Analysis and implementation of packet preemption for Time Sensitive Networks

A standard priority-queuing system is capable of arranging packets with different traffic classes to guarantee a relatively low latency for the high priority traffic. However, in practical cases, severe delay may be caused by starting a large, low-priority frame ahead of a time-critical frame. In this paper, interspersed express traffic is evaluated, which enables preemption of non-time-critical transmission, in particular, the preemptive queuing system allows the cut-through transmission for critical traffic and minimizes the jitter. We analyse the performance of packet preemption through a system level simulation in Riverbed Modeler. The simulation is complemented by numerical analysis which provides the average queuing delay for both types of traffic (preemptable and express). Furthermore, the paper describes an approach to implement the packet preemption solution on an FPGA in VHDL, which illustrates the complexity of hardware implementation.

Optimizations in Heterogeneous Mobile Networks

Heterogeneous Mobile Networks bring advantages over homogeneous deployments in achieving the demand for mobile network capacity and coverage not just outdoor rural and urban areas, but also to homes and enterprises where the large portion of the mobile traffic is generated. However, the heterogeneity in the mobile networks bring many challenges that are discusses with this dissertation. More focus is placed on specific issues with indifferent areas of heterogeneity by proposing optimizations in order to overcome the considered problems. The heterogeneity of mobile networks, together with the densification of the base stations, bring into a very complex network management and operation control for the mobile operators. Furthermore, the need to provide always best connection and service with high quality demands for a joint overall network resource management. This thesis addresses this challenge by proposing a universal hierarchical framework that enables flexible and effective management of diverse resources, namely spectral, optical and
computational. Dual Connectivity (DC) is an emerging architecture, which allows for simplified and flexible mobility management and enhanced load balancing among nodes. The independent control of the user’s transmit power at each node may cause degradation of the overall performance. In this line, a dedicated study of power distribution among the carriers is performed. An optimization of the power allocation is proposed and evaluated. The results show significant performance improvement to the achieved user throughput in low as well as in high loads in the cell. The flow control of the data between the nodes is another challenge for effective aggregation of the resources in case of dual connectivity. As such, this thesis discusses the challenges in providing efficient flow control, and investigates an optimal traffic rate allocation method. Cloud Radio Access Network (C-RAN) designates a leading technology for the Radio Access Network (RAN) architecture that is able to support dense deployments, while ensuring network level energy and cost efficiency for the operator. This thesis thoroughly investigates the achievable multiplexing gains under C-RAN through a mathematical model based on the teletraffic theory. The work allows for evaluation of the key parameters and conditions for optimized cell deployment. The model can be applied to dynamically re-assign cells to a pool of baseband units. Furthermore, an evaluation of the various functional splits in the baseband processing is introduced. The proposed mathematical model quantifies the multiplexing gains and the trade-offs between centralization and decentralization concerning the cost of the pool, fronthaul network capacity and resource utilization. Among the benefits that C-RAN brings is the possibility for sharing of the radio spectrum and the resources required for baseband processing among operators. This thesis investigates strategies for active sharing of radio access among multiple operators and analyses the individual benefits depending on the sharing degree.

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Design of energy efficient optical networks with software enabled integrated control plane
The growing energy consumption has posed new challenges for the future development of networks. Some earlier work has proposed solutions to improve energy consumption based on the existing control plane, for example, node/links sleeping. This study presents a new possibility to reduce network energy consumption by proposing a new integrated control plane structure utilising Software Defined Networking technologies. The integrated control plane increases the efficiencies of exchanging control information across different network domains, while introducing new possibilities to the routing methods and the control over quality of service (QoS). The structure is defined as an overlay generalised multi-protocol label switching (GMPLS) control model. With the defined structure, the integrated control plane is able to gather information from different domains (i.e. optical core network and the access networks), and enable energy efficiency networking over a wider area. In the case presented, the integrated control plane collects the network energy related information and the QoS requirements of different types of traffic. This information is used to define the specific group of traffic's (flow's) routing behaviours. With the flexibility of the routing structure, results show that the energy efficiency of the network can be improved without compromising the QoS for delay/blocking sensitive services.

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Reliability in automotive ethernet networks
This paper provides an overview of in-vehicle communication networks and addresses the challenges of providing reliability in automotive Ethernet in particular.

Cloud RAN for Mobile Networks - a Technology Overview
Cloud Radio Access Network (C-RAN) is a novel mobile network architecture which can address a number of challenges the operators face while trying to support growing end-user's needs. The main idea behind C-RAN is to pool the Baseband Units (BBUs) from multiple base stations into centralized BBU Pool for statistical multiplexing gain, while shifting the burden to the high-speed wireline transmission of In-phase and Quadrature (IQ) data. C-RAN enables energy efficient network operation and possible cost savings on base-band resources. Furthermore, it improves network capacity by performing load balancing and cooperative processing of signals originating from several base stations. This article surveys the state-of-the-art literature on C-RAN. It can serve as a starting point for anyone willing to understand C-RAN architecture and advance the research on C-RAN
Energy efficiency with QoS control in dynamic optical networks with SDN enabled integrated control plane

The paper presents energy efficient routing algorithms based on a novel integrated control plane platform. The centralized control plane structure enables the use of flexible heuristic algorithms for route selection in optical networks. Differentiated routing for various traffic types is used in our previous work. The work presented in this paper further optimizes the energy performance in the whole network by utilizing a multi-objective evolutionary algorithm for route selection. The trade-off between energy optimization and QoS for high priority traffic is examined and results show an overall improvement in energy performance whilst maintaining satisfactory QoS. Energy savings are obtained on the low priority traffic whilst the QoS for the high priority traffic is not degraded.
A Framework for Joint Optical-Wireless Resource Management in Multi-RAT, Heterogeneous Mobile Networks

Mobile networks are constantly evolving: new Radio Access Technologies (RATs) are being introduced, and backhaul architectures like Cloud-RAN (C-RAN) and distributed base stations are being proposed. Furthermore, small cells are being deployed to enhance network capacity. The end-users wish to be always connected to a high-quality service (high bit rates, low latency), thus causing a very complex network control task from an operator’s point of view. We thus propose a framework allowing joint overall network resource management. This scheme covers different types of network heterogeneity (multi-RAT, multi-layer, multi-architecture) by introducing a novel, hierarchical approach to network resource management. Self-Organizing Networks (SON) and cognitive network behaviors are covered as well as more traditional mobile network features. The framework is applicable to all phases of network operation like planning, deployment, operation, maintenance and therefore aids network operators in improving their business potential.

Evaluation of a Cross Layer Scheduling Algorithm for LTE Downlink

The LTE standard is a leading standard in the wireless broadband market. The Radio Resource Management at the base station plays a major role in satisfying users demand for high data rates and quality of service. This paper evaluates a cross layer scheduling algorithm that aims at minimizing the resource utilization. The algorithm makes decisions based on the channel conditions, the size of the transmission buffers and different quality of service demands. The simulation results show that the new algorithm improves the resource utilization and provides better guarantees for service quality.

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Future High Capacity Backbone Networks

This thesis - Future High Capacity Backbone Networks - deals with the energy efficiency problems associated with the development of future optical networks.

In the first half of the thesis, novel approaches for using multiple/single alternative energy sources for improving energy efficiency are proposed. The work focuses on energy efficient routing algorithms in a dynamic optical core network environment, with Generalized MultiProtocol Label Switching (GMPLS) as the control plane. Energy efficient routing algorithms for energy savings and CO₂ savings are proposed, and their performance is studied in details with dynamic network simulations using OPNET. Dynamic routing optimization methods are proposed. The influences of re-routing and load-balancing factors on the algorithm are evaluated with a focus on different re-routing thresholds. Results from dynamic network simulations show that re-routing strategies can further lower CO₂ emissions compared to basic energy source routing scheme, and that a lower re-routing threshold achieves more savings. The increased blocking probability brought by using rerouting schemes can be compensated by applying load balancing criteria. A trade-off between blocking probability and obtained CO₂ savings is studied. Specifically, the use of solar energy as an alternative energy source is also studied with the assumptions of bundled links usage. However, due to the incoherence between the solar generation level and the traffic variation of the day, the algorithms proposed aiming for reducing the dynamic part of the energy consumption of the network may increase the fixed part of the energy consumption meanwhile.

In the second half of the thesis, the conflict between energy efficiency and Quality of Service (QoS) is addressed by introducing a novel software defined integrated control plane. The programmable control platform enables exchange of information between different network domains, and traffic flow concepts are introduced to replace the traditional routing/forwarding mechanisms. The functional design is defined, which introduces new possibilities to the routing methods and the control over QoS. In the presented case, the integrated control plane collects the network energy related information and the QoS requirements of different types of traffic. This information is used to define the routing behavior for a specific class of service. Due to the flexibility of the routing structure, results show that the energy efficiency of the network can be improved without compromising QoS parameters such as delay or blocking probability. A multi-objective evolutionary algorithm is employed to further improve the performance from the dynamic network simulations under the context of the integrated control plane structure. Results show improvements of energy efficiency over three types of traffic, while still keeping acceptable QoS levels for high priority traffic.

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On the Design of Energy Efficient Optical Networks with Software Defined Networking Control Across Core and Access Networks

This paper presents a Software Defined Networking (SDN) control plane based on an overlay GMPLS control model. The SDN control platform manages optical core networks (WDM/DWDM networks) and the associated access networks (GPON networks), which makes it possible to gather global information and enable wider areas' energy efficiency networking. The energy related information of the networks and the types of the traffic flows are collected and utilized for the end-to-end QoS provision. Dynamic network simulation results show that by applying different routing algorithms according to the type of traffic in the core networks, the energy efficiency of the network is improved without compromising the quality of service.

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Resource Allocation: Current Issues and Future Directions

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Traffic Steering Framework for Mobile-Assisted Resource Management in Heterogeneous Networks

With the expected growth of mobile data traffic it is essential to manage the network resources efficiently. In order to undertake this challenge, we propose a framework for network-centric, mobile-assisted resource management, which facilitates traffic offloading from mobile network to Wi-Fi or open access small cells. A provision of desired quality of experience to the end-user is carried out by an operator-configurable monitoring application that is running on a mobile device. A potential to enhance network-centric resource management is provided by delegating traffic steering authorities to the network backbone. What is more, we give an overview of existing standardization activities on offloading the mobile traffic through Wi-Fi.

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Cross layer scheduling algorithm for LTE Downlink

The LTE standards is leading standard in the wireless broadband market. In order to accommodate the increased demand for mobile data services the radio interface in the LTE standard is enhanced with advanced technologies such as OFDMA (Orthogonal Frequency Division Multiple Access) and MIMO (multiple antenna) techniques. The Radio Resource Management at the base station plays major role in satisfying the users demand for high data rates and QoS. Resources for both downlink and uplink transmission need to be assigned such that the capacity, throughput, and cell edge performance are optimized. This paper evaluates a cross layer scheduling algorithm that aims at minimizing the resource utilization. The algorithm makes decisions regarding the channel conditions and the size of transmission buffers and different QoS demands. The simulation results show that the new algorithm improves the resource utilization as well as
provides better guaranties for QoS.

Energy Efficiency in Future PONs
There is a still increasing tendency to give energy efficiency a high priority, even in already low energy demanding systems. This is also the case for Passive Optical Networks (PONs) for which many different methods for saving energy are proposed. This paper uses simulations to evaluate three proposed power saving solutions for PONs which use sleep mechanisms for saving power. The discovered advantages and disadvantages of these methods are then used as a basis for proposing a new solution combining different techniques in order to increase the energy efficiency further. This novel solution is also presented in this paper.

All simulations are done using OPNET Modeler where an EPON model is implemented with the necessary mechanisms for simulating basic functionality and for expanding the model with sleep methods. The individual sleep methods are implemented on top of the basic EPON model, making it easy to switch between them and to let each method seamlessly be an integrated part of the EPON model without affecting other sleep methods or the normal EPON functionality. For simulating different kinds of approximately realistic traffic patterns, traffic generators are implemented in an easy interchangeable and customizable way, making it possible to simulate both generic traffic following general traffic patterns and individual types of traffic following documented real life traffic patterns.
Analysis of Sleep-Mode Downlink Scheduling Operations in EPON Systems

Energy management strategy has been considered as an important component in the future Ethernet Passive Optical Networks (EPONs). In this paper, a sleeping mode operation is studied, and a downlink packet scheduling scheme is analyzed to preserve energy consumption and maintain the required QoS. This paper proposes a novel sleep-mode downlink packet scheduling scheme in order to enhance the sleep control function. Simulation results confirm that the proposed approach offers effective power management on the basis of the traffic conditions. The trade-off between network performances and the power saving is examined and compared.

Energy Efficiency in Ethernet Passive Optical Networks (EPONs): Protocol Design and Performance Evaluation

As concerns about energy consumption grow, the power consumption of the EPON becomes a matter of increasing importance. In respect of energy efficiency, the current standard has no management protocols aiming to reduce power consumption in EPONs. In this paper, we propose an Energy Management Mechanism (EMM) for downlink EPON systems. The proposed mechanism is designed to enhance the standardized control scheme in EPON with the objective to increase energy efficiency while satisfying diverse QoS requirements. The main idea is to put an Optical Network Unit (ONU) into the sleep mode and determine a suitable wakeup time scheduler at the Optical Line Terminal (OLT). A generic EPON system is considered, which is composed of an OLT and several ONUs that are EMM enabled. An energy consumption optimization problem aimed at saving energy is proposed and two heuristic sleep mode scheduling policies are addressed to solve it. The scheduling algorithms are tightly coupled with the upstream bandwidth allocation and downstream transmission scheduling together through an integrated approach in which awake time in ONUs is minimized. There is a trade-off decision between maximizing the power saving and guaranteeing the network performance at the same time. Simulation results show that an EMM-based EPON with well designed scheduling disciplines is essential to achieving significant energy saving while meeting the delay constraint.
Enhanced Sleep Mode MAC Control for EPON

This paper introduces sleep mode operations for EPON. New MAC control functions are proposed to schedule sleep periods. Traffic profiles are considered to optimize energy efficiency and network performances. Simulation results are analyzed in OPNET modeler.

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Modeling and Simulation of Handover Scheme in Integrated EPON-WiMAX Networks

In this paper, we tackle the seamless handover problem in integrated optical wireless networks. Our model applies for the convergence network of EPON and WiMAX and a mobility-aware signaling protocol is proposed. The proposed handover scheme, Integrated Mobility Management Scheme (IMMS), is assisted by enhancing the traditional MPCP signaling protocol, which cooperatively collects mobility information from the front-end wireless network and makes centralized bandwidth allocation decisions in the backhaul optical network. The integrated network architecture and the joint handover scheme are simulated using OPNET modeler. Results show validation of the protocol, i.e., integrated handover scheme gains better network performances.

Integrated control platform for converged optical and wireless networks

The next generation of broadband access networks is expected to be heterogeneous. Multiple wired and wireless systems can be integrated, in order to simultaneously provide seamless access with an appropriate Quality of Service (QoS). Wireless networks support ubiquitous connectivity yet low data rates, whereas optical networks can offer much higher data rates but only provide fixed connection structures. Their complementary characteristics make the integration of the two networks a promising trend for next generation networks. With combined strengths, the converged network will provide both high data rate services and connectivity at anytime and anywhere. One major challenge in the interworking is how to achieve seamless integration. There are many aspects involved in designing an integrated control platform, such as QoS provisioning, mobility, and resiliency. This dissertation introduces the complementary characteristics of the optical networks and the wireless networks, addresses motivations for their interworking, discusses the current progress in hybrid network architectures as well as the functionalities of a control system, and identifies the achieved research contributions in the integrated control platform design. To achieve an integrated and unified control platform, enhanced signalling protocol plays an important role in gluing the two different technologies. Consequently, an integrated resource management system is developed. Furthermore, and admission control scheme for connections in the wireless domain can be jointly designed with the optical upstream bandwidth allocation scheme in the optical domain. Higher resource utilization is achieved due to an effective manipulation of the overall resources of two networks. In the converged optical and wireless network scenario, multiple wireless networks are adjacent to the backbone optical network. Although the local resource allocation mechanisms implemented in the wireless networks individually can provide certain levels of QoS provisioning, proper load balancing and resource allocation schemes are needed in order to utilize the integrated resources effectively and efficiently. An integrated load balancing mechanism is proposed to take advantage to the
centralized control in the optical network. A modified signalling protocol is developed to improve information exchanged between optical and wireless domains. Traffic load and network resources are distributed based on the network states, channel conditions, and QoS requirements. A new aspect in the design of future network is the energy efficiency. An energy management mechanism is proposed and evaluated for the optical network. With regard to power saving, a sleep mode operation is developed. Therefore, power is conserved by switch off some operating functions. The sleep period and wake up period are computed and assigned using two alternative scheduling schemes, which show trade-off performances on energy efficiency, queuing delay and network bandwidth utilization. To summarize, this dissertation presents new knowledge by developing a novel integrated control platform for the converged optical and wireless network. Several contributions are presented by investigating network architectures, protocols, and energy issues to obtain hybrid networks.

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Load balancing in integrated optical wireless networks: Algorithms and evaluation

In this paper, we tackle the load balancing problem in Integrated Optical Wireless Networks, where cell breathing technique is used to solve congestion by changing the coverage area of a fully loaded cell tower. Our objective is to design a load balancing mechanism which works closely with the integrated control scheme so as to maximize overall network throughput in the integrated network architecture. To the best of our knowledge no load balancing mechanisms, especially based on the Multi-Point Control Protocol (MPCP) defined in the IEEE 802.3ah, have been proposed so far. The major research issues are outlined and a cost function based optimization model is developed for power management. In particularly, two alternative feedback schemes are proposed to report wireless network status. Simulation results show that our proposed load balancing mechanism improves network performances.

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Mobility support in integrated EPON-WiMAX network access architecture

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Enhanced signaling scheme with admission control in the hybrid optical wireless (HOW) networks

The hybrid optical wireless (HOW) network has been viewed as a promising solution to meet the increasing user bandwidth and mobility demands. Due to the basic differences in the optical and wireless technologies, a challenging problem lies in the Media Access Control (MAC) protocol design so that it can support stringent Quality of Service (QoS) requirements. In this paper, we describe and evaluate a resource management framework designed for the HOW networks. There are two parts in the resource management framework The first part is the Enhanced MPCP (E-MPCP) scheme aiming at improving signaling ability between the optical and wireless networks. The second part is an Integrated Optical Wireless Admission Control (IOW-AC) scheme aiming at providing the integrated bandwidth allocation in the HOW networks. Our results show that the performances of the system in terms of throughput, delay and packet dropping probability depend on several factors. These factors include the frame duration, the traffic load and the total number of shared users. The results also highlight that our proposed system achieves significant improvements over the traditional approach in terms of user QoS guarantee and network resource utilization.
Integrated control platform with load balancing algorithm in hybrid optical wireless networks

Efficient utilization of available bandwidth over hybrid optical wireless networks is a critical issue, especially for multimedia applications with high data rates and stringent Quality of Service (QoS) requirements. In this paper, we propose an integrated resource management including an enhanced resource sharing scheme and an integrated admission control scheme for the hybrid optical wireless networks. It provides QoS guarantees for connections through both optical and wireless domain. Simulation results show that our proposed scheme improves QoS performances in terms of high throughput and low dropping probability.
IPTV traffic management using topology-based hierarchical scheduling in Carrier Ethernet transport networks

Carrier Ethernet is becoming a favorable access technology for Next Generation Network (NGN). The features of cost-efficiency, operation flexibility and high bandwidth have a great attraction to service providers. However, to achieve these characteristics, Carrier Ethernet needs to have Quality of Service (QoS) provisioning abilities, which guarantee end-to-end performances of voice, video and data traffic delivered over networks. This paper introduces a topology-based hierarchical scheduler scheme, which controls the incoming traffic at the edge of the network based on the network topology. This work has been carried out as a part of the research project HIPT (High quality IP network for IPTV and VoIP) founded by Danish Advanced Technology Foundation.

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MPCP assisted power control and performance of cell breathing in integrated EPON-WiMAX network

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Topology-based hierarchical scheduling using deficit round robin: Flow protection and isolation for triple play service
This paper proposes a topology-based hierarchical scheduling scheme using Deficit Round Robin (DRR). The main idea of the topology-based hierarchical scheduling is to map the topology of the connected network into the logical structure of the scheduler, and combine several token schedulers according to the topology. The mapping process could be completed through the network management plane or by manual configuration. Based on the knowledge of the network, the scheduler can manage the traffic on behalf of other less advanced nodes, avoid potential traffic congestion, and provide flow protection and isolation. Comparisons between hierarchical scheduling, flow-based scheduling, and class-based scheduling schemes have been carried out under a symmetric tree topology. Results have shown that the hierarchical scheduling scheme provides better flow protection and isolation from attack of malicious traffic. This is significant for IPTV services in Carrier Ethernet networks.

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http://conference.bjtu.edu.cn/index.php

Bibliographical note
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Wireless channel condition aware scheduling algorithm for hybrid optical/wireless networks

General information
State: Published
Organisations: Networks Technology and Service Platforms, Department of Photonics Engineering
Authors: Yan, Y. (Intern), Yu, H. (Intern), Dittmann, L. (Intern)
Publication date: 2008
Conference: International Conference on Access Networks : October 15-17, Las Vegas, USA, 01/01/2008
Main Research Area: Technical/natural sciences

Bidirectional RSVP-TE for Multimedia Applications in GMPLS Networks

General information
State: Published
Organisations: Networks, Department of Photonics Engineering
Authors: Yan, Y. (Intern), Wessing, H. (Intern), Berger, M. S. (Intern)
Publication date: 2006
Conference: 10th Conference on Optical Network Design and Modelling, Copenhagen, Denmark, 22/05/2006 - 22/05/2006
Main Research Area: Technical/natural sciences

Prioritized OSPF-TE Mechanism for Multimedia Applications in MPLS Networks

General information
State: Published
Organisations: Networks, Department of Photonics Engineering
Authors: Yan, Y. (Intern), Wessing, H. (Intern), Berger, M. S. (Intern), Dittmann, L. (Intern)
Publication date: 2006
Main Research Area: Technical/natural sciences

Simulation bases analysis on dynamic resource provisioning in optical networks using GMPLS technologies

General information
State: Published
Organisations: Networks, Department of Photonics Engineering
Authors: Wessing, H. (Intern), Yan, Y. (Intern), Berger, M. S. (Intern)
Pages: 9-16
Publication date: 2006
Modelling direct application to network bandwidth provisioning for high demanding research applications

General information
State: Published
Organisations: Networks, Department of Photonics Engineering, Systems
Authors: Wessing, H. (Intern), Yan, Y. (Intern), Berger, M. S. (Intern)
Publication date: 2005

Host publication information
Title of host publication: Proc. of 5th International Conference on Applied Information and Communications
Volume: CD-ROM
Main Research Area: Technical/natural sciences
Conference: AIC 2005, Malta, 01/01/2005
Source: orbit
Source-ID: 183470
Publication: Research - peer-review › Article in proceedings – Annual report year: 2005

Projects:

Latency Critical Networking
Department of Photonics Engineering
Period: 15/09/2017 → 14/09/2020
Number of participants: 4
Phd Student: Zhou, Zifan (Intern)
Supervisor:
Berger, Michael Stübert (Intern)
Wessing, Henrik (Intern)
Main Supervisor:
Yan, Ying (Intern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Samfinansieret - Andet
Project: PhD

**H2020-Shift2Rails-Safe Architecture for Robust Distributed Application Integration in Rolling Stock**
Department of Photonics Engineering
Networks Technology and Service Platforms
Period: 01/03/2017 → 30/06/2018
Number of participants: 3
Acronym: Safe 4Rails
Project participant:
Soler, José (Intern)
Yan, Ying (Intern)
Dittmann, Lars (Intern)

**Network management, control and operation of future optical access networks using SDN**
Department of Photonics Engineering
Period: 15/04/2015 → 14/04/2018
Number of participants: 7
Phd Student:
Mehmeri, Victor (Intern)
Supervisor:
Vegas Olmos, Juan José (Intern)
Tafur Monroy, Idelfonso (Intern)
Main Supervisor:
Dittmann, Lars (Intern)
Examiner:
Yan, Ying (Intern)
Liotta, Antonio (Ekstern)
Monti, Paolo (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Science Without Borders, Brasi
Project: PhD

**Future high capacity backbone networks**
Department of Photonics Engineering
Period: 01/10/2010 → 18/06/2014
Number of participants: 7
Phd Student:
Wang, Jiayuan (Intern)
Supervisor:
Ruepp, Sarah Renée (Intern)
Yan, Ying (Intern)
Main Supervisor:
Dittmann, Lars (Intern)
Examiner:
Christiansen, Henrik Lehrmann (Intern)
Skjoldstrup, Bjarke (Ekstern)
Valcarenghi, Luca (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)
Project: PhD

**Cross layer optimization in Heterogeneous Networks**
Department of Photonics Engineering
Period: 01/08/2010 → 15/06/2016
Number of participants: 7
Phd Student:
Popovska Avramova, Andrijana (Intern)
Supervisor:
Ruepp, Sarah Renée (Intern)
Yan, Ying (Intern)
Main Supervisor:
Dittmann, Lars (Intern)
Examiner:
Soler, José (Intern)
Popovski, Petar (Ekstern)
Roullet, Laurent (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)

**Relations**
Publications:
Optimizations in Heterogeneous Mobile Networks
Project: PhD

**Strategies for next generation optical networks**
Department of Photonics Engineering
Period: 01/03/2005 → 26/05/2010
Number of participants: 6
Phd Student:
Yan, Ying (Intern)
Supervisor:
Berger, Michael Stüb (Intern)
Main Supervisor:
Dittmann, Lars (Intern)
Examiner:
Christiansen, Henrik Lehmann (Intern)
Develder, Chris (Ekstern)
Madsen, Tatiana Kozlova (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: 1/3 DTU-stip, 2/3 FUR/andet
Project: PhD