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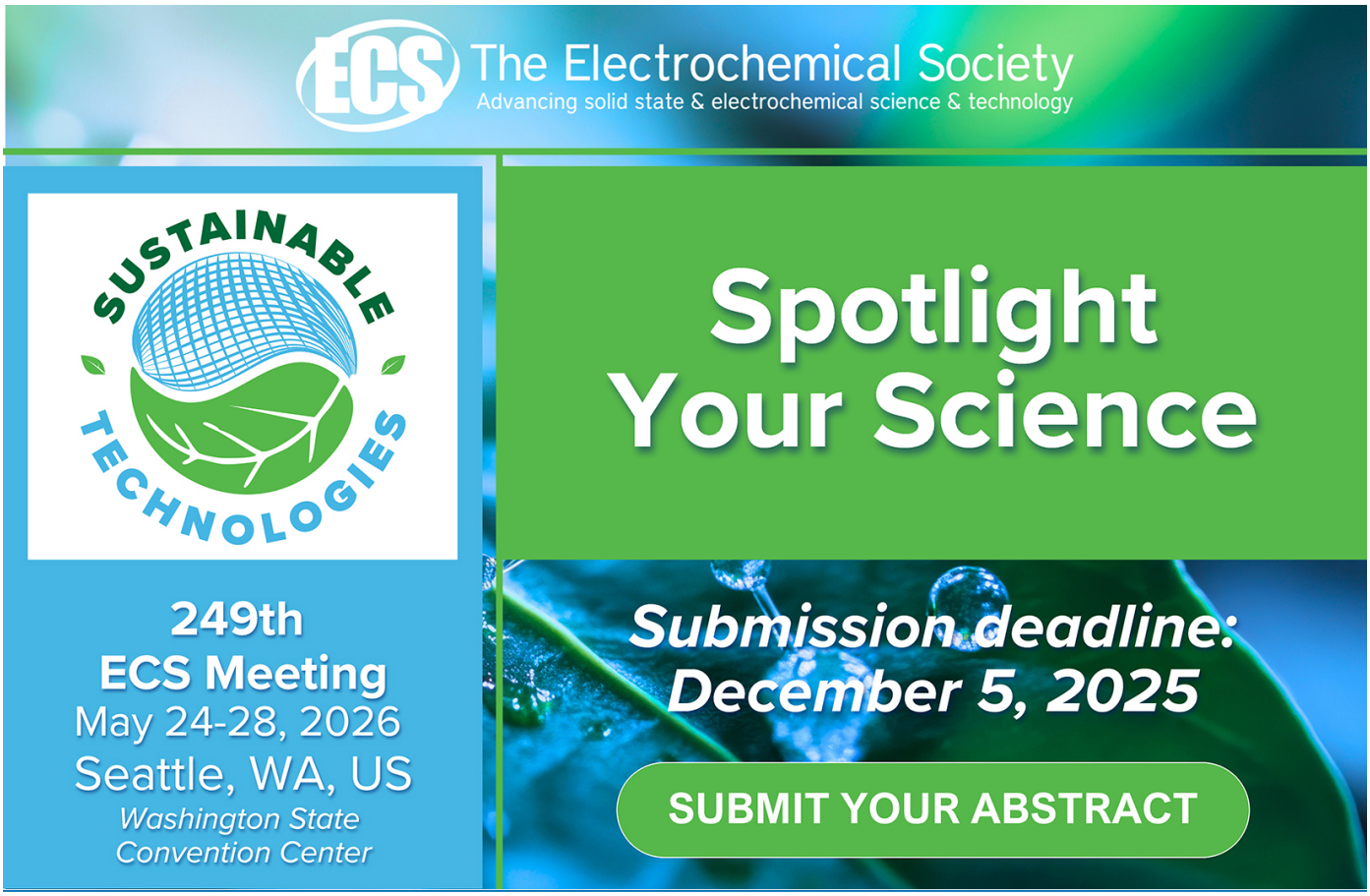
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# Design of a hybrid transmission system using wavelength division multiplexing and subcarrier under the frequency frame for 5G

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**Abstract.** This article proposes the design of a hybrid transmission system using wavelength division multiplexing and subcarrier under the frequency frame for 5G. The proposal is evaluated through modeling based on simulation of the generation of optical carriers using a broadband source in combination with an optical filter configured with different pass bands and transmission at different distances. The simulation model evaluated the signal quality levels in terms of the Q factor, taking into account the frequency framework for 5G (5 GHz, 30 GHz and 60 GHz) and the optical fiber length (5 km, 10 km, 15 km, 20 km, 25 km, 30 km). The results obtained show that the best performance of the Q factor compared to distances was that of the 30 GHz frequency, both in the access network and in the metro network. It was also possible to demonstrate that through a broadband light source and a waveguide grating array it is possible to obtain optical carriers for the transmission of signals in a hybrid wavelength division multiplexing and subcarrier transmission system.

## 1. Introduction

With the advent of 5G technologies, it is possible to consider completely replacing the current optical fiber and telecommunications systems, but it is not enough just to improve the electric radio spectrum, the high speeds that are expected can only be achieved through optical networks [1]. To support this position the head of Nokia Mobile Networks Oceania, Mark Barnett mentions "You need a lot of fiber optics, you really need, high capacity fixed networks [2]. The 5G is more than a wireless network it is a wireless and fixed network. It's the future of network convergence [3]. Increased capacity and coverage can be achieved not only through continuous densification of radio sites, but also through the introduction of technologies such as multiple inputs and multiple outputs (MIMO). In order to satisfy the evolution of 5G radio and cell/site densification, 5G transport must satisfy greater capacities and support a greater number of cells and sites. 5G will also involve the continuous evolution of different deployment architectures where the functional division and placement of radio access network (RAN) functionality will have an impact on transport and the requirements it must meet in terms of bandwidth, latency and phase fluctuation [4]. Most WDM networks carry homogeneous traffic, e.g. all

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optical channels carry synchronous optical network (SONET) optical carrier-48 (OC-48) (2.5 Gbit/s) and OC-192 (10 Gbps) frames [5]. However, in the case of non-homogeneous traffic (either analogue/digital, or digital with different speeds and modulation formats) it is more efficient to turn to alternative solutions, such as hybrid systems [6-9]. The main objective of this proposal is to design a wavelength and subcarrier multiplexed transmission system for a converged metropolitan network using spectral partitioning.

## 2. Background

In the design of optical networks, various schemes are proposed to provide high-speed unicast data services and multicast data/video services, such as time division multiple access (TDM), dense wavelength division multiplexing (DWDM), subcarrier multiplexing (SCM), wavelength division multiplexing-passive optical network (WDM-PON) and orthogonal modulation formats. Polarization displacement polarization (PolSK) is considered one of the promising modulation techniques in the future optical network, which provides constant power per bit and is useful for eliminating interference between unicast data and multicast data signal [10]. Subcarrier multiplexing (SCM) is considered an excellent complement to WDM [11]. SCM consists of generating and multiplexing several subcarriers in the electrical domain, where each subcarrier can be assigned to a subscriber. The high demands for quadrature amplitude modulation (QAM) and Nyquist pulse transformation of each subcarrier result in high spectral efficiency, which contributes to a greater number of subcarriers per optical channel and the relaxation of the number of optical modulators required at each optical line terminal (OLT) [11]. when, a real-time experiment at 108 Gbits/s was performed emulating a wavelength division multiplexing (WDM) system composed of five optical channels. The optical carriers were provided by an optical frequency comb with externally injected gain switching. Each optical channel transmitted an orthogonal subcarrier multiplexing (SCM) signal of 21.6 Gbit/s which was modulated and demodulated in the electrical domain without the requirement of digital signal processing. One way to increase spectral efficiency is through the combination of orthogonal multi-carrier techniques and microwave components [12]. This assertion is confirmed by [13], when, a real-time experiment at 108 Gbit/s was performed emulating a wavelength division multiplexing (WDM) system composed of five optical channels [14]. He costs of the line optical terminal of the conventional wavelength division multiplexed passive optical network system (WDM-PON) are reduced by introducing the multi-carrier optical generator source (MOG) on the side of the line optical terminal (OLT) of the WDM-PON system for high-capacity WDM-PON that supports numerous users, this effect is achieved by connecting three cascading modulators with a laser source, where the laser is connected with an amplitude and two cascading Mach-Zehnder modulators (MZM) with two Mach-Zehnder modulators (MZM) cascade. Where all modulators are powered by 30 GHz RF signal, where no specially designed grids or bragg fiber are required [15] There is currently research on the monitoring of optical system infrastructure failures. Where optical time domain reflectometer (OTDR), can perform rapid detection and troubleshooting. The required monitoring equipment is located in the central office and, therefore, the system offers centralized monitoring remotely. The results in this experiment allowed to verify that the system can provide an acceptable DR for a SCM/WDM-PON with 32 wavelengths, each one has 8 subcarriers while the data transmission is not interrupted and is insignificantly affected [16]. According to [3,17-19] the particular bands of interest are the millimetre wavebands, Figure 1 illustrates the mmw spectrum potentially available for use in 5G.

## 3. Proposed network infrastructure

Figure 2 illustrates the proposed design and is described below, the network architecture is composed of the spectral partitioning system consisting of a laser and an amplifier, an AWG configured as a demultiplexer, which performs the broadband partitioning and an AWG configured as a multiplexer, which will be responsible for multiplexing the carriers generated by DEMUX and sending them to the access segment via the optical circulator (a) - which directs the non-modulated carrier to the optical

modulator at each of the base stations of the access network to form the uplink signal in this segment. The access network consists of a pseudo-random bit-sequence generator, a pulse generator (NRZ), an electric amplitude modulator, an AM modulator, an AWG configured as a demultiplexer (each port will represent a user), two ideal circulators and two fiber optic modules. Once the RoF signal is obtained, the optical circulator (b) enables the uplink and directs the signal towards the metro network. The OADM (two Switches and two AWGs) will allow to extract and add channels from and to the rest of the information flow that will circulate in the network (to the left or to the right).

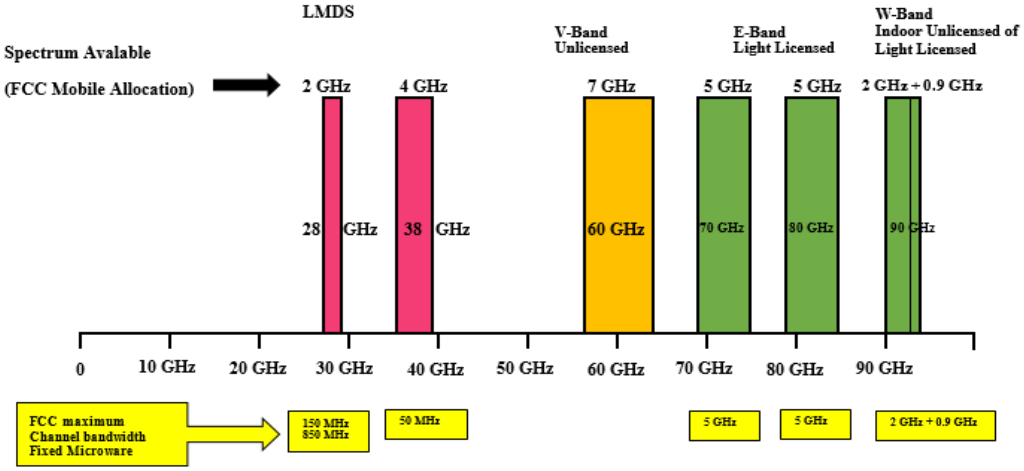



**Figure 1.** Potential spectrum for 5G in mmw [18].

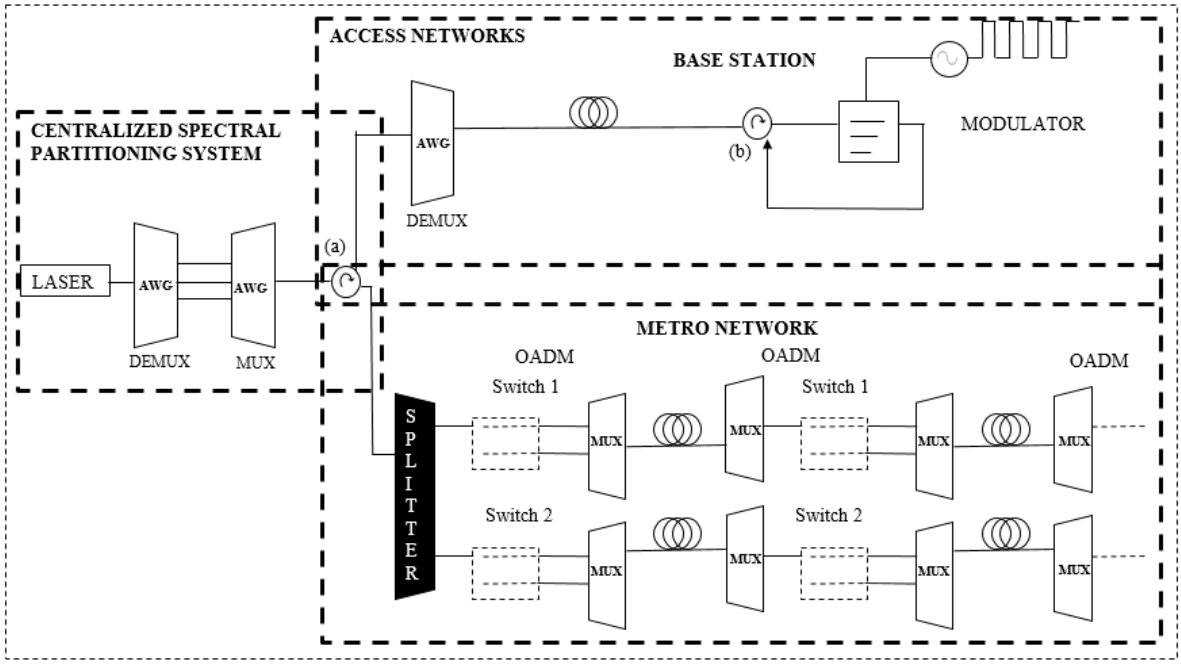
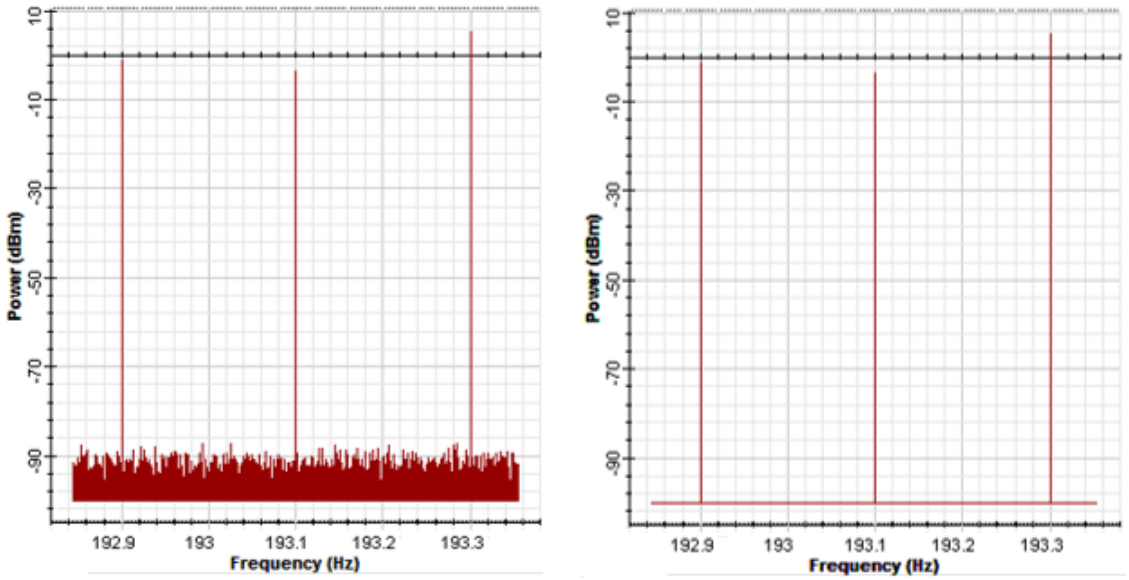



**Figure 2.** General scheme of the network.

## 4. Design evaluation

In order to evaluate the design behavior of the WDM-SCM transmission system, a set of tests was carried out by means of the OptiSystem software, which allowed defining the main characteristics of the optical and electrical components of fiber optic systems. It should be noted that the designed scheme is subject to the limitations of the software.

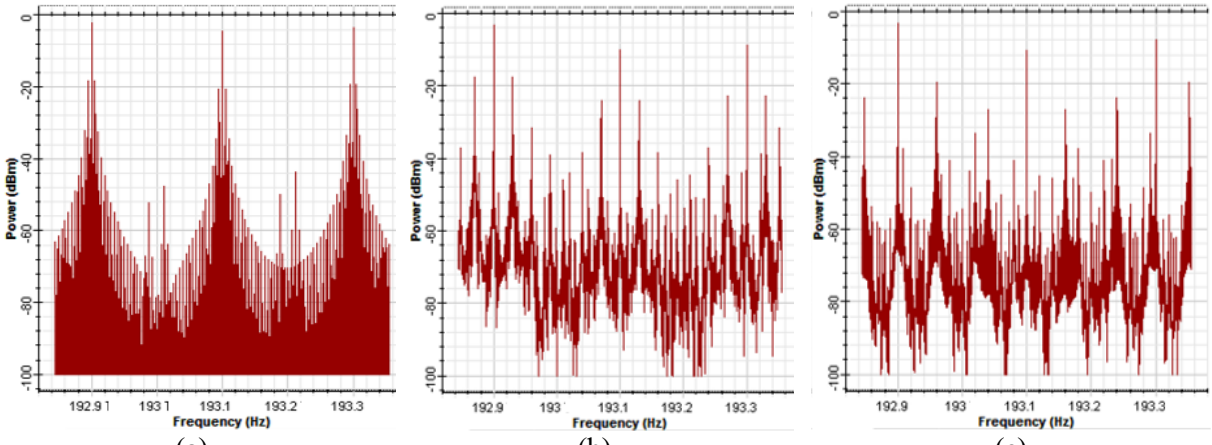
Evaluation of the spectral partitioning of the system. Through a spectrum analyzer it was possible to observe the behavior of the spectral partitioning when passing through the AWG that is configured as a demultiplexer. Figure 3(a) illustrates the carriers to the outputs of both the AWG DEMUX and Figure 3(b) the AWG MUX.




(a) (b)

**Figure 3.** Output of carriers in (a) DEMUX, and (b) MUX.

Evaluation of the access network. After having validated the spectral partitioning system, it was determined whether the access network allowed the display of modulated carriers, taking into account the frequencies of 5 GHz (Figure 4(a)), 30 GHz (Figure 4(b)) and 60 GHz (Figure 4(c)), and the fiber optic module, with a constant length of 30 km. Figure 4 illustrates the modulated carriers after passing through the two circulators of the access network.




(a) (b) (c)

**Figure 4.** Modulated carriers at (a) 5 GHz , (b) 30 GHz, (c) 60 GHz and with a fibre length of 30 km.

Evaluation of the Metro network. The flow of information after passing through the access network, enters the Metro network through a power splitter, which is responsible for splitting the signal. Figure 5 shows the modulated carriers at the output of the two splitter, port 1 (Figure 5(a)) and port 2 (Figure (b)).

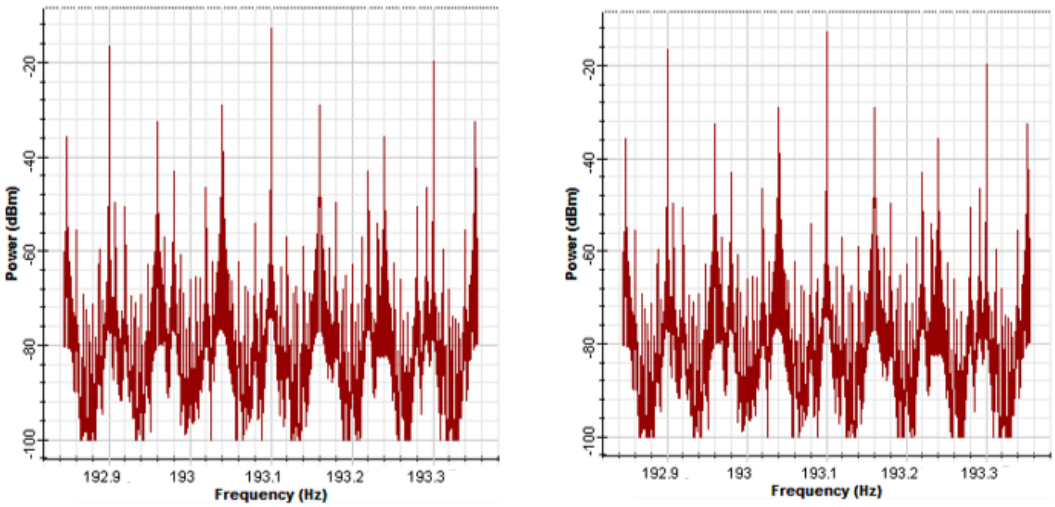



**Figure 5.** Modulated carriers at the output of the two splitter ports (a) port 1 and (b) port 2.

## 5. Results

Figure 6 shows the behavior of the Q factor at the output of the second circulator, varying the frequencies 5 GHz, 30 GHz and 60 GHz, as well as the fiber length at 5 km, 10 km, 15 km, 20 km, 25 km and 30 km in the access network. It is evident that the best performance of the Q factor, to send a data rate of 1 GHz, is offered by the frequency of 30 GHz, over all distances, however the frequencies 5 GHz and 60 GHz offer a very acceptable performance.

Figure 7 illustrates the Q factor of the Metro network by varying the distances of 5 km, 10 km, 15 km, 20 km, 25 km, 30 km, 35 km, 40 km, 45 and 50 km in each section of the fiber and the frequencies of 5 GHz, 30 GHz and 60 GHz. It should be noted that the behavior of the frequency of 30 GHz is the best Q factor, for sending a data rate of 1 GHz, also appreciates that the Q factor is directly proportional to the distance of the optical fiber, it should be noted that the results of both the Metro network and Access network were not used amplifiers after the optical fiber.

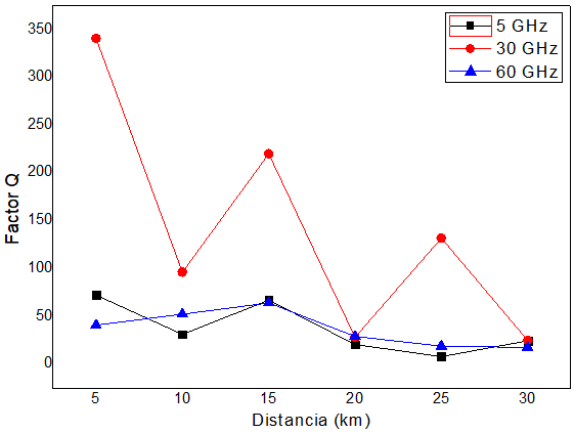



**Figure 6.** Frequency behaviour (5 GHz, 30 GHz, 60 GHz) and distance variation (5 km, 10 km, 15 km ,20 km, 25, km, 30 km) in the access network.

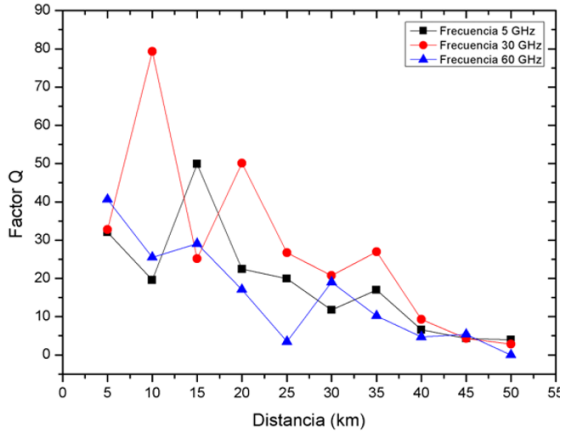



**Figure 7.** Frequency behaviour (5 GHz, 30 GHz, 60 GHz) and distance variation (5 km, 10 km, 15 km, 20 km, 25 km, 30 km) in the metro network.

## 6. Conclusions

The design proposed in this research allowed providing an additional level of multiplexing on each of the optical channels, generating a hybrid WDM-SCM multiplexing scheme. In this proposal it was possible to evaluate an independent information channel for each of the subcarriers that compose each of the WDM optical channels. The contribution of the use of the WDM-SCM combination, under the paradigm of spectral partitioning, lies in enabling the sending of each carrier to a certain optical node in the Metro network according to its wavelength so that, later in the Access network, the radio frequency subcarrier can be detected and processed at each base station. During the design process the carrier suppression effect was found, an effect that is generated due to the propagation of RF frequencies along the fiber and subsequent detection through the photodiode. For this reason, it was necessary to propose a solution to mitigate this problem, of the two possible solutions found, namely: single sideband transmission or optical filtering in detection, the second option was chosen, due to its independence from the value of transported RF subcarrier. With this solution, the central carrier is eliminated through an inverted filter and the carrier suppression effect is eliminated. Signal quality levels were measured in terms of the Q factor, taking into account the ITU 5G (5 GHz, 30 GHz and 60 GHz) frequency framework. It should be noted that the best performance of the Q factor compared to distances was that of the 30 GHz frequency. It should also be noted that for the Access network together with the proposed Metro network it was not necessary to use amplifiers.

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