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Inter-networking, VCSEL-Based Low-Cost Hybrid Base Stations Towards the Integration of Wireless and Wireline Access Networks

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ABSTRACT — **A low-cost VCSEL-based base station scheme that has the potential to establish inter-communications among neighboring base stations without sending the signals to the central office to provide simultaneous access to wireless and wireline services is proposed.**

I. INTRODUCTION

The demand for higher bandwidth necessitated by data-intensive multimedia and real-time applications is increasing in the access networks. To meet this bandwidth demand, a variety of access technologies are being introduced in the last mile access network, incorporating both wireless and wireline media. Among these solutions, passive optical networks remain the most future proof technology for the delivery of broadband to users [1]. Radio-over-fiber (RoF) networks that can be categorized as the networking of wireless access points are very attractive for the delivery of broadband via wireless last mile solutions [2]. Carriers and service providers are seeking a convergent network architecture that can facilitate a rich mix of value added and differentiated services via a mix of wireless and wireline solutions to meet the demand for mobility, bandwidth and range of connectivity options for the customers [3, 4]. All of these requirements can be met by offering an integrated telecommunications package, for which an integrated access network that can support both wired and wireless last mile solutions is essential.

A generic integrated network incorporating both wireless and wireline technologies are shown in Fig. 1. In the downlink direction, optically modulated wireless and wireline signals are transported from the CO to the remote access nodes (RANs), where the composite signal is divided either by a demultiplexer or a star coupler (SC) and distributed to the antenna base stations (BSs) and the optical network units (ONUs) for delivering to the customer units. In the uplink direction, the wireless and wireline signals from the customer units come to the RAN via the BSs and the ONUs, combined and transported to the CO. Therefore, to enable simultaneous transport of wireless and wireline services in the hotspots such as airports, shopping malls, and universities, both ONUs and BSs are needed to be co-located, which means multiple optical access points are required to cover the same geographical area. The requirements of multiple optical access points and the co-located BSs and ONUs can be avoided if the BSs can be enabled to support both the wireless and wireline services. Moreover, inter-networking among the customers of different antenna sites (without sending the signal back to the CO) are widely expected in modern wireless access networks, as future wireless devices in customer sites will also serve as routers to communicate in a multi-hop mesh network.

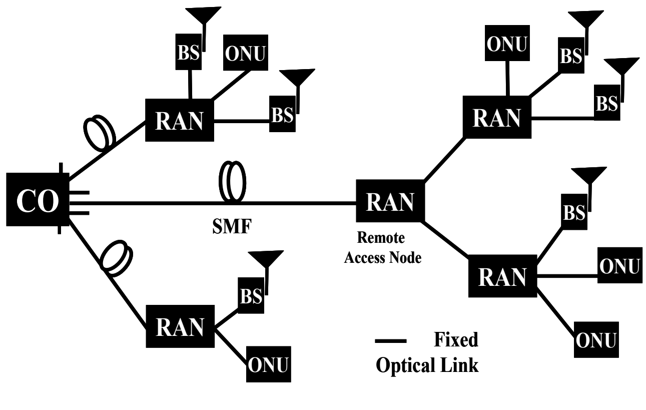

Fig. 1: Generic integrated optical network architecture.

In order to resolve these problems, we previously proposed a hybrid base station (H-BS) scheme based on a reflective semiconductor optical amplifier (RSOA), an optical local oscillator (LO) and a coarse-wavelength-division-multiplexed (CWDM) coupler, along with other necessary devices [5]. The performance of the proposed scheme however, was limited by the narrow modulation bandwidth of the RSOA and selection of the optical LO from a coarse-wavelength (at least 20 nm apart from the downlink for the use of low cost realization of CWDM couplers). Also the proposed scheme was relatively expensive, as it uses an expensive RSOA and an optical LO source for each H-BS. This paper simplifies the scheme by replacing the expensive RSOA and optical LO source with a directly modulating low-cost vertical cavity surface emitting laser (VCSEL) diode.

II. VCSEL-BASED HYBRID BASE STATION SCHEME

Fig. 2 depicts the configuration of the proposed hybrid base station. It consists of a 3 port optical circulator, a

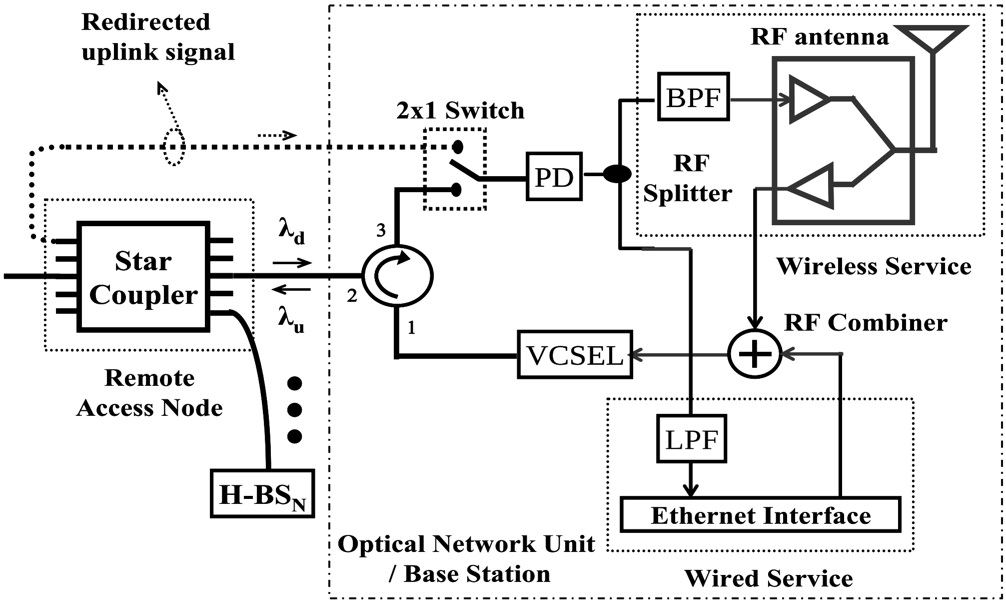

Fig. 2: Hybrid base station architecture providing simultaneous wireless and wireline services.

VCSEL, a photodetector (PD), a radiating antenna and electrical signal conditioning devices, in addition to a provisional 1x2 opto-mechanical switch (OSW) to establish inter-communication among the neighboring customers, bypassing the CO. Optically modulated downlink wireless (RoF signal) and wireline (baseband Ethernet) signals from the RAN come across the H-BS via the optical circulator. The downlink signals are detected by the PD and divided into two parts by a 3 dB electrical splitter. The RoF signal is separated from the Ethernet signal using an electrical bandpass filter (BPF) prior to its radiation to the customers via the antenna. The second part of the divided signal is sent through a low pass filter (LPF) to separate the Ethernet signal, before it is plugged into the wall to feed the Ethernet hub. In the uplink direction, the uplink electrical signals from wireless and wireline customers are combined and directly modulated by the VCSEL diode. The modulated uplink signal was then sent to the remote access node via the optical circulator. To support inter-communication among neighboring H-BSs, another optical receiving port, followed by a 1x2 OSW, is also provisioned to the scheme. This second receiving port can be connected to the RAN to receive the broadcast signal from the neighboring H-BSs, reducing the cost and complexity of the CO. Thus, the proposed H-BS has the potential to establish inter-communication among the customers of neighbouring H-BSs, while effectively enables both the wireless and wireline signals, leading to

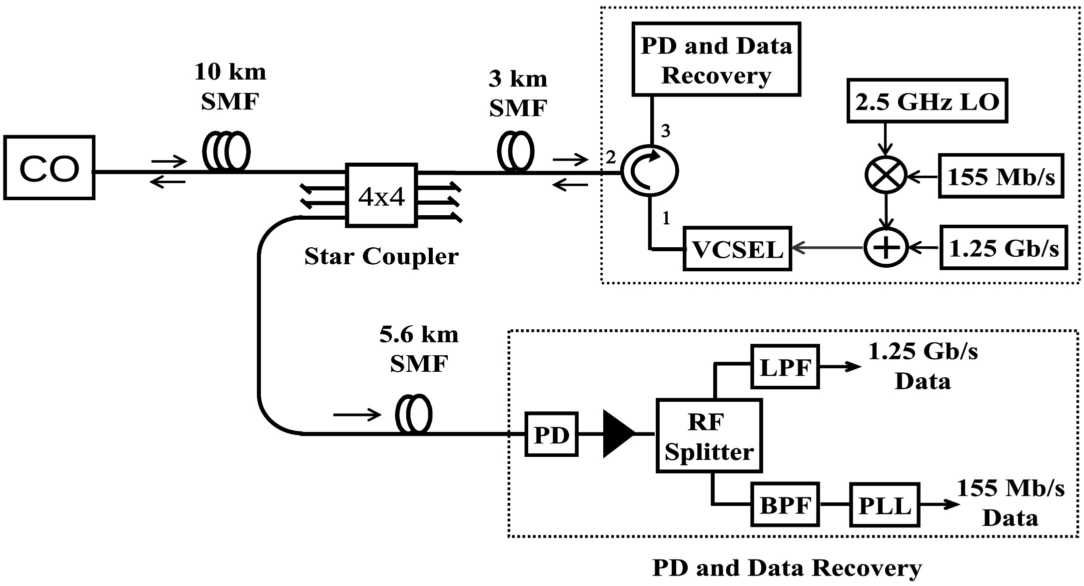

Fig. 3: Experimental setup for the demonstration of the proposed hybrid base station.

an integrated network for the access and metro domain.

III. EXPERIMENTAL DEMONSTRATION & RESULTS

Fig. 3 shows the experimental setup that demonstrates the capabilities of the proposed scheme. In the uplink direction, a 2.5 GHz binary-phase-shift-keyed (BPSK) RoF signal, which was generated by mixing an LO signal of 2.5 GHz with a 155Mb/s 2^{31}-1 PRBS NRZ data, was electrically combined with a 1.25 Gb/s baseband signal of 2^{31}-1 PRBS NRZ data. Before combing, the performance of the combined signal was duly optimized by managing and controlling the intensities as well as the harmonic components of each of the signal by using suitable electric filters and RF amplifiers. The RF spectra of the combined signal can be seen in Fig. 4. The composite signal was then applied to a VCSEL diode via a bias-T. The

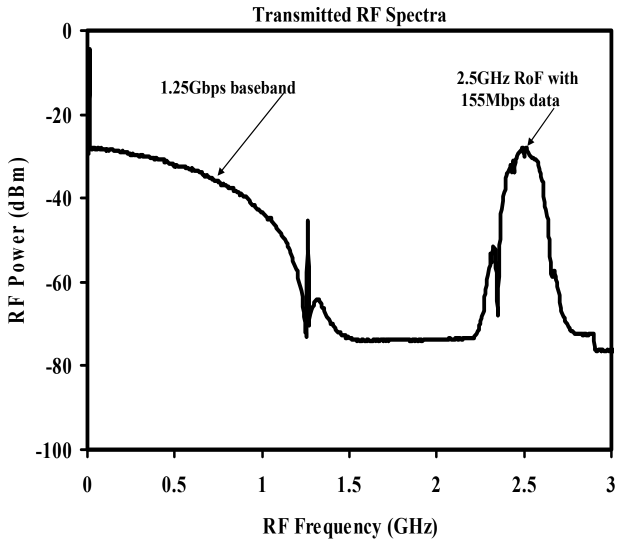

Fig. 4: Observed RF spectra showing the transmitted RF signals at the H-BS.

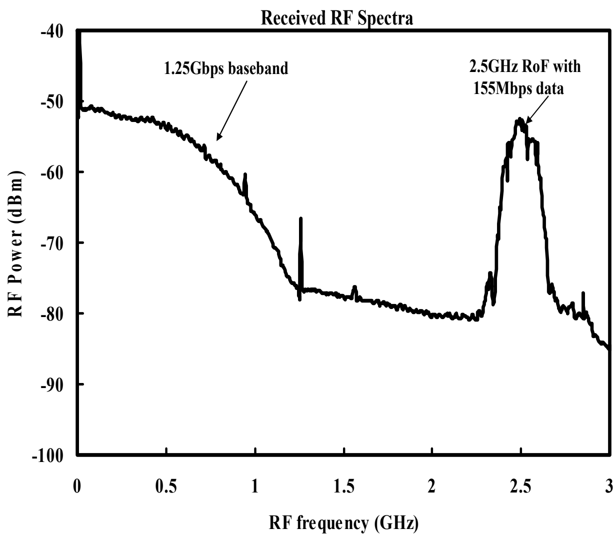

Fig. 5: Observed RF spectra showing the recovered RF signals at the PD and data recovery circuit.

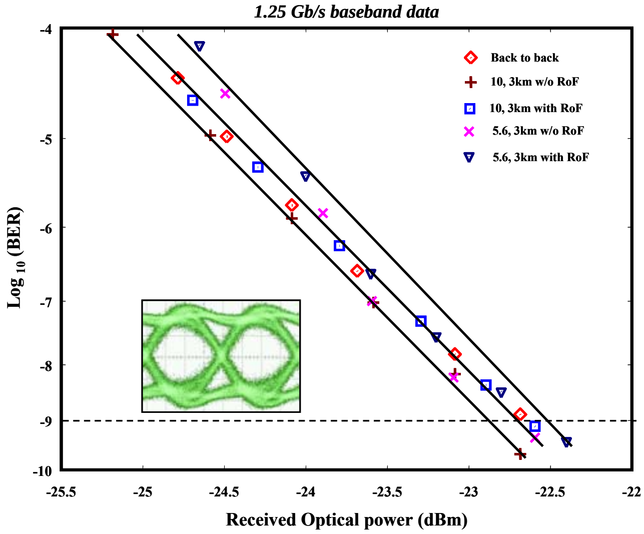

Fig. 6: Measured BER curves for baseband Ethernet data.

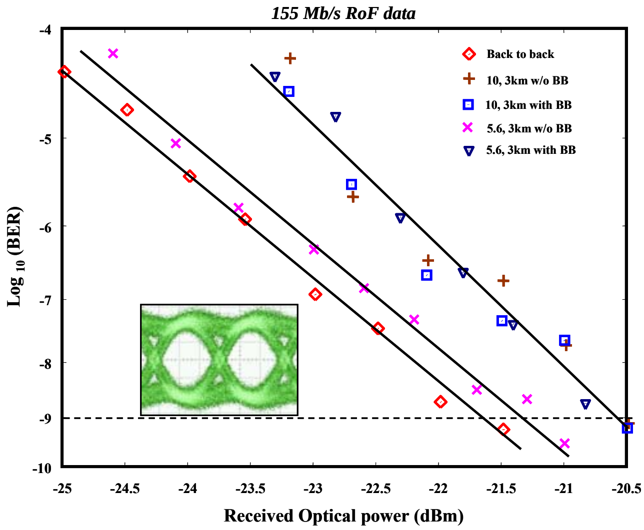

Fig. 7: Measured BER curves for RoF wireless data.

remaining port of the bias-T was used to inject the drive current to the VCSEL diode. The VCSEL diode used in the demonstration was capable of handling a drive current of up to 15 mA offering a tunable emission bandwidth of 4 nm (1548 to 1552 nm). This specific demonstration has used a 9.3 mA drive current, which resulted in the directly modulated 1551 nm optical signal with an intensity of approximately 0 dBm. The directly modulated signal was then passed through a 3 port optical circulator and 3 km distribution single mode fiber (SMF) to the remote access node (RAN) where it is broadcasted via a 4 x 4 star coupler (SC). The SC is connected with the CO and another H-BS (as described in Fig. 2) via a 10 km feeder and a 5.6 km distribution SMF respectively. To see the performance in point-to-multipoint communication, the broadcasted signal was then detected and both Ethernet and RoF data was recovered in the CO using suitable PD and data recovery circuit. Shown in the inset of Fig. 3, the PD and data recovery circuit is comprised of a 3 dB electrical splitter, one 1.25 GHz low-pass filter (LPF), one 2.5 GHz band-pass filter (BPF) with a 3 dB bandwidth of 200 MHz and required signal conditioning devices. Similar to the point-to-multipoint communication, for multipoint-to-mulipoint transmissions enabling inter-communication among the customers of the neighboring H-BSs, the broadcasted signal was also detected and both Ethernet and RoF data was recovered in a neighbouring H-BS after the 5.6 km distribution SMF. The measured composite RF spectra and the BER curves for baseband Ethernet and RoF signals are shown in Figs. 5 to 7 respectively. The recovered RF spectra and the error free data recovery confirm the functionality of the proposed scheme enabling the integration of baseband and RoF signals. Regarding the scalability and link budget of the proposed scheme, VCSEL under consideration is capable of generating modulated signals with an intensity of approximately 0 dBm. Therefore, sufficient power margin is available.

VII. CONCLUSION

We have proposed and demonstrated a hybrid base station scheme for the integration of wireless and wireline access technologies. The proposed scheme is based on standard device technologies and is suitable for any optical access/metro networks, irrespective of topologies and architectures. Moreover, this scheme has the potential to establish multipoint-to-multipoint communication without sending the signal back to the CO. The error-free data recovery confirms the functionality of the scheme without any noticeable power penalty.

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