Pragmatic Analysis of High Speed Communication Medium as used in South African Market, Fiber and copper based Communications for Service Providers

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***Abstract*—the telecommunication industry is in constant metamorphosis with an increase in smart phones, the upcoming of 5G (5th Generation of the Mobile Communication) and the pre-deployment of IoT technology; hence, a big projection in number of future users. The expansion in the domain introduces new challenges in the transmission layer of the protocol stack, efficiency in transmission medium, considering cost effectiveness and data transportation reliability. A high speed and efficient transmission medium for telecommunication can benefit not only internet users today, but also the cable television, engineering technology, industrial instrumentation and computer networking. There are couple of challenges and constrains which have been presented by the telecommunication medium of copper wires for example, as in the South African market, when comparing it to fiber optic transmission medium. In this research project, we analyze and compare copper-based transmission, which is the base of the traditional ADSL communication to fiber-based data transmission medium, which is the base of the FTTx (Fiber-to-the X), and which provides a certain level of service independence to the Internet Service Providers. The project is executed by performing onsite test on fiber link, measuring selected performance indicators. The research project has helped identified the technological in-lab benefits of fiber connection over long distance, and its sensitivity to attenuation.**

Keywords— High-Speed Communication, Fiber optic links, , Multimode fiber, single mode fiber, Asymmetric Digital Subscriber Line (ADSL), Fiber Optic Association, International Telecommunication Union.

I. INTRODUCTION

Copper-based communication has dominated the South African market in particular and the world market in general for a long time and constitutes the integral piece of broadband solutions [1]. The South African market on Copper based broadband transmission has been in the monopoly of Telkom until 1991 [2]; although the request for competition approval by the Regulatory committee, Telkom has savored a longer exclusivity in the market due to its resources and infrastructures in place [3]. However, the openness of the market allows other Service Providers, such as Mobile Operators and other broadband players to put in place their own infrastructures, providing communication services to the South African market. Building network infrastructures could be very costly and that pushes Service Providers to either leverage on existing infrastructure or invest in future technologies, also next generation technologies to provide communication access to the end-users. Since Technology is expanding continually, at a fast rate, the need for the Nation to get access to information at a fast rate and reasonable cost also becomes vital, which creates the need to implement or deploy communication channels that will ensure signals are received at end user in fast speed, with less distortion, reasonable attenuation and secured. Communication signals move in different channels, which can be either guided channel or wireless. The use of physical quantity to create path for signal flow characterizes the type and the performance indicators of the medium. In this research project, two popular types of communication channels are analyzed as source of high speed communication transportation medium, the copper-based transmission, which is twisted pair, used mostly in office computer communication, office telephone communication and asymmetrical digital subscriber line and fiber-based transmission, using glass guide to transfer the signal data to the receiver, which is considered as future technology with the expansion of Fiber-to-the-Home solution (FTTH) [4]. Based on the end-user's requirements, the research project also leaves a room of research for South African Service Providers on which technology to invest on to stay competitive with the market trend.

Fiber optics present several characteristics unlike copper cables. In designing and deploying communication infrastructures, Radio, Access and Core, it is capital to determine obstacles and other parameters that can impact the transmission of signal, in order to have reliable communication network. When comparing the two highlighted medium, the fiber optics and copper cables present their own advantages and disadvantages. For many researchers, copper transmission tends to be in declined and fiber communication should take its toll. Ibraheem Kateeb and Al. [1] address this topic by exploring recent improvements and technological overtures implemented in broadband communication over copper cables.

Traditionally, twisted pair cables have been the workhorse for communications of all sorts [4]. High data rates over longer distances can be achieved with coaxial cable, which means it can be used for high speed communication over long distances. However, the tremendous capacity of optical fiber has made the medium more attractive than its predecessor, coaxial cable and thus, fiber optics is taking over the market for high speed communication and long-distance application in the world. Copper cable is affordable and is going to be used in the South African market for a long time.

II. REVIEW & PROBLEMATIC

South African Uncapped internet bundles and long-distance fixed communication on the enterprise level or consumer level is mostly based on Copper cable. Mobile access is growing significantly with a slight decline in fixed line broadband services [5]. However, certain service providers have started rolling out ADSL lines to provide FTTH solution to end-users. The cost at which the fiber line service is introduced is higher than the previous ADSL service, which can be reverted to the transmission medium cost of deployment. Nevertheless, the end-users have little or no knowledge on the technology behind the demand of high-speed communication medium. Hence, a balance is required between technology, demand and end-users' capabilities. On one side, the characteristics of copper cables creates a level of limitation on the signal flowing in the channel. Considering the metal components of copper cables, with the induced resistance, the electrical conductivity characteristic of the medium affects the speed of data transfer during transmission. The signal in the copper medium can generate harmonics and degrades signal over time. Copper conductor cables are also sensitive to noise, crosstalk and electromagnetic interference unlike in fiber optic links, where interference is minimal. Couple of techniques have been implemented to improve performance in copper transmission medium, such as twisting of copper cables or wire transposition [6]. Copper medium can induce a high amount of attenuation thus, limiting the coverage footprint. On the other side, fiber-based transmission medium relies on light pulses transfer in the transmitting process of digital data. Considering the characteristics of fiber optics, less attenuation can be observed in the network over long distances. However, limitations are also highlighted in fiber optics medium, to signal composition, especially when traveling over long distances.

The vital question that can be asked is, despite the technological emphasis on the communication lines, what is the perception of the end-users? Which should be the core element of Service Providers investment in one or another infrastructure. The research shows the measured differences in terms of transmission over Copper and Fiber, using the same transmission line bandwidth. The motivation in the research is that the South African popular uncapped ADSL commercial lines range from 5 Mbps to 20 Mbps bandwidth for consumers, over legacy copper cable, and this technologically achieved using ADSL2 or higher, which was introduced quite since 2011 [7]. With customers being requested to upgrade to fiber lines of similar characteristics, 5 to 20 Mbps fiber lines to the Home, at a price which is approximately twice the ADSL line, it is vital to underline the partake in the upgrade. That insinuates that companies in South Africa started committing to Fiber optics communication to the consumers [8].

III. Physical Components

A. Copper Cable as Transmission Medium

Copper cables as mean of transmission medium is susceptible to interference, noise, and signal attenuation, mostly attributed to the electromagnetic coupling fields. The wires are shielded or unshielded depending on the design types and needs. The physical constraints of the environment influence the choice of the copper cable. However, the dual conductor dependency and the material (copper) characterize the physical components of copper-based cables used for transmission lines. Previously used to transport voice, the technology has been expanded to cater high speed data services (ADSL, VDSL, etc...).

B. Fiber Optics as Transmission Medium

Using a different technology to the traditional copper transmission, fiber optics uses light to transmit data and is characterized by one conductor only to exchange data. Based on glass, the physical aspect of fiber optic cables can also be compromised due to cable stress, for which micro scrapes can bring minor scratch expandable over time [9]. Depending on the transmitted light, a fiber optic cable can be single mode or multi-mode. Fig. 1 illustrates a single mode fiber optics with a single beam of light carrying information.

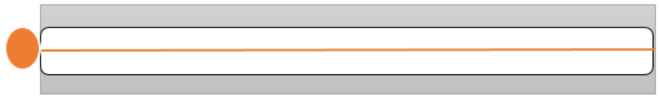

Fig. 1: Single Mode fiber Optic

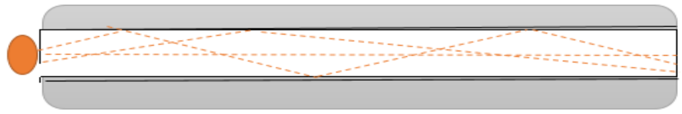

Fig. 2: step index MM

Fig. 2 and Fig. 3 illustrate multi-mode fiber optics step index and graded respectively.

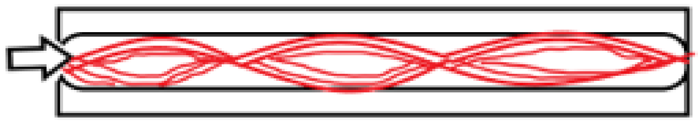

Fig. 3: Graded Index MM

The physical structure of fiber optic cable is shown in Fig. 4, consisting of core, cladding, coating, and buffer with the core being the central part of the glass and represent the transmitting region of the cable. Cladding, the first layer around the core, acts as an optical waveguide, on which light reflection is achieved. Buffer protects the fiber from breaking during installation and termination.

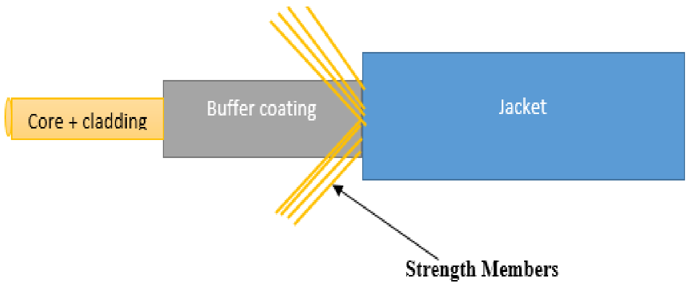

Fig. 4: Fiber structure

IV. CONTRIBUTION OF STUDY

The study evaluates on a research lab stand point, the performance index of copper based vs. fiber-based communication, which is key for service providers to understand of technological focal point and critical for end-users of consumers migration from one technology to another and at which expense. Although various methods are used to address the "cost" point of fiber in order to accelerate the demand, it is still important to project the adoption and future of each technology in the South African environment.

V. METHODOLOGY AND DESIGN

The fiber optical used in this experiment typically consists of a glass core, approximately 5 one thousand of an inch in diameter. Surrounding this core is a layer of glass or plastic.

A. Fiber Optics Medium: Link loss calculation

The following calculation demonstrate the procedure used in the lab, in getting total link loss through a fiber optic cable, where the fiber length is measured with the use of an Optical Time-Domain Reflectometer, as well as the number of splices and connectors, are known. The attenuation in dB is given by:

$$f_{LS} = \alpha f_l + n s_L + k c_L + S_m \qquad (1)$$

Where f_{LS} is the fiber link loss, α is the attenuation per km, f_l is the fiber length, n the number of splices, s_L the splice loss, k the number of used connectors, c_L the loss on the connectors and S_m the safety margin. Given the minimum Transmitting power Tx_m and the minimum receiving power Rx_m, the cable power budget β is given by:

$$\beta = Tx_m - Rx_m \qquad (2)$$

The fiber optic distance df can be then computed as follow with α the fiber loss or attenuation loss per km:

$$df = \frac{\beta - f_{LS}}{\alpha} \qquad (3)$$

The typical accepted loss for a single mode fibre optic network is illustrated in Table 1.

Table 1: SM Accepted attenuation

SM Accepted loss	
Mated connector loss	0.5 dB
Typical cable attenuation at 1310nm	0.35 dB/km
Typical cable attenuation at 1550nm	0.22 dB/km
Typical splice attenuation	0.1 dB
Safety margin	3 dB
Distance between splices	6 km

Optical Time-Domain Reflectometer (OTDR)

The performance is simulated using the OTDR, whose operation relies on sending a high power laser light pulse down the fiber cable, waiting for the reflected light's response, used to calculate the attenuation of the link, the characteristics of loss and the length of fiber span. In other words, the OTDR provides a view of the fiber link by reading the light level returned from the sent pulse [10].

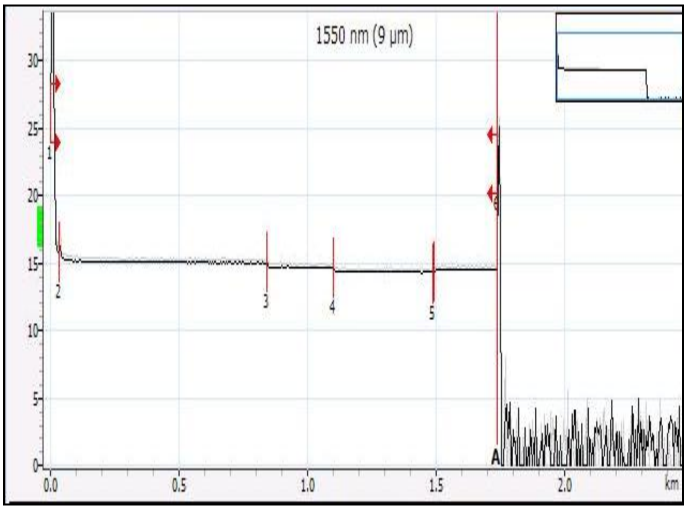

Fig. 5 Measured SM Result

The OTDR displays obvious faults and connections on a generated graph, known as trace, and provides the loss values in dB as a function of distance. Fig. 5 shows the measured results read on the OTDR using fibre optic transmission cables, displaying graphically events taking place in the transmission medium. We analyse the graph obtained, measuring from the wall box to a street cabinet.

1) Graph Interpretation

Six events are highlighted in the transmission link as shown on table 2.

- Point 1 shows a pick of high reflectance equal to -24.6 dB, which is very high meaning the connector in the initial stage could be dirty or dusty. Dirt and dust in the fibre optic cable can cause signal attenuation, resulting in poor performance of fibre optic link.
- Four points are the splice in the link, this include point 2, 3, 4 and 5. Point 6 indicate a connector with pick, high reflectance and fibre optic end

Table 2 OTDR results of SM

1550 nm (9 µm)					
No.	Pos./Length (km)	Loss (dB)	Reflectance (dB)	Att. (dB/km)	Cumul. (dB)
1	0.0000	---	-24.6		0.000
	(0.0322)	0.016		0.500	0.016
2	0.0322	0.744	-71.1		0.760
	(0.8089)	0.180		0.223	0.940
3	0.8411	0.268			1.209
	(0.2605)	0.033		0.126	1.242
4	1.1016	0.307			1.548
	(0.3865)	0.078		0.202	1.626
5	1.4881	-0.260			1.366
	(0.2519)	0.053		0.209	1.419
6	1.7399	---	-42.0		1.419

- The points marked with red in the graph shows were attenuation in fiber optic link take place. Point 2,3,4,5 is the indication of splice loss in the network. Point 1, indicate the reflection in the coupling of the start point of fiber optic.
- Between point 1 and point 2 there is red highlight attenuation of 0.5dB, which is high according to S.M accepted attenuation per kilometre which should be around 0.35dB.
- There is another maximum loss encountered in the link at point 4, splice loss is very high compared to the typical accepted loss in splice of SM which should be 0.1dB.
- Point 6 indicates a total distance of the fibre optic cable which is measured to be 1.739 km.

The distance scale is displayed on the vertical axis of the OTDR graph, in kilometres. The optical link cables can run for a long distance, with little loss associated in the network. In the OTDR one can set up the distance scale, when performing link test. The setting of distance scale on the OTDR is used in order to analyse the end of run for the link. Table 3 and table 4 provides the distance measurement and the total distance respectively.

Table 3 onsite Distance Measurement

color Code	Port core	Address	Distance to AG (Km)
Blue1	1-2	1065 Hotel	1.095
Orange	3-4	1063 Hotel	1.127
Green	5-6	1061 Hotel	1.154
Brown	7-8	1059 Hotel	1.159
Grey	9-10	1057 Hotel	1.209
White	11-12	1055 Hotel	1.216
Red	13-14	1053 Hotel	1.263
Black	15-16	1051 Hotel	1.265
Yellow	17-18	1049 Hotel	1.283
Violet	19-20	1047 Hotel	0.316
Rose	21-22	1045 Hotel	0.317
Aqua	23-24	1043 Hotel	0.332

Table 4 Total distance measured on site

Distance to AG (Km)	Distance AG to POP (Km)	Total Distance (Km)
1.095	2.953	2.92
1.127	2.953	2.952
1.154	2.953	2.979
1.159	2.953	2.984
1.209	2.953	3.034
1.216	2.953	3.041
1.263	2.953	3.088
1.265	2.953	3.10
1.283	2.953	3.108
1.316	2.953	3.141
1.317	2.953	3.142

The computational parameters are given as follow:

f_L=2.92 Km, n=5, k=4

α=0.35 dB, at 1310 dB/Km,

s_L= 0.1 dB, S_m= 3dB, c_L= 0.5 dB

Using the equation (1), the fiber link loss is f_{LS}= 6.522 dB. With the link budget β calculated as in equation (2).

Table 5 Transmission Medium Comparison

Transmission Medium	Frequency Range	Distance
Twisted copper pair	0 – 3.5 KHz	2 km
Optical fiber	180 – 370 THz	40 km

B. Copper based transmission medium

There are couple of equations to be used prior to operating twisted pair cables, as a function of cable dimensions. This includes basic material parameters and frequency of operation.

The variations in twisted pair have made it, possible for engineers to design standard-compliant category 3 UTP cables, specified for frequency up to 16 MHz [2, 3]. The twisted copper cable has primary parameters, which has significant effect on communication channel frequency, this includes R, L, G and C. The parameters of a copper wire consist of an impedance Z, which is a function of series resistance R, inductance L, shunt capacitor C and shunt conductance G. The cable property impedance is given by:

$$Z_{\circ} = \sqrt{(R + jwL)/(G + JWC)}$$

$$= R_{\circ} + jX_{\circ} \qquad (3)$$

The resistance of the twisted conductor is given by:

$$R = \frac{2\ Rs}{\pi\ d}\left[\frac{D/d}{\left(\frac{D}{d^2}\right)-1}\right] \quad (\Omega/\text{m}) \qquad (4)$$

The Inductance and shunt conductor equations are expressed by equations (5) and (6) respectively.

$$L = \frac{\mu d}{\pi}\cosh^{-1}\left(\frac{D}{d}\right) \ (\text{H/m}) \qquad (5)$$

$$G = \frac{\pi * \sigma d}{\cosh^{-1}\left(\frac{D}{d}\right)} \ (\text{S/m}) \qquad (6)$$

The shunt capacity given by:

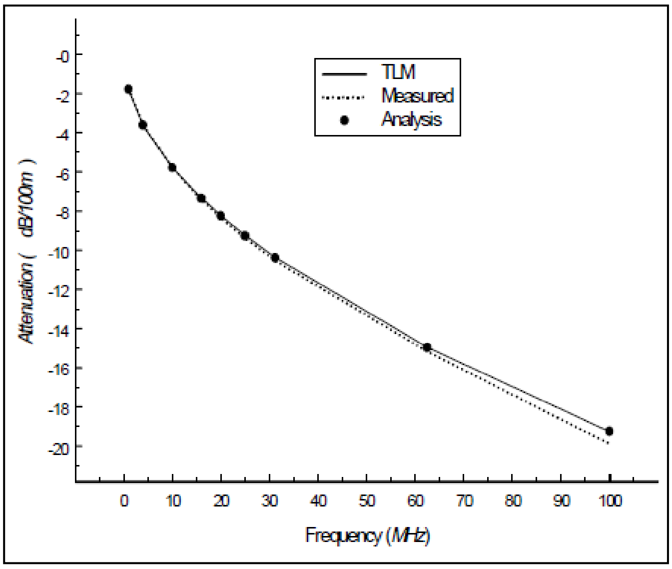

Fig. 6 Copper Frequency vs. Attenuation

$$C = \frac{\pi * \epsilon}{\cosh^{-1}\left(\frac{D}{d}\right)} \ (\text{F/m})$$

The result shows twisted pair copper wire, limited to 100 meter of distance application.

Fig. 6 shows the attenuation loss versus frequency on the copper twisted pair wire used in the communcation link. The attenuation in dB\100m will increase as the frequency increases in the system. For a 10MHz frequency the attenuation is -6dB per 100m.

When the frequency reaches 100MHz or higher, there is very high attenuation equal to -20 dB per 100m.

The major cause affecting the transmission on copper cable is the property of resistance, inductance, and capacitance.

The design circuit Diagram shown in Fig. 7, and the implementation on fig. 8 demonstrates a voice fiber optic transmitter, this circuit make use of a plastic optic for transmission medium.

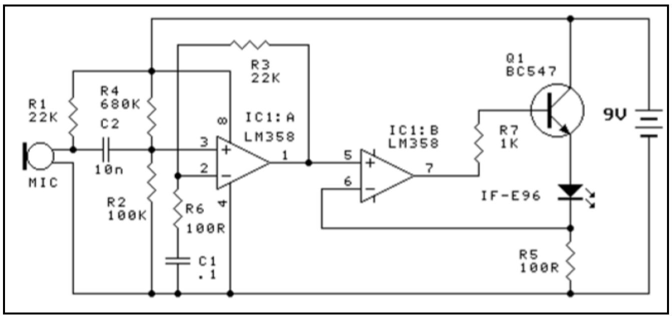

Fig. 7 Fiber audio sound transmitter

The circuit considers two oparational amplifiers used for sound conversion into light wave.

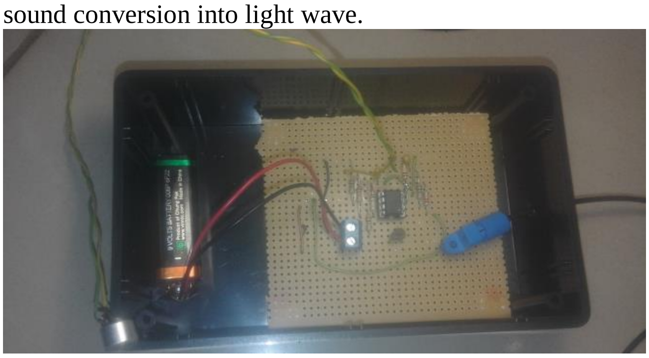

Fig. 8 Physical Design of Transmitter

Op-amp 1, a negative feedback is employed with feedback resistor of 22k, and input resistor of 100 ohms. A portion of the output is feedback to the inverting terminal to establish fixed gain for amplifier A. considering the inverting amplifier gain

The following are the Functional features of IC LM358

Supply range of 3V to 36V, supply current of 300μA, unity gain bandwidth of 1.2MHz, low input offset voltage of 3mv at $25°C$, internal RF and EMI filter. The gain A is given by:

$$A = -\frac{R\ fb}{R\ in} \qquad (8)$$

Where feedback resistor equal to R f = 22k Ώ
Input resistor R in = 100 Ώ, A = -220 as per equation (8).

Since the output drives a basic voltage divider, the maximum voltage available at inverting terminal is full output voltage. The current through the input resistor is $I = {}^{Vi}/_{Ri}$ = 67.7 mA

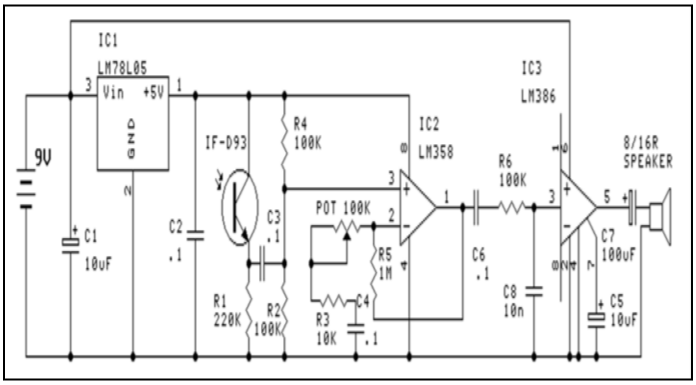

Fig. 9 Fiber optic Receiver design

Fig. 9 and Fig. 10 show the circuit design and physical design of the receiver end of the transmission. Audio signal is successfully sent through the fiber medium, with a better signal reconstitution than a copper-based transmission.

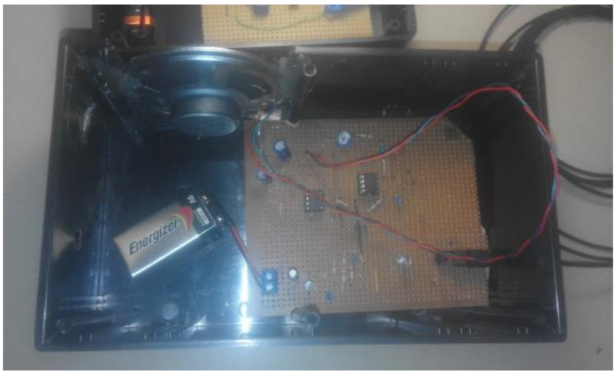

Fig. 10 Physical Design of Receiver

VI. ENVIRONMENTAL & SOCIAL STUDY

After the experiment, copper transmission tends to be relatively susceptible to noise and attenuation, the further the communication signal travels, the weaker it gets. This obstacle is therefore, remediated on fiber communication due to the absence of electrical induced current in the transmission line.

As network transmission speeds increase, the sensitivity to crosstalk increases. The use of fiber optic transmission medium tends to be beneficial to the environment for its immunity to electromagnetic interference. The dielectric property of fiber optic provides complete electrical isolation, as well as the interference-free signaling. The positive impact of copper infrastructure consists of the fact that, it does not course damage to environment.

The positive impact for the use of copper-based infrastructure is that no much environment damage is being considered because mostly they are used for TV distribution networks, which is a building type of infrastructure, including short run computer systems links. The telecommunication of fiber-optic medium uses no electricity and therefore there is no danger of an electrical fire as with copper wires. In a data center environment where thousands of ports are being used, a fiber-based architecture could save hundreds or thousands of KWH per year compared to the equivalent copper-based network just in port power consumption.

VII. PERTAKE IN THE SOUTH AFRICAN MARKET

For most communication networks, the wider bandwidth advantage of fiber links provides a competitive edge in back haul transmission infrastructures. From a service provider perspective, the investment in to fiber optics communication is a long run safety measure for a durable communication backbone, preparing for future technologies such as IoT and 5G which will require high speed medium for data transfer, specifically for real time transmission. From the end-user perspective, as highlighted by Ibrahim Kateeb & al. [1], adoption economics have a major role in the decision from consumers. Enterprises are likely to adopt the Fiber-based transmission medium for business productivity. However, the embrace on the consumer level will be slow until the economical implication is addressed and the line between copper-based and fiber-based technologies is clearly visible to non-technical consumers. However, as an exciting technology in an emerging South African market, the excitement of users grows year by year on adopting fiber links as shown in Fig. 11 [11]. Contrary to a doubtful early adoption and pull back of FTTH deployment in USA Verizon, to maintain existing copper cable services back in 2010 [12], the South African market response is *slowly* positive, especially in large metropolitan areas such as Pretoria, Johannesburg, Port-Elizabeth, Cape Town, and Durban [13] in which the geographical coverage of fiber penetration can be overlooked over the entire national space. Similar research to the analysis of fiber-based and copper-based transmission can be attributed to Jens Myrup and M. Tahir Riaz, who analyzed the introduction of FTTH to rural areas in Denmark and its actual impact on the end-users [14].

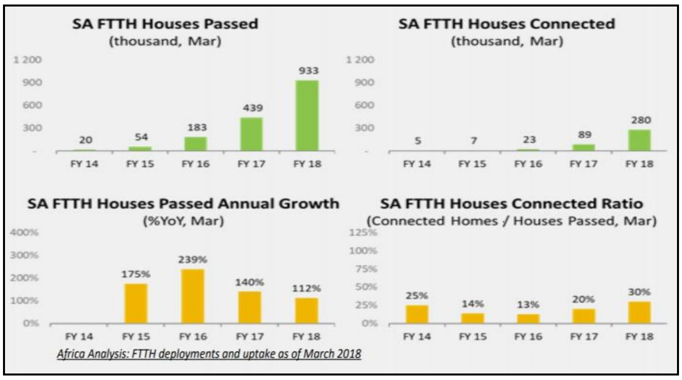

Fig. 11 FTTH adoption in South African (March 2018) [11]

CONCLUSION

There is much growth in the telecommunication industry for fiber optic and twisted pair copper wires, as both has shown that they can co-exist. Each cabling system has advantages and disadvantages and can be used for different use case applications. Which transmission technology is better depends on several factors, such as the communication type, the application or service to be delivered, the communication distance, the types of terrain to encounter and many more considerations. However, in the wake of IoT and 5G preparation, it is of capital importance to have solid, efficient and high-speed telecommunication medium. Thus, the justification of South African market strong investment towards fiber optics back haul networks. The end-user targets remain a big investment for service providers, not only on sales success but also on technological education.

The research project has helped identified the technological in-lab benefits of fiber connection over long distance, and its sensitivity to attenuation.

VIII. Future Applications

With higher emphasis in fiber investment, the fiber optics technical application grows rapidly comparing to the traditional copper transmission applications. In the area of health monitoring, transmission power lines and communication towers built upon sensing optical shows greater performance with long testing phase [15]. New applications of fiber-optics are also a drive force of researches [16], [17], [18].

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