

# Internetworking VCSEL-Based Hybrid Base Station Towards Simultaneous Wireless and Wired Transport for Converged Access Network

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**Abstract**—A hybrid base-station (H-BS) scheme that has the potential to establish intercommunications among neighboring access nodes without sending the signals to the edge node to simultaneously transport wireless and wireline services to integrated access nodes is proposed. As the scheme uses vertical-cavity surface-emitting lasers as the light source in the H-BS, it can potentially be realized at low cost without any temperature control.

**Index Terms**—Converged access network, hybrid base station (H-BS), optical network unit, reflective semiconductor optical amplifier (RSOA), remote access node (RAN), vertical-cavity surface-emitting laser (VCSEL).

## I. INTRODUCTION

THE demand for higher bandwidth necessitated by data-intensive multimedia and real-time applications is increasing in the “last mile” access networks. To meet this bandwidth demand, a variety of access technologies such as digital subscriber line, fiber-to-the-curve (FTTC), fiber-to-the-home (FTTH), ultramobile broadband, worldwide interoperability for microwave access (WIMAX), etc., have been evolved, incorporating both wireless and wireline media. Among these solutions, passive optical network (PON)-based wired solutions (e.g., FTTC/FTTH) remain the most future proof technology for the delivery of broadband to the users, as they offer higher bandwidths at longer distances. Also, due to fixed physical connections, they are more secure and reliable [1]. On the other hand, wireless-based access solutions are also very attractive due to their inherent advantage of portability and flexibility [2]. In order to exploit the benefits of both of these transmission media, carriers and service providers are actively seeking a convergent network architecture that can facilitate a rich mix of value added and differentiated services via an integrated wireless and wireline network, so that the demand for mobility, bandwidth, reliability, security, and flexibility can be met [3]–[5]. A generic integrated network incorporating both wireless and wireline transmission media is shown in Fig. 1. The philosophy behind such architecture is to cover the

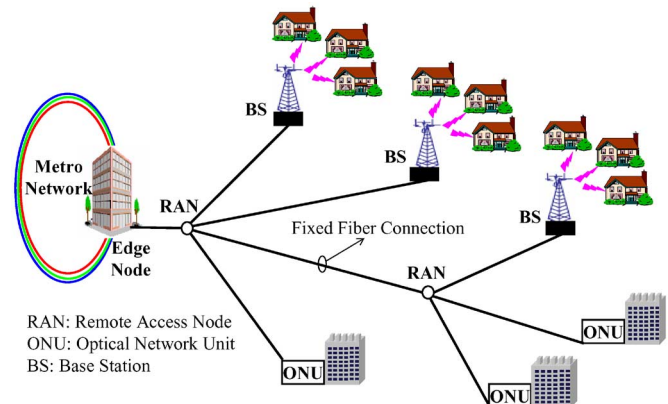


Fig. 1. Generic integrated optical-wireless network architecture.

distance with an already implemented fiber infrastructure and maximize the throughput of the wireless access offering with a minimized cell size, as it is assumed that the effect of wireless interference in the areas close to the antenna base station (BS) is very low with a maximized signal-to-interference ratio. In this concept, multiple wireless signals from customers with different medium access control protocols, such as Ethernet for WIMAX, asynchronous transfer mode (ATM) for 3 G or time-division multiplexing (TDM) for 2 G come across the remote BS, processed and transported to the remote access node (RAN) to combine with the wired signals depending on the network architectures. This conventional integration architecture, shown in Fig. 1, serves well in feeding the wired and wireless optical network units (ONUs) located in separate geographical areas. In order to enable the wireless and wired services simultaneously in the telecommunication hotspots such as airports, shopping malls, and universities, as well as for in-house personal networks, both wireless and wired ONUs are needed to be co-located (overlay structure), which means multiple optical access points as well as multiple ONUs are required to cover the same geographical area. The architecture of such networks can be simplified by introducing a hybrid base-station (H-BS) (or hybrid ONU) that simultaneously supports both the wireless and wired services. We previously proposed such an 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 [6]. The performance of that scheme is limited by the narrow modulation

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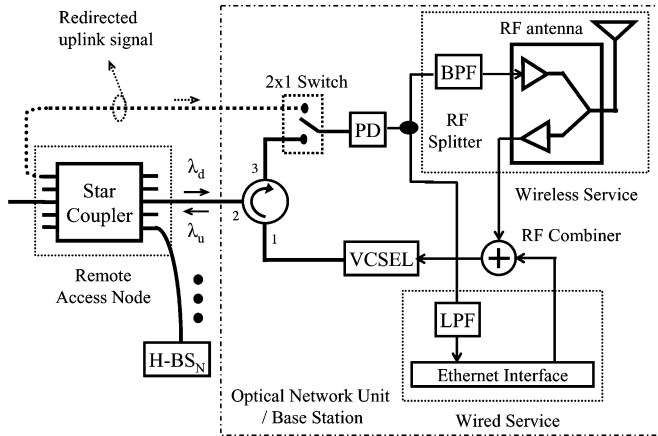


Fig. 2. H-BS architecture providing simultaneous wireless and wired services.

bandwidth of the temperature-controlled RSOA and the 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, that scheme was relatively expensive, as it uses an expensive RSOA and an optical LO source for each H-BS. Moreover, if the baseband Ethernet signals and the intermediate-frequency data signals are redirected to the edge node to provide a communication channel between the hybrid BSs and the edge node, then a separate feeder fiber may well be required to prevent the backscattering that limits the performance of the upstream signals, which might increase the cost of the network deployment. These have prompted us to investigate other optical sources that could potentially be used at the H-BSs without trading the complexity and cost. In that regard, it was found that single-mode free running vertical-cavity surface-emitting lasers (VCSELs) can be used to directly modulate high radio-frequency (RF) signals without any external modulators and they are relatively inexpensive compared to RSOAs and, therefore, provide a much more feasible solution for the use at the H-BSs [7].

## II. VCSEL-BASED H-BS SCHEME

Fig. 2 depicts the configuration of the proposed H-BS. It consists of a three-port optical circulator, a VCSEL, a photodetector (PD), a radiating antenna, and electrical signal conditioning devices, in addition to a provisional  $1 \times 2$  optomechanical switch (OSW) to establish internetworking among the neighboring customers, bypassing the edge node, as it is assumed that future wireless devices in customer sites will also serve as routers to communicate in a multihop mesh network. Optically modulated downlink wireless (RF 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 RF signal is separated from the Ethernet signal using an electrical band-pass 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

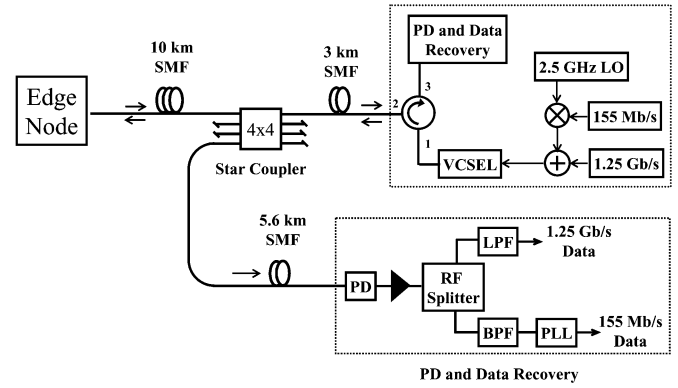


Fig. 3. Experimental setup for the demonstration of the proposed H-BS.

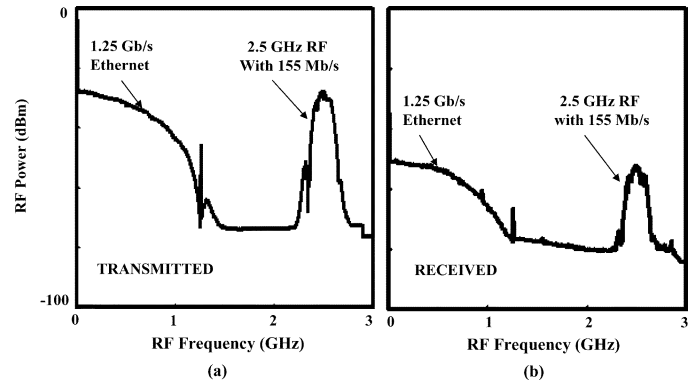


Fig. 4. Observed RF spectra showing the (a) transmitted and (b) recovered RF signals to and from the H-BS, respectively.

VCSEL diode. The modulated uplink signal was then sent to the RAN via the optical circulator. To support internetworking among neighboring H-BSs, another optical receiving port, followed by a  $1 \times 2$  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 edge node. Thus, the proposed H-BS has the potential to establish internetworking among the customers of neighbouring H-BSs, while effectively enables both the wireless and wireline signals, leading to an integrated network for the access and metro domain. As the scheme incorporates a VCSEL, it can potentially be uncooled.

## III. EXPERIMENTAL DEMONSTRATION AND 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) RF signal, which was generated by mixing an LO signal of 2.5 GHz with a 155-Mb/s  $2^{31} - 1$  pseudorandom binary sequence (PRBS) nonreturn-to-zero (NRZ) data, was electrically combined with a 1.25-Gb/s baseband signal of  $2^{31} - 1$  PRBS NRZ data. Before combining, 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 signals by using suitable electric filters and RF amplifiers. The RF spectra of the combined signal can be seen in Fig. 4(a). The composite signal was then applied to a VCSEL diode via a bias-T. The remaining

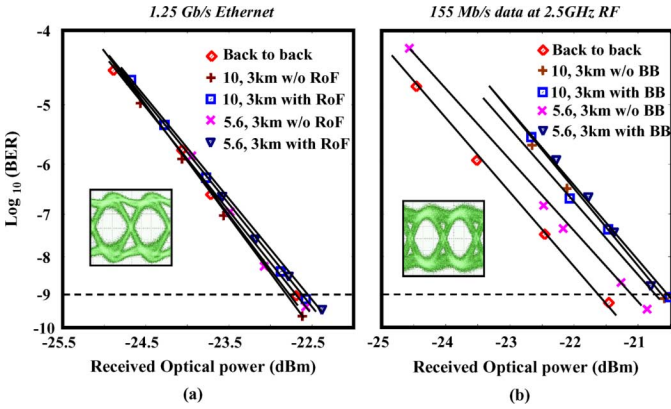


Fig. 5. Measured BER curves for (a) wired Ethernet and (b) wireless RF data.

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 (1548–1552 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 three-port optical circulator and 3-km distribution single-mode fiber (SMF) to the RAN where it is broadcasted via a  $4 \times 4$  star coupler (SC). The SC is connected with the edge node 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 broadcast signal was then detected and both Ethernet and RF data was recovered in the edge node 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 LPF, one 2.5-GHz BPF with a 3-dB bandwidth of 200 MHz, and required signal conditioning devices. Similar to the point-to-multipoint communication, for multipoint-to-multipoint transmissions enabling intercommunication among the customers of the neighboring H-BSs, the broadcast signal was also detected and both Ethernet and RF data was recovered in a neighbouring H-BS after the 5.6-km distribution SMF. The measured composite RF spectra and the bit-error-rate (BER) curves for baseband Ethernet and RF signals are shown in Figs. 4(b) and Fig. 5(a) and (b), respectively. The recovered RF spectra and the error-free ( $\text{BER} < 10^{-9}$ ) data recovery confirm the functionality of the proposed scheme enabling the integration of baseband and RF 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. Table I shows the parameters of an Ethernet-PON incorporating the proposed H-BS with varying splits of the SC. It shows that with the receiver sensitivity of the PD currently in use ( $\sim -20.5$  dBm), power margins of at least 3.75 and 0.75 dB can be obtained for

TABLE I  
PARAMETERS FOR POWER BUDGET ANALYSIS

| Split Ratio                     | 8     | 16    | 32    | 64    |
|---------------------------------|-------|-------|-------|-------|
| Output power (dBm)              | 0     | 0     | 0     | 0     |
| Feeder fiber loss @ 0.25 dBm/km | 2.5   | 2.5   | 2.5   | 2.5   |
| Star coupler loss (dBm)         | 9     | 12    | 15    | 18    |
| Dist. fiber loss @ 0.25 dBm/km  | 0.75  | 0.75  | 0.75  | 0.75  |
| OSW loss (dBm)                  | 0.75  | 0.75  | 0.75  | 0.75  |
| Optical circulator loss (dBm)   | 0.75  | 0.75  | 0.75  | 0.75  |
| Receiver sensitivity (dBm)      | -20.5 | -20.5 | -20.5 | -20.5 |
| Power Margin                    | 6.75  | 3.75  | 0.75  | -2.25 |

the composite baseband and RF signals for SC splits of 16 and 32, respectively. The adequate power margins for SC splits of 64 or 128 can, however, be achieved with standard commercial PDs with a sensitivity of approximately  $-26$  to  $-28$  dBm. Compared with the 50-mA drive current of the RSOA [6], the VCSEL under consideration uses only 9.3 mA and does not require any temperature control.

#### IV. CONCLUSION

We have proposed and demonstrated an H-BS 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. As this scheme uses VCSELs as the light source in the hybrid BS, it can potentially be realized at low-cost without any temperature control. Moreover, this scheme has the potential to establish multipoint-to-multipoint communication without sending the signal back to the edge node. The error-free data recovery confirms the functionality of the scheme without significant power penalty observed.

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