Optical Performance Monitoring Systems in Disaggregated Optical Networks

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ABSTRACT In this paper, optical performance monitoring is presented as enabler to address the key challenges in disaggregated optical networks. In fact, data plane elements for non-intrusive monitoring of different modulation formats will be discussed, reviewing different options based on high resolution spectral analysis. Furthermore, we will report how the information retrieved by these monitoring probes can be used to actually control the transceivers and other data plane elements, emphasizing on the suitable figures of merit to be delivered to the SDN control, orchestration and management planes.
Keywords Optical performance monitoring, disaggregated optical networks, optical OFDM.

1. INTRODUCTION

Recently, the approach of disaggregation of a chassis-based design into commodity (off-the-shelf) components has been gaining popularity, since it allows telecommunication operators and service providers to appropriately size their infrastructure and grow as needed [1]. For the sake of an optimal network configuration and management, this paradigm implies a functional disaggregation, rather than block-by-block disaggregation. Thus, different data plane aspects have to be redesigned in order to favor an appropriate integration and provide high scalability. Additionally, interoperability aspects should be taken into account, since a smooth migration can be expected, moving from chassis-based (proprietary) network elements to the so-called network white boxes [2]. White boxes refer to the use of generic, off the shelf hardware (bare metal) which can be purchased from any vendor as a commodity part and customized with software from a different source.

Along a different line, proactive and reactive automation of optical networks with white box switches, computing and storage, is arguably the most significant challenge that needs to be addressed in order to further increase efficiency and cost-effectiveness of telecommunication networks. Such automation is based on actively processing real-time network monitoring information and learning from the effects of the decisions taken to validate and provide optimal selection of network resources to satisfy new service demands and dynamically re-optimize existing service demands. Therefore, a key element of the disaggregated network is the optical performance monitoring that is expected to deliver the feedback needed for guaranteeing end-to-end quality of transmission (QoT) and quality of service (QoS). Several techniques can be employed for acquiring the suitable figures of merit, ranging from highly intrusive receiver-based monitoring to non-intrusive optical probes independent from the modulation format [3], [4].

The QoT of a lightpath can be acquired at the transceivers by means of several figures of merit. Among the different available options for such transceivers, a convenient one is based on coherent reception [4]. This option can provide many interesting figures of merit, including bit error ratio (BER) prior to forward error correction (pre-FEC), optical signal to noise ratio (OSNR), Q-factor, wavelength, power, chromatic dispersion, and relative state of polarization [4]. This allows the control and management plane to take the right decision at any time. Nevertheless, optical disaggregated elements are particularly attractive for the metro and access network segments, where the requirements are substantially different in terms of cost and data rate compared to the core segment. Therefore, cost effective and high capacity solutions are pursued. For example, direct detection orthogonal frequency division multiplexing (DD-OFDM) transceivers are a promising solution, since they can provide high capacity at low cost while acquiring a wide range of figures of merit, including pre-FEC BER, OSNR and power among others [5].

The aforementioned technologies are highly intrusive, since they require to actually demodulate and/or equalize the signals in order to obtain the proposed figures of merit. Therefore, in order to monitor a certain lightpath, the performance can only be acquired at the edges of each lightpath, posing serious difficulties for a diagnose of the network status. In order to solve this issue, a non-intrusive optical performance monitoring system can be deployed at the network nodes to automatically extract the different performance parameters. This approach also poses different challenges. In fact, the existing optical performance monitoring techniques are either valid for specific transmission technologies [3] (e.g. those based on polarization nulling are not suitable for polarization multiplexed signals) or exhibit a limited range of functions for extracting the figures of merit that will be employed to configure the different network resources, including the parameters of the transceivers [6]. Thus, a key challenge is the advancement in optical performance monitoring techniques in order to create a common subsystem that is agnostic to the optical signal waveforms (which may feature different multiplexing schemes

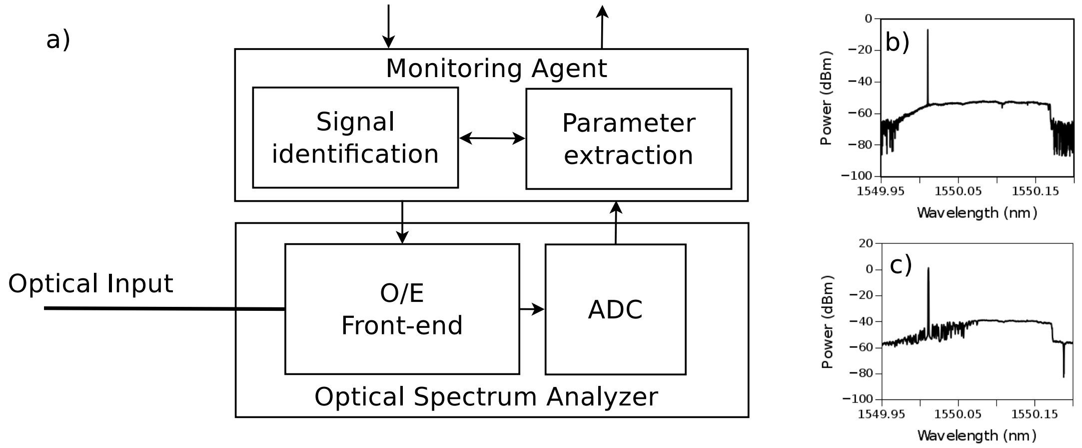

Figure 1. *(a) Generic scheme for the proposed monitoring probe. (b) Sample spectrum acquired for SSB-OFDM using uniform loading and (c) employing adaptive modulation [6].*

and modulation formats) and capable to provide the suitable figures of merit to the control, orchestration and management planes.

In this paper, we will deal with a generic scheme for optical performance monitoring probes, while focusing on the challenges for coping with the disaggregation optical networking paradigm. In fact, we will focus on high resolution optical spectrum analysis as suitable tool for coping with the aforementioned challenges.

2. CONCEPT AND OPTIONS

Figure 1(a) shows the basic concept of the monitoring probes. It is an entire modular approach where two main blocks are identified: the optical spectrum analyzer (OSA) and a suitable monitoring agent.

2.1 Optical spectrum analyzer

The OSA can be regarded as an optical/electrical (O/E) front-end plus an analog to digital converter (ADC). So, it can be controlled by the monitoring agent by means of an agreed API (e.g. SCPI commands) o by low-level commands interfacing the different devices composing the OSA, in case a full custom design is approached. For example, the optical front-end can be interfaced in order to specify the wavelength range to acquire, the wavelength resolution, the sweep speed and other relevant parameters for the acquisition of the optical spectrum. In that case, the ADC is the part that feeds the spectrum samples (i.e. wavelength/frequency and power) to the monitoring agent in order to further process them.

The O/E front-end can be based on any kind of spectrometry technique, including a full custom design for monitoring purposes. Among all the options available, we find that the common OSA approaches are based on diffraction gratings [7], interferometers [7], coherent detection [8], [9], and Brillouin scattering [10]. The main performance figures of these approaches are summarized in table I according to [7], [8], [10] and/or related commercial products.

The OSA based on diffraction grating filters enables a high selectivity and dynamic range, offering a wide spectral tuning range. This option also provides low sensitivity, being able to detect very low power signals.

Regarding the interferometer-based option, it can achieve a high wavelength certainty trading against power uncertainty. For example, it features limited performance when detecting peaks and increased noise floor in the presence of multiple channels. Therefore, the interferometer-based OSA can offer a narrow resolution bandwidth and the widest wavelength range while it has a poor dynamic range.

Coherent OSA shows an excellent performance in terms of resolution bandwidth and dynamic range. However, its wavelength measurement range is quite limited.

Brillouin Scattering OSA is also a relatively new approach. This technique overcomes the problems of previous coherent techniques. It enhances the dynamic range thanks to the optical amplification inherent to Brillouin effect [10]. Also, it offers a fast sweeping speed.

TABLE I

SUMMARY OF PERFORMANCE FOR THE MAIN O/E FRONT-END OPTIONS FOR THE OSA.

	Diffraction Grating	Interferometer	Coherent	Brillouin Scattering
Resolution bandwidth	0.1 to 2.0 nm	Approx. 0.01 nm	0.16 pm – 3.6 nm	0.08 pm
Dynamic range	70 dB	$\sim$35 dB	78 dB	80 dB
Sensitivity	-90 dBm	-72 dBm	-	-70 dBm
Maximum power	+20 dBm	+10 dBm	+10 dBm	+13 dBm
Minimum power	-90 dBm	-72 dBm	-68 dBm	-70 dBm
Sweeping speed	-	-	0.4 nm/s up to 1.2 nm/s	20 nm/s
Wavelength range	600 nm – 1700 nm	350nm – 1750 nm	1526 nm – 1567 nm	1525nm – 1607 nm

Please note that all these OSA options can be operated in polarization diversity. Despite the fact that it requires doubling the spectrum acquisition resources, this option is quite interesting for monitoring purposes, as it allows to acquire a polarization resolved spectrum, giving additional advantages for extracting/deriving the suitable figures of merit of the monitored signals [3].

2.2 Monitoring agent

Thanks to the OSA, the monitoring agent can recover the desired spectrum. Besides configuring the OSA for a proper spectrum acquisition, the monitoring agent can also include a signal identification module and a parameter extraction module. The selected figures of merit are then passed to the control plane in order to optimally configure the different network elements.

Since the acquired spectrum can be quite large and contain several wavelength division multiplexed (WDM) signals, the signal identification module is in charge of detecting the power peaks and slicing the spectrum accordingly in order to obtain the specific spectrum of each transmitted signal. This data is then fed to the parameter extraction module. Additionally, the signal identification module could be able to recognize the optical waveform present in the spectrum, as each modulation format usually features a characteristic spectrum.

The parameter extraction block is in charge of extracting the different relevant parameters and/or figures of merit for a given signal spectrum. These parameters may include overall power, peak to average power ratio, noise, OSNR, and power spectral density. It should be noted that the OSNR is the most common parameter used to measure the degradation of the signal quality, because it is transparent to bit rate and modulation format, and can be easily related to the BER, which is the main performance indicator [3]. Nevertheless, the other parameters may suggest other network malfunction like a fiber break or proneness to fiber non-linear effects.

3. RESULTS AND DISCUSSION

Given the monitoring probe described in the previous section, we find appropriate to approach a high resolution OSA in order to estimate the performance of transmission systems with enhanced frequency granularity. We focus our investigations on intensity modulated OFDM featuring direct detection and, in some cases, based on SSB. High resolution spectral analysis has a high potential for multicarrier modulation formats in order to monitor optical performance parameters such as the OSNR. In [11], an OSNR measurement employing Brillouin OSA has been demonstrated. Depending on the range of frequencies considered for the measurement, the noise level in 0.1nm bandwidth could be estimated with less than 0.5dB error.

In [12] we have proposed a methodology to estimate the sub-carrier OSNR and we have demonstrated the direct correlation between the BER performance of individual sub-carriers and the measured sub-carrier OSNR. This methodology can be easily adapted to be used when employing other OFDM techniques, as coherent optical OFDM. The relationships between OSNR, electrical signal to noise ratio (SNR) and BER at the receiver were experimentally analyzed and compared to theoretical results. A linear dependency in dB was found between electrical SNR and subcarrier OSNR for total OSNR values below 26 dB. Above this limit, the correlation degree decreased due to the electrical SNR degradation at the edge subcarriers.

Leveraging the results obtained in [12], a adaptive bit/power loading of the OFDM subcarriers was achieved in an IM/DD system, with SNR measurements in the optical domain using high-resolution OSA [6]. There, experimental testbed results demonstrated good agreement with the DSP estimation at the receiver side. The proposed method featured an error of less than 10% in terms of signal capacity. This result is particularly interesting for disaggregated optical networking. In fact, it enables the control layer to dynamically reconfigure the transceiver parameters at the OFDM subcarrier level, in order to cope with signal degradation at the network nodes, without the need of signal demodulation. A sample of the measured spectra is shown in figure 1(b)-(c). There it can be observed an SSB-OFDM signal (figure 1(b)) that is adaptively modulated according to the monitoring data retrieved by the probes (figure 1(c)).

Since the results obtained in [6], [11], [12] were promising, the monitoring subsystem based on high resolution spectrum analysis was deployed in a hybrid optical packet switching and optical circuit switching (OPS/OCS) testbed [13]. There, such a non-intrusive optical performance monitoring probe was deployed at the nodes of the OCS part of the testbed. This domain was heterogeneous and challenging, as it included different optical signals, depending on the reach/purpose of the established connections. Thus, the deployed monitoring probe was able to scan the whole C-band and automatically extract the different performance parameters, including WDM channel allocation, effective guard-band, signal power and OSNR of each multi-format flexi-WDM channel. This allowed to suitably configure the different domain network resources, including the parameters of the transponders, according to the signal quality.

The feasibility of the proposed monitoring probes has been also studied for coherent OFDM systems [14]. Results show that signal and noise levels can be monitored by direct optical spectrum analysis, avoiding the need for data demodulation. This result agrees with the model developed in [12]. In fact, the noise level is estimated in selected zones of the spectrum where OFDM subcarriers are set to 0. So, the noise level could be estimated with different error margins depending on the number of null subcarriers present on those zones.

4. CONCLUSIONS

Optical performance monitoring has been presented as enabler for disaggregated optical networks. A general architecture of monitoring probes based on high resolution spectrum analysis is discussed, reviewing different options. Among all the available options, Brillouin scattering spectrometry offers high performance, not only in terms of resolution bandwidth but also in terms of dynamic range and spectrum scanning speed. Importantly, the monitoring agents of these probes should feature automatic signal slicing/identification for a correct extraction of its main parameters and estimating/deriving the associated figures of merit.

Furthermore, several experiments including optical performance monitoring based on high resolution spectrum analysis is reported together with the corresponding theoretical models. This shows that a suitable configuration of different network resources, including the parameters of the transponders, is possible with the proposed non-intrusive performance monitoring probes.

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