

Passive Optical Network Supporting Seamless Integration of RoF and OFDMA Signals

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Abstract: Radio over Fiber (RoF) Technology is integration of radio emission in optical fibre transmission at intervals network infrastructures that's thought of to be cost-efficient, sensible and comparatively versatile system configuration for long-haul transport wireless signals. This project propose a Next generation PON design supports RoF and OFDMA signal integration while not WDM lasers, and demonstrate that 10-Gb/s OFDMA and 3 RF signals at two.1GHz area unit with success transmitted over 20km SMF during a 32-ONU in each upstream and downstream direction.

Keywords: Radio Over Fiber (RoF), Orthogonal Frequency Division Multiplexing Access (OFDMA), Passive Optical Network (PON), glass fibre Communication, Optical Modulation.

I. INTRODUCTION

Next-generation PONs are thus expected to seamlessly transport wireless signals to reduce the deploying cost while taking advantage of huge capacity of optical fiber. However, supporting multiple remote antenna ports in one trunk fiber gives rise to the optical beat interference (OBI) problem. To alleviate the problem, the approaches exploit either wavelength division multiplexing (WDM)-PON or multiple upstream lasers at specially selected widely-apart wavelengths, which are relatively expensive and impractical.

In a RoF link, laser light is modulated by a radio signal and transported over an optical fiber medium. The laser modulation is analog since the radio-frequency carrier signal is an analog signal. The modulation may occur at the radio signal frequency or at some intermediate frequency if frequency conversion is utilized. The basic configuration of an analog fiber optic link consists of a bi-directional interface containing the analog laser transmitter and photodiode receiver located at a base station or remote antenna unit, paired with an analog laser transmitter and photodiode receiver located at a radio processing unit. One or more optical fibers connect the remote antenna unit to the central processing location.

Increasing demand of wireless access for greater bandwidth and longer reach. One of the approaches is to miniaturize the cell size to increase network capacity. However, it gives rise to a high-cost backhauling deployment hurdle. To this end, recent work has focused on integrating radio signals over high capacity fibers, referred to as radio-over-fiber (RoF) [1,2]. With the increasingly deep penetration of PON infrastructure into users' premises, RoF can be realized by placing low-power small-size remote antenna ports at the optical network units (ONU's) of the PON's. Such a design

eliminates the need of allocating base stations for longer reach, thereby greatly reducing the hardware complexity. Accordingly, this integration takes advantage of the high capacity of the optical fiber while reducing deployment cost and with the rapid growth of high-speed services like Internet protocol television (IPTV) and high-definition (HD) video, a further increase in bandwidth over 10 Gb/s in access networks is needed.

In OFDM, multiple subcarriers with equal frequency interval are utilized to form parallel data transmission, and each separate data stream is modulated with one of equally-spaced subcarriers [3]. Reducing the spacing between subcarriers in OFDM system, results in improved bandwidth. operators' deployment. In order to increase the bandwidth up to 10 Gb/s and beyond while maintaining an acceptable cost of deployment, recent research in optical access networks has been focusing on multicarrier modulation like orthogonal frequency-division multiplexing (OFDM) due to the high spectral efficiency of m-quadrature amplitude modulation (m-QAM). The main advantage of OFDM is that it can transmit parallel data at low rates on each subcarrier simultaneously. Therefore, a frequency-selective channel is transformed into a collection of flat channels. As a result, this modulation technique inherits robustness to fiber chromatic dispersion. In addition, OFDM has become extremely popular due to its efficient implementation using fast Fourier transforms (FFTs) to modulate and demodulate data.

In this paper, a novel architecture for next generation orthogonal frequency division multiple accesses (OFDMA)-based PON's, referred to as ROFPON [4]. ROFPON seamlessly integrates RoF signals with the local broadband data without using costly WDM lasers. It supports multiple remote antenna ports at ONU's with the use of only one optical receiver at the OLT while completely eliminating the OBI problem. Via experimentation and analysis, we study the receiver sensitivity to OFDMA signals and the RF signal's performance. The exploitation of a notch filter for removing RF interference. Experimental results show that ROFPON allows three 20 MHz wireless RF channels at the 2.1 GHz band (from three remote antenna ports) to be overlaid with a 10 Gb/s OFDMA-PON signal via a single wavelength. The integrated signals are successfully transported both downstream and upstream over a 20 km single-mode-fiber PON. Finally, experimental results demonstrate that QPSK-encoded WiMAX-format RF signals are transmitted/relayed upstream with E-O-E conversion at each ONU, and received error-free at the OLT after cascading 32 ONU's.

II. ROFPON ARCHITECTURE

ROFPON (Figure 1) connects multiple ONU's to OLT through a passive optical distribution node (ODD), which is connected to the OLT via a long trunk fiber. Each ONU has one short section of feeder fiber to the ODD. ROFPON uses WO wavelength channels, λ_d and λ_u , to convey downstream and upstream data, respectively. Channels are further divided into synchronous time slots, called frames. As shown in Figure 1, within each optical frame, downstream wireless signal is overlaid with the OFDM signals by occupying a separate frequency range. For signals passing downstream, the splitter in ODD generates multiple signal copies from the OLT and broadcasts the signal to each ONU through a splitter, a circulator, and a feeder fiber. Within each ONU, after λ_d and λ_u are separated by a coarse WDM (CWDM), the downstream wavelength (λ_d) is received by the optical receiver, which converts the optical signal into the electrical form. Next, an electrical splitter separates the signal into two paths. Downstream OFDM data is demodulated in the first path, while in the second path; the wireless signal is filtered by a bandpass filter for wireless downlink communication.

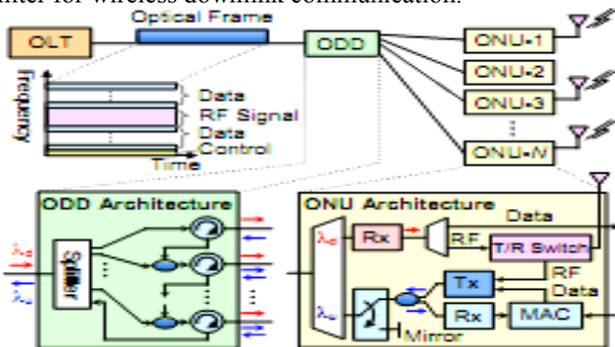


Figure.1 ROFPON

For signals passing upstream on wavelength λ_u , ONU-1 first sends its upstream data and control information to ONU2 through ODD's circulators and coupler. Notice that due to the use of OFDMA-based modulation, control information can be placed in pre-allocated subcarriers. Once the data/control is received by the upstream receiver module at ONU-2, its upstream medium access controller (MAC) performs bandwidth allocation to determine the subcarrier(s) for carrying the local upstream data. The MAC then regenerates the combined OFDMA signal by the upstream OFDMA signal by the upstream transmitter module and sends it to the next node, ONU-3. By the same token, the upstream signal is relayed point-to-point with an electrical-optical electrical (E-O-E) conversion mechanism from ONU-3 until ONU-N. Note that dynamic bandwidth allocation must be used to govern the fair sharing of upstream bandwidth among all ONU's. Finally, at ONU-N, the upstream wavelength is passed to the OLT through the ODD and fiber. It is worth noting that, to prevent signal loss in the event of an accidental blackout or a shutdown of any ONU's, each ONU is additionally equipped with a protection switch for the upstream signal. If an ONU is inactive, its optical switch (see Figure 1) is set to being an optical mirror (i.e., the default state), reflecting incoming upstream wavelengths from the previous ONU back to the ODD.

III. SIGNAL INTEGRATION

ROFPON system has been designed to accommodate multiple wireless signals received from different distributed antennas [5] located at different ONU's. Figure 2 illustrates how the multiple wireless RF signals are integrated and overlaid with the broadband OFDMA signals. Two RF signals are received by two remote antennas (located at ONU-1 and ONU-2), respectively. In Figure 2, we show the spectra of both OFDM data and RF signal at four stages, (i) through (iv), at ONU-1 and ONU-2. First, as shown at ONU-1's stage (ii), the wireless signal received by an antenna is frequency-shifted to the allocated band by a mixer, an oscillator, and a bandpass filter (BPF) called BPF1. Note that we intentionally keep the band clear by inserting zeros on corresponding IFFT points. The shifted signal is then combined with the upstream OFDMA signal (see ONU-1's stage (iv)), which is sent together by the directed modulated laser to ONU-2. Note that because there are no subcarriers in the allocated band, interference between the wireless signal and upstream OFDMA signal is controllable.

After having received the upstream wavelength from ONU-1, ONU-2 first splits the received signal into two paths. In the first path, the upstream OFDMA PON signal is regenerated by the upstream data processor. For the second path, the system uses a bandpass filter BPF2 on the allocated radio band to remove the OFDMA signal, while preserving all previous wireless signals, as shown in ONU-2's stage (iii). The RF combiner then combines the local antenna's signal from BPF1 with the previous ONU's wireless signals from BPF2. Finally, the system integrates the radio signal with the upstream OFDMA PON signal (see ONU-2's stage (iv)) via an RF directional coupler before driving the upstream laser. With this mechanism, multiple remote antennas' signals can be carried from ONU-1 to ONU-N and finally back to the OLT.

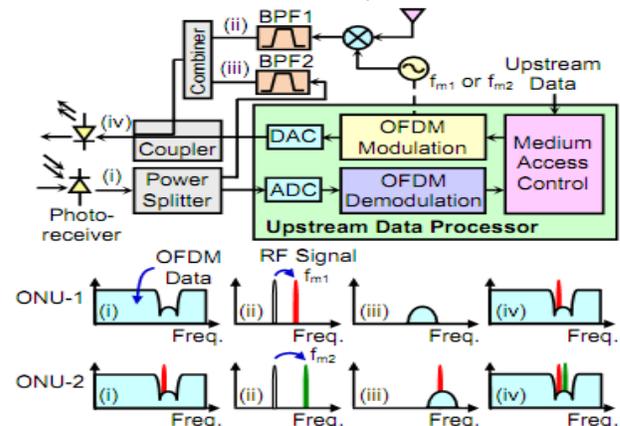


Figure 2. RoF-signal overlay with OFDMA-PON data.

ROFPON eliminates the use of expensive upstream WDM lasers, and is free from the aforementioned OBI problem. It is worth noting that such advantages are achieved at the expense of two drawbacks. First, such a ring-based signal flow inherently induces additional propagation and OEO processing delays for upstream traffic. The propagation delay through many drop fibers (between ONU's) in the distribution cable section is only limited to several tens of microseconds. On the processing part, since there is no buffering delay, the OEO processing delay takes less than a microsecond under the 10-Gb/s line rate. The

second drawback is the extra cost and insertion loss due to using more passive components in the ODD

IV. INTERFERENCE BETWEEN OFDM AND RF SIGNALS

For the integrated-signal system, the performance profoundly hinges on a crucial parameter- signal power ratio. In the following, we first give the definition, which is followed by the discussion on the interference. Recall that the RF signal is superimposed on the broadband OFDM signal, thereby

$$BRPR = \frac{\text{AveragePower(OFDM)}}{\text{AveragePower(RF)}}$$

A. RF Signal Interference to OFDM-PON Signal

After the combined signal is received by the optical receiver, the OFDM receiver needs a notch filter after the ADC to remove the RF signal. However, introducing the notch filter at the radio band itself affects the orthogonality of nearby OFDM subcarriers. To study the notch filter effect, we assess the OFDM signal performance by applying different filter orders, denoted as k . Note that the Keiser window method is used to design the filter, while the filter's 100 MHz stop band depth is determined by the filter order. Figure 5(b) shows the sub channels' SNR after the filter of $k = 400$ are applied under an ideal electrical back to back case. It is clear that the sub channels around the radio band encounter significant penalty. Figure 5(c) shows the simulation results of the overall BER performance of the OFDM signal with different notch filter orders applied. From these results, we observe that using deeper notch filters results in higher error floors. However, a shallow notch filter cannot completely remove the RF signal.

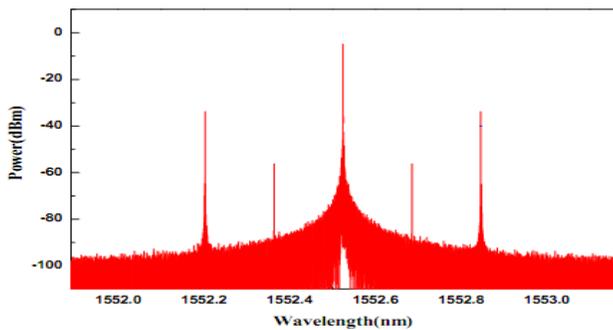


Figure 3. RF spectrum

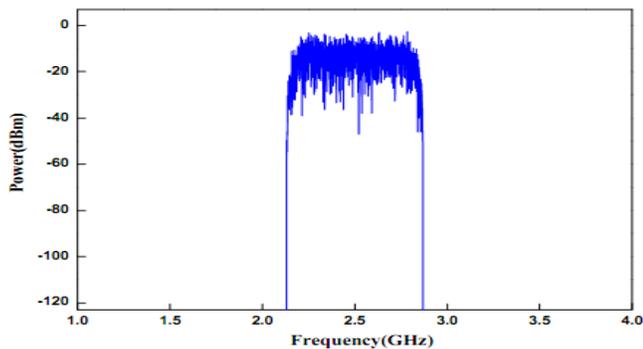


Figure 3 OFDM signals

B. OFDM Signal Interference to RF Signal

The existing of side lobes of neighbouring OFDM subcarriers will interfere with the RF signal. The simulation results are shown in Figure 6. We present in the figure the RF spectrum under different BRPR values. It is clear that the BRPR value directly affects the signal to interference ratio (SIR) of RF signal. We also carried out a simulation to predict the performance of the RF signal in a point to point optical link. As shown in Figure 7, the results show that the recovered signal's SNR depends almost linearly on the BRPR value. When BRPR is increased from 0 dB to 6 dB, the wireless signal's SNR decreases from 34.5 dB to 28.5 dB at -10 dBm receiver power. In this case, the OFDM signal interference is a major factor in RF signal's performance. Noise to accumulate along the ONU's. At each ONU, the RF signal passes through a coupler, an E-O-E conversion, and a BPF. The coupler combines the OFDM signal with the RF.

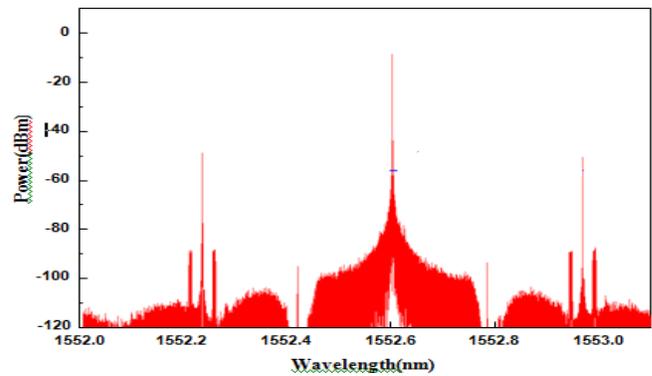


Figure 4 Spectrum After Coupler

V. EXPERIMENTAL SETUP

The experimental setup is illustrated in Figure 6. We evaluate the performance of both the OFDM and wireless RF signals when they are combined and transported over a 20 km optical link. The OFDM signal, which occupies 0.05 ~ 2.8 GHz of bandwidth, is generated offline with a DSP program.

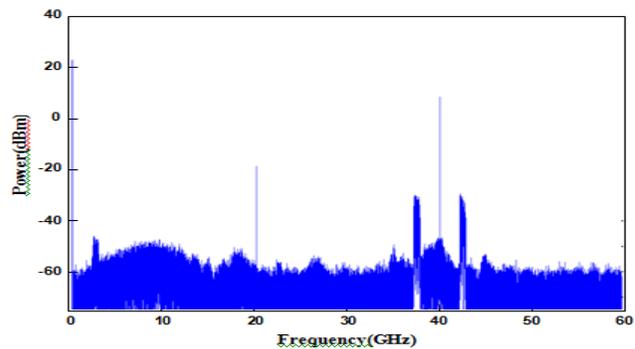


Figure 5 Received Signal

The IFFT size is 2048, from which 457 16-QAM encoded subcarriers are used for data transmissions. The raw data rate is 10.7 Gb/s. To accommodate multiple RF signals, the allocated radio band is 123 MHz wide and centered at a frequency of 2130 MHz. The analog waveform consists of 1000 OFDM symbols, and is generated by an arbitrary waveform

generator (AWG1). To generate the wireless signal, we follow WiMAX's format and use another AWG (AWG2) to produce three 20 MHz bandwidth RF signals at 2100 MHz, 2130 MHz, and 2160 MHz, respectively.

To evaluate downstream performance and fiber impairment, OFDM and RF signals are combined by a directional coupler to drive an intensity modulation optical transmitter that is of 5 dBm output powers, 2.5 GHz bandwidth, and 1550 nm. Note that two electrical attenuators are applied to set the BRPR value.

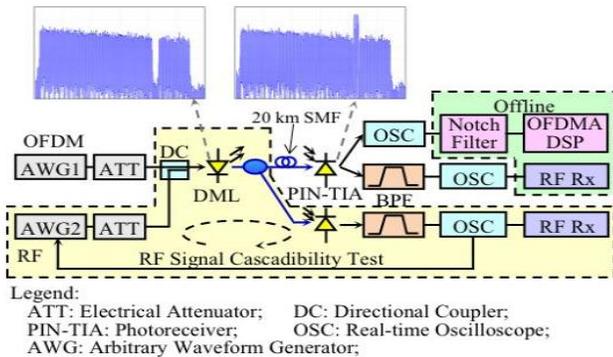


Figure 6 Experimental Setup

The spectrum density of the combined signal is shown in the right inset of Figure 6. The combined signal reaches the PIN-based photo receiver after travelling a 20 km single mode fiber and passing through an optical attenuator, which emulates the component loss and tests the receiver sensitivity. The received signal is split into two paths. For OFDM demodulation, a 50 GHz sampling rate real-time scope captures the signal for offline DSP processing. On the other path, an 80 MHz bandwidth band pass filter at 2130 MHz is implemented to extract bandwidth wireless signal for offline demodulation.

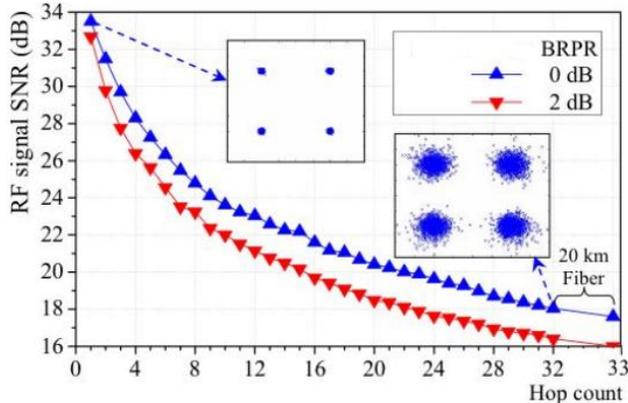


Figure 7 Performance of RF's SNR

Using a 12.5 GHz sampling rate, a real-time scope then captures and stores a 20M section of the waveform in a file. After the

waveform is stored, it is re-sampled to 12 GHz by a DSP program and fed to the AWG2 for the next hop transmission. For each hop, we load different OFDM signals to AWG1 so that the hops' interferences would not be correlated. In this way, we could emulate the accumulated interference imposed on the RF signal from ONU-1 to ONU-32.

VI. CONCLUSION

ROFPON, successfully integrates broadband OFDM data and wireless RF signals from multiple remote antennas. In ROFPON, only two wavelengths, one for downstream and the other for upstream traffic. Experimental results show that after-coding direct detection receiver sensitivity of OFDMA over a 20 km fiber s -14 dBm. The RF signal's robustness against OFDMA interference from ONU's is analyzed and demonstrated by running an offline recirculating loop experiment. Under a BRPR of 2 dB, the RF signal can be relayed in a 32 ONU's chain and recovered successfully.

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