Effect of PON Geographical Distribution on Monitoring by Optical Coding

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Abstract We derive the performance and critical design issues of optical-coding based centralized live PON monitoring technique allowing more than 512 clients. We consider PON geographical distribution models in our performance evaluation.

Introduction

As the capacity of passive optical networks (PONs) increases, allowing hundreds of clients to share the same infrastructure, the importance of performance monitoring increases [1-5]. Centralized monitoring (*i.e.*, from the CO: central office) is highly desired because it provides full in-service information and control for the service providers. In [2], we introduced the use of a modified optical code division multiplexing (OCDM) scheme for centralized monitoring of architecture agnostic PONs (Fig.1).

Monitoring by optical coding is spectrally efficient, low cost, and highly stable. In this paper, we analyze monitoring capacity by simulating the signal-to-noise ratio (SNR) and signal-to-interference ratio (SIR). We take into account the geographical distribution and density of the PON clients (using analytical methods from wireless networks), as well as the nature of the light source used.

Centralized PON Monitoring System

As illustrated in Fig. 1, a pulse with peak power P_S and duration T_S is transmitted through the feeder (with length d_f), split by 1:N at the remote node (RN) into N sub-pulses, each of which is encoded and reflected back to the CO by the optical coders, OC_i (i =1 to N). Each fiber drop is terminated by an optical coder with a unique code, and is located physically close to the optical network terminal (ONT). Encoded sequences mix together at the RN (upstream). Information on individual distribution fibers is discernable at the CO due to the near orthogonality of the codes. The CO OCDM monitoring equipment decodes the received signal and obtains autocorrelation peaks from the healthy distribution fibers and cross-correlation spikes from unhealthy ones.

We consider time-spreading codes defined by F, w, λ_a=1 and λ_c=1: respectively the code length, weight, maximum out-of-phase auto, and cross-correlation values [7]. We suppose that coding is implemented by simple fiber couplers [2]. High spectral efficiency is achieve by using a single wavelength source (we consider both laser and incoherent sources).

Geographical distribution and SIR

At the CO the OCDM decoder of a given user (say OC_d) will correlate the returned signal with a copy of that code. The correlation will cover a time equal to F (the code length) times T_S the pulse width. Only returns from clients that fall within this window of duration FT_S will interfere with the desired return – all other returns will be zeroed out by the receiver. This time window has a corresponding distance window, whose length $\ell_{CD} = cFT_S/n$ we call the correlation distance (CD) where c is the speed of light and n is the refractive index. Only ONTs that are separated from the desired ONT by less than the coherence distance will contribute to interference. Clearly, the geographical distribution of the ONTs will impact the percentage of clients falling within the correlation distance, and this percentage will in turn determine the signal-to-interference ratio (SIR).

In Fig.2 we consider five models of client geographic distribution; these models are also used for assessing interference in wireless systems [6]. The feeder coverage area is fixed to a^2 for all distributions, and we consider a^2 ranging from .25 to 5 km^2. In cases [a-d] the clients are uniformly distributed over the square coverage region; only the position of the RN feeder varies (center, corner, mid-edge, or random). In case [e] the RN is centered and clients are located

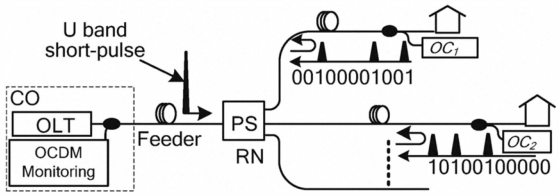

Fig. 1: OCDMA PON monitoring

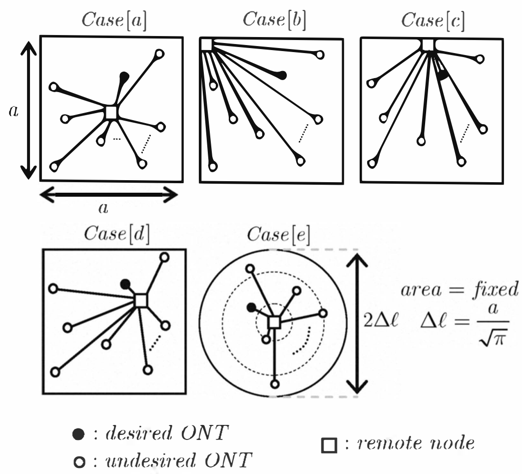

Fig. 2: Five PON density models.

radially from the RN at a uniformly distributed distance. Each case has an associated distance probability density function.

We define the SIR as the average of the desired signal μ_{SIG} term to the average of interference μ_{INT} ;

$$SIR \triangleq \mu_{SIG} / \mu_{INT} \qquad (0.1)$$

Fig. 3 gives the SIR as a function of the number of clients (or monitored branches) for four different areas (0.25, 1, 2 and 5 km^2). We observe high SIR when the number of clients is low; this situation leads to low CD. As the network size increases for fixed area (*i.e.,* increasing the client density), the SIR plateaus out to ~5 dB; this is equivalent to a traditional OCDM system where all users contribute to the interference. For high density we observe little difference in SIR for the five cases. For low density the geographical layout will influence SIR.

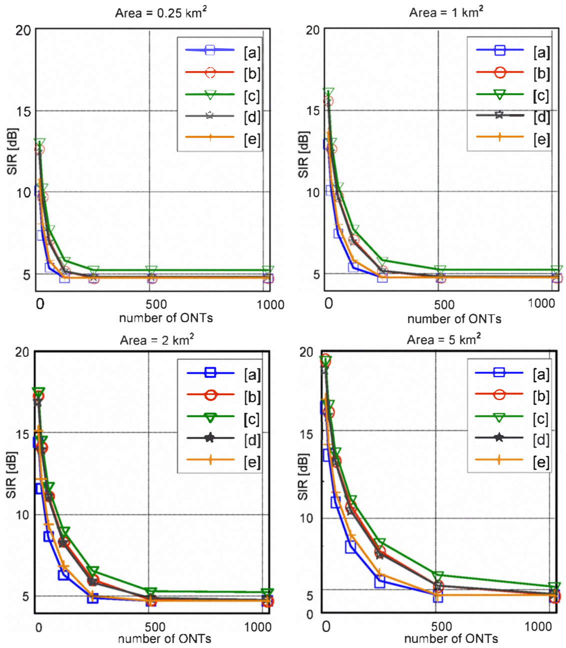

Fig. 3 SIR vs. network size and distribution area

Signal to Noise Ratio

Having determined the level of interference, we can now proceed with calculating the total SNR given by

$$SNR \triangleq \frac{\mu_{SIG}^2}{\sigma_N^2} \triangleq \frac{\mu_{SIG}^2}{\sigma_{TH}^2 + \sigma_D^2 + \sigma_{SH}^2 + \sigma_{BN}^2} \qquad (0.2)$$

Index TH is used for thermal noise (spectral density 0.1 pA.Hz$^{-0.5}$ assumed), D for dark current (average current =160 nA), SH for shot noise and BN for beat noise (where we include the interference noise). In consideration of the system loss budget, an avalanche photodiode is assumed (gain G=100, and excess noise factor ζ=0.05). We considered both laser (100 MHz linewidth) and broadband source (BBS, width 1 THz in the U band).

In the case of a BBS we include intensity noise in the beat noise term. Fig. 4 illustrates the SNR versus the network size for a laser and a BBS. Beat noise is the major source of SNR degradation.

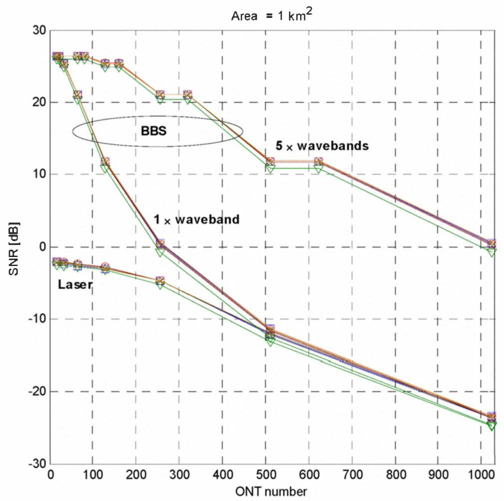

Fig. 4: SNR for different scenarios

The long coherence time of the laser (~10ns) leads to significant beating of the superposed pulses at the correlator: we observe an SNR lower than -3 dB even for a network with only one client. The BBS coherence time of ~1 ps leads to better performance. At 1 THz, the BBS system can monitor more than 64 (128 respectively) clients network with SNR higher than 15 dB (7.5 dB respectively). Incoherent pulses beat less, but suffer from intensity noise.

In order to increase the capacity of the monitoring system, we slice the 50 nm U band (1625 to 1675) into five slices of 8 nm (= 1THz); the remaining 10 nm is left for guard bands. Fig. 4 includes the five waveband case, where system monitoring capacity is as high as 256 (512 respectively) clients with an SNR of about 15 dB (7.5 dB respectively).

Conclusions

We considered the impact of PON geographical distribution models as well as the light source nature in analyzing the client capacity of an OCDM-based monitoring technique. For high client density we observe little difference in SIR for various geographical distributions. Laser sources show poor performance, however a sliced BBS allows monitoring of 512 clients.

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