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Regular Articles

A VCSEL-based backbone extended-reach optical fibre network: Supporting up to 10 Gbps flexible access networks for Africa

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ABSTRACT

In this paper, using vertical cavity surface-emitting lasers (VCSELs) and Raman amplification, a low power consuming, energy-efficient and cheap technique to transmit high speed data signals over optical fibre is experimentally demonstrated. Several channels are joined through dense wavelength division multiplexing (DWDM) technique and transmitted over a single fibre link. With a 24.7 dBm forward Raman pump, a 8 dB flat gain is distributed over a spectral width of 5.2 nm (650 GHz). Moreover, different wavelength paths are realized by tuning the emission of the VCSEL from 1546.8 nm to 1552 nm while adjusting its bias currents. In realizing extended-reach, two DWDM/flexible channels spaced at 50 GHz and with each transmitting at 10 Gbps have been transmitted for 76.8 km while incurring a 3.2 dB power penalty as measured at a bit-error-rate (BER) threshold of 10^{-9}. In a typical network, the wavelength adjustment of the VCSEL avoids incidences of denial of service whenever there is either fibre-cuts, increased network traffic or channel collisions. Finally, by combining Raman amplification and chromatic dispersion mitigation using negative dispersion shifted fibres, this work presents robust VCSEL-based technique that is tailored to provide 10 Gbps per channel for backbone optical fibre supporting long-haul access networks in Africa.

1. Introduction

Optical transport network and hardware capabilities have been stretched by the tremendous demand for bandwidth by end-user devices such as bring-your-own-devices (BYODs) and fixed terminal-electronics such as CCTVs, HDTVs, telepresence (TP) units and cell-towers. Several technologies that increase capacity and reach for most backbone optical fibre transport networks have been reported and implemented. These technologies include wavelength/time/polarization division multiplexing (xDM), amplification, advanced modulation formats and coherent detection [1]. Apart from improved capacity and reach, most technological advances have and will focus on cost and energy efficiency so as to minimize the CapEx and OpEx [2]. In terms of infrastructural, geographical, economic and social challenges, optical fibre deployment in Africa becomes a disadvantage as compared to most developed countries across Europe, Asia and America. From the sparse distribution of population to the energy-power shortages in Africa, cost and energy efficient technologies that support the realization of high speed internet and 5G access are needed.

Fibre-to-the-home connections have been rolled out in some African cities such as Harare (Zimbabwe), Cape Town and Johannesburg (South Africa), Kigali (Rwanda), Nairobi and Mombasa (Kenya), Lagos (Nigeria) and other major cities around the continent. In terms of cost, internet access costs 30–40 time more than in most developed countries [3]. An example illustrating the typical geographical and distribution of buildings in the city of Barcelona and the sparse distribution of house/huts in an African village is shown in Fig. 1. In the densely populated and well-planned cities, multiple users can easily be connected using fibre-to-the-home (FTTH). For the African homesteads that spread over 50 km away from the metropolitan region, an integration of both fibre and free-space networks prove to be an ideal topology. With the availability of network access, platforms have revolutionized and enabled e-health, e-governance, e-agriculture, e-education and e-commerce [4,5]. A major example is the Mpesa service and mobile banking in Kenya which despite the huge terrestrial and demographic disadvantages, many people are able to access socio and economic empowerment [6].

Vertical cavity surface-emitting lasers (VCSELs) have proven to be attractive signal carriers due to their low power consumption, low current threshold (in mA range), single longitudinal-mode operation

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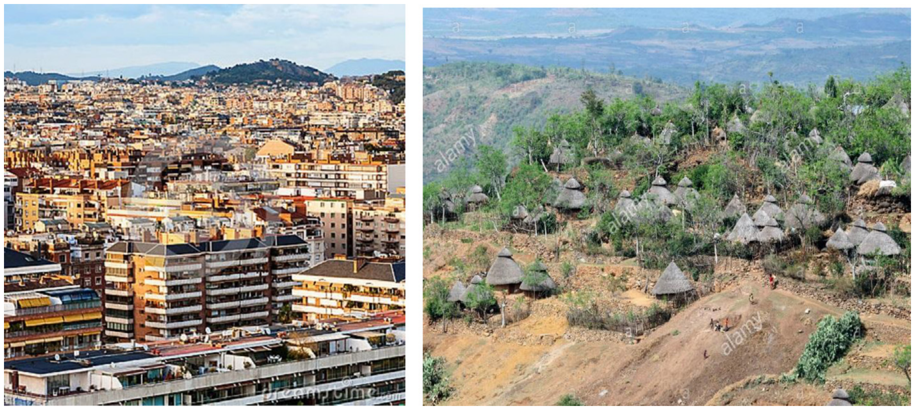

Fig. 1. An illustration of a well-planned modern city in Barcelona and a remote African village.

and low cost [7]. VCSELs for up to 10 Gbps per channel for 850 nm, 1310 nm and 1550 nm transmissions are available. Additionally, VCSELs with the capability of transmitting 40 Gbps and 71 Gbps have also been reported [8,9]. An interesting characteristic of the VCSEL is the ability to tune its emission wavelengths by adjusting the bias currents. The advantage of VCSEL wavelength tuneability makes it ideal for DWDM and wavelength conversion [10].

A backbone fibre deployment to serve long distance multi-users is shown in Fig. 2. In a typical fibre transmission, data or analogue signals are modulated into signal carriers (lasers) and transmitted to either point to point (P2P) or point to multi-point (P2MP) users. In distributing the optical signal, a wavelength selective switch (WSS), hub or an optical splitter can be used to supply the signal to the last mile users.

Signal continuity and having a reliable end to end communication is a real challenge to most transport networks. Flexible spectrum techniques eliminate the rigidity of most fixed network parameters by allowing dynamic adjustments during fibre-cuts, traffic overload, spectrum demands, routing and channel assignment [11]. Subsequently, the fixed channel spacing associated with WDM systems can be replaced by flexible channel spacing which allows sub-and super-channels to be assigned to transmissions [12]. Thus, in a typical network, a self-healing, demand-aware and end-to-end multi bitrate fibre transmissions can be implemented.

In this study, the advantages of wavelength tuneability of a VCSEL and Raman amplification have been implemented to transmit 10 Gbps per DWDM/flexible channel over the standard G.655 fibre-links for 76.8 km. Cascaded G.655 fibres with both positive and negative dispersion coefficients are used to increase transmission distance and reduce the cumulative dispersion effects that lower the quality of the transmitted signal. In this paper, single and multiple DWDM channels at a 50 GHz channel spacing have been experimentally transmitted within the 1550 nm transmission window. The VCSEL emission wavelengths were adjusted from 1547 nm to 1552 nm which also fall within the DWDM and flexible nominal central wavelengths [13]. Above their threshold bias levels, the VCSELs demonstrated a 5 nm (725 GHz) spectrum range which represents approximately 14 DWDM or flexible channels spaced at 50 GHz spacing. The low 3.2 dB transmission penalty for a 76.8 km, makes the low cost and energy effective VCSELs ideal candidates for providing 10 Gbps backbone optical fibre data transport to the end users in Africa and developing continents.

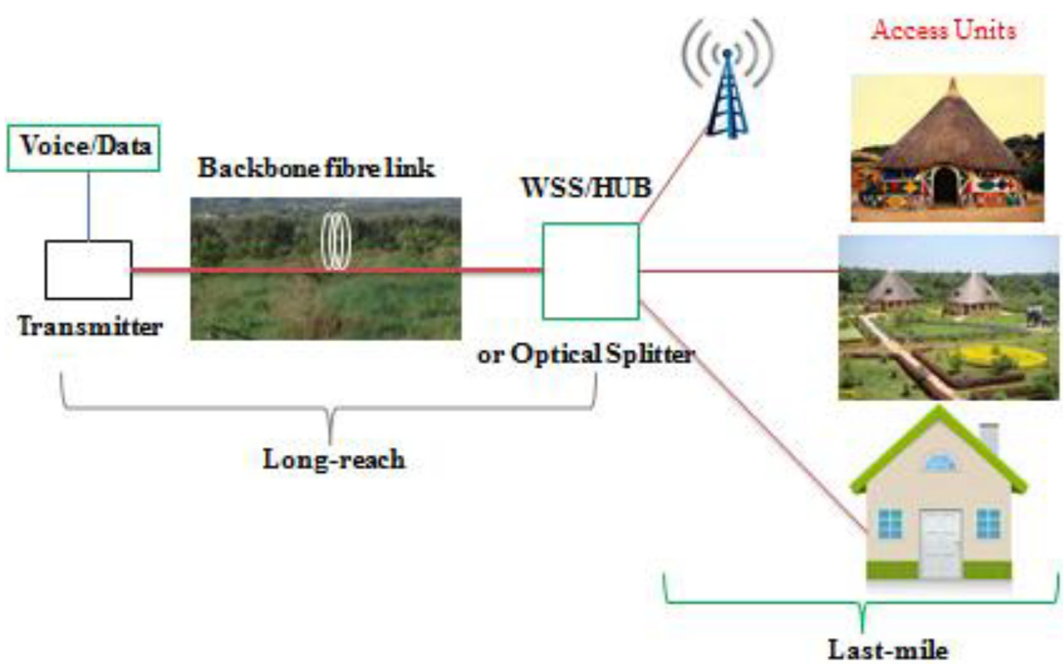

Fig. 2. A schematic illustrating a point to multipoint signal distribution from a data/voice modulated signal transmitter to the last mile access users via a backbone fibre link.