

RESEARCH ARTICLE

EVALUATION OF 1 TBIT/S WDM-OIL-TDM-PON PERFORMANCE ON 28 GHZ FREQUENCY BAND

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Abstract

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Radio Over Fiber (RoF), Optical Injection Locking (OIL), Millimeters Waves, Hybrid Passive Optical Network (PON)

..... In this proposal, we design and evaluate a convergent architecture which offers one terabit/s 28 GHz frequency band. This hybrid system is designed according to four technology principles. It is a Passive Optical Network (PON) which integrates Wavelength Division Multiplexing (WDM) and Times Division Multiplexing (TDM) associates to Optical Injection Locking (OIL) on 28 GHz frequency band at a throughput of one terabit/s. The Optical Injection Locking (OIL) method consists of a correlation of two slave lasers controlled by a master laser modulated with a Mach Zehnder Modulator to generate a millimeter wave at 28 GHz frequency band. This scheme will offer high bit rate and will serve several base stations in rural areas allowing them to benefit broadband ICT services. These base stations can be those of next generation wireless networks such as Worldwide Interoperability for Microwave Access (WiMax), Wireless Fidelity (WiFi), Long Term Evolution (LTE), 5G technologies, etc.

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Introduction:-

Bit rate increase in current multimedia services and the need to connect the most remote areas such as the rural locations are the major concerns of network access providers. Therefore providing a network allowing access to services such as telemedicine and e-learning to rural populations is not an easy deal. Passive Optical Networks (PON) and the convergence network technology ROF (Radio Over Fiber) are part of the solutions proposed by scientists to provide high throughput to customers in the most remote areas [1][10]. Our proposal focuses on the performance study of a hybrid network based on WDM-OIL-TDM hybrid PON in order to guarantee the effectiveness of this deal.That architecture combines bothWavelength Division Multiplexing (WDM),OpticalInjectionLocking (OIL) [11][13]which is part of signal generation methods in Radio on Fiber (RoF) [11][13].technology and Time Division Multiplexing (TDM) in a single PON, offering reduced phase noise, negligible chromatic dispersion, reduced cost, high scalability and increased data rates. The Optical Injection Locking (OIL) method is used to generate a millimeter wave at 28 GHz frequency band. This frequency band is one of the millimetric signal bands standardized by regulatory authorities to provide high bit rate to next generation

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wireless networks. Thus our proposal architecture can offer a significant increase in the coverage area and the overall capacity of the current optical network. It will also offer the benefits of high data throughput, spectral purity and increased mobility to connect the rural population. So it will serve several base stations in rural areas to allow them to benefit broadband ICT services. These base stations can be those of next generations of Worldwide Interoperability for Microwave Access (WiMax), Wireless Fidelity (WiFi), Long Term Evolution (LTE) and even from 5G technologies, depending on the type of service.

Therefore, the introduction of our proposal will be followed by a related work in section II and a general study of Materials and methods is presented in section III. Before the presentation of the performances obtained through our simulations and results in V, we have described in section IV the WDM-OIL-TDM-PON system model of our proposal. The conclusion and the future work will complete this study in VI.

Related Works:

The increase of capacity of an optical link by the OTDM technique was proven in 1968 for the first time [1]. But the proposal of Tao-rong Gong et al. [2] reported the OTDM transmission over 36 km at 100 Gbit/s in 1993 for the first time. Thus the dazzling progress of optical transmission with the use of the multiplexing technologies have made the possible to reach record lengths with high bit rate. A WDM-OTDM architecture with increase efficiency and throughput while reducing delays and errors is presented in [1]. V. Lohani and R. S. Prasad [3] studied the performance of the WDM-TDM hybrid system in the presence of an optical amplifier to increase the maximum number of users to 320 users up to 160 km with a data rate of 1.25 Gbit/s. In [4] Amritpal Singh and al.proposed a bidirectional hybrid PON with a downstream signal of 10 Gbit / s and a modulated upstream signal of 5 Gbit / s supporting 8 ONU over a transmission distance of 45 km. The upstream signal remodulation is carried out using a Reflective Semiconductor Optical Amplifier (RSOA) and the impacts on the upstream signal are studied when the RSOA is injected with a continuous wave light injection and a DQPSK modulated light injection. The architecture discovered in the works of G.Talli and P. D. Townsend [5] allows to reach higher distances. They designed a 100 km bidirectional hybrid PON with a symmetrical 10 Gbit / s data rate and supporting a 1: 256 distribution with 17 TDM PONs each operating at different wavelengths, giving a total number of 4352 users. Yousaf Khan et al. [6] demonstrated a symmetrical WDM PON in 10 Gbit /s full duplex with ON-OFF Keying (OOK) techniques for upstream remodulation over a transmission distance of 25 km.

N. Choudhary and S. Pawar [7] demonstrated a 4x10 Gbit / s WDM-TDM-PON over 32 km of SMF with 0.3 dB / km with EDFA at 30 dB gain. 1:128 splitters were used, i.e. 64 users. Amplifiers extend the number of users to the maximum. Without an amplifier they reached 20 km with 128 users. DE VALICOURT et al. [8] presented an economical hybrid WDM / TDM-PON which could potentially supply 2048 subscribers at a bit rate of 2.5 Gbit/s. The RSOA made it possible to extend the range of the link up to 45 km instead of the standard 20 km. A.O. Aldhaibani et al. [9] demonstrated a WDM-TDM-PON over 25 km at 2.5 Gbit / s with 8-DPSK for 32 to 64 users.

P. Sangeetha and I. Muthumani [10] showed the coexistence of WDM-RoF-TDM-PON and compared the network performance for digital modulation 8-DPSK and 16-QAM, for four data rates (2.5 Gbit/s, 1,5 Gbit/s, 1.25 Gbit/s and 1 Gbit/s), for 25 km of optical fiber for 32 to 64 users. Wei Ji and Zhaoyuan Kang [11] reported the WDM-RoF-PON coexistence for an O-OFDM modulation at 8x40Gb / s with 60 GHz radio-over-fiber systems for 512 users over 100km.

In short, all of these works focuse on the use of the multiplexing techniques to provide high bit rate to large numbers of customers, and even those who are in the most remote areas. Our work brings the use of the Optical Injection Locking (OIL) technique to generate a millimiter radio frequency signal at 28 GHz, a WDM-TDM hybrid PON. The advantages of these technologies offer a convergent fixe/ mobile network to reach the rural populations and give them high bit rate to access to news services such as the telemedicine, the cloud, the e-learning etc.

Materials and Methods:-

In this section, the different technologies and methods used are presented. It explains the four technology systems of our proposal designed by the wavelength division multiplexing, the radio over fiber (rof)/optical injection locking, the optical time-division multiplexing and the passive optical network techniques.

Wavelength Division Multiplexing (WDM):

WDM principle consists of sending several wavelengths ($\lambda 1$, $\lambda 2$, ..., λn) on the same fiber. The conventionally modulated waves are then multiplexed by passive optical systems. A fiber can support more than ten wavelengths, thus allowing it to carry all the services that customers need. WDM system is an equipment saver. For example, a single optical amplifier replaces several regenerators [12]. WDM has low latency. WDM can build the all-optical network with high flexibility, high reliability and high survivability using OADM (Optical Add-Drop multiplexer) and OXC (Optical Cross-Connect).

Radio over Fiber (RoF)/Optical Injection Locking (OIL):

A RoF technology consists of modulating a light signal by a radio frequency (RF) signal and transmitting the modulated signal over a fiber optic link to facilitate wireless access. In these systems, wireless signals are transported in optical form between a central station and a set of base stations before being radiated into the air. It considerably reduces the equipment and maintenance costs of the network by centralizing the processing management and radio functions of the base stations at the central station level [10]. It supports current and next generation wireless network deployment and management strategies. Optical millimeter-wave signal generation in a RoF system is usually based on heterodyning techniques by beating two optical carriers separated by the desired frequency. In this paper we use Optical Injection Locking (OIL) method where two slave lasers are correlated and controlled by a master laser [11] [13]. Conombo et al. [13] have shown that when the master laser signal of f_p frequency is modulated by a signal of f_m frequency, one can obtain, by the OIL method, an integer number of the f_m frequency. $f_{RF}=2nf_m$ where n is the number of the harmonic on witch a slave laser is hooked. Indeed in this article $f_m = 1$ GHz and the two slave lasers are attached to the harmonics ± 14 thus giving $f_{RF} = 2x14x1$ GHz = 28 GHz. It is the desired f_{RF} frequency that is generated and transmitted on the optical fiber to serve a base station. In an optical heterodyning system, the network implements wireless access without adding a radio source [11]. OIL eliminates phase noise and chromatic dispersion.

Optical Time-Division Multiplexing (OTDM):

OTDM basic principle is to multiplex a number of low bit rate optical channels in the time domain. This system has the advantage of operating on only one wavelength [1]. An optical signal from a laser diode is shared between N paths. The signal portion in each path is modulated by an electrical data signal in RZ format. A time slot representing a fraction of the period T is allocated to each branch to allow time multiplexing using a passive optical coupler. Laser source must be able to generate optical pulses with a duration <1 / N of the clock period T to counter the phenomenon of crosstalk between interlaced channels. Multiplex an optical signal with period T ps on channel N, the required delay $\Delta \tau$ for each path is [1]: $\Delta \tau i = i * T/N$ (ps) i = 1, 2, ..., N-1. Where $\Delta \tau i$ is the delay for the ith path. OTDM goal is to increase the overall rate B_{OTDM} = NB_{ch} in the Tbit/s range (T ~ 1ps). Where, N is the number of time channels and Bch is the bit rate of the channel.

OTDM eliminates the effect of chromatic dispersion, the speed effect of electronic devices. It is free from the nonlinear effects of fiber. OTDM offers greater flexibility and efficiency, dynamically allocating more time periods to signals that need more bandwidth, while reducing time periods to signals that do not.

Passive Optical Network (PON):

PON consists of an Optical Line Terminal (OLT), a single-mode fiber, passive optical splitters and/or Multiplexers and demultiplexer and Optical Network Units (ONU). To connect a large number of users, we use cascade optical couplers [1][10]. OLT broadcasts signal to all users. Each ONU uses multiple access protocols to supplement shared access to information in transmission channel [1][10].

Proposal System Model:

The design of our hybrid system model is presented in Fig. 1. It focuses on one Terabit/s WDM-OIL-TDM-PON using 28 GHzfrequency signal. The Fig. 2 shows the simulation diagram realised with Optisystem.



Fig. 2:- WDM-OIL-TDM-PON simulation diagram realized with Optisystem.

Architecture Presentation:

In this article, Optical Time Division Multiplexing (OTDM) consists of optically multiplying four optical signals modulated at 64 Gbit/s bit rate delivered by the Pseudo-Random Binary Sequence (PRBS) generator in Return to Zero (RZ) format through a Mach-Zehnder Modulator (MZM) using the same carrier frequency provided by the CW Laser (Master Laser) to form a composite optical signal at a 4x64 Gbit/s bit rate, where 4 is the number of multiplexed optical channels. Multiplexer is most simply implemented using passive fiber couplers with appropriate optical delays between the channels. Laser source must be able to generate optical pulses with a duration <1/4 of the clock period T to counter the phenomenon of crosstalk between interlaced channels. Multiplex an optical signal with period T ps on channel 4, the required delay $\Delta \tau$ for each path is: $\Delta \tau i = i *T/4$ (ps) i = 1,2,3. Where $\Delta \tau i$ is the delay for the ith path, 4 is the number of time channels. OTDM transmitter delivers 256 Gbit/s. Fig. 3 shows the OTDM transmitter structure.64 Gbit/s RZ format is detailled in Fig. 4.



Four 256 Gbit/s composite optical signals from four OTDM transmitters are wavelength multiplexed at the WDM multiplexer. The 1 Tbit/s composite optical signal obtained is modulated through an MZM by an electrical signal f_m (equal to 1 Ghz) delivered by a sine generator. The composite optical signal modulated at 1 Tbit/s is injected into the OIL moduleshown in Fig. 5. This module is composed of four 28 GHz submodules separated by a power splitter which will receive the four composite optical signals from the four OTDM transmitters. Each sub-module (Fig. 6) will optically lock by injection one of the four composite optical signals, will be controlled by the corresponding master laser (master laser and sub-modules are in the same frequency band) and will deliver at its output the 28 GHz

signal whose principle is explained in [13]. Signals from the four sub-modules are recombined by a power combiner to obtain the 28 GHz modulated composite optical signal. The composite optical signal modulated at 28 GHz is injected into the transmission block which consists of fibers in the case without amplification or fibers, possibly control loop, amplifiers,... (Fig. 7).





The wavelength demultiplexing is then carried out and the four composite optical signals at 28 GHz are obtained. Time demultiplexing with 1: 4 splitters will give 16 optical TDM channels at 64 Gbit/s in the 28 GHz band. If the speed requirement is 64 Gbit/s per Optical Network Unit (ONU) then 16 ONUs are connected. Otherwise from each 64 Gbit/s channel, 128 users can be connected using a 1:128 splitter. This will give a total of 16x128 users; viz 2048 users for 1 Tbit/s and therefore 512 Mbit/s per user.

Reception block supports optical/electrical conversion. This block is composed of a PIN photodetector, a Bessel low-pass filter, a 3R regenerator, an eye diagram analyzer/BER.(Fig. 8). Photodetector converts the optical flow into an electrical current, which can then be amplified and processed [14]. The Low Pass Bessel Filter filters the electrical signal. BER Analyzer measures the performance of the system based on the signal before and after the propagation [15]. The Eye Diagram Analyser displays multiple traces of a modulated signal to produce an eye diagram [15].



Components settings:

Parameters of the components located between the OTDM transmitter and the OIL module included are listed in Table 1.

WDM-OIL-TDM-PON Transmitter			
Components	Settings	Value	
PRBSG	Bite rate	64 Gbit/s	
RZ Pulse Generator	Rise time	0.15 bit	
	Fall time	0.25 bit	
CW Laser (Master Laser)	Frequency	193.C Thz	
	Power	0 dBm	
	Linewidth	0.005 Mhz	
	Initial phase	0 deg	
	polarization	0 deg	
	Noise bandwidth	125 Thz	
	Noise threshold	-100 dB	
	Noise dynamic	3 dB	
MZM	Extinction ratio	30 dB	
	Symmetry factor	-1	
WDM Mux/Demux	Bandwidth	28 GHz	
	Insertion loss	0 dB	
	Depth	100 dB	
	Filter type	Bessel	
	Filter order	2	
	Frequency[0]	193.1 THz	
	Frequency[1]	193.2 THz	
	Frequency[2]	193.3 THz	
	Frequency[3]	193.4 THz	
	Noise threshold	-100 dB	
	Noise dynamic	3 dB	
Sine Generator	Frequency	1 GHz	
	Amplitude	1 a.u	
Ideal isolator	Insertion loss	40 dB	
Slave Lasers	Frequency	193.C045/C185 Thz	
	Power	10 dBm	
	Linewidth	0.005 Mhz	
	Initial phase	0 deg	
	polarization	0 deg	
	Noise bandwidth	0 Thz	
	Noise threshold	-100 dB	
	Noise dynamic	3 dB	

 Table 1:- WDM-OIL-TDM-PON Transmitter settings.

NB: Freqency SL1 = 193.C045 ThzFrequency SL2 = 193.C185 Thz; C=1,2,3,4 referring to the four WDM Mux / Demux channels; PRBSG: Pseudo-Random Bit Sequence Generator.

Transmission block settings are listed in Table 2.

Table 2:- Transmission block co	mponents settings.
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Transmission Block		
components	Settings	Value
SSMF	Dispersion	16.75 ps/nm/km
	Dispersion Slope	0.075 ps/nm^2/km
	PMD Coefficient	0.5 ps/km
	Effective area	80 um^2
	Nonlinearity Coefficient	2.6×10^{-20}
	Attenuation	0.2 dB/km
EDFA	Length	5 m
Loop control	Number of loops	12

SSMF=Standard Single Mode Fiber;

Reception block settings are listed in Table 3.

Table 3: - Reception block components set	ttings.
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Reception Block			
Components	Settings	Value	
PPIN	responsivity	1A/W	
	Dark current	5 nA	
	Center frequency	193.1 Thz	
	Sample rate	5*(sample rate) Hz	
	Noise calculation type	numerical	
	Add signal-ASE noise	ok	
	Add ASE-ASE noise	ok	
	Thermal noise	1e-022 W/Hz	
	Add shot noise	ok	
	Shot noise distribution	Gaussian	
LPBF	Cutoff frequency	0.75*Bit rate Hz	
	Insertion loss	0 dB	
	Depth	100 dB	
	Order	4	
3RRegenerator	Reference bit rate	4 Gbit/s	
EDA	Time window	1.5 Bit period	
	Threshold mode	relative	
	Relative threshold	50%	
	Decision instant	0.5 Bit period	

NB: LPBF: Low Pass Bessel Filter; PPIN: Photodetector PIN; EDA: Eye Diagram Analyzer

Simulation and Results:-

Evaluation of our architecture is carried out with the performance indicators of the quality of an optical network. Usually, these are three transmission quality criteria, which are evaluated after detection of the signal: the eye diagram, the Bit Error Rate (BER) and the quality factor Q. We evaluated the performance of three systems: the back to back link, a system without amplifier and system with an amplifier.

Back to Back Link:

The back to back link consists of connecting the WDM-OIL-TDM-PON transmitter directly to the reception block without fiber. On the one hand, we have visualized in Fig. 9 and Fig. 10 the power spectrum of signals at the output of the OIL module and frequency demodulator respectively. On the other hand, link quality of the back to back is given by eye diagram and quality factor presented in Fig. 7. Simulation results obtained at the output of 1:4 splitter give a quality factor Q = 17.8974 which is equivalent to a BER = 6.16229e-072 (Fig. 11).



Optical Spectrum Analyzer

Fig. 9:- 4x28 GHz radio frequency spectrum.





Fig. 10:- 28 GHz radio frequency spectrum.



Fig. 11:- Eye diagram of back to back link at 1:4 splitter output.

Simulation without Amplifier:

In this paragraph we have introduced a standard single mode fiber between emission block and reception block without using an amplifier. Depending on the length of the fiber, we have evaluated transmission quality. Simulation results obtained at the output of 1:4 splitter show that transmission quality is maintained up to 70 km (Fig. 12). Q=6.04987 and BER=7.12645e-010.

Eye Diagram Analyzer



Fig. 12:- Eye diagram at 70 km with 1:4 splitter.

Simulation with Amplifier:

If at70 km of fiber length an amplifier is placed between the splitters 1: 4 and 1:128, Q = 13.5125 and BER = 6.59621e-042 (Fig. 13). An amplifier can be placed every 70 km to be able to serve base stations in rural areas. In this link fibers, EDFA and loop control are used in transmission block. Therefore by demultiplexing with the 1: 4 splitters, we were able to reach 1015 km, viz 70 km x 14 loops + 35 km with Q = 7.0466 and BER = 8.99623e-013 (Fig. 14). To allocate 512 Mbit/s to each user, 1:128 splitters were used in cascade with 1: 4 splitters for each 64 Gbit/s channel. We have 4x4x128 users for a total of 2048 users. In this case, an amplifier must be inserted between the 1: 4 and 1: 128 splitters and we obtaied Q = 6.09464 and BER = 5.48435e-010 (Fig. 15). All the results of the simulations are summarized in Table 4.



Fig. 13:- Eye diagram at 70km with amplifier between 1:4 and 1:128 splitters.







Fig. 15:- Eye diagram at 1015 km at the output of 1:128 splitter.

Table 4 shows that 16 users can be connected to 64 Gbit/s each up to 70 km without amplifier and 1015 km with amplifier every 70 km with very good transmission quality. It also shows that 2048 users at 512 Mbit/s each can be connected up to 1015 km with amplifier every 70 km and with an amplifier between 1:4 and 1:128 splitters.

Simulation Results					
Link	Maximum length in km	Q factor	BER	Channel bit	Users
				rate	number
Back to	0	17.8974 for	6.16229e-072 for 1:4	64 Gbit/s	16
back		1:4 splitters	splitters		
without	70 for 1:4 splitters	6.04987	7.12645e-010	64 Gbit/s	16
amplifier					
With	70 with an amplifier between 1:	13.5125	6.59621e-042	512 Mbit/s	2048
amplifier	4 and 1:128 splitters in cascade				
every 70	1015 for 1:4 splitters	7.0466	8.99623e-013	64 Gbit/s	16
km	1015 with an amplifier between	6.09464	5.48435e-010	512 Mbit/s	2048
	1: 4 and 1:128 splitters in				
	cascade				

Table 4:- Simulation results.

Conclusion and Future Work:-

In this work we investigated performance of a hybrid system based on the WDM-OIL-TDM hybrid PONtechnologies at 1 Tbit/s on 28 GHz frequency band. Simulation step was done at three scenarios. The first one consisted of simulating the back to back link. Good transmission quality was obtained. After demultiplexing with 1:4 splitters the quality indicators are Q = 17.8974 and BER = 6.16229e-072. The second one consisted of simulating link without amplifier. The quality was maintained up to 70 km with 1:4 splitter (Q= 6.04987 and BER=7.12645e-010). The third one consisted of simulation with amplifier. We obtained satisfactory quality up to 1015 km with Q = 7.0466 and BER = 8.99623e-013 for 1:4 splitters. For 1:4 and 1:128 cascading splitters with an amplifier between them Q = 6.09464 and BER = 5.48435e-010at 1015 km. Simulation confirms that it works very well and will be in good shape for serving broadband ICT in rural areas. The use of 1: 128 splitters in the 1 Tbit/s WDM-OIL-TDM-PON architecture on the 28 GHz frequency band makes it possible to connect 2048 users and each user can obtain a bit rate of 512 Mbit/s .As future work, the performance of WDM-OIL-TDM-PON in multi-level modulation can be investigated.

References:-

- 1. Mohammed,H. A. (2013). Optical Time Division Multiplexing (OTDM) and Hybrid WDM/OTDM PON Performance Investigation. International Journal of Electronics Communication and Computer Engineering, vol. 4, n°3, pp. 747-754.
- 2. Gong,T. -r. et. al. (2009). Demonstration of single channel 160-Gb/s OTDM 100-km transmission system. Optics Communications 282, pp. 3460–3463.
- 3. Lohani, V. and Prasad, R. S. (2015). Design and Simulation of Hybrid WDM/TDM Passive Optical Network. International Journal of Computer Applications(0975 – 8887), vol. 119, n°6, pp. 27-28.
- Singh, A. and Singh, K. (2014). Demonstration of a Bidirectional WDM-PON with 10 Gb/s Downstream DQPSK and 5 Gb/s Upstream Re-modulated OOK Data Based on Reflective Semiconductor Optical Amplifier. International Journal of Innovative Science, Engineering & Technology, vol. 1, n°4, pp. 292-296.
- 5. Talli, G. and Townsend, P. D. (2006). Hybrid DWDM–TDM Long-Reach PON for Next-Generation Optical Access. JOURNAL OF LIGHTWAVE TECHNOLOGY, vol. 24, n°7, pp. 2827-2834.
- 6. Khan, Y.,Idress, M., Khan, N. A., Khan, J. and Latif, S., (2013). A cost effective architecture for full duplex hybrid WDM/TDM-PON using DPSK downstream and colorless re-modulated upstream OOK data. International Journal of Emerging Sciences, vol. 3, n°1, pp. 28-35.
- 7. Choudhary, N. and Pawar, S. (2015). Design and implementation of bi-directional 4×10 Gb/s WDM-TDM PON with upstream remodulation. 2015 IEEE Bombay Section Symposium (IBSS).
- de Valicourt, G.,Maké,D.,Landreau, J.,Lamponi, M.,Duan,G. H.,Chanclou,P. and Brenot, R. (2010). High Gain (30 dB) and High Saturation Power (11 dBm) RSOA Devices as Colorless ONU Sources in Long-Reach Hybrid WDM/TDM-PON Architecture. IEEE PHOTONICS TECHNOLOGY LETTERS, vol. 22, n°3, pp. 191-193.

- 9. Aldhaibani, A. O., Idrus, S. M. and Zulkifli, N. (2012). 2.5-Gb/s Hybrid WDM/TDM PON Using Radio over Fiber Technique. 3rd International Conference on Photonics 2012, pp. 255-257.
- Sangeetha, P. andMuthumani, I. (2016). Implementation of Hybrid WDM-TDM PON Using Radio over Fiber. Middle-East Journal of Scientific Research 24 (Special Issue on Innovations in Information, Embedded and Communication Systems), pp. 265-271.
- 11. Ji, W. and Kang,Z. (2013). Design of WDM RoF PON Based on OFDM and Optical Heterodyne. Journal of Optical Communications and Networking, vol. 5 n°6, pp. 652-657.
- 12. Ali, H. A. and Farhood, D. A. (2019). Design and Performance Analysis of the WDM Schemes for Radio over Fiber System With Different Fiber Propagation Losses. *Fibers*.
- Conombo, S.,Diouf, M. D.,Ouya, S. and Kora, A. D. (2020). Radio Signal Generation over Fiber by Optical Injection Locking. 22nd International Conference on Advanced Communication Technology (ICACT), Phoenix Park, PyeongChang,, Korea (South), 2020, pp. 430-436.
- 14. Boudkhil, A., Ouzzani, A. and Soudini, B. (2015). Analysis of Fundamental Photodetection Noises and Evaluation of PIN and APD Photodiodes Performances using an Optical High Debit Transmission Chain Simulated by Optisystem. International Journal of Computer Applications (0975 8887), vol. 115, n°18.
- 15. Johny, J. and Shashidharan, S. (2012). Design and Simulation of a Radio Over Fiber System and its Performance Analysis. Optical Networking Technologies and Data Security OPNTDS.
- 16. Gay, M. (2006). Étude théorique et expérimentale de l'impact de la régénération 2R dans un système de transmission optique haut débit. Physique [physics]. INSA de Rennes 2006. Français. <tel-00086500>.