Fibre-to-the-Hut Technology: A solution for Cheap Access for High Speed-Optical Network in South Africa

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Abstract. Fibre-to-the-Home (FTTH) is a technology where optical fibre networks are deployed from a central access point to individual homes to provide high-speed broadband access. FTTH has extensively been deployed in many countries with high population density within large cities and urban centres and high per capital income in Asian and Europe. However, African countries are still facing some challenges like uneven population distribution with isolated remote villages and socio-economic challenges. This hinders direct implementation of traditional FTTH solutions in Africa. It is for these reasons that we specially customize the traditional FTTH, based on challenges facing Africa and design a Fibre-to-the-Hut (FTTHut) optical network to suit the African scenario. The use of vertical cavity surface emitting Laser (VCSEL) within a Raman amplified optical fibre framework to support FTTHut technology in South Africa is studied. VCSELs offer high bandwidth at low drive currents, while fibre Raman amplifiers offer longer amplification spans. We therefore investigate experimentally the noise figure (NF) and optical signal to noise ratio (OSNR) performance of fibre Raman amplifier (FRA) using a directly modulated 1550 nm VCSEL as the signal source. Two pumping techniques namely co- and counter pumping were employed. An OSNR of 6.8 dB and 6.4 dB was achieved for co- and counter pumping schemes, respectively, for 25 km SMF-Reach. An OSNR of 4.5 dB and 4.3 dB was attained for 50 km fibre for co- and counter pumping respectively. A NF of -1.3dB and -0.7dB was achieved for co- and counter pumping schemes, respectively, for 25 km fibre at 23 dB pump power. The NF also increased with increase in fibre. This work is valuable in providing South Africa with increased Hut-to-Hut broadband access especially in long-reach networks serving rural populations at reasonable low cost.

1. Introduction

The demand for internet services by residential homes in South Africa has risen rapidly [1]. End users are demanding for a fast, reliable and affordable communication network that can support broadcast television, radio, voice telephony, video-based multimedia, peer-to-peer file transfer, high definition multimedia on-line gaming among many other services. Previously, a limited number of carriers monopolised access to the only major cable serving the country, driving the access cost high. However, the landing of four international submarine fibre-optic cables in South Africa between 2009 and 2012 brought down the cost of international bandwidth dramatically. As a result, fibre to the home (FTTH) optical networks is becoming a reality in South Africa due to its network transparency and bandwidth advantage [2].

As a matter of fact, a number of companies in South Africa have committed to initiate the roll out of FTTH in some major cities namely Johannesburg, Cape Town, Port Elizabeth, Pretoria, Durban and Bloemfontein. These cities have been singled out because they make up the most developed and highly populated urban areas in South Africa; hence the FTTH models applied in developed countries overseas can be followed and implemented to benefit people living in these cities. However, the larger part of the South African population lives in rural areas, where the social and geographical dynamics differ significantly as these areas are associated with uneven population distribution with isolated remote villages [3]. The rural population has also been marginalized from access to facilities, as well as isolated from some basic services. This hinders the implementation of traditional FTTH solutions in rural South Africa thus a customized, high cost sensitive solution is urgently required.

It is for these reasons that we specially customize the FTTH based on these challenges and design a Fibre to the Hut (FTTHut) optical network to suit the larger part of the South African population who live in the rural areas [4]. FTTHut is expected to act as an alternative to electrical signal based technologies such as digital subscriber line techniques (DSL, ADSL and VDSL) and cable modem which are increasing in speed but at the cost of reduced network reach.

The FTTHut approach factors in all the constraints involved. In our approach, we introduce VCSEL technology and Raman amplification in the Access network to lower the transmission cost as well as increase network reach. VCSEL laser sources were preferred because they offer a cheap solution to access networks since they are relatively of low cost. Additionally, these devices consume very low power as they only operate in the mA region.

2. Theory

VCSELs are semiconductor sources with a monolithic laser resonator. The emitted light leaves the device in a direction perpendicular to the surface. The cavity is made up of two semi-conductors Bragg mirrors between which there is an active region with numerous quantum wells and a total thickness of only a few micrometres [5]. A lot of study on VCSELs application in fibre-optic networks and as optical interconnects has so far been carried out [6, 7, 8]. VCSELs have drawn much attention because of their; compatibility, low cost wafer scale fabrication and testing techniques, high-volume, lower-cost manufacturing and compatibility with most active optical devices. These devices also possess some other special features that make them attractive for fibre-optic systems. These include a circularly shaped output beam for high coupling efficiency, high modulation bandwidths at low current levels, single mode operation, low power consumption and the potential to produce integrated modules and arrays on wafer [8].

However, Frequency chirp and chromatic dispersion is the main limiting factor for VCSELs. Frequency chirping is the instantaneous change of the central optical frequency υ in response to variations in optical power. The instantaneous frequency chirp is expressed as [9, 10].

$$\Delta\nu(t) = -\frac{\alpha}{4\pi}\left(\frac{d}{dt} InP(t) + kP(t)\right) \tag{1}$$

where P(t) is the instantaneous optical power, and α is the laser linewidth enhancement factor and the k parameter are constants. The k parameter is related to the non-linear gain and depends on the geometry of the device.

3. Research Design

A complete experimental scheme is illustrated in Fig.1. A 10Gbps 1550 nm VCSEL is directly modulated with a non-return to zero pseudo-random binary sequence (PRBS) of pattern length of 2^7-1. The reach needs to be extended due to geographical fluctuations, and uneven population distributions within remote villages, at the same time maintain the signal integrity. This calls for proper signal amplification thus Raman amplification was adopted due to its low noise and remarkable signal recovery. The signal source was then coupled with a Raman pump operating at a wavelength of 1450 nm with a maximum output power of 25 dBm, then transmitted over an ITU-T G. 655 fibre at varied lengths and the recovered signal analyzed using an optical oscilloscope and a power meter. Two pumping techniques namely co-pumping and counter pumping were adopted.

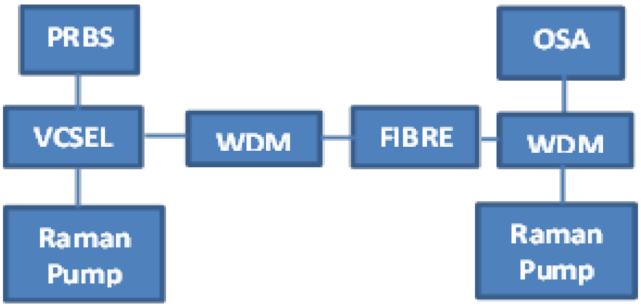

Figure 1: Raman amplified optical transmission

Their performances were then investigated based on the OSNR and NF so as to determine the best pumping technique for extended reach application. An ITU-T G.655 optical fibre manufactured by the Optical Fiber Solutions (OFS) Company was used. G.655 fibre is well suited for long transmissions because of its low attenuation, low dispersion and flexibility for dispersion management purposes.

4. Results

The OSNR behaviour for co and counter pumping techniques at different pump powers is shown in fig 2**.**

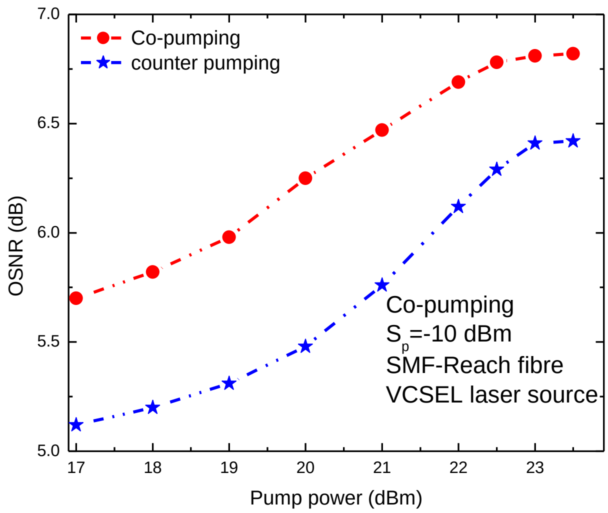

Figure 2: OSNR variation with pump power for co-pumping and counter pumping schemes of a 25 km ITU-T G.655 fibre.

The OSNR increases with increase in pump power in both pumping techniques. However, at 23 dBm pump power, the OSNR flattens due to gain saturation. Co-pumping shows superior OSNR performance of 0.45 dB than counter pumping at 23dBm pump power.

From Fig 2, Co-pumping shows a better OSNR performance than counter pumping. This is because for co-pumping, the signal is co-propagated with the pump. This ensures that much of the pump power is transferred to the signal to achieve higher amplification levels.

Fig 3 shows the OSNR performance of a 25 km and 50 km ITU-T G.655 fibre lengths at co-pumping scheme.

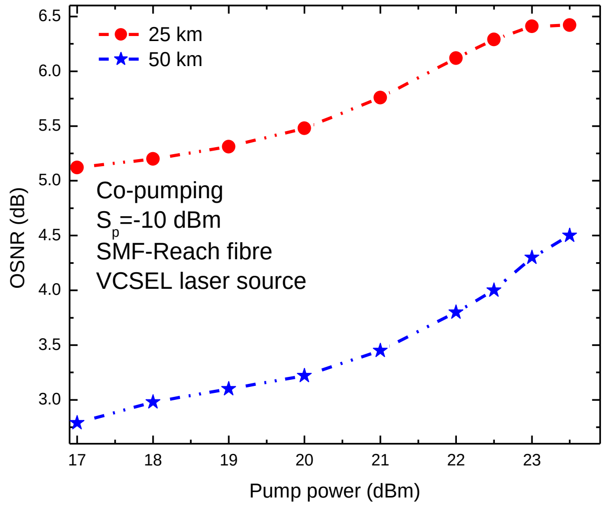

Figure 3: OSNR as a function of pump power at different fibre lengths for co-pumping scheme.

An OSNR of 6.41 dB and 4.50 dB is recorded for a 25 km and 50 km fibre ITU-T G.655 fibre respectively, at 23 dBm pump power. The OSNR degradation with increase in fibre length is attributed to ASE noise accumulation within the transmission fibre.

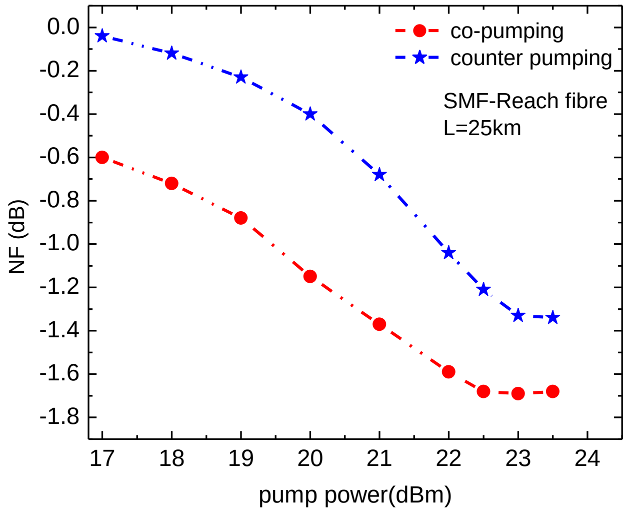

Figure 4:NF variations with pump power for co-pumping and counter pumping schemes.

Fig.4 shows the noise figure (NF) performance of the two pump techniques. Co-pumping shows a better NF performance than counter pumping. This is due to the fact that for co-pumping scenario, both the pump power and the signal power propagate in the same direction. This in turn results to more pump to signal power transfer hence higher amplification levels are attained. Secondly, the ratio between the pump power and the signal power is maintained almost at the same level throughout the transmission span. For the case of counter pumping, the signal propagates counter to the pump direction. This limits the pump to signal power transfer thus leaving much of the pump power unutilized.

5. Conclusion

We have presented results on the OSNR and NF performance analysis of a Raman amplified optical network using a directly modulated 4.25Gbps 1550 nm VCSEL. Signal degradation in optical fibres during Raman amplification depends on the fibre length, pump power and the pumping scheme used.

The OSNR decreases with an increase in fibre length. This decrease is more pronounced in counter pumping than in co-pumping scheme.

From our results, the ASE noise accumulation was minimal in the co- pumping thus accounting for the higher OSNR recorded in this pumping scheme. This makes co-pumping superior in noise performance compared with the counter pumping. We therefore recommend co-pumping technique for the FTTHut extended reach applications. This work is valuable in providing FTTHut project in South Africa with a VCSEL technology and suitable signal recovery technique through forward Raman amplification for increased broadband access in the extended reach networks to serve the rural population at a very reasonable cost.

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