QoS-aware precautionary performance monitoring for PCE-based coherent optical OFDM networks

Yueming Lu (陆月明) and Lianxing Hou (侯连兴)*

Key Laboratory of Trustworthy Distributed Computing and Service, Ministry of Education,
Beijing University of Posts and Telecommunications, Beijing 100876, China
**Corresponding author: lancyhou@gmail.com*

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A quality-of-service (QoS) aware scheme, called precautionary performance monitoring, is proposed to solve the optical impairments and congestion control in coherent optical orthogonal frequency division multiplexed (CO-OFDM) networks. The centralized path computation element (PCE) extensions based on the QoS level are applied to optical performance monitoring in this letter.

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Due to the increased transparency and maximum reach in modern dynamic optical networks, signal quality has become more vulnerable to the optical layer impairments, such as amplified spontaneous emission (ASE) noises, fiber nonlinearities, residual chromatic dispersion (CD), polarization mode dispersion (PMD), multi-path interference crosstalk, etc. Numerous external physical factors, such as pressure, temperature, and man-made factors, may also lead to faults. Thus, for proper operation and management of such dynamic optical networks, it is essential to have the capability of directly monitoring the parameters affecting the performance of the network in the optical layer. Such critical parameters include signal power, optical signal-to-noise ratio (OSNR), CD, and PMD[1]. Coherent optical orthogonal frequency division multiplexed (CO-OFDM) networks is a serious contender for future optical fiber transmission systems, because it effectively removes the inter-symbol interference from CD and PMD[2−5]. This characteristic has become prominent in high-speed optical fiber transmissions. However, previous studies have stated that the OSNR estimated using this method can be quite erroneous in the dynamically reconfigurable optical network, where each channel may traverse through different routes and different number of optical amplifiers. To overcome this problem (i.e., monitoring the “true” OSNR by measuring “in band” noises), various techniques have been proposed based on the receiver noise analysis, depolarization of optical signal, and electrical amplitude sampling, to name a few[6−9].

In many previous reports, physical impairment parameters, such as OSNR, could be statically configured as link attributes. However, the path computation capability should be desired to utilize measured link performance by optical performance monitoring (OPM) systems. The centralized path computation element (PCE) can potentially simplify the implementation of network nodes that may avoid complex routing modules; it can also provide effective routing and wavelength assignment[10]. However, this model still does not include precautionary performance monitoring, which is effective in future high-speed transport network, because the services might avoid too much recovery time or information loss for optical impairments and congestion. Moreover, the path computation clients (PCCs) can request the computation of an explicitly routed path given a set of constraints that are motivated by quality-of-service (QoS) management.

In this letter, we focus on the monitoring of optical telecommunication channels with destination-initiated reservation (DIR)[11]. The PCE is integrated with the processes of performing OPM[12], to support the monitoring of optical impairments that lead to faults, and evaluating the wavelength occupation probability, which may cause the collisions. The proposed precautionary performance monitoring mechanism (PPMM) is expected to be more efficient, because it directly supports the QoS management of the lambda service in advance.

The OPMs can monitor the optical power and light wave of each wavelength division multiplexing (WDM) channel, and estimate the OSNR by linearly interpolating the ASE level aside of the signal. In this letter, the pilot tones technology is used to monitor various optical parameters of the signals. It can be extremely cost-effective, because this can perform monitoring without using the expensive de-multiplexing filters (e.g., tuneable optical filter and diffraction grating); it is also well suited for use in dynamic optical networks. Figure 1 depicts the investigated CO-OFDM transmission system. Two independent baseband signals were used to modulate the orthogonally polarized parts of the TX signal. Pilot tones were located at predetermined positions for optical modulator, and they carried a symbol (known as the receiver), which had a fixed magnitude and phase. The OPM coherent detection was deployed at the receiver. We chose the OSNR as the indicator of optical impairments so as to simplify our analysis. Although a minimum OSNR has been demonstrated to be indispensable in transmission as a threshold, there is always an interim from the normal state to the failed state for the component, when the performance becomes increasingly worse but does not lead to failure. This is called the critical state. One example is shown here. Firstly, we assume that the threshold OSNR is 20 dB for the transmission link, whereas in the range

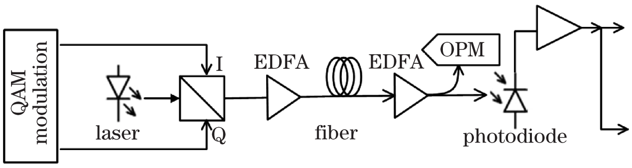

Fig. 1. Description of the CO-OFDM transmission system with OPM.

of 25–20 dB, it may act as critical state. If the OSNR is below 20 dB, it can lead to failure. According to the information captured from the fiber/wireless sensors, if a node finds that a component has already entered critical state, it should start the protection and restoration (P&R) algorithms in advance.

As shown in the sampled spectra of the TX and RX signals represented by the sub-carriers of the OFDM symbols, the calculations can be directly carried out on a number of OFDM symbols that are known to the receiver. Obviously, a certain number of preamble symbols have to be transmitted; alternatively, one can think of the analysis of data after equalization and decision. Our proposed monitoring technique in OPM is based on a system identification approach, which describes the optical transmission path.

An ensemble of corresponding signal spectra, namely, $X(f)$ and $Y(f)$, which are derived by Fourier transform leads to the linear transfer function. The criterion of minimum power of the noise-like signal should be used for estimating the linear transfer function computation. The spectral power density of nonlinearity can also be estimated by another averaging process over the ensemble of the input and output spectra.

$$\Phi_{\mathrm{nn}}(f)=E\left\{\left|Y(f)-\frac{E\{Y(f)\cdot X^{*}(f)\}}{E\{|X(f)|^{2}\}}\cdot X(f)\right|^{2}\right\}, \tag{1}$$

where $\Phi_{\mathrm{nn}}(f)$ is the expectation measured for the nonlinearity distortions.

We integrate over the used frequency band, and work with signal power rather than spectral power densities over the discrete sub-carriers d given by

$$\frac{N}{S}=\frac{\sum_{d=1}^{D}\Phi_{\mathrm{nn}}(d)}{\sum_{d=1}^{D}\left|\frac{E\{Y(d)\cdot X^{*}(d)\}}{E\{|X(d)|^{2}\}}\cdot X(d)\right|^{2}}, \tag{2}$$

Meanwhile, the PCE is proposed to estimate the probability of concurrent wavelength reservation in order to avoid congestion. Its model is shown in Fig. 2. We assign a weight ω to the wavelength of link with the initial value 0 which denotes the concurrent occupation probability. When the wavelength is occupied for a lightpath, the weight is set to ∞. As for the multi-fiber optical networks, it means the wavelengths in all fibers (several fibers in one link) have already been occupied. Once a connection request or path message arrives, the node evaluates the available/reserved wavelengths set ($A\omega$) from the source to this node along the route. Then, we increase the weight ω', as $\omega'=\omega+1/[F\times \mathrm{Num}(A\omega)]$, where F is the number of the fibers in the link. Once $\omega\geqslant 1$, the collision is inescapable; thus, if a node finds the weight of wavelength in a link close to 1, which is also called critical state, it should block parts of new requests for this wavelength to avoid collision.

The deployment sketch of the PPMM is shown in Fig. 3. Sensors were set to monitor the performance of the transport plane for OSNR. The communication units of these sensors sent the captured information of the performance or fault to the PCE, which realized the analysis of the captured information to motivate the constraints for computation. Comparing the impairment information from the sensors and wavelength weight information from the controller in the control plane, the PCE can then determine whether a certain component is in the normal state; if not, the precaution system should start.

The PCE should be informed of the latest performance by two kinds of notification for the purpose of optimal path calculation (in Fig. 3). After the notification procedure, the suffered services give rise to the protection and restoration mechanism and new request blocking (P&R&B). In the no QoS scheme (NQS), only one threshold is defined, all the lightpaths requests are restored, and new lightpaths are blocked if the parameter exceeds the thresholds. It is inefficient because the critical state may be reversible and return to the normal state. The oscillating states may also deteriorate the network load. One improvement is to set a three-level QoS scheme (TQS) for the lightpaths, and the different level decides different P&R&B mechanisms. For example, if the OSNR is below 25 dB, only the services with high QoS adjust to the new paths, and if the OSNR turns to 23 dB, the middle-level services are restored, whereas the low-level services are only rerouted when the OSNR comes to 20 dB. Again, once $1>\omega\geqslant 0.9$, only the new high-level

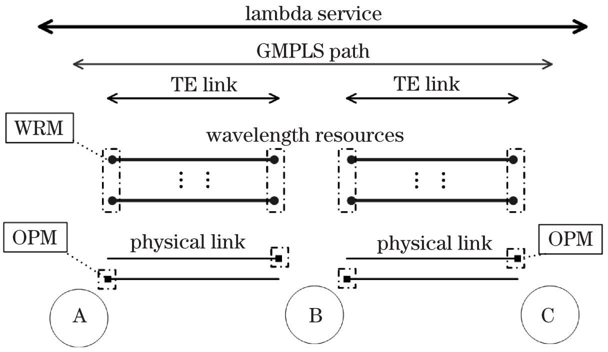

Fig. 2. Layer models for the CO-OFDM networks.

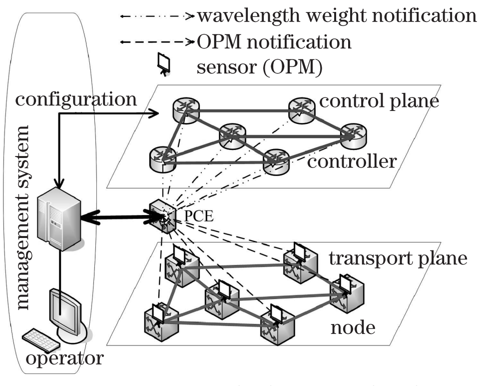

Fig. 3. PPMM deployment sketch.

connection requests for the wavelength are permitted, after which permission is granted to the middle-level requests when $0.9> \omega \geqslant 0.8$; in this case, each request is blocked if ω reaches to 1. From the above, the range of the captured performance parameter values by the sensors corresponds to different QoS levels according to their attributes.

The implementation of the QoS-based scheme must enhance the RSVP-TE and the PCE communication protocol (PCEP) for performance notifications. The Path message must be extended to carry the information of the QoS level for the lightpaths. QoS levels in the classification can be defined by management system. The requests and responses with the information of impairment information and wavelength weight interact in both the PCEs and PCCs through the extended PCEP.

We evaluate the PPMM using the COST239 topology (11 nodes). In order to achieve a realistic network load, lightpath provisioning requests with three QoS levels were dynamically generated according to a Poisson process and then uniformly distributed among the source-destination pairs. The data rate was 10 Gb/s and the block length was 1 024 bits, giving D=32 sub-carriers of OFDM symbols in an optical bandwidth of 5 GHz with 4-quadrature amplitude modulation (QAM). Each link comprised a number of uncompensated 80-km spans. The fiber had a loss of 0.2 dB/km, and the nodes were connected by 10 fibers with one PCE server. Each fiber contained 20 wavelengths. The proportional distribution of QoS-based services was high:mid:low=1:2:3.

Figure 4 shows the Q factor as a function of the input traffic between the no threshold scheme (NTS), as well as the respective NQS and the TQS after 800, 1 600, and 2 400 km. Following the distance growth, system performance becomes worse. In the 800-km scenario, TQS scheme performs significantly better than others. Meanwhile, the NQS scheme performs similarly to the TQS scheme in 800 km, while it is close to the NTS scheme in 1 600 and 2 400 km. It is apparent that the more dissipation there is in traffic, the better the NQS scheme performance. Especially under higher load, the services are shifted to the superior path according their QoS factor step by step, thereby avoiding drastic deterioration of the congesting path. In long-haul communication, this seems inefficient because the centralized data processing of the PCEP becomes instable. Further improvements must be applied to pre-processing in order to avoid reaction timeout.

In Fig. 5, we compare the performance among the NTS, the NQS, and the TQS under various service traffic levels that need restoration. The restoration probability (RP) denotes the effectiveness of both schemes, whereas the number of the signaling packages (SPs) denotes the protocol complexity. The figure shows that the packages generated by the TQS are much less than those by the NQS. The TQS also performs better than others on RP, and even under high suffered services, 90% RP is still maintained. In contrast, the NTS performs the worst, because the lack of limited available wavelength information can lead to local congestion.

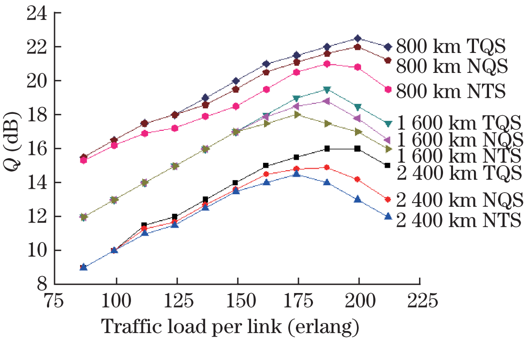

Fig. 4. Q Value under various loads.

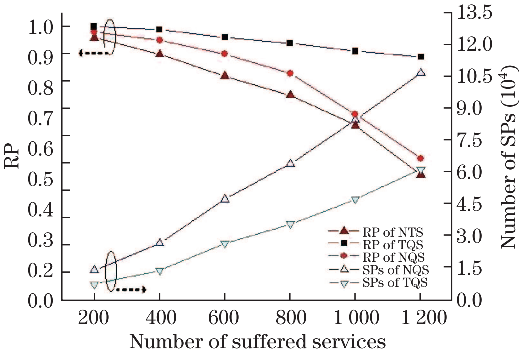

Fig. 5. Performance on the single link failure.

In conclusion, in order to deal with optical impairments and congestion control, we show that the CO-OFDM network is extended for the precaution mechanism. The PPMM extends the PCE protocol in critical state on collisions or faults. Simulations show that the TQS achieves better performance. Therefore, the PPMM is a suitable precaution mechanism in CO-OFDM networks.

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