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ABSTRACT

High degree of heterogeneity of future optical networks, such as services with different quality-of-transmission requirements, modulation formats and switching techniques, will pose a challenge for the control and optimization of different parameters. Incorporation of cognitive techniques can help to solve this issue by realizing a network that can observe, act, learn and optimize its performance, taking into account end-to-end goals.

In this letter we present the approach of cognition applied to heterogeneous optical networks developed in the framework of the EU project CHRON: Cognitive Heterogeneous Reconfigurable Optical Network. We focus on the approaches developed in the project for optical performance monitoring, which enable the feedback from the physical layer to the cognitive decision system by providing accurate description of the performance of the established lightpaths.

Keywords: optical networks, cognition, dynamic optical networks, optical performance monitoring.

1. INTRODUCTION

Optical networks are nowadays becoming more heterogeneous, ranging from different types of services, switching paradigms to physical interfaces. Therefore, network operators are facing the challenge of supporting a plethora of services, each with individual requirements on quality of service (QoS). Operators have also available different transmission technologies for their optical transport networks, such as coding, modulation formats or data rates. Moreover, in the short and medium term, optical networks may simultaneously support different switching paradigms such as semi-static and dynamic circuit switching. Hence, a key issue of highly heterogeneous networks is how to efficiently control and manage network resources while fulfilling user demands and complying with QoS requirements.

A solution for such a scenario may come from cognitive networks. A cognitive network is defined as "a network with a process that can perceive current network conditions, and then plan, decide and act on those conditions. The network can learn from these adaptations and use them to make future decisions, all while taking into account end-to-end goals" [1]. Hence, a cognitive network should provide better end-to-end performance than a non-cognitive network. Cognitive paradigm have already shown to be a promising solution for wireless networks [1,2]. Cognition is also applicable to optical communication architectures [3-5], since it can offer flexibility to telecom operators by optimizing simultaneously physical layer components' characteristics (modulation format, forward error correction – FEC, wavelength capacity, etc.) and network layer parameters (bandwidth, number of simultaneous lightpaths, QoS, etc.) depending on application or service requirements.

The aim of CHRON is to develop a showcase network architecture and a control plane that efficiently uses resources in a heterogeneous scenario, while fulfilling the QoS requirements of each type of services. To achieve this goal, CHRON relies on cognition, so that control decisions must be made with an appropriate knowledge of current status, and supported by a learning process to improve the performance with the acquired past knowledge. In this paper, we present in section 1.1 the global CHRON architecture. In section 2 we describe the approaches followed in CHRON for optical performance monitoring (OPM). In section 3 we describe a Quality-of-Transmission (QoT) estimator that combines OPM with cognition. We finish with conclusions and future work in section 4.

1.1 CHRON Architecture

The central element of our proposed CHRON architecture is a cognitive decision system (CDS).CDS runs a generic cognitive decision process which is in charge of taking decisions, which are in turn based on the observed network behavior. Figure 1 presents the building blocks of the CDS module, as well as their relationship to the network monitoring system and the control and management system. This architecture shows how the CDS implements the cognitive loop [1]. The network monitoring system gathers the network status and store it into a generic knowledge database. Separately, there are several specific knowledge databases, containing all the information associated with each of the cognitive processes. Therefore, there are as many specific knowledge databases as cognitive processes in the CDS. These databases are updated through a specific learning module, which is associated to a single cognitive process per database. Consequently, the cognitive process module can access the general and specific databases to retrieve and update them. Finally, the specific cognitive process provides the decision and action information to the control plane when request arrives. Based on this

architecture, a robust optical signal monitoring needs to be developed in order to feed the CDS with information and implement intelligence into the network.
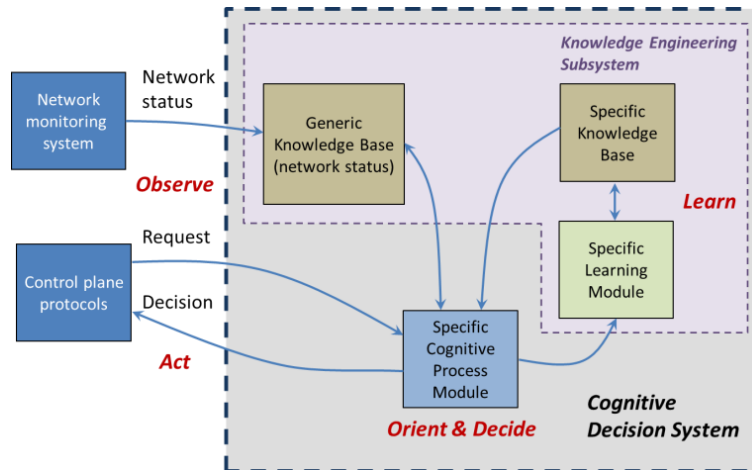

Figure 1. Building blocks of the cognitive decision system as defined in the CHRON project

2. OPTICAL PERFORMANCE MONITORING

OPM is a basic mechanism providing inputs to the cognitive processes. In traditional scenarios, OPM is performed by monitoring the signal tapped before the receiver with devices such as an oscilloscope or an optical spectrum analyzer [6]. Combining the advantage of coherent detection, where both amplitude and phase are recovered with digital sampling and signal processing, forms an inexpensive and robust alternative to traditional OPM methods. Figure 2a) shows location of an OPM subsystem in the digital signal processing (DSP) module of a coherent receiver. The received optical field is transferred into electrical domain for further treatment with DSP algorithms. In the sense used here, monitoring can be understood twofold: 1) observation of the received signal performance parameters that indicate detrimental effects of signal generation, fiber-optic transmission and reception (OPM); and 2) observation of the received signal to enable advanced receiver functionalities, such as reconfiguration of the software-defined digital coherent receiver.

Typical performance indicators used in the digital communication systems include quality factor Q^2, error vector magnitude (EVM), modulation error ratio (MER), or pre- and ultimately post-FEC bit error rate (BER). Those are, however, synthetic indicators where information about the contribution of each specific impairment affecting the signal is lost. Since in a digital coherent receiver it is possible to compensate deterministic linear impairments, it is highly desirable to separate the influence of all impairments acting upon the signal in order to efficiently mitigate them in DSP. Most of impairments that affect the signal performance in the coherent fiber-optic transmission system are listed in Table 1, which includes effects originating in the transmitter, fiber-optic link and the receiver [7]. OPM techniques can be divided into data-aided (DA) and non-data-aided (NDA). Comparison between both approaches is shown in Table 2.

a)   b)
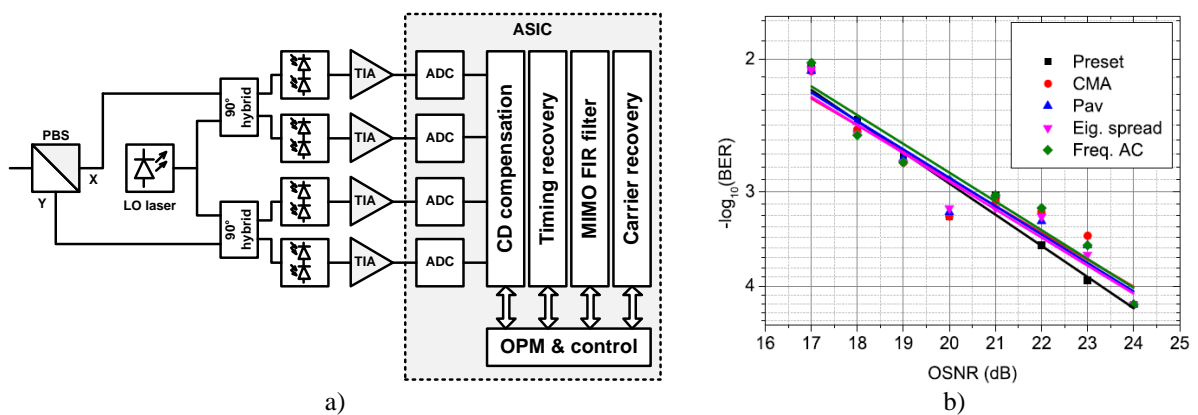
Figure 2. a) Typical structure of a digital coherent receiver with CD monitoring and equalization block. b) Performance of different CD compensation methods [8]. Methods: Preset – reference; CMA – constant modulus algorithm; Pav – mean signal power; Eig. spread – eigenvalue spread; Freq. AC – frequency spectrum autocorrelation.

Table 1. Important impairments in a fiber-optic coherent transmission system

Transmitter	Link
In-phase/quadrature (I/Q) imbalance	Amplifier spontaneous emission (ASE)
Electrical distortion in the generation stage	Chromatic dispersion (CD)
	Differential group delay (DGD)
Receiver	Polarization mode dispersion (PMD)
	Polarization dependent loss (PDL)
Timing misalignment	Nonlinear effects due to high input power
Local oscillator offset	Linear and nonlinear effects due to copropagation
Polarization mixing angle	

Table 2. Summary of advantages and disadvantages of NDA and DA techniques for digital OPM [7].

		Data-aided	Non-data-aided
Pros		High accuracy	No training overhead
		Guaranteed convergence	Compatible with legacy nodes
		Short convergence length	Efficient for short memory channels
Cons		Training overhead	Long convergence time
		Incompatible with legacy nodes	Inferior accuracy

In DA approach, a training sequence (TS) is transmitted along the message. Based on the received TS and knowing the ideal transmitted TS, the receiver can estimate the transfer function of the system (zero-forcing solution). This allows for accurate channel monitoring [9,10]. The NDA approach on the other hand does not use any predefined sequences and relies on statistics of random transmitted data. An example of blind estimation performance is shown in Fig. 2b) for CD estimation of polarization division multiplexed (PDM) quadrature phase shift keying (QPSK) system after 80 km of fiber transmission using four different estimation methods [8].

Another important contribution in the monitoring subsystem is the modulation format recognition (MFR) which enables software-defined algorithms of the receiver. Since for every modulation format the algorithms that shall be applied for optimal signal demodulation differ slightly, the MFR block shall continually observe the signal to determine the modulation format used, and use the most optimal DSP algorithms. At the same time MFR allows for operation of dynamically switched networks in which the arriving signal may be of unknown nature and the receiver has to determine the way to demodulate it. We have developed a technique for modulation format recognition that is insensitive to frequency offset and polarization mixing based on Stokes space receiver and Bayesian expectation maximization and Gaussian mixture models [11]. Figure 3 shows the experimental results for PDM-QPSK and PDM-16-quadrature and amplitude modulation (PDM-16QAM) demodulated and the corresponding clustering identification using the Stokes space MFR.
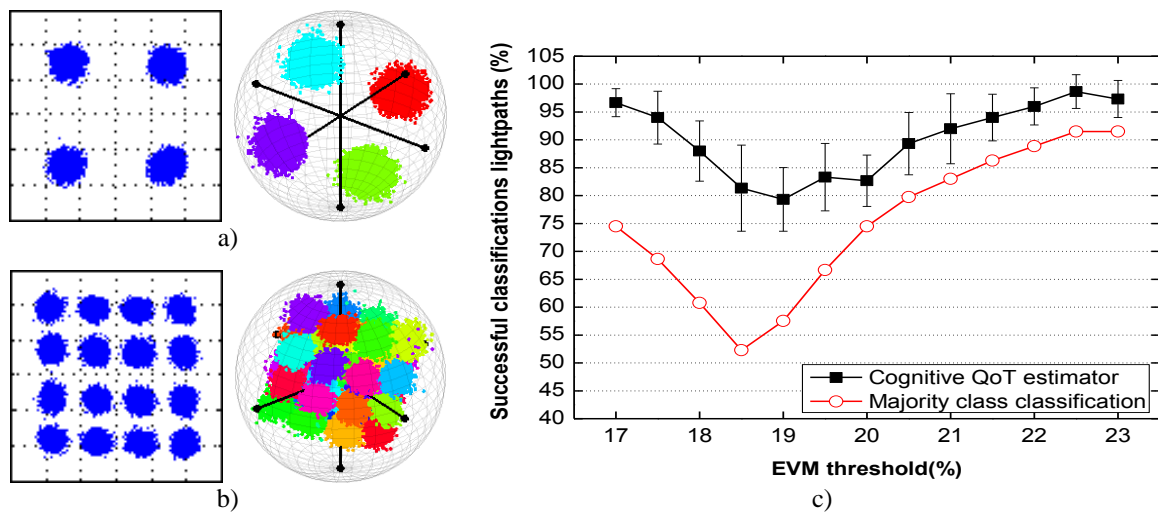

Figure 3. Modulation format recognition in Stokes space, experimental results for a) DP-QPSK b) DP-16QAM c) Experimental demonstration of QoT based on CBR for PD-QPSK WDM networks with high successful ratio for small KB [13].

3. QUALITY-OF-TRANSMISSION ESTIMATOR

The aim of the QoT estimator is to make a prediction of signal quality of the new lightpaths to be established in the network and to address its impact on existing connections. The approach of CHRON combines the information of past history and the feedback from the network monitoring system. This information may be used to update its knowledge base and thus adapt to changing conditions, like component ageing or substitution.

The cognitive operation of this module relies on the utilization of a data mining technique called case-based reasoning (CBR). The CBR approach achieves more than 99% successful classifications of optical connections, and is much faster for on-line operation than an existing non-cognitive approach, thus demonstrating the advantages of cognition. In [12] the basic cognitive QoT estimator was enhanced by including learning and forgetting capabilities. These capabilities are used to optimize the set of experiences stored in the knowledge base, and thus to improve performance accelerating the classification procedure by an order of magnitude. The CBR QoT estimator was experimentally validated in [13]. We implemented a wavelength division multiplexed, homogeneous point-to-point optical transmission system consisting of 5 channels carrying 80 Gb/s PDM-QPSK, with a number of adjustable parameters such as: optical launch power, fiber link length, and number of co-propagating channels, in order to support different lightpath and system configurations. The estimator performance is shown in Fig. 4, where a total of 150 different link configurations were measured and channel error-vector magnitude (EVM) calculated. The estimator was able to show high successful classification ratio, over 75% even for small KB of only 150 cases.

4. CONCLUSION AND FUTURE WORK

Cognitive heterogeneous reconfigurable optical networks are expected as a breakthrough technology to implement future optical communication networks in highly heterogeneous environment. In this paper we have described the approach followed in the CHRON project to include cognitive techniques in order to efficiently control and manage an optical network. In this context, there are several research lines that CHRON is working on. In optical performance monitoring, the development of robust algorithms for signal monitoring is being investigated to provide accurate and fast information to the cognitive decision system on the status of the physical layer.

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