Prospects for the development of e-Health in Africa through the integration of optical networks

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Abstract. Telemedicine is a field that will be increasingly developed in African countries south of the Sahara. These countries are generally characterised by low health coverage and a lack of financial resources. The maturity of the optical transmission and access networks associated with the development of connected objects in the field of health suggests the achievement of the goal n°3 relating to health for all by 2030 defined by the United Nations Organization. Today, the telemedicine model adopted in the developed countries cannot meet the African context described above, as it requires fairly complex solutions not yet mastered by the Internet of Things and a content-centric network approach (CCN). In this paper, we propose an integrated optical transport and distribution solution based on Wave Length Multiplexing (WDM) and Passive Optical Networks (PON) technologies to deliver health services to rural centres from urban referral centres. We will use simulation to evaluate the performance of our proposal taking into account the requirements of telemedicine.

Keywords: WDM (Wave Length Multiplexing), PON (and Passive Optical Networks), ICT4SDG Information and Communication Technologies Four Achieving the Sustainable Development Goals), EKG (Electrocardiogram), EEG Electroencephalogram).

1. Introduction

In developing countries, particularly those south of the Sahara, access to health care is a major issue. This situation is lived with acquittal and is manifested by a very high infant mortality rate and the lowest life expectancy compared to other regions of the world. This situation is due to the lack of specialist doctors in the villages and the inadequacy of medical devices (equipment) in the secondary health centers.

According to a study by the World Health Organization (WHO), in 2020, most of the diseases in the world will be chronic, hypertension or cardiovascular diseases that require costly care and permanent medical monitoring by health specialists.

The evolution of information and communication technologies, in particular the emergence of optical systems in telecommunication access networks, allows us today to face these problems in the concept of telemedicine such as Internet of Things and a content-centric network approach (CCN)[1][2].

In this study, we will explore the levels of data quality inherent in transmission media, particularly in optical networks, which are the best candidates for telemedicine data transport.
In any case, the use of a full-scale test involving all dimensions would be necessary to finalize the deployment of a new telemedicine infrastructure or its integration into an existing infrastructure [3].

Thus, we propose at this level, a hybrid integration of the Wavelength Division Multiplexing (WDM) system and the Passive Optical Access Network (PON) capable of containing the requirements of medical applications such as medical imaging and radiology, demanding in terms of throughput, bandwidth and quality of service for the collection of parameters from patients in rural areas for care by specialists [4][5].

The performance of the proposed solution will be evaluated using the parameters of distance, signal throughput, transmitter power and the possibility of combining different types of signals on the same medium. The bit-rate error rate (BER), the quality factor (Q) and the aperture level of the signal eye diagram will be the elements of analysis.

2. WDM-PON Architecture

This part of the document describes the technologies to be integrated for the transmission network and the access network for telemedicine applications.

2.1 WDM-PON Concept

Today, the extension of optical solutions in telecommunication access networks such as WDM-PON and the use of advanced body sensor technologies (heart rate, body temperature, electrocardiogram (EKG), electroencephalography (EEG), monitoring and assistance to patients with chronic diseases, etc.) is a major challenge.), using wired and wireless infrastructures, real-time data processing, interactive interfaces, allows the interconnection of rural health points with the support of connected medical equipment (connected objects) ranging from simple thermometers, scales, blood pressure monitors for primary parameters to medical imaging equipment such as scanners, microscopes, X-rays, magnetic resonance imaging (MRI), etc... It is therefore necessary to insist on high quality, security and confidentiality of data to ensure correct interpretation of information and appropriate intervention by remote experts.

The choice of Wavelength Division Multiplexing (WDM) technology is based on the possibility of simultaneously collecting the different parameters on the same medium without the risk of interference between the different wavelengths dedicated to the different medical devices. This ensures greater dedicated bandwidth, quality of service and security. Its association with the Passive Fiber Access Network (PON), which is a "last mile" technology, is perfectly suited to the context of developing countries characterized by recurrent disruptions in electrical power. However, it should be noted that this solution requires transmitters and receivers for each of the medical equipment to be connected, which will make the solution relatively expensive compared to traditional PON solutions (EPON, GPON, 10GPON); however, the sensitivity to public health issues in this part of the world sufficiently justifies these costs [6].

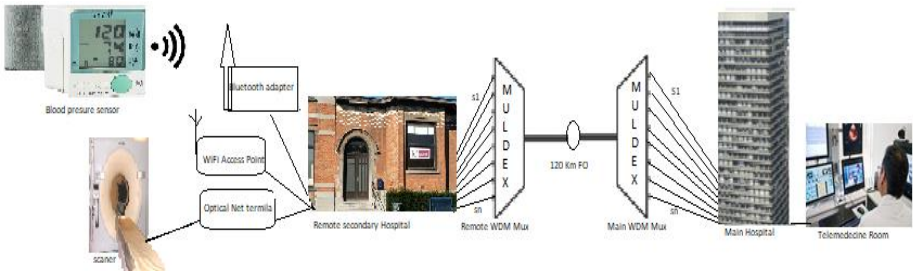

Fig 1: WDM-PON Network

2.2 Principle of WDM

Wavelength Division Multiplexing (WDM) is a technique that involves multiplexing and transmitting multiple signals of different wavelengths over an optical fibre. Multiplexing takes place at the time of transmission through the multiplexer, while at the receiving end it is up to the demultiplexer to decouple the signals through multi-band filtering. The technique therefore consists of simultaneously transmitting several light beams at different wavelengths, each of which represents a signal from the point of view of the final equipment using it.

Thus, in order to multiplex several optical sources, it is necessary to modify their wavelengths using transponders. Each information stream is transposed onto a carrier by amplitude or phase modulation. Multiplying equipment is usually passive equipment, acting as multi-band filters that select signals in the corresponding wavelength regions. This multiplexing technique further optimizes the bandwidth of the optical fibres [6]. The identification of the different channels is done using the carrier frequencies or associated wavelengths. The two are associated by the following empirical formula:
$\lambda = C/F$: (with λ; wavelength, C: velocity (or speed of light in a vacuum) and F: frequency of the transmission channel).

There are two types of wavelength division multiplexing. When the wavelength spacing is 20 nm, it is called CWDM. The advantage of CWDM is its cost. Indeed, because of the large spacing left for each channel, it is not necessary to regulate the emission laser in temperature. On the other hand, the limit is set at 18 unallocated channels where only 8 wavelengths at 10 GB/s are used in practice (1471 to 1611 nm). The second consists of a densification of the wavelengths then called dense WDM (DWDM), more than 32 wavelengths are multiplied by a spacing of about 0.8 nm (100 GHz) or 0.4 nm (50 GHz) or even 0.1 nm (12.5 GHz). It is therefore possible to combine up to 160 wavelengths [7].

Six bands have been standardized by ITU-T, including C-band (conventional); 191.560 to 195.942THz (1 565 to 1 530 nm), a bandwidth close to 4 THz. It has the advantage of being the least attenuated by the 0.2 dB/Km slope absorption and also the one whose spectrum is amplified by EDFA (erbium doped Fiber Amplifiers. This makes this band the most widely used over long distances [8].

For FTTH access links using GPON and WDM-PON technology, the O-band (1290 nm - 1130 nm) is used for uplink TDM streams with a linear attenuation of 0.3dB/Km. It should be noted that the latest generation of "peak less" fibers has a slope linearity over the entire spectrum from 1330 to 1530 nm with a linear attenuation of 0.2 dB/Km. This results in a bandwidth greater than 35 THz [9]. Due to the increased bandwidth requirements, L-band as well as Raman scattering amplifiers are also used [10].

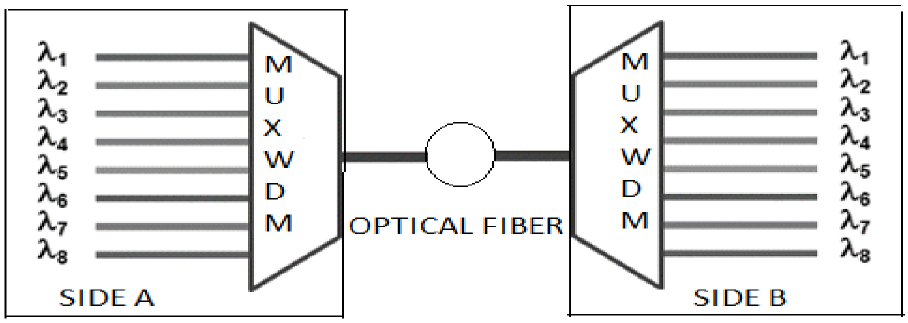

Fig 2: WDM Multiplexing

3. THE SIMULATION

3.1 OptiSystem 7

The main simulation resource at our disposal for the evaluation of the proposed solution is OptiSystem7, a software developed by a Canadian company Optiwave; Optical Communication System Design Software, it allows engineers and researchers to design, simulate and analyze optical transmission systems. It is in fact a software that is based on the principle of simulation in order to realistically order fiber optic communication systems. The simulation spectrum of OptiSystem can be extended by the possibility of inserting user-made function blocks that can be easily integrated into the simulated systems. The virtual components in the library are capable of reproducing the same behavior and effect as the real components. It should be noted that OptiSystem is currently at version 16 [11].

3.2 Network requirement

After an in-depth analysis of the network requirements for telemedicine applications, we have identified the critical conditions to simulate the solution to be proposed. Thus, based on Table 1, we have a bit rate requirement for digital medical imaging "MRI" applications at a distance of at least 1 Gbit/s, a bit error rate (BER) generally less than 1.10-10, a latency of less than 100 ms and an allowable packet loss rate of 0.1%.

Table 1: e-health network requirement

Service Type	Functions	Applications	Rate	BER	La-tency	Packet loss
Digital Medicine Imaging	Remote expertise	Imaging trans-fer	1Gbps	‹10^{-10}	100ms	0.1%
	Medical remote as-sistance	Remote radiol-ogy	10Mbps	‹10^{-10}	100ms	0.1%
Visual Relation	Remote consulting	Web conference	10Mbps	‹10^{-10}	100ms	0.1%
	Remote expertise	Visio confer-ence	1Mbps	‹10^{-10}	100ms	0.1%
Remote follow-up	Telemedicine	Pulse, Temper-ature, blood pressure	1Mbps	‹10^{-3}	‹300ms	‹0.5%
Medical Applica-tions	EKG, EEG	Data recording	2 Mbps	‹10^{-5}	100ms	‹0.5%

3.3 Network configuration

Despite the lack of infrastructure in sub-Saharan Africa, it is worth noting the countries' efforts to develop optical backbones at the national level, which has facilitated the connection of transport in the largest cities. The current problem is the connection of secondary towns and villages to broadband infrastructure. In the Republic of Niger, the majority of these localities are located between 20 and 120 km from the national fibre optic network, which is why we opted for WDM with PON at the end; this solves both the problem of broadband service with WDM, but also the problem of energy that lives with the acquittals in these areas with PON.

The choice also takes into account the need to optimize costs given the financing difficulties in the areas to be served. We opted for low-power transmitters (CW-Laser at 0dBm) and 4 wavelength multiplexing in WDM to establish several simultaneous links on the same medium (Digital Medical Imaging, visual link, Patient Monitoring, EKG, EEG, etc...). In the remote health center to be served, we have selected devices connected in GE, FE wired mode on the Optical Network Unit (ONU) and in wireless mode via the IEEE WiGig 802.11ad standard [12].

Four 1Gbit/s streams each modulating a CW laser at 1550, 1551, 1552 and 1553 nm respectively with 0 dBm power. The four signals are multiplexed and transmitted over a 120 km long single-mode optical fiber. Reception takes place without amplification after demultiplexing. Figure 1.3 shows the synoptic configuration of the solution.

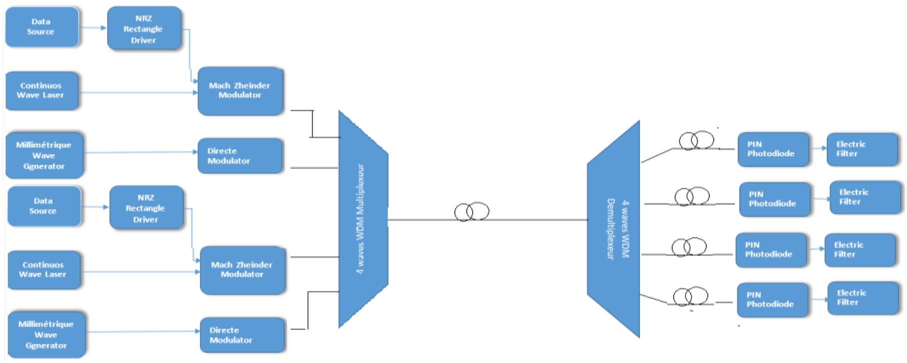

Fig 3: WDM 4 waves block diagram

3.4 Simulation and results

Figure 4 shows the general architecture of our simulated connection with the OptiSystem 7 software. Like any communication architecture, we can easily identify the transmission part characterized by laser diodes, modulators and WDM multiplexer, the transmission channel which is represented by a single-mode optical fiber and the reception part consisting of a set of receivers and optical amplifiers.

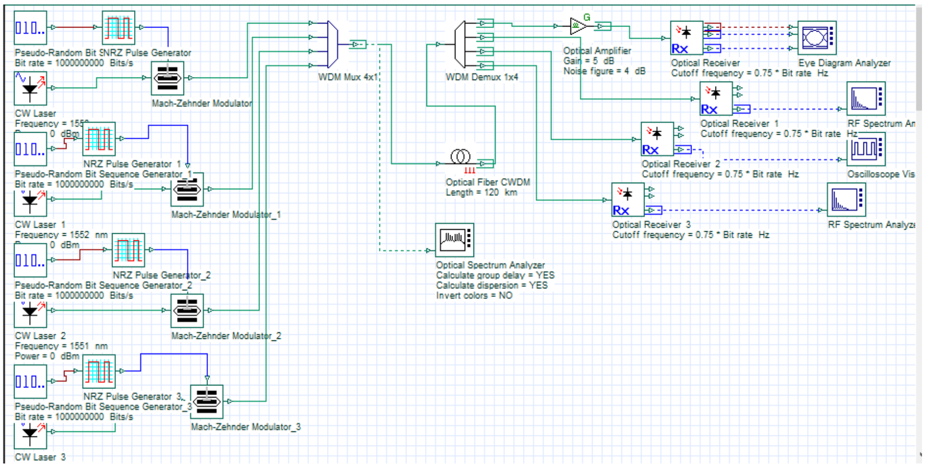

Fig 4: Four channels WDM Multiplexing

Once the assembly has been completed and recorded, the simulator must be started. Once the compilation is complete, double-click on the spectrum analyzer at the output of the multiplexer to observe the presence of the four carriers as shown in Figure 4.1.

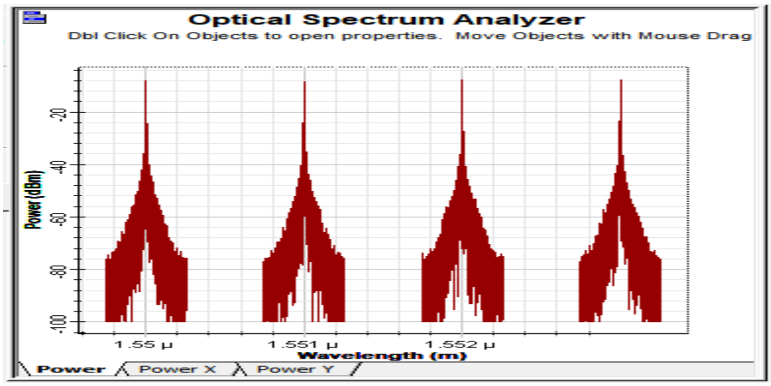

Fig 4.1: Spectral representation of 4 channels WDM Mux out put

Figure 4.2 shows the state of the relative eye diagram. The associated table shows that the quality Q-factor is only 5.01, the bit error rate (BER) is 2.10^{-7} and the eye aperture (height) is 15.10^{-7}.
The optical power received before detection for each channel is of the order of -28 dBm.

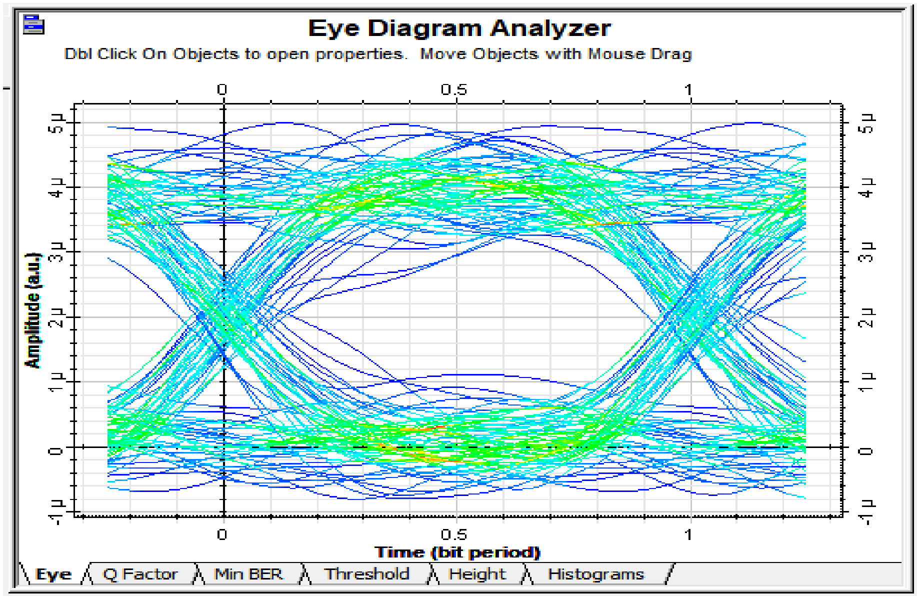

Fig 4.2: Outflow eye diagram at 1550 nm

These characteristics do not guarantee efficient transmission in a telemedicine environment which is characterized by bit error rate requirements (10^{-10}) and a latency of less than 100 ms. There is also a collapse of the 2U eye diagram and a signal shift over at least 3 divisions.

Table 2: Eye Diagram Analysis without Amplifier at 1550 nm

Max. Q Factor	5.05869
Min. BER	2.10829e-007
Eye Height	1.53656e-006
Threshold	1.93229e-006
Decision Inst.	0.724543

In view of the requirements of telemedicine networks described above, such a link cannot guarantee the efficiency of the services. Targeted possibilities include reducing the distance from 120 to 100 km or adding an amplifier in the receiving chain. In view of the infrastructure coverage constraint in the study area, we opted instead for maintaining the distance and adding a 5 dB gain amplifier.

Figure 4.3 reflects the improvement induced by the addition of this amplifier. The improvement in Q-factor at 15.59, bit error rate at 4.10^{-55} (al-most zero) and eye height at 1.10^{-5} can be observed.

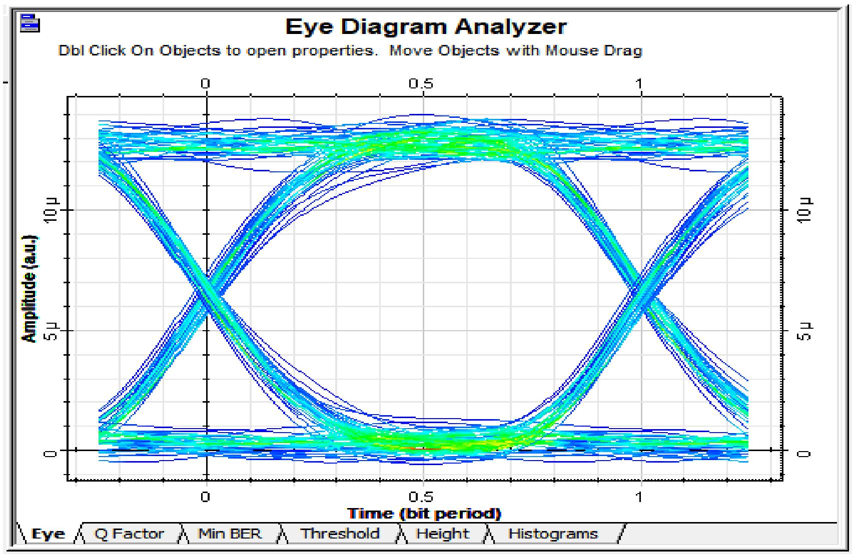

Fig 4.3: Outflow eye diagram at 1550 nm with 5dB amplifier.

The addition of a 5 dB amplifier in the receiving chain shows in Fig. 4.3 a maximum eye aperture of more than 10U, the signal slip is reduced to less than one division and the related Table 1.4 shows a bit error rate of the order of 10^{-55} (almost zero). These parameters meet the requirements of telemedicine perfectly.

Table 3: Eye Diagram Analysis with 5 dB Amplifier at 1550 nm

Max. Q Factor	15.59
Min. BER	4.24006e-055
Eye Height	1.00731e-005
Threshold	5.99434e-006
Decision Inst.	0.677546

Table 4: BER as a function of power with 5 dB amplifier

TX POWER (dBm)	FIBER LENGTH (Km)	Bit Error Rate
-20	120	10^{-1}
-10		10^{-1}
-5		10^{-1}
-3		$1,721.10^{-7}$
0		$4.24.10^{-55}$

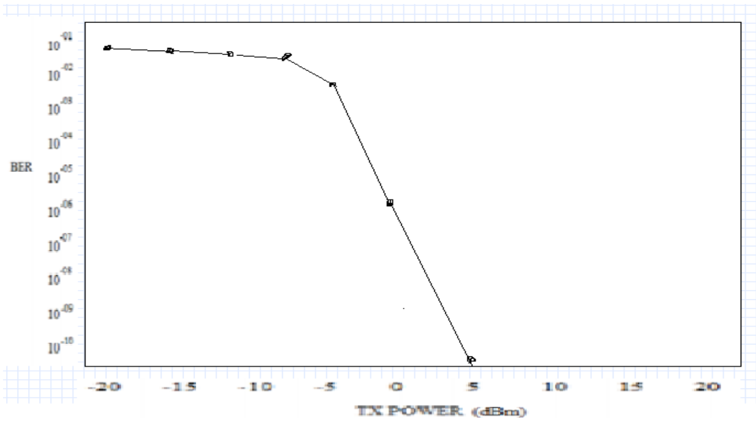

Figure 4.4 shows the variation in bit error rates in relation to the variation in power. We find relatively high bit error rates of the order of 10^{-1} to 10^{-6} for transmit powers between -20 and 0 dBm, but when the transmit power reaches +5 dBm, the bit error rate falls to about 10^{-10}, hence the need for a good choice of transmitters in such a system.

4. CONCLUSION AND PERSPECTIVES

The sensitivity and demand for telemedicine applications make fiber optics in transport and access networks the best candidate in terms of transport infrastructure. Analysis of Figures 4.3, 4.4 and associated tables clearly indicates the impact of optoelectronic links on the rate, range, dispersion and quality of service of telemedicine applications. Indeed, the association of WDM with the PON makes it possible to have optimized and robust infrastructures in the context of the financial difficulties that characterize the developing countries south of the Sahara. The optimization of these resources will therefore provide an opportunity to extend broadband with a view to achieving sustainable development objectives through the use of ICTs (ICT4SDG), including objective number 3, which concerns health for all issues.

Indeed, this integrated solution makes it possible not only to immediately initiate telemedicine practices in this disadvantaged region of the planet, but also to continue the development of telemedicine through progressive extensions of connected health equipment according to the availability of financial resources and existing infrastructures.
In terms of perspective, it would also be possible to experiment with dual-source laser transmitters coupled to graded index multimode fibers, which will reduce investment costs by eliminating multiplexers and the use of multimode fibers, whose costs are relatively low compared with the single-mode fibers currently in use.

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