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Extending usability of old terrestrial fibre optic cables in Third-World Economic Zones

DEHAYEM-KAMADJEU Alix[1,*], NDUNDA Moses[2], WAFULA David[1],

[1]Department of Physics, University of Nairobi, Nairobi, P.O Box 30197-00200, Kenya

[2]Liquid Telecom Kenya, Sameer Business Park Block A, Mombasa Road, P.O. Box 62499-00200 Nairobi, Kenya

*Corresponding author email: alix@uonbi.ac.ke

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ABSTRACT

Communication Fibre Optic Cables (FOC) experience mechanical perturbations while in service thereby deforming their cylindrical shape and increasing birefringence. This leads to Polarization Mode Dispersion (PMD). This work investigated PMD fluctuations in cables that have been buried underground for more than 10 years in a semi-arid climatic region in Kenya. PMD was measured using EXFO-FTB5700 analyzer at hourly intervals in the target cables for 2,480 hours. PMD coefficient of $0.215\ ps/\sqrt{km}$ was recorded. Outage margin (M_T) of 2.13 for the 10 Gbps system running an On-Off Keying Non-Return-to-Zero (OOK-NRZ) scheme (with 10ps receiver tolerance) was obtained. Similar analysis for the 100 Gbps system running a Dual Polarization Quadrature Phase-Shift Keying (DPQPSK) scheme (with 30 ps receiver tolerance), revealed an outage margin of 6.38. The availability of 99.29 % (corresponding to a downtime of 53.44 hours per year) revealed that, the cable under test could not sustain PMD limitations in a Dense Wavelength Division Multiplexing (DWDM) system that is deployed with a 10 Gbps transponder in a non-regenerated fibre span exceeding 450 km. 100 Gbps DWDM systems proved more resilient when using DP-QPSK than 10Gbps when using OOK-NRZ. The outage of 53.44 hours per year in a high capacity traffic system can translate to a substantial amount of losses in terms of credit notes to customers for not meeting the standard service level agreement of 99.999 % service availability. To overcome this limitation, it is recommended that 10 Gbps transponders that use OOK-NRZ channel modulation technique be replaced with 100 Gbps that uses DP QPSK technique to mitigate dispersion related outages in the links. This would also effectively provide a lot of idle capacity that can accelerate digitization of institutions and villages.

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1. Introduction

Data communication systems use a medium to transfer data signals between sender and receiver terminals. Modern systems prefer Fibre Optic Cable (FOC) as a medium of transfer. The reliability of an optical communication system in a hazardous area may be adversely affected as FOC deployed in the field face harsh environments that cause twists, bends, strains, stress and tamper with their cylindrical property [1]–[3]. Structural changes in FOC result in their transmission characteristics being temporarily or permanently degraded due to birefringence. Birefringence causes pulses spreading [4] as shown in Figure 1, overlaps with a mean time duration known as Differential Group Delay (DGD) on the signal, as it propagates along the cable. DGD is stochastic and multiple tests are averaged to determine the cable Polarization Mode Dispersion (PMD) [5].

$$PMD = \langle DGD \rangle = PMD_C * \sqrt{L} \qquad (1)$$

Where $\langle DGD \rangle$ represents the mean value of the DGD, PMD_C the PMD Coefficient and L the length of fibre.

Each receiver terminal has a maximum PMD tolerance that it can accommodate based on the encoding/decoding scheme. Table 1 presents the PMD tolerance for an OOK-NRZ decoding scheme.

Table 1: PMD tolerance for an OOK-NRZ decoding scheme [6].

Bit rate (Gbps)	Bit period (ps)	Max Tolerable PMD (ps)
2.5	400	40
10	100	10
40	25	25
100	6	0.6~1 not recommended

PMD hampers transmission in high-speed networks. These speed-limiting phenomena in the optical communication system threaten the integrity of the signal starting at 10 Gbps, which in turn affects the quality of service. Novel active optical networks demand significantly greater transmission characteristics. To simplify high capacity transmission across cities that are many kilometres a part, backbone links interconnecting cities use Dense Wavelength Division Multiplexing (DWDM) technology. The technology simultaneously channels data to different wavelengths, through the same single pair of fibre at significantly less cost. The high processing speeds however requires good quality cables to easily manage PMD in the signal as it propagates from sender to receiver terminals.

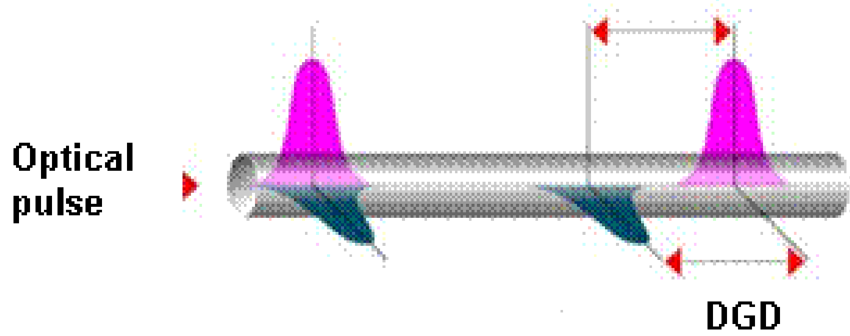

Figure 1: Fast and slow axis that result from PMD in a cable [7].

Newer techniques based on Phase Shift Keying (PSK) were introduced to overcome capacity challenges and revealed higher PMD tolerance. A 100 Gbps transponder using DP-QPSK has a PMD tolerance of 30 ps [8], [9]. This tolerance clears the fears of PMD constraints in 100 Gbps schemes and beyond. The increased tolerance in 100 Gbs/s systems and beyond opens up an opportunity to upgrade the existing 10 Gbps networks that are constrained by PMD tolerance not because of the capacity demand but the extending usability of the cables.

This research study aimed at investigating the upgrade of a 10 Gbps transponders that use OOK-NRZ channel modulation technique with the 100 Gbps that uses DP-QPSK technique to mitigate dispersion related outages in the links and extend usability of the cables. The case study was conducted on Liquid Telecom Kenya backbone infrastructure. The Fibre under test was commissioned to connect a DWDM network system running on 10 Gbps channels in 2008 and later a 100 Gbps channel was added in mid-2015 to cope with increasing bandwidth demand. The 100Gbps channels used a DP–PSK encoding/decoding format while 10Gbps used anOOK-NRZ) encoding/decoding format to transmit and process received traffic. The system that was using the fibre under test was therefore a hybrid DWDM system. The experiments tested and calculated PMD coefficient and data obtained was used to calculate outage margin in DWDM transponders that use OOK-NRZ and DPD-QPSK schemes.

2. Materials and Methods

2.1 Experimental Set-up

The extendibility of the cable under test was analysed based on comparisons of PMD tolerances in both 10 Gbps and 100 Gbps systems. The cable spanned between the cities of Mombasa and Nairobi connected with a 477 km optic cable. The cable was initially deployed to run a 10 Gbps DWDM system to interconnect the two cities with terminals at both ends and four In-Line Amplifiers (ILA) spanned at an average of 80 km along the line. PMD sample collection sections of 60 km long were identified within the 477 km. The analyses were conducted using EXFO FTB-5700 analyzer shown in Figure 2. EXFO FTB-5700 analyzer is a single ended PMD analyzer and runs on Scrambled State-of-polarization Analysis (SSA) technique [10]. The 60 km length was suitable because the PMD analyser uses a reflectometry technique and the test pulses are expected to travel a round trip.

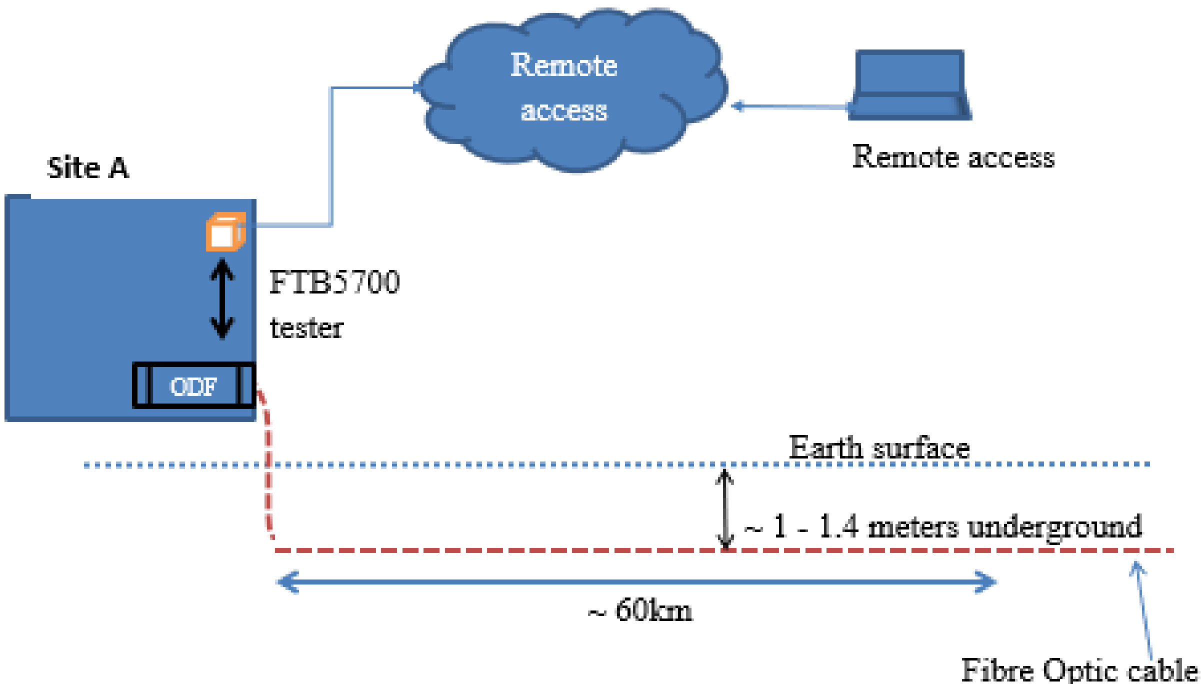

Figure 2: Diagram of the EXFO FTB5700 CD-PMD analyzer setup used for field tests.

The FOC PMD coefficient was determined and the Optical Time Domain Reflectometer (OTDR) used to calculate the fibre cable length. The two parameters were then used to evaluate the measured PMD with equation (1). Transponder tolerances provided by the manufacturer specifications allowed outage margins determination.

2.2 Outage Margin

The outage margin (M_T) is the ratio of the maximum PMD tolerance that the receiver can process without data losses and the measured PMD given as;

$$M_T = \frac{PMD_{max}}{PMD_{measured}} \qquad (2)$$

where PMD_{max} is the maximum PMD tolerance by the receiver without data losses and $PMD_{measured}$ the measured PMD in the target cable.

3. Results and Discussion

The PMD tester ran for a period of 2,480 hours, spanning for a continuous period of 103 days. The Probability Distribution Functions (PDF) of the PMD coefficient is giving in Figure 3.

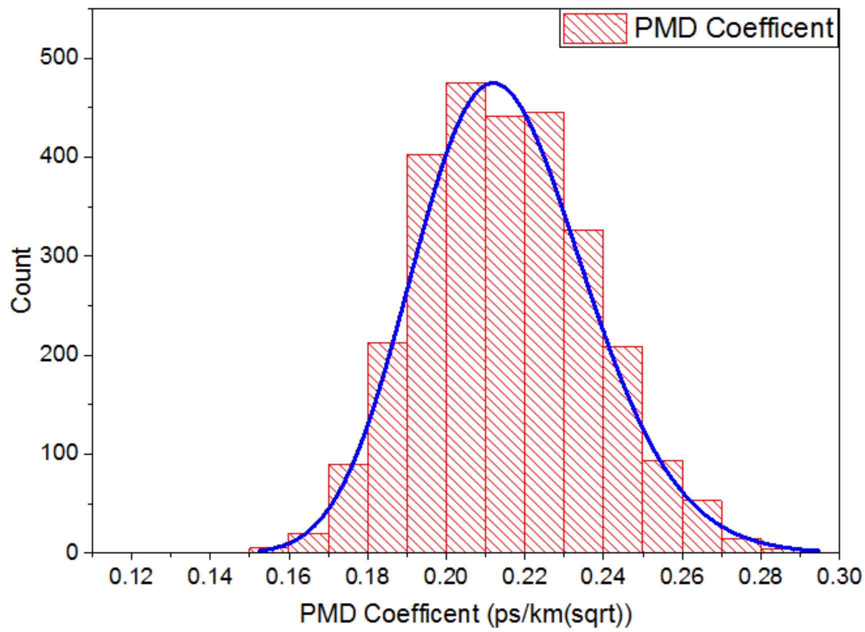

Figure 3: Histogram of the measured PMD coefficient.

The cable average PMD coefficient of $0.2154\, ps/\sqrt{km}$ was obtained. With a known distance of 477 km between the two transponders, the measured PMD of 4.678 ps was calculated using equation (1). For the 10ps receiver tolerance of the 10 Gbps system running an OOK-NRZ scheme, an outage margin of 2.13 was obtained with equation (2). Similar approach was used for the 100 Gbps system running a DP-QPSK scheme with 30ps receiver tolerance, and the outage margin was 6.38.

Using a normal distribution to probability table look-up, the outage margin of 2.13 was obtained in a 10 Gbps system translating availability of 99.29 % per year. The 6.38 obtained in a 100 Gbps system guarantees Service Level agreement (SLA) availability of 0.999 or higher since M_T is higher than the minimum margin ratio of 3. Converting 99.29 % availability gives a downtime (outage) of 53.44 hours per year. The migration to 100 Gbps technically clears any fear of PMD issues in deployments equivalent to the analyzed length. If the rate of cable aging remains unchanged, a margin ratio of 3 in the 100 Gbps system will be achieved when total line PMD will reach 10 ps. A newly deployed cable has a PMD coefficient of $0.02\, ps/\sqrt{km}$ and the cable under test has been in the field for a maximum of 10 years and has so far reached $0.215\, ps/\sqrt{km}$, this means it has annual PMD aging rate of $0.0215\, ps/\sqrt{km}$ per year. This effectively means it will take more than 16 years for a network using 100 Gbps transponders to start experiencing PMD related outages thereby extending usability of the cable.

5. Conclusions

The results obtained indicate that 100 Gbps DWDM systems are more resilient when using QPSK than 10 100 Gbps when using OOK in dilapidated fibre cables. The outage of 53.44 hours per year in a high capacity traffic system can translate to a substantial amount of losses in terms of credit notes to customers for not meeting the standard service level agreement of 99.999 % service availability. In situations where PMD in dilapidated cables increases to an extend of impacting traffic on 10 Gbps DWDM lines, it is now advisable to upgrade the DWDM system to 100 Gbps DWDM lines to extend usability of the cables. This approach will save cable infrastructure investors from heavy CAPital EXpenditure (CAPEX) in immediate cable replacement or abandoning the dead cable altogether. It is also a double benefit to service providers because the upgrade to 100 Gbps DWDM system grows capacity availability ten-fold. As to how many years the usability can be extended will depend on the rate of aging of the target cable. The specific cable that was used in this investigation would take 16 more years for a 100 Gbps system to start worrying of PMD impacts.

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