosinska, J. Chen, "Energy-Efficient Elastic Optical Interconnect Architecture for Data Centers," IEEE Communications Letters, Vol. 18, Issue 9, pp. 1531 - 1534, Sept. 2014 (number of citations: 2)

1.45. E. Di Pascale, D. B. Payne, L. Wosinska, M. Ruffini, "Locality-Aware Peer-to-Peer Multimedia Delivery Over Next-Generation Optical Networks," IEEE/OSA Journal of Optical Communication and Networking (JOCN), Vol. 6, Issue 9, pp. 782-792, Sept. 2014 (number of citations: 1)

1.46. Y. Yang, K.W. Sung, L. Wosinska, J. Chen, "Hybrid Fiber and Microwave Protection for Mobile Backhauling," IEEE/OSA Journal of Optical Communication and Networking (JOCN), Vol. 6, Issue 10, pp. 869-878, Oct. 2014

1.47. * N. Skorin-Kapov, A. Jirattigalachote, L. Wosinska, "An integer linear programming formulation for power equalization placement to limit jamming attack propagation in transparent optical networks," Wiley Security and Communication Networks, Vol. 10, Issue 12, Dec. 2014

1.48. M. Mahloo, J. Chen and L. Wosinska, "PON versus AON: which is the best solution to offload core network by Peer-to-Peer Traffic Localization," Elsevier Optical Switching and Networking (OSN) Journal, Vol. 15, pp. 19-28, Jan. 2015 (number of citations: 1)

1.49. M. Forzati, A. Bianchi, J. Chen, K. Grobe, B. Lannoo, C. Mas Machuca, Jean-Charles Point, B. Skubic, S. Verbrugge, E. Weis, L. Wosinska, D. Breuer, "Next-Generation Optical Access Seamless Evolution: Concluding Results of the European FP7 Project OASE," IEEE/OSA Journal of Optical Communication and Networking (JOCN), Vol. 7, Issue 2, pp. 109-123, Feb. 2015

1.50. P. Wiatr, J. Chen, P. Monti, L. Wosinska, "Energy Efficiency versus Reliability Performance in Optical Backbone Networks [Invited]," IEEE/OSA Journal of Optical Communication and Networking (JOCN) [OFC2014 Special Issue], Vol. 7, Issue 3, pp. A482-A491, March 2015

Peer-reviewed journal articles (accepted for publication):

1.51. Z. Xu, C. Tremblay, É. Archambault, M. Furdek, J. Chen, L. Wosinska, Michel P. Bélanger, and P. Littlewood, "Flexible Bandwidth Allocation in Filterless Optical Networks," accepted for publ. in *IEEE Communications Letters*, to appear in Apr. 2015

1.52. L. Chiaraviglio, P. Wiatr, P. Monti, J. Chen, J. Lorincz, F. Idzikowski, M. Listanti, L. Wosinska, "Is Green Networking Beneficial in Terms of Device Lifetime?," accepted for publ. in *IEEE Communications Magazine, Green Series*, to appear in May 2015

1.53. * A. Rosa, P. Wiatr, C. Cavdar, S. Carvalho, J. Costa, L. Wosinska, "Statistical Analysis of Blocking Probability and Fragmentation based on Markov Modeling of Elastic Spectrum Allocation on Fiber Link," *Elsevier Optics Communications*, to appear in Apr. 2015

2. Peer-reviewed conference contributions:

2.1. J. Chen and L. Wosinska, "Performance Analysis of Protection Schemes Compatible with Smooth Migration from TDM-PON to Hybrid WDM/TDM-PON," *in Proc. Optical Fiber Communication/National Fiber Optic Engineers Conference OFC/NFOEC'07*, Anaheim, CA, March 2007. (number of citations: 4)

2.2. A. Muchanga, A. B. Bagula and L. Wosinska, "On Using Fast Signalling to Improve Restoration in Multilayer Networks," *in Proc. Optical Fiber Communication/National Fiber*

Optic Engineers Conference OFC/NFOEC'07, Anaheim, CA, March 2007. (number of citations: 9)

2.3. L. Wosinska and JiaJia Chen, "Reliability Performance of Passive Optical Networks," *in Proc. of IEEE International Conference on Transparent Optical Networks/Reliability Issues in Optical Networks, ICTON/RONEXT'07*, Rome , Italy, July 2007. (number of citations: 4)

2.4. F. Callegati, L. Wosinska, M. Tornatore and F. Cugini, "Research in Optical Transport Networks: the e-Photon/ONe+ experience," *in Proc. of IEEE International Conference on Transparent Optical Networks, ICTON'07*, Rome , Italy, July 2007.

2.5. C. Raffaelli, L. Wosinska, F. Callegati, N. Andriolli, P. Castoldi, L. Valcarenghi, W. Kabacinski, G. Mayer and A. Pattavina, "Photonics in Switching in NoE e-Photon/One+," *in Proc. of IEEE International Conference on Transparent Optical Networks, ICTON'07*, Rome , Italy, July 2007. (number of citations: 2)

2.6. L. Valcarenghi, R. Inkret, B. Mikac, A. Patavina, M. Tornatore, M. Pickavet, K. Wajda, L. Wosinska, "Which Resilience for the Optical Internet ? An e-Photon/ONe+ Outlook," *in Proc. of IEEE International Conference on Transparent Optical Networks/Reliability Issues in Optical Networks, ICTON/RONEXT'07*, Rome , Italy, July 2007.

2.7. J. Chen and L. Wosinska, "Novel Architectures of Asynchronous Optical Packet Switch," *in Proc. of European Conference on Optical Communication ECOC'07*, Berlin, Germany, September 2007. (number of citations: 5)

2.8. J. Chen, L. Wosinska and S. He, "A Novel Protection Scheme for Hybrid WDM/TDM PONs," *in Proc. of Asia-Pacific Optical Communications Conference APOC'07*, Wuhan, China, November 2007. **Best Student Paper** (number of citations: 1)

2.9. M. Kantor, J. Chen, L. Wosinska, K. Wajda, "Techno-economic analysis of PON protection schemes," *in Proc. of BroadBand Europe Conference BBE'07*, Antwerp, Belgium, December 2007. (number of citations: 3)

2.10. L. Wosinska, J. Chen, M. Kantor, K. Wajda, "Reliability and cost analysis of Passive Optical Networks," *in Proc. of IEEE International Conference on Transparent Optical Networks – Mediterranean Winter, ICTON-MW'07*, Sousse , Tunisia, December 2007. (number of citations: 3)

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Erik Agrell – Publications

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3 Research review articles and invited presentations

[1] Henk Wymeersch *et al.*, invited paper (not yet submitted) at *Tyrrhenian International Workshop on Digital Communications,* Firenze, Italy, Sept. 2015. *Number of citations: –.*

[2] Alex Alvarado, Erik Agrell, *et al.*, "Coding and modulation for optical communication systems: Replacing the soft FEC limit paradigm," invited presentation (no paper) at *Canadian Workshop on Information Theory (CWIT),* St. John's, Newfoundland and Labrador, Canada, July 2015. *Number of citations: –.*

[3] Ben Puttnam *et al.*, "Multi-core modulation formats for spatial superchannels," invited presentation (no paper) at *International Symposium on Ultrafast Photonic Technologies (ISUPT/EXAT),* Kyoto, Japan, July 2015. *Number of citations: –.*

[4] Magnus Karlsson, Cristian B. Czegledi, and Erik Agrell, "Coherent transmission channels as 4d rotations," invited paper in *Proc. Signal Processing in Photonics Communications (SPPCom),* Boston, MA, June–July 2015. *Number of citations: –.*

[5] Henk Wymeersch, Naga V. Irukulapati, Isaac Sackey, Pontus Johannisson, and Erik Agrell, "Backward Particle Message Passing," invited paper in *Proc. IEEE International*

Workshop on Signal Processing Advances in Wireless Communications (SPAWC), Stockholm, Sweden, June–July 2015. *Number of citations: –.*

[6] Alexandre Graell i Amat, Christian Häger, Fredrik Brännström, and Erik Agrell, "Spatially-coupled codes for optical communications: State-of-the-art and open problems," invited paper in *Proc. OptoElectronics and Communication Conference (OECC)*, Shanghai, China, June–July 2015. *Number of citations: –.*

[7] Erik Agrell, Alex Alvarado, and Frank R. Kschischang, "Implications of information theory in optical communications," invited paper in *Philosophical Transactions of the Royal Society A: Physical Sciences* and invited presentation at the *Royal Society Meeting*, London, U.K., May 2015. *Number of citations: –.*

[8] Erik Agrell and Giuseppe Durisi, "Information-theory-friendly models for fiber-optic channels: A primer," invited paper at *IEEE Information Theory Workshop*, Jerusalem, Israel, Apr.–May 2015. *Number of citations: –.*

[9] Henk Wymeersch, Naga V. Irukulapati, Domenico Marsella, Pontus Johannisson, Erik Agrell, and Marco Secondini, "On the use of factor graphs in optical communications," invited paper in *Proc. Optical Fiber Communication Conference (OFC)*, Los Angeles, CA, Mar. 2015. *Number of citations: –.*

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[11] Erik Agrell, Alex Alvarado, Giuseppe Durisi, and Magnus Karlsson, "Capacity of a nonlinear optical channel with finite memory," invited paper in *IEEE/OSA Journal of Lightwave Technology*, vol. 32, no. 16, pp. 2862–2876, Aug. 2014. *Number of citations: 11.*

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[14] Erik Agrell, "Nonlinear fiber capacity," invited paper in *Proc. European Conference on Optical Communication (ECOC)*, London, UK, Sept. 2013. *Number of citations: 6.*

[15] * Erik Agrell and Magnus Karlsson, "WDM channel capacity and its dependence on multichannel adaptation models," invited paper in *Proc. Optical Fiber Communication Conference (OFC)*, Anaheim, CA, paper OTu3B.4, Mar. 2013. *Number of citations: 9.*

[16] Erik Agrell and Magnus Karlsson, "Satellite constellations: Towards the nonlinear channel capacity," invited paper in *Proc. IEEE Photonics Conference (IPC)*, Burlingame, CA, pp. 316–317, Sept. 2012. *Number of citations: 12.*

[17] Magnus Karlsson and Erik Agrell, "Spectrally efficient four-dimensional modulation," invited paper in *Proc. Optical Fiber Communication Conference (OFC)*, Los Angeles, CA, paper OTu2C.1, Mar. 2012. *Number of citations: 16.*

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4 Books and book chapters

[1] Magnus Karlsson and Erik Agrell, "Multidimensional optimized optical modulation formats," invited chapter in *Enabling Technologies for High Spectral-Efficiency Coherent Optical Communication Networks,* Xiang Zhou and Chongjin Xie, eds. Wiley, submitted, Aug. 2014; to appear, 2015. *Number of citations: –.*

[2] Magnus Karlsson and Erik Agrell, "Power-efficient modulation schemes," invited chapter in *Impact of Nonlinearities on Fiber Optic Communication,* Shiva Kumar, ed. New York: Springer, 2011. *Number of citations: 6.*

5 Patents and patent applications

[1] Erik Agrell and Martin Sjödin, "Data transmission system and method," US Patent, no. 8,676,055, Mar. 18, 2014. (Based on US Patent Application, no. 13/503,692, Apr. 24, 2012; PCT Patent Application, no. PCT/EP2010/066,454, Oct. 29, 2010; and US Provisional Patent Application, no. 61/255,884, Oct. 29, 2009.)

[2] Johnny Karout, Gerhard Kramer, Frank R. Kschischang, and Erik Agrell, "Modulation method and apparatus for amplitude- or intensity-modulated communication systems," US Patent Application, no. 13/491,655, June 8, 2012. (Based on US Provisional Patent Application, no. 61/602,104, Feb. 23, 2012.)

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6 Open access computer programs and databases

[1] Erik Agrell, "Tables of binary block codes," http://codes.se/bounds, 2000–2015.

[2] Erik Agrell, "Database of sphere packings," http://codes.se/packings, 2014–2015.

7 Popular science articles/presentations

[1] Erik Agrell, "The knowledge transfer paradox," seminar about supervision principles for the Management Group of Volvo Buses, May 2013.

[2] Erik Agrell,"Introduktion till kanalkoding" (Introduction to channel coding), tutorial at Ericsson Microwave Systems, Apr. 2012.

Most cited publications

[1] Erik Agrell, Thomas Eriksson, Alexander Vardy, and Kenneth Zeger, "Closest point search in lattices," Report no. 1, Chalmers Lindholmen University College, Göteborg, Sweden, Feb. 2000. *Number of citations: 1169.*

[2] Erik Agrell and Magnus Karlsson, "Power-efficient modulation formats in coherent transmission systems," *IEEE/OSA Journal of Lightwave Technology,* vol. 27, no. 22, pp. 5115–5126, Nov. 2009. *Number of citations: 167.*

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[4] Magnus Karlsson and Erik Agrell, "Which is the most power-efficient modulation format in optical links?," *Optics Express,* vol. 17, no. 13, pp. 10814–10819, June 2009. *Number of citations: 114.*

[5] Erik Agrell, Johan Lassing, Erik G. Ström, and Tony Ottosson, "On the optimality of the binary reflected Gray code," *IEEE Transactions on Information Theory,* vol. 50, no. 12, pp. 3170–3182, Dec. 2004. *Number of citations: 110.*

List of publications, Marija Furdek (2007 – 2015)

Remark: Number of citations according to Google Scholar, March 2015

1. Peer-reviewed journal articles:

1.1. Zhenyu Xu, Christine Tremblay, Émile Archambault, Marija Furdek, Jiajia Chen, Lena Wosinska, Paul Littlewood, and Michel P. Bélanger, "Flexible bandwidth assignment in filterless optical networks," to appear in *IEEE Communication Letters*, doi: 10.1109/LCOMM.2015.2394401. *Number of citations:* -.

1.2. Matija Džanko, Marija Furdek, George Zervas, and Dimitra Simeonidou, "Evaluating availability of optical networks based on self-healing network function programmable ROADMs", *IEEE/OSA Journal of Optical Communications and Networking*, vol. 6, no. 11, pp. 974-987, Nov. 2014. *Number of citations: 0.*

1.3. Ramon Aparicio Pardo, Belen Garcia Manrubia, Pablo Pavon Marino, Nina Skorin-Kapov, and Marija Furdek, "Balancing CapEx reduction and network stability with stable routing-virtual topology capacity adjustment (SR-VTCA)", *Optical Switching and Networking*, vol. 10, no. 4, pp. 343-353, Nov. 2013. *Number of citations: 0.*

1.4. * Nina Skorin-Kapov, Marija Furdek, Ramon Aparicio Pardo, and Pablo Pavon Marino, "Wavelength assignment for reducing in-band crosstalk attack propagation in optical networks: ILP formulations and heuristic algorithms", *European Journal of Operational Research*, vol. 222, no. 3, pp. 418-429, Nov. 2012. *Number of citations: 7.*

1.5. Amornrat Jirratigalachote, Nina Skorin-Kapov, Marija Furdek, Jijaija Chen, Paolo Monti, and Lena Wosinska, "Sparse power equalization placement for limiting jamming attack propagation in transparent optical networks", *Optical Switching and Networking*, vol. 8, no. 4, pp. 249-258, Dec. 2011. *Number of citations: 6.*

1.6. * Marija Furdek, Nina Skorin-Kapov, and Maša Grbac, "Attack-aware wavelength assignment for localization of in-band crosstalk attack propagation", *IEEE/OSA Journal of Optical Communications and Networking*, vol. 2, no. 11, pp. 1000-1009, Nov. 2010. *Number of citations: 17.*

2. Peer-reviewed conference contributions:

2.1. Md. Nooruzzaman, Nabih Alloune, Feriel Nabet, Zhenyu Xu, Émile Archambault, Christine Tremblay, Marija Furdek, Jiajia Chen, Lena Wosinska, Paul Littlewood, and Michel P. Bélanger, "Filterless architecture for coherent undersea networks" in *Proc. 19th International Conference on Optical Networks Design and Modeling (ONDM)*, Pisa, Italy, May 2015.

2.2. Sandu Abeywickrama, Marija Furdek, Paolo Monti, Lena Wosinska, Avishek Nag, and Elaine Wong, "Dual-homing based protection for enhanced network availability and resource efficiency", in *Proc. Asia Communications and Photonics Conference (ACP)*, Shanghai, China, Nov. 2014. *Number of citations: 0.*

2.3. Ajmal Muhammad, Marija Furdek, Paolo Monti, Lena Wosinska, and Robert Forchheimer, "An optimization model for dynamic bulk provisioning in elastic optical networks", in *Proc. Asia Communications and Photonics Conference (ACP)*, Shanghai, China, Nov. 2014. *Number of citations: 0.*

2.4. Ajmal Muhammad, Marija Furdek, Paolo Monti, Lena Wosinska, and Robert Forchheimer, "Dynamic provisioning utilizing redundant modules in elastic optical networks based on Architecture on Demand nodes", in *Proc. 40th European Conference on Optical Communications (ECOC)*, Cannes, France, Sep. 2014. *Number of citations: 0.*

2.5. Marija Furdek, Matija Džanko, Patrik Glavica, Lena Wosinska, Branko Mikac, Norberto Amaya, George Zervas, and Dimitra Simeonidou, "Efficient optical amplification in self-

healing synthetic ROADMs", in *Proc. 18th Conference on Optical Network Design and Modelling (ONDM),* May 2014. *Number of citations: 2*.

2.6. Matija Džanko, Marija Furdek, Norberto Amaya, George Zervas, Branko Mikac, and Dimitra Simeonidou, "Experimental demonstration and benefits of self-healing hard-wired and synthetic ROADMs", *in Proc. Optical Fiber Communication Conference and Exposition (OFC),* Mar. 2014. *Number of citations: 5.*

2.7. Matija Džanko, Marija Furdek, Norberto Amaya, George Zervas, Branko Mikac, and Dimitra Simeonidou, "Self-healing optical networks with Architecture on Demand nodes", in *Proc. 39th European Conference on Optical Communication (ECOC),* Sep. 2013. *Number of citations: 6.*

2.8. * Marija Furdek and N. Skorin-Kapov, "Attack-survivable routing and wavelength assignment for high-power jamming", in *Proc. 17th Conference on Optical Network Design and Modeling (ONDM),* Apr. 2013. *Number of citations: 4.*

2.9. Marija Furdek, Nina Skorin-Kapov, and Anna Tzanakaki, "Survivable routing and wavelength assignment considering high-powered jamming attacks", *post-deadline,* in *Proc. SPIE-OSA-IEEE Asia Communications and Photonics (ACP 2011), SPIE Vol. 8310, Network Architectures, Management and Applications IX,* Nov. 2011. *Number of citations: 4.*

2.10. Marija Furdek, Jiajia Chen, Nina Skorin-Kapov, and Lena Wosinska, "Compound attack-aware routing and wavelength assignment against power jamming", SPIE-OSA-IEEE Asia Communications and Photonics (ACP 2011), SPIE Vol. 8310, Network Architectures, Management and Applications IX, Nov. 2011. *Number of citations: 2.*

2.11. Marija Furdek, and Nina Skorin-Kapov, "Physical-layer attacks in all-optical WDM networks", in *Proc. 34rd International Convention on Information and Communication Technology, Electronics and Microelectronics MIPRO 2011, CTI - Telecommunications and Information,* May 2011. **Excellent outstanding paper award**. *Number of citations: 4.*

2.12. Amornrat Jirattigalachote, Nina Skorin-Kapov, Marija Furdek, Jiajia Chen, Paolo Monti, and Lena Wosinska, "Limiting physical-layer attack propagation with power equalization placement in transparent WDM networks", in *Proc. Asia Communications and Photonics (ACP 2010),* Dec. 2010. *Number of citations: 1.*

2.13. Marija Furdek, Marko Bosiljevac, Nina Skorin-Kapov, and Zvonimir Šipuš, "Gain competition in optical amplifiers: A case study", in *Proc. 33rd International Convention on Information and Communication Technology, Electronics and Microelectronics MIPRO, CTI - Telecommunications and Information,* May 2010. *Number of citations: 2.*

2.14. Marija Furdek, Nina Skorin-Kapov, Marko Bosiljevac, and Zvonimir Šipuš, "Analysis of crosstalk in optical couplers and associated vulnerabilities", in *Proc. 33rd International Convention on Information and Communication Technology, Electronics and Microelectronics MIPRO, CTI - Telecommunications and Information,* May 2010. *Number of citations: 8.*

2.15. Marija Furdek and Nina Skorin-Kapov, "A scalable wavelength assignment approach for preventive crosstalk attack localization in optical networks", in *Proc. 19th International Conference on Telecommunications (ConTEL 2009),* Jun. 2009. *Number of citations: 2.*

2.16. Nina Skorin-Kapov and Marija Furdek, "Limiting the propagation of intra-channel crosstalk attacks in optical networks through wavelength assignment", in *Proc. Optical Fiber Communication Conference and Exposition (OFC) and the National Fiber Optic Engineers Conference (NFOEC),* Mar. 2009. *Number of citations: 8.*

2.17. Goran Tomaš, Marija Furdek, Siniša Fajt, Vladimir Olujić, and Karlo Bruči, "Perceptibility of aggressive dynamics processing in digital audio broadcasting", in *Proc. 3rd Congress of the Alps Adria Acoustics Association,* Graz, Austria, Apr. 2007. *Number of citations: 2.*

3. Research review articles and invited presentations:

3.1. Marija Furdek, Matija Džanko, Branko Mikac, and Lena Wosinska, "Multi-period network provisioning utilizing synthetic programmable ROADMs", invited paper (not yet submitted) at *17th International Conference on Transparent Optical Networks (ICTON)*, Budapest, Hungary, Jul. 2015.

3.2. Marija Furdek, Matija Džanko, Patrik Glavica, and Lena Wosinska, "Can Architecture on Demand nodes with self-healing capabilities improve reliability of optical networks?", invited paper in *Proc. OSA Advanced Photonics for Communications, Photonics in Switching*, San Diego, USA, Jul. 2014. *Number of citations: 0.*

3.3. Branko Mikac, Matija Džanko, Marija Furdek, Emilio Hugues-Salas, George Zervas, and Dimitra Simeonidou, "Availability aspects of self-healing optical nodes designed by Architecture on Demand", invited paper in *Proc. 16th International Conference on Transparent Optical Networks (ICTON)*, Graz, Austria, Jul. 2014. *Number of citations: 0.*

3.4. * Marija Furdek, Nina Skorin-Kapov, Szilard Zsigmond, and Lena Wosinska, "Vulnerabilities and security issues in optical networks", invited paper in *Proc. 16th International Conference on Transparent Optical Networks (ICTON)*, Graz, Austria, Jul. 2014. *Number of citations: 1.*

3.5. Marija Furdek, Matija Džanko, and Lena Wosinska, "Resilience of optical networks based on Architecture on Demand nodes", invited presentation at *Proc. European Conference on Networks and Communications (EuCNC)*, Bologna, Italy, Jun. 2014.

3.6. * Marija Furdek, Nina Skorin-Kapov, and Lena Wosinska, "Shared path protection under the risk of high-power jamming", invited paper in *Proc. 19th European Conference on Networks and Optical Communications (NOC)*, Milan, Italy, Jun. 2014. *Number of citations: 0.*

3.7. Marija Furdek, "Attack-aware optical network planning", invited presentation (no paper) at DISCUS workshop, ONDM conference, Stockholm, Sweden, May 2014

4. Book chapter:

4.1. Marija Furdek and Nina Skorin-Kapov, "Physical-layer attacks in transparent optical networks", Optical Communication Systems, N. Das (Ed.), InTech, Rijeka, Croatia, 2012.

5. Popular science article/presentations

5.1. Marija Furdek, "Optical networks – lighting up telecommunications", Future Friday, KTH career event, Stockholm, Sweden, March 2014. Broadcasted by Swedish TV channel Kunskapskanalen.

5.2. Marija Furdek, "The Right to Research – the importance of Open Access from student perspective", Open access to scientific information workshop, Zagreb, Croatia, Oct. 2012.

5.3. Group of authors, Croatian Open Access Declaration, Zagreb, Croatia, Oct. 2012.

6. Five most cited publications

6.1. Marija Furdek, Nina Skorin-Kapov, and Maša Grbac, "Attack-aware wavelength assignment for localization of in-band crosstalk attack propagation", *IEEE/OSA Journal of Optical Communications and Networking*, vol. 2, no. 11, pp. 1000-1009, Nov. 2010. *Number of citations: 17.*

6.2. Nina Skorin-Kapov and Marija Furdek, "Limiting the propagation of intra-channel crosstalk attacks in optical networks through wavelength assignment", in *Proc. Optical Fiber Communication Conference and Exposition (OFC) and the National Fiber Optic Engineers Conference (NFOEC)*, Mar. 2009. *Number of citations: 8.*

6.3. Marija Furdek, Nina Skorin-Kapov, Marko Bosiljevac, and Zvonimir Šipuš, "Analysis of crosstalk in optical couplers and associated vulnerabilities", in *Proc. 33rd International*

Convention on Information and Communication Technology, Electronics and Microelectronics MIPRO, CTI - Telecommunications and Information, May 2010. *Number of citations: 8.*

6.4. Nina Skorin-Kapov, Marija Furdek, Ramon Aparicio Pardo, and Pablo Pavon Marino, "Wavelength assignment for reducing in-band crosstalk attack propagation in optical networks: ILP formulations and heuristic algorithms", *European Journal of Operational Research*, vol. 222, no. 3, pp. 418-429, Nov. 2012. *Number of citations: 7.*

6.5. Amornrat Jirratigalachote, Nina Skorin-Kapov, Marija Furdek, Jijaija Chen, Paolo Monti, and Lena Wosinska, "Sparse power equalization placement for limiting jamming attack propagation in transparent optical networks", *Optical Switching and Networking*, vol. 8, no. 4, pp. 249-258, Dec. 2011. *Number of citations: 6.*

CV

Name: Lena Wosinska	**Doctorial degree:** 1999-06-18
Birthdate: 19511026	**Academic title:** Professor
Gender: Female	**Employer:** Kungliga Tekniska högskolan

Research education

Dissertation title (swe)

Dissertation title (en)

A Study of the Reliability of Optical Switching Nodes for High Capacity Telecommunications Networks

Organisation	Unit	Supervisor
Kungliga Tekniska Högskolan, Sweden Sweden - Higher education Institutes	Skolan för informations- och kommunikationsteknik	Lars Thylén

Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
20204. Telekommunikation	99-2975815-1	1999-06-18

CV

Name: Marija Furdek	**Doctorial degree:** 2012-12-10
Birthdate: 19850123	**Academic title:** Doktor
Gender: Female	**Employer:** Kungliga Tekniska högskolan

Research education

Dissertation title (swe)
Routing and wavelength assignment for limiting jamming attack propagation in optical networks

Dissertation title (en)
Routing and wavelength assignment for limiting jamming attack propagation in optical networks

Organisation	Unit	Supervisor
University of Zagreb, Croatia Not Sweden - Higher Education institutes	Faculty of Electrical Engineering and Computing	Nina Skorin-Kapov

Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
20204. Telekommunikation		2012-12-10

CV

Name: Erik Agrell	**Doctorial degree:** 1997-04-14
Birthdate: 19651122	**Academic title:** Professor
Gender: Male	**Employer:** No current employer

Research education

Dissertation title (swe)
Voronoi-Based Coding

Dissertation title (en)
Voronoi-Based Coding

Organisation	Unit	Supervisor
Chalmers tekniska högskola, Sweden Sweden - Higher education Institutes	Inst för informationsteori	Per Hedelin

Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
20204. Telekommunikation	91-7197-464-4	1997-04-14

Publications

Name: Lena Wosinska	**Doctorial degree:** 1999-06-18
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Wosinska, Lena has not added any publications to the application.

Publications

Name: Marija Furdek	**Doctorial degree:** 2012-12-10
Birthdate: 19850123	**Academic title:** Doktor
Gender: Female	**Employer:** Kungliga Tekniska högskolan

Furdek, Marija has not added any publications to the application.

Publications

Name: Erik Agrell	**Doctorial degree:** 1997-04-14
Birthdate: 19651122	**Academic title:** Professor
Gender: Male	**Employer:** No current employer

Agrell, Erik 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.