FONTE EID NEWSLETTER

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FOCUS on RESEARCH

Fibre-optic communication systems form the backbone of the world's communication infrastructure as they provide for lion fraction (more than 99%) of the global data traffic. The ongoing exponential growth in network traffic, however, is pushing current technology, whose data rates had increased over several decades, towards its limits. It is widely accepted that the nonlinear transmission effects in optical fibre are now a major limiting factor in modern fibre-optic communication systems. Nonlinear properties of the optical fibre medium limit the conventional techniques to increase capacity by simply increasing signal power. Most of the transmission technologies utilized today have been originally developed for linear (wired or wireless) communication channels. Over the past several decades, significant improvements in data rates were obtained by improvements and modifications within the overall linear transmission paradigm. However, there is much evidence that this trend is going to end within the next decade due to fibre nonlinearity. There is a clear need for radically different approaches to the coding, transmission, and processing of information that take the nonlinear properties of the optical fibre into account. This also requires education and training of a new generation of optical communication engineers and specialists with knowledge on nonlinear methods and techniques.

Research in EID FONTE focusses on development of disruptive nonlinear techniques and approaches to fibre-optic communications beyond the limits of current technology. The consortium, which includes the world leading telecom centre Nokia Bell Labs Germany, ***is already making important innovative steps*** in development of the technique of the nonlinear Fourier transform (NFT) and its implementation in the practical communication systems.

This **Newsletter** focusses on the most recent scientific results produced by our ESRs

OUTPUT

Journal Papers by ESRs
3

Conference Proceedings by ESRs
2

Research Deliverables
12

Conference Talks by ESRs
3

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WP1: Development of new NFT transmission methods

Lead ESR1:
V. Neskorniuk

What is WP1 about?

WP1, led by Aston University (Prof. S. Turitsyn), is focused on the design of novel NFT-based modulation and demodulation schemes and (with the help of the industry partner, NOKIA BELL LABS) the integration of these schemes into practical optical fibre communication systems.

MOTIVATION

Although several communication methods based on the NFT have been already proposed in the literature, the practical use of the NFT in optical communication systems requires further research. As of today, no commercially viable product based on the NFT exists due to several engineering challenges. FONTE will pioneer the design of new modulation, demodulation and signal processing techniques that take into account the unique advantages of the NFT and real-world constraints. WP1 seeks to improve and optimize existing NFT approaches that are already established by the members of the consortium.

Summary of Progress in WP1

The existing NFT spectrum modulation techniques have been reviewed. We inferred that the following two methods have the potential to render the highest efficiency: b-modulation allowing us to attain the control over the signal's duration, and the periodic NFT, which can bring about benefits in signal processing and signal-noise interference.
Within WP1 we developed a new data-driven approach (neural networks-based, NN) to nonlinearity mitigation in optical fibre links, addressing, specifically, the regime of high nonlinearity. We showed that the NN is able not only to recover the nonlinear impairments caused by optical fiber propagation but also the imperfections resulting from the usage of low-cost legacy transceiver components, such as digital-to-analog converter and Mach-Zehnder modulator.

Detailed results in WP1 so far

Review and optimization results for the NIS NFT-based systems

The distortion induced in the optical channel by Kerr nonlinearity is one of the main bottlenecks of the modern fibre-optic communications. Nonlinear Fourier transform (NFT) is the mathematical technique allowing for cancelling the nonlinear distortion easily. NFT transforms a signal from time domain into a spacial domain, referred to as the nonlinear spectrum, where the complex evolution of a signal by the interplay of Kerr nonlinearity and chromatic dispersion is represented as the linear localized phase shift. In this work, we describe nonlinear frequency division multiplexing (NFDM) systems where the information is encoded into and received from the nonlinear spectrum. Nonlinear inverse synthesis (NIS) systems utilizing only the continuous part of the nonlinear spectrum as an information carrier are a particular case of the broader NFDM concept. We describe NFDM systems utilizing continuous (NIS) and the discrete spectrum. For each type of NFDM system, we bring the main technological breakthroughs and performance milestones achieved.
(read more: D1.1)

New modulation techniques for NFT systems

D1.2 reviews the advanced modulation techniques which can be employed for the NFT-based transmission systems. In particular, it address the case when both continuous spectrum(the quasi-linear part of nonlinear spectrum) and discrete eigenspectrum (the solitonic part) are modulated. This type of modulation can be achieved by the simultaneous application of Darboux transform and the numerical solution of Gelfand-Levitan-Marchenko equations. D1.2 also reviews the advances in the most recent nonlinear frequency-division multiplexing (NFDM) technique, which allows explicit control over the duration of the generated signal: the b-modulation. With the use of exponential scaling for b-function, we can achieve 400 Gbit/s data rate for the dual-polarisation case, which is the up-to-date number obtained by any NFDM system.
(read more: D1.2)

Numerical verification advanced modulation techniques

D1.3 reviews the most up-to-date nonlinear frequency division multiplexed (NFDM) based systems: the system based on the utilisation of periodic nonlinear solutions and end-to-end learnt system. The numerical simulations of the performance of the first system demonstrate that periodic nonlinear Fourier transform can be used to mitigate the drawbacks of the "ordinary" NFDM. The numerical simulations of the second NFDM system demonstrate that the application of the advanced concepts of the machine learning, particularly

Results so far *(cont.)*

end-to-end learning realised via neural networks, can be applied to effectively mitigate the drawbacks of the NFDM concept related to the non-realistic case of the integrable channel.
(read more: D1.3)

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(read more: D1.3)

Scientific output in WP 1 so far:

Journal papers:	0
Conference Proceedings:	0
Conference talks:	0
Scientific Deliverables:	3

WP2: Impact of practical impairments on the NFT

Lead ESR2:
V. Bajaj

What is WP2 about?

WP2 led by TUD (Dr. S. Wahls), deals with the analysis of realistic impairments on the NFT and aims at using this knowledge to aid the development of robust numerical NFT algorithms, modulation formats, and equalization methods.

MOTIVATION

Any real fibre-optic transceiver suffers from a multitude of impairments such as, for example, various forms of noise, non-ideal amplification, quantization effects, aliasing, or also cross-talk. The impact of such impairments on the NFT is currently not well-understood. The classical analyses of these effects apply only in the weakly non-linear regime. For the highly-nonlinear regime FONTE aims at, only very little is known. The goal of this work package is to analyse the impact of real-world impairments on the NFT and to exploit this knowledge for the development of robust numerical NFT algorithms, modulation formats and equalization techniques that are as insensitive as possible against such impairments.

Summary of Progress in WP2

Nonlinear distortions limit the transmission capacities of current fiber-optic communication systems. Non-conventional transmission techniques based on nonlinear Fourier transforms (NFTs) are an interesting approach to address these issues. These transmission techniques, however, rely on an ideal lossless fiber model, while in practice fibers are lossy. The impact of the fiber-loss on NFT-based fiber-optic transmission systems has been investigated. A novel approach to incorporating loss into NFT-based systems that uses a modified NFT and operates in specialized dispersion decreasing fibers (DDFs) was investigated. The combined use of DDF along with the modified NFT eliminates the degrading effects due to fiber-loss completely in a mathematical ideal scenario. The numerical assessments showed significant gains achieved using the proposed solution.

Detailed results in WP2 so far

Report on major impairments in NFT-based transmission

The rapidly increasing demand of high data rates is pushing the transmission capacity of optical fiber communication system towards its limit. Modern optical fiber communication systems uses coherent receiver along with digital signal processing to compensate the linear impairments. It is widely accepted that the capacity of current systems is mainly limited by the nonlinear effects. Over the past decade, different techniques have been proposed to mitigate the nonlinear impairments in optical and digital domain. In Wavelength Division Multiplexing (WDM) systems, where carriers are multiplexed in linear frequency domain, nonlinear interference among the carriers due to fiber nonlinearity limits the transmission capacity. Recently, Nonlinear Fourier Transform (NFT) based transmission techniques have been proposed as promising approach to overcome the nonlinear behaviour of optical fiber. These transmission methods are consider nonlinear behaviour of optical fiber as essential element in designing communication system as the optical fiber is inherently nonlinear channel. NFT is a mathematical tool that linearizes nonlinear fiber optic channel into set of parallel linear channel. As like, in the ordinary Fourier domain the effect of dispersion is translated into simple phase rotations, the NFT converts the combined effect of nonlinearity and dispersion into trivial phase rotations in nonlinear Fourier domain. Many research groups have demonstrated proof-of-concept experiments using NFT. While NFT based techniques offer attractive solution, originally these techniques are applicable to ideal lossless optical fiber system. In practical systems it face challenges due to loss and amplification noise. In addition to this, there are implementation challenges at transceiver due to component imperfection, quantization noise and algorithmic limitations. In order to make NFT based techniques realizable, signal processing techniques to compensate such impairments and modulation formats which are more robust to such impairments are needed. D2.1 surveys the major impairments in NFT as first step towards this goal.
(read more: D2.1)

Software implementations of the developed robust NFT algorithms

The proposal of using nonlinear Fourier transform (NFT) for data transmission through optical fibers has triggered extensive research in the development of algorithms for the fast computation of NFTs for fiber optics. NFT based transmission techniques however are still far from practical implementation due to the major challenges whichcome from loss and noise. In order to overcome the

Results so far *(cont.)*

challenges imposed by fiber loss, we have recently investigated the use of a suitably tapered fiber for NFDM systems. Such fibers are specially designed to the challenge of signal power attenuation and make the NFDM transmission exact. The (I)NFT operations at both transceiver sides need to be adapted for such fibers. Furthermore, specialized code is required in order to simulate transmissions. In this report, we describe our implementations of both the specialized (I)NFT and fiber simulation algorithms. They have both been added to NFDM Lab, which is a publically available open source simulation environment for fiber-optic transmission systems based on NFTs, together with specific simulation code that can recreate the examples presentation in our paper.
(read more: D2.2)

Numerical and experimental validation of the robust modulation format
Nonlinear Fourier transform (NFT) based transmission techniques are seen as a way to mitigate the nonlinearity of the optical fiber. These transmission techniques are very different from the conventional linear transmission techniques. Thus, the modulation techniques used in the conventional linear transmission techniques may not be optimal for NFT based systems and a proper investigation is needed. There are many aspects that need to be considered in order to find suitable modulation for NFT systems such as spectral efficiency (time-bandwidth product), control of pulse-duration, noise sensitivity. Furthermore, attention is needed on the challenges related to practical impairments such as bandwidth limitations and fiber-loss. In a previous report, a modified NFT for the modulation of data in dispersion-decreasing fibers was described that can take fiber loss into account and therefore neutralizes one of the major impairments in standard NFDM systems. In this report, we evaluate this new data modulation technique numerically and quantify the improvements over standard NFDM systems
(read more: D2.3)

Exact NFDM Transmission in the Presence of Fiber-Loss
(Peer reviewed published research)
Nonlinear frequency division multiplexing (NFDM) techniques encode information in the so-called nonlinear spectrum which is obtained from the nonlinear Fourier transform (NFT) of a signal. NFDM techniques so far have been applied to the nonlinear Schrödinger equation (NLSE) that models signal propagation in a lossless fiber. Conventionally, the true lossy NLSE is approximated by a lossless NLSE using the path-average approach which makes the propagation model

Results so far *(cont.)*

suitable for NFDM. The error of the path-average approximation depends strongly on signal power, bandwidth and the span length. It can degrade the performance of NFDM systems and imposes challenges on designing high data rate NFDM systems. Previously, we proposed the idea of using dispersion decreasing fiber (DDF) for NFDM systems. These DDFs can be modeled by a NLSE with varying-parameters that can be solved with a specialized NFT without approximation errors. We have shown in simulations that complete nonlinearity mitigation can be achieved in lossy fibers by designing an NFDM system with DDF if a properly adapted NFT is used. We reported performance gains by avoiding the aforementioned path-average error in an NFDM system by modulating the discrete part of the nonlinear spectrum. In this paper, we extend the proposed idea to the modulation of continuous spectrum. We compare the performance of NFDM systems designed with dispersion decreasing fiber to that of systems designed with a standard fiber with the path-average model. Next to the conventional path-average model, we furthermore compare the proposed system with an optimized path-average model in which amplifier locations can be adapted. We quantify the improvement in the performance of NFDM systems that use DDF through numerical simulations.
(read more: V. Bajaj, S. Chimmalgi, V. Aref and S. Wahls, "Exact NFDM Transmission in the Presence of Fiber-Loss," in Journal of Lightwave Technology, vol. 38, no. 11, pp. 3051-3058, 1 June1, 2020, doi: 10.1109/JLT.2020.2984041.)

Scientific output in WP 2 so far:

Journal papers:	1
Conference Proceedings:	1
Conference talks:	2
Scientific Deliverables:	3

WP3: Machine learning techniques for fibre-optic channels

Lead ESR3:
S. M. Ranzini

What is WP3 about?

WP3 led by DTU (Prof. D. Zibar), focuses on the development of the optical performance monitoring schemes and channel estimation algorithms for system that use NFT. Tools from machine learning and data-driven models will be considered for system optimization.

MOTIVATION

Optical performance monitoring is vital to ensure robust and reliable operation of optical communication systems. It provides quality-of-transmission metrics, such as Q-factor, and helps approximate channel parameters. The Q-factor is related to the optical signal-to-noise-ratio and can be computed by looking at the eye-diagrams at the monitoring points along the transmission link. These issues are well-studied in systems that use traditional waveforms. However, if future optical networks are going to employ NFT transmission schemes with unconventional waveforms, it is necessary to develop algorithms for measuring quantities such as Q-factor or OSNR. Currently, there is no known method to estimate the Q-factor from the eye-diagrams in NFT signals. Furthermore, fibre parameters are needed to compute the forward and inverse NFT. This calls for accurate estimation algorithms in the presence of the signal-dependent non-Gaussian noise. Machine learning could help with this task.

Summary of Progress in WP3

ESR3 is developing a new receiver based on optoelectronic machine learning for intensity-modulated and direct detection systems. The optical pre-processing stage slices the received signal spectrum in small sub-bands with passive optical filters and each is detected by a photodetector. The digital post-processing is based on a recent technique in machine learning called reservoir computing. We demonstrated the potential of the receiver for 32-GBd OOK signal transmission, and showed an increase in reach from 10 km to 40 km, corresponding to 400%, compared with digital-only techniques

Detailed results in WP3 so far

Survey of machine learning algorithms for optical performance monitoring
Nowadays, nonlinear effects in optical fibers are one of the major limiting factors for optical communications. Different technologies have attempted to address these impairments for optical transmission. Nonlinearity mitigation through digital signal processing (DSP)[2], optical phase conjugation (OPC) [3] and nonlinear frequency division multiplexing (NFDM) [4]are the most known topics in this area. Although great results show the increase of the transmission data rate and reach, the implementation costs of any of them are still prohibitive. It is also worth to mention that all the mentioned techniques require full knowledge of the fiber transmission parameters to work properly. Optical performance monitoring (OPM) techniques estimates the parameter of the optical fiber channel, which is required at multiples point along the link. The multiple uses of this technology imply the necessity of simpler and cheaper solutions [5]. Machine learning (ML) techniques may help solve the fiber nonlinearities for optical transmission and OPM, potentially reducing implementation costs. ML tools has a broad area of application and are very well known for being extremely effective for classification problems, typically for image classification and speech detection. Nonetheless, ML implementations with central processing units (CPU) are suboptimal in terms of speed and power efficiency [6]. Considering the optical communication field, it also implies the necessity to convert the signal from optical domain to electrical/digital domain. In other words, an expensive solution. Alternatively, several researches using hybrid optical-electronic systems with reservoir computing (RC) and full optical neural networks (ONN) with programmable nanophotonic processor (PNP) have been demonstrated
(read more: D3.1)

System identification and parameter estimation
System identification is the field that studies techniques to build mathematical models of dynamic systems. It can be used when no previous information is available from the system or when there is a model, but some parameters are unknown. The latter can also be called parameter identification. This is a powerful tool to simulate and understand real complex devices. The basic steps to build a model of a real system starts by collecting information (data) about it. Followed by choosing a structure that will represent the desired system. An error function is defined to measure the difference between the collected information and the estimative from the model. The difference between both systems is used to improve the model and approximate it from the real system as close as possible.One of the most important step of building a model is the choice of the

structure that will represent the system. This can be a hard limitation of the model. For example, trying to model a nonlinear system with a linear model. Over the years, many different approaches were developed in the literature for system identification[1, 2]. A possible classification between the varieties of possibilities in structure is dividing them by linear and nonlinear models. In this report, it will be given a general idea in how to apply system identification for linear system using a finite impulse response (FIR) filter and for a nonlinear system using Volterra filter

(read more: D3.2)

Performance analysis of monitoring techniques based on machine learning

The constant increase in information due to inventions coming from internet-of-things, autonomous cars, and others, forces the network to re-inventing itself to keep demand efficiently. Optical performance monitor(OPM)techniques ensure that communication in an optical link, where most of the information goes through, is reliable. The current OPM techniques require full signal demodulation, which is too complex and expensive. Therefore, it is desirable to create a simple and cheaper mechanism to extract the necessary information. Using only photodetectors (PDs) to measure the power of the signal might be an alternative solution. However, due to the square-law detection, the phase information is lost in the process. In this scenario, machine learning (ML) techniques might be used to overcome this challenge. ML working as regression is a powerful tool that can determine a nonlinear relationship between input and output. Hence, a good promise in learning the relationship between the power signal and the channel parameters. In D3.3we show some of the state-of-art solutions to address the topic highlighted previously and report a new approach using an optoelectronic receiver with ML to mitigate the CD in the direct detected system.

Although this technique is used for mitigation, the idea of using an optical pre-processing might be extendable to OPM. The optoelectronic receiver consists of slicing the spectrum and detecting each of them with a photodetector, followed by an ML technique to reconstruct the transmitted information. Through this process, our previous works showed an increase in the transmission reach compare to a single PD receiver.

(read more: D3.3)

Results so far *(cont.)*

Reservoir-computing based equalization with optical pre-processing for short-reach optical transmission

(Peer reviewed published research)

Chromatic dispersion is one of the key limitations to increasing the transmission distance-rate product for short-reach communication systems relying on intensity modulation and direct detection. The available optical dispersion-compensation techniques have lost favor due to their high impact on the link loss budget. Alternative digital techniques are commonly power-hungry and introduce latency. In this work, we compare different digital, optical and joint hybrid approaches to provide equalization and dispersion compensation for short-reach optical transmission links. Reservoir computing, as a promising technique to provide equalization with memory in an easily trainable fashion, is reviewed and the properties of the reservoir network are directly linked to system performance. Furthermore, we propose a new hybrid method relying on reservoir computing combined with a simple signal pre-conditioning stage directly in the optical domain. The optical pre-processing uses an arrayed waveguide grating to split the received signal into smaller sub-bands. The performance of the proposed scheme is thoroughly characterized both in terms of reservoir properties and appropriate pre-processing. The benefits are numerically demonstrated for 32-GBd on-off keying signal transmission, and show an increase in reach from 10 km to 40 km, corresponding to 400 %, compared with more complex digital-only techniques. *(read more: Francesco Da Ros, Stenio M. Ranzini, Henning Bülow, & Darko Zibar. (2020). Reservoir-computing based equalization with optical pre-processing for short-reach optical transmission. http://doi.org/10.1109/JSTQE.2020.2975607)*

Tunable Optoelectronic Chromatic Dispersion Compensation Based on Machine Learning for Short-Reach Transmission

(Peer reviewed published research)

A machine learning-based tunable optical-digital signal processor is demonstrated for a short-reach optical communication system. The effect of fiber chromatic dispersion after square-law detection is mitigated using a hybrid structure, which shares the complexity between the optical and the digital domain. The optical part mitigates the chromatic dispersion by slicing the signal into small sub-bands and delaying them accordingly, before regrouping the signal again. The optimal delay is calculated in each scenario to minimize the bit error rate. The digital part is a nonlinear equalizer based on a neural network. The results are analyzed in terms of signal-to-noise penalty at the KP4 forward error correction threshold.

Results so far *(cont.)*

The penalty is calculated with respect to a back-to-back transmission without equalization. Considering 32 GBd transmission and 0 dB penalty, the proposed hybrid solution shows chromatic dispersion mitigation up to 200 ps/nm (12 km of equivalent standard single-mode fiber length) for stage 1 of the hybrid module and roughly double for the second stage. A simplified version of the optical module is demonstrated with an approximated 1.5 dB penalty compared to the complete two-stage hybrid module. Chromatic dispersion tolerance for a fixed optical structure and a simpler configuration of the nonlinear equalizer is also investigated
(read more: Ranzini, S.M.; Da Ros, F.; Bülow, H.; Zibar, D. Tunable Optoelectronic Chromatic Dispersion Compensation Based on Machine Learning for Short-Reach Transmission. Appl. Sci. 2019, 9, 4332.

Scientific output in WP 3 so far:

Journal papers:	2
Conference Proceedings:	1
Conference talks:	1
Scientific Deliverables:	3

WP4: Network applications of the NFT technology

Lead ESR4:
A. Shahkarmi

What is WP4 about?

WP4, led by Telecom ParisTech (Prof. M. I. Yousefi), focuses on the development of the NFT based nonlinear frequency-division multiplexed systems for optical fibre networks.

MOTIVATION

Nonlinear frequency-division multiplexed (NFDM) can be applied to single- and multi-user channels. Present simulations and experimental demonstrations are mostly limited to point-to-point transmission. However, the great advantage of NFDM occurs in networks, where there are multiple transmitters and receivers. WP4 is dedicated to network application of the NFT. This is the most relevant case for the industry partner NOKIA BELL LABS and commercial systems.

Summary of Progress in WP3

End-to-end deep learning of the optical fiber channel has recently been proposed to address the limitation that the Kerr nonlinearity sets on the transmission rates of fiber optic communication systems. It is important to understand how this approach compares with the conventional methods. By designing a neural network approximating the channel, we studied this comparison for a small-scale system, which we are currently extending to large-scale systems. In addition, we carried out some research on an approach based on representation learning and feature transfer to help protect the sequence of symbols at the transmitter against errors introduced by the channel.

Detailed results in WP4 so far

Principles of linear and nonlinear frequency-division multiplexing

Wavelength-division multiplexing (WDM) and nonlinear frequency-division multiplexing (NFDM) are the two multiplexing schemes for optical fiber communication. In WDM, which is the same as linear frequency-division multiplexing (FDM) in radio communication systems, user's signals are linearly multiplexed in the frequency domain. However, in nonlinear channels, such as optical fibers, linear multiplexing causes interactions. To address this, NFDM has been proposed. In NFDM, which is based on the nonlinear Fourier transform (NFT), users' signals are multiplexed in the nonlinear Fourier domain and propagate independently in a lossless noiseless optical fiber modeled by the nonlinear Schrödinger (NLS) equation. In light of recent notable progress in these schemes, ever-increasing attention has been attracted to this area. In D4.1 mathematical principles underlying modulation and multiplexing in linear and nonlinear communication systems are reviewed.

(read more: D4.1)

Multi-user communication and information theory

Nonlinear frequency-division multiplexing (NFDM) has been introduced to address nonlinearity in optical fiber communication. This approach is a signal multiplexing scheme based on the nonlinear Fourier transform (NFT). Problematically, the computational complexity of the inverse nonlinear Fourier transform (NFT), typically conducted by integral equations, is high. This makes it hard, in multi -user nonlinear optical fiber communication, to perform both nonlinear modulation and multiplexing. A varie ty of approaches has been proposed to enhance NFDM to address this problem. We, however, consider a machine learning approach to tackle the nonlinearity problem in optical fiber communication. An end to end communication system was simulated. The equalizer at the receiver, which was based on Backpropagation (BP) algorithm, was targeted to be optimized, as BP has high complexity. A neural network (NN) was succeeded to be devised that approximates the high-complexity BP, with the accuracy of 99.9% in noiseless condition, while having 87.3% lower complexity. This NN equalizer also works well in noisy environments. In this article, after providing a brief background on machine learning and neural networks, we elaborate on this NN equalizer and analyse the results. D4.2 also discusses how machine learning can enhance the achievable information rate of fiber-optic communication systems by reducing the receiver complexity.

(read more: D4.2)

Scientific output in WP 4 so far:

Journal papers:	0
Conference Proceedings:	0
Conference talks:	0
Scientific Deliverables:	2

WP5: Experimental implementation & testing of NFT systems

All ESRs involved

NOKIA
Bell Labs

What is WP5 about?

WP5, led by the FONTE industrial partner NOKIA BELL LABS (Dr. H. Buelow), focuses on the experimental demonstration of the developed algorithms in WP1-WP4, new system designs and techniques, implementation and commercialisation of results.

MOTIVATION

The academic partners at FONTE are world leading experts in the NFT. This extraordinary cluster of experts positions NOKIA BELL LABS very well to identify promising technologies in the very early stage, to develop IP licensing, and to decide on commercialization and product development

Summary of Progress in WP3

The performance of coherent optical high-speed transceivers are limited by their physical limitation and impairments. To operate with their maximum capacity, we should mitigate undesired distortions of these devices. A cost-effective way to overcome this challenge is using digital pre-distortion (DPD) techniques. ESR2 investigated a neural network DPD technique and showed in lab experiments an improvement of 3 dB compared to traditional methods. The ESR3 is investigating a new transceiver based on sharing the complexity between the optical and digital domain with machine learning techniques. Experimental analyses were carried out at NBL and showed a transmission reach gain of 800%, compared to digital-only techniques.

Detailed results in WP5 so far

Transmission regime definition and plan of experiments

The practical challenges of interest that the ESRs plan to tackle in the scope of the project are defined in D5.1. Since ESRs follows their individual research direction according to the work packages, we defined different experimental plans for each ESR. In the current report, the experimental plans are detailed based on the progress of ESRs in their research.

ESR 1 is investigating on the machine learning (ML)-based approaches to improve the performance of nonlinearity mitigation (NLM) techniques in fibre-optic communication systems, in particular the performance of nonlinear frequency-division multiplexing (NFDM) systems where the information in encoded into the nonlinear Fourier spectrum. In this report, we overview the practical challenges and define the next experimental plans to address these challenges.
ESR 2 follows his research on the impairments mitigation of NFDM systems. NFDM systems are severely suffered from some practical impairments such as non-ideal fiber amplification, and non-ideal transceiver's characteristics. ESR 3 has been working on some solutions to mitigate such impairments. we briefly review the challenges in designing NFDM experiments and define our plans for compensation of the nonlinear distortion arising from transceivers.
ESR 3 is investigating on Reservoir Computing (RC) as a new tool for implementing signal processing in the optical domain. It follows the architecture of a recurrent neural network (RNN), which allows the process of time-dependent signals. The advantage of RC over RNNs is that the recurrent connections are determined randomly (called reservoir) and do not require any changes/training over time. This characteristic makes RC an excellent option to be used in photonic systems. In this report, we define our experimental plans to boost the performance of some RC structure in practice.
ESR 4 is working on machine-learning solutions for optical fiber communications, including NFDM systems. The research direction is to use neural networks and kernel methods for mitigation (equalization) of the impairments of optical fiber. The plan is first to develop such solutions in simulation environment for nonlinear Schrodinger's (NLS) equation, the basic model for an optical fiber. Then, we verify the developed solutions on the real fiber and assess their performance on a high-speed transmission experiment.
(read more: D5.1)