Comparison of typical access networks with AMOOFDM based access networks

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Abstract. Access networks are under constant development looking for customer's satisfaction by enhancing the internet service speed and the cost of the service. Moreover, trying to serve as many residential units as possible by extending the distance reach of the access network to cover a part of a big city or to reach a rural area in a range up to 60 km. Nowadays' networks still experience limitations in services, coverage area, and still pricey for average customers. However, a significant percentage of these networks still using the terrestrial radio wave telecommunications to distribute the service inside or between city blocks, while others use the fiber to the home (FTTH). In this article, we are comparing the performance of the currently operated access networks to the adaptively modulated optical orthogonal frequency multiplexing (AMOOFDM) based access networks, according to the bit-rate, and the distance reach of these networks; highlighting the advantages of the AMOOFDM system using some types of the semiconductor optical amplifier (SOA) as an intensity modulator.

Keywords: wireless communication; digital subscriber line (DSL); passive optical network (PON); adaptively modulated optical orthogonal frequency multiplexing (AMOOFDM); semiconductor optical amplifier (SOA).

1. Introduction

Internet infrastructure is vital for civilisation as same as water and electricity. International Telecommunication Union (ITU) declared that in 2018, the world reached the 50/50 milestone of internet usage. Where it is the base of e-health, education and catastrophe aid. Notably, optical networks spread with the developing internet of things (IoT). So, the number of globe's copper networks shrank by 6%, while optical fiber connections boosted by 28%, and that just in one year (2016-2017). The plan for the fiber networks is to satisfy services up to 10 million residences and enterprises by 2020 [1].

Fiber technology is easy to upgrade, it presents symmetrical bandwidth, driving to a unique performance with high speed, low cost and low energy consumption resulting in a chance to create new sorts of services and applications [2]. However, in Europe, as mentioned in [3] expanding broadband networks by 10% results in an increment of 1% in GDP per capita per year and a 1.5% extra work productivity for the subsequent 5 years. Furthermore, investments in broadband play a functional role in education quality and promote developing countries and help rural regions.

In developing countries, there are still around 4 billion people don't have access to the internet. One of the causes of the shortage of internet is inhabiting rural regions and in this case fiber networks are the best solution, with a shared infrastructure, established with other utilities such as power cables [4] and using AMOOFDM system for such cost-sensitive networks, not only because it is more cost-effective, but also, it has a long-distance reach.

Access networks not only for providing the internet but also, are used to transmit and receive all kinds of data we generate and demand from the international under-ocean optical network, that connects the continents (figure 1) [5].
This network is denominated the core network or Wide Area Network (WAN); it uses the mesh network as a physical topology. Moreover, inside continents, there are vast networks that connect the countries, where each country contains edge networks or Metropolitan Area Networks (MANs) for the cities, it utilizes the ring network as a physical topology. Inside each city, several access networks or Local Area Networks (LANs) to connect the city blocks, buildings and residential units, it uses the star network as a physical topology. Access networks can be wireless (mobile networks) or wireline (copper networks, fiber optics). However, for the core and edge networks, they are always optical networks.

1.1 Mobile networks
The mobile networks have a backbone of an optical fiber system to transmit and receive the data faster and to be connected to the global fiber ocean network. However, the distribution of the service is through microwave telecommunications that divide the entire country into hexagonal cells, and at the center of each cell a base transceiver station (BTS) (see figure 2) in touch with each customer in its territory to serve his calls, internet and data [6], BTS covers a city block if the buildings are not too high and there is not too much steel in the concrete structure of buildings. Wireless Fidelity Wi-Fi is also a wireless media for telecommunications, and it is the easiest way to distribute the service indoor. Each time the user wants to use the internet he doesn't have to connect a cable into his computer, he can use laptops, mobile phones or any other gadget to access the internet via Wi-Fi router, that ends the access networks, receiving the service from wireless access points or wireline (copper, fiber optics).

Figure 2. Base Transceiver Station BTS [6].

1.2 Copper networks
Digital subscriber line DSL (Figure 3) still used worldwide particularly in Europe and North America [7], to distribute data and video simultaneously with the voice services over the ordinary telephone lines,
without affecting the analogue transmission of the telephone services. There are many types in the digital subscriber line technology known as xDSL. The first generation is the asymmetric digital subscriber line ADSL, used as a small network. ADSL followed by an enhanced version like ADSL2 and ADSL2+, noting that ADSL2+ was a significant development in the distance reach wise. The second generation of the DSL technology is the very-high-bit-rate VDSL; it took the DSL service to another level in terms of network speed compared to the first generation. Also, it was updated to a better version (VDSL2) improving the distance reach and the bandwidth. Both generations of DSL saved too many investments because of the already existing copper telephone network, and this is the reason made it useful until the current time. Although it is very beneficial to exploit the existing copper network, it has many drawbacks. The main disadvantage is the oxidation of the copper wires. It affects the transmission signal by highly increasing the resistance of the transmission line that leads to signal loss. Not only oxidation decreases the performance of the copper network, but also the current leakage to other lines or ground, not tight wire contacts, inappropriate wire cut, moist mediums and many others [8].

![Digital subscriber line DSL architecture](image)

**Figure 3.** Digital subscriber line DSL architecture [8].

### 1.3 Optical fiber networks

The optical fibers are a glass pipes consists of a core and cladding; each has a different density. Therefore, the laser propagates inside the core carrying the information in the form of light modulated signals. At the transmitter, electrical data is converted to the optical domain to be transmitted through the fiber cable, and at the receiver, it is converted back to an electrical domain.

Fiber networks have too many advantages over any other type of networks. The main advantage is that they have a broad bandwidth allow them to send a considerable amount of data simultaneously in both upstream and downstream without affecting each other. Moreover, they are thin, and light compared to copper networks. Although copper networks physically are more robust, fiber optics networks have a too much longer life-span, too low signal loss, and they have no signal interference, this means good quality signals are received very fast, with less cost.

It is the fastest media of communication now, wherever it can send in one single fiber upstream data and downstream data each on a different wavelength (\(\lambda\)). Nowadays used optical access networks are called E-PONs (Ethernet passive optical networks) and G-PONs (Gigabit passive optical networks). The PON contain an optical line terminal (OLT), which is the service provider that provides the data over the optical fiber cable and passively distribute it to the optical network units (ONUs) or residential units using an optical splitter that split each wavelength \(\lambda\) to the relevant destination (figure 4) [9].
1.3.1 AMOOFDM system

Although the GPON technology is successful, it has some drawbacks. That's why science endures finding a solution for each disadvantage or substitute the system by another more successful technology. The adaptively modulated optical orthogonal frequency division multiplexing (AMOOFDM) proved that it's way better than others. It consists of an electrical OFDM transmitter, generating an electrical OFDM signal. This signal is converted to an optical signal using an electrical to optical converter (E/O), and then the optical OFDM signal is being sent to the ONU side via single mode fiber. The transmission procedure involves a negotiation between the transmitter and the receiver to determine the modulation format, to send as much data as possible. That's why it's designated an adaptive modulation. At the receiver side, the optical OFDM signal is converted back to electrical using a positive-intrinsic-negative (PIN) photodiode and processed by the electrical OFDM receiver. So just like most of the existing optical networks AMOOFDM system based on the intensity modulation and direct detection (IMDD) concept. The simplicity and the low cost of the IMDD systems render it profitable for cost-sensitive optical access networks since coherent optical systems are more expensive and more involved in the design. The AMOOFDM system setup illustrated in figure 5 [10].

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In this system (E/O) converter can be employed as a semiconductor optical amplifier (SOA). SOA is an optoelectronic device, that can under appropriate operating conditions amplify an incident light signal. A basic structure of an SOA is shown in figure 6 its central element called the active region that provides optical gain when the amplifier is electrically pumped. Pumping is necessary to achieve the population inversion and the stimulated emission. An integrated waveguide is used to contain the wave signal in the active region. This active region has many shapes that determine its type and operation; for example, when the active region designed as dots, it is called quantum dot SOA (QD-SOA). When the SOA have mirrors on the input and output facets, it is named reflective SOA (RSOA). Moreover, SOA can be used as in a cascaded way to improve its operation, like the two-cascaded SOA (2C-SOA) it is a two Bulk SOAs connected in series (the output of the first device used as an input to the second device).
In the available to us literature, we didn’t face any comparison of the AMOOFDM optical access networks with other varieties of access networks. Therefore, this study aims to compare the AMOOFDM access networks in terms of bit-rate, distance reach and splitting ratio with wireless, copper and other optical fiber networks.

2. Materials and methods
The publications in the field of access networks (wireless, copper, fiber optics) for the latest 10 years were gathered. All the information about the speed and distance reach were collected in tables. The data for each class of access networks were analyzed and compared, to find the best solution for the cost-sensitive networks. The proper splitting ratios were calculated for each. Then, only the bests of each sort of access networks were compared to each other. Eventually, a conclusion was derived.

3. Results and discussion
As shown in table 1, the wireless telecommunication technologies are listed starting from the 1st generation (1G) cellular network till the current 4th generation (4G) network, and the near future 5th generation (5G) network. Comparing them to the Wi-Fi (IEEE 802.11a) and Wi-Max technologies (IEEE 802.16e). The 1st generation cellular network offered 2.4 Kbps bit-rate for the area of the cell coverage, and this was used only for calls. While it increased to 150 Kbps in the 2nd generation with the addition of data exchange. In the 3rd generation, it reached the 42 Mbps which was a good improvement over the 2nd generation for that time, but it still not good enough to support the bandwidth demanding applications like live streaming of high definition videos, online gaming and the voice over IP (VOIP) different applications. This problem was solved in the 4th generation, where the bit-rate reached the 100Mbps, and it is noticed that it is similar in bit-rate to the Wi-Max, but the coverage area is way less than Wi-Max. By 2020 [11], the 5th generation (5G) will be widely applied with a bit-rate up to 1 Gbps that gives the possibility of a variety of new applications to be set on the service. When talking about wireless technology, we must mention a viral way of using internet data. It is the Wi-Fi, where it’s bit-rate up to 54 Mbps with a limited coverage area to 9 meters only. However, it’s good to know that it’s a straightforward way to use the data signals inside buildings and living units, notably the ones who don't contain too much steel. Because steel shields are the greatest enemies for wireless communication. As a result, the 5th generation is the best choice to use wireless communications, but it still not in practice in all capitals. While the Wi-Fi can't be avoided for indoor usage.

| Table 1. Wireless telecommunication technologies distance reach and bit-rates [7, 12]. |
|---------------------------------|--------|--------|--------|--------|--------|--------|--------|
| Technology                      | 1G     | 2G     | 3G     | 4G     | 5G     | Wi-Fi  | Wi-Max |
| Coverage area (km)              | Cell area | Cell area | Cell area | Cell area | Cell area | 0.009  | 64     |
| Bit-rate (Mbps)                 | 0.0024 | 0.15   | 42     | 100    | 1000   | 6-54   | 100    |

Table 2 depicts the wireline telecommunication technologies; some of them are still in use and others extinct. Starting from the coaxial cables, ending with the ITU-T G.9701 series fast access to subscriber terminals (G. Fast) technology, through all the sorts of digital subscriber line (xDSL) from ITU-T
G.992.1/2 Asymmetric digital subscriber line (ADSL), to ITU-T G.993.2 very high bit-rate digital subscriber line 2 (VDSL2). Coaxial cable networks are not in use anymore because it sends the data for less than 100 meters, although it allows 100 Mbps bit-rate. While, the ADSL transferred the data for 2 km with a rate of only 4 Mbps, but the next generation ITU-T G.992.3 (ADSL2) increased the rate to 12 Mbps. The ITU-T G.992.5 (ADSL2+) doubled the bit-rate to 25 Mbps, and the tripled the distance to 6 km, that was an exciting result distance wise, wherever it was better than the ITU-T G.993.1 (VDSL) that had only 1.5 km range, although the rate of data transmission was 52 Mbps. The ITU-T G.993.2 (VDSL2) doubled the distance to 3 km and the bit-rate to 100 Mbps, and that was a good trade-off between the distance-reach and the data-rate for that time. A big boost in the bit-rate to 1 Gbps applied by the (G. fast) but unfortunately, it is very limited in the distance to less than 0.5 km. We can select network technology according to the situation. If we need to serve more speed or more residential units, we can select G. fast. Else, if we want to serve far city blocks, we can select ADSL2+. Nevertheless, the best compromise between the speed and the distance is by selecting the VDSL2.

| Table 2. Wireline telecommunication technologies distance reach and bit-rates [7]. |
|---------------------------------------------------------------|
| Technology | ADSL | ADSL2 | ADSL2+ | VDSL | VDSL2 | G. Fast | Coaxial |
|---------------------------------------------------------------|
| Distance reach (km) | 2 | 2 | 6 | 1.5 | 3 | 0.5 | <0.1 |
| Bit-rate (Mbps) | 4 | 12 | 25 | 52 | 100 | 1000 | 100 |

In table 3 (a & b), there are two types of optical fiber access networks. The typical used passive optical networks (PONs) and the Adaptively modulated optical orthogonal frequency digital multiplexing (AMOOFDM) based PONs, employing a variety of intensity modulator (IM), optimizing the bandwidth to get the maximum possible bit-rates. In the conventional PONs (table 3a), we have the IEEE 802.3ah Ethernet-PON (E-PON) with a distance 20 km and a speed of 1.25 Gbps. With a splitting ratio of 1:64 it can serve approximately 20 Mbps per optical network unit (ONU) or residential unit while the ITU-T G.984.x Gigabit-PON (G-PON) doubles the bit-rate to 2.5 Gbps with a splitting ratio of 1:64. Hence, approximately 40 Mbps per residential unit, further for a distance between 20 and 60 km. In the AMOOFDM based PONs (table 3b) when the reflective and the quantum-dot semiconductor optical amplifier (RSOA-IM) and (QD-SOA-IM) were applied as an intensity modulator an extraordinary bit-rate up to 30 Gbps achieved to a distance reach of 60 km. While using the semiconductor optical amplifier intensity modulator (SOA-IM), the distance stretched to 80 km, which is 4 folds longer than the usual PONs. However, the best was applying the two-cascaded semiconductor optical amplifier as an intensity modulator (2C-SOA-IM), it prolonged the distance reach up to 120 km. That made it a robust full-service access network. As noticed that all the AMOOFDM based PONs have an equivalent bit-rate about 30 Gbps, and this proposes that we can control the splitting ratio according to our aim. To serve less residential units with a very high bit-rate, we can use 1:64 splitting ratio that offers roughly 470 Mbps per one residential unit, or owning a fast-enough speed but serving too many customers using a splitting ratio of 1:256, that offers approximately 120 Mbps per a residential unit. Moreover, that substitutes the expense of the network, presenting it more economical than the other currently utilized networks, comparing 256 to only 64 customers, that means 4 multiples of the profit.

| Table 3. Fiber optics telecommunication technologies (a) typical, (b) AMOOFDM based, distance reach and bit-rates [7, 10, 13, 14, 15] |
|-----------------------------------------------|
| Technology | Typical PON|
|------------------------------------------------|
|------------------------------------------------|
| Distance reach (km) | E-PON [7] | G-PON [7] |
|------------------------------------------------|
| Bit-rate (Gbps) | 1.25 | 2.5 |


| Technology | AMOOFDM |
|------------|---------|
|            | (SOA-IM) | (RSOA-IM) | (QD-SOA-IM) | (2C-SOA-IM) |
| (b) Distance reach (km) | 80 | 60 | 60 | 120 |
| Bit-rate (Gbps) | 30 | 30 | 30 | 30 |

4. Conclusion

This work is a comparison of different types of access networks in the cities judging each by its bit-rate, splitting ratio and distance reach. Both wireless and wireline access networks have been reviewed. In the wireless networks, it is evident that the 5th generation is the best solution for the mobile networks where it supports 1 Gbps in the cell region, and any other kind of access networks can’t replace it, but it still not available enough. In the wireline networks, the best in the copper networks was the VDSL2. It can serve 64 residential unit with a speed of approximately 1.5 Mbps. In the optical fiber access networks, the best was the AMOOFDM based access network using the two-cascaded SOA (2C-SOA-IM), using a single fiber it can serve 256 residential unit with a speed of 120 Mbps for each, instead of 64 residential unit with a speed of 40 Mbps for G-PON. As a summing-up, 2C-SOA-IM in AMOOFDM offers service for 4 times more residential units than the best existing access networks (G-PON), with 3 multiples more speed per each unit, with a distance reach up to 6 folds longer. It is way too much economical and beneficial.

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References

[1] Phillipa B, Ivan V, Ahone N, et al. 2018 The State of Broadband 2018: Broadband Catalyzing Sustainable Development (Switzerland, Geneva: International Telecommunication Union) chapter 2 pp 10-33
[2] Ivette O and Filippo M 2015 Socio-Economic Benefits of High Speed Broadband (Brussels: DG connect) chapter 2 pp 6-12
[3] Angelika Z, Niels-Erik B, Romauld K, et al. 2018 Broadband in the EU Member States: Despite Progress, Not All the Europe 2020 Targets Will Be Met (Luxembourg: Publication office of the EU) chapter 1 pp 1-12
[4] Gallegos D, Narimatsu J, Batorio O, et al. 2018 Innovative Business Models for Expanding Fiber-Optic Networks and Closing the Access Gap (Washington, D.C.: World bank group) chapter 1 pp 20-26
[5] William S and Ivan D 2010 Orthogonal Frequency Division Multiplexing for Optical Communications (Elsevier) chapter 3 pp 53-118
[6] Larry D and Lars D 2011 Digital Forensics for Legal Professionals, Understanding Digital Evidence from the Warrant to the Courtroom (USA: Syngress) chapter 33 pp 225-37
[7] Yiran M and Zhensheng J 2017 Evolution and Trends of Broadband Access Technologies and Fiber-Wireless Systems (Switzerland: Springer) chapter 2 pp 43-75
[8] Fredrik L 2009 Estimation of Line Properties in the Copper Access Network (Lund, Sweden: Tryckeriet i E-Huset) pp 1-17
[9] Samael H, Jose A and Jose L 2018 «Passive optical networks: Introduction» Wiley Encyclopedia of Electrical and Electronics Engineering (Catalonia, Spain: Wiley Online Library) pp 1-20
References:

[10] Jinlong W, Ali H, Roger G and Jianming T 2009 Semiconductor optical amplifier-enabled intensity modulation of adaptively modulated optical OFDM signals in SMF-based IMDD systems Lightwave Tech. 27(16) pp 3678-88

[11] Oluwakayode O, Muhammad Ali I, Junaid Q and Arjuna S 2016 Will 5G see its blind side? evolving 5G for universal internet access e-prints 1 p 1603

[12] SagarKumar P, Vatsal S and Maharshi K 2018 Comparative study of 2G, 3G and 4G Int. J. of scientific Research in comp. sci. Engineering 3(3) pp 1962-4

[13] Jinlong W, Ali H, Robert G, Emilio H, Xi Z, Saad M and Jianming T 2010 Adaptively modulated optical OFDM modems utilizing RSOAs as intensity modulators in IMDD SMF transmission systems Optics express 18(8) pp 8556-73

[14] Ali H, Mohamad H, Jinlong W, Ammar S and Jianming T 2011 Theoretical investigations of quantum-dot semiconductor optical amplifier-enabled intensity modulation of adaptively modulated optical OFDM signals in IMDD PON system Optics express 19(25) pp 25696-711

[15] Ali H, Mohamad H, Haidar T, Layaly M, Ammar S, Ali A, Ali H, Elias G and Jianming T 2014 Two cascaded SOAs used as intensity modulators for adaptively modulated optical OFDM signals in optical access networks Optics express 22(13) p 15763