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Optical/Wireless Physical Layer Integration – Radio-over-Fiber Systems

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Abstract: Broadband millimeter-wave wireless access with optical backbone is an ideal candidate for the provision of future broadband services. We provide an overview of our research activities in this area.

Introduction

Fixed wireless access networks operating at millimeter wave (mm-wave) frequencies with an optical fiber backbone offer the capacity to deliver future broadband services. Such networks require a pico-cellular architecture which in turn requires the deployment of a large number of antenna base stations (BSs). With a drastic increase in the total number of BSs, it is essential to simplify them and reduce their cost. This can be achieved by migrating all of the signal processing, routing and switching functionalities to the optical headend or central office (CO) where they can be shared among all the BSs. Fig. 1 shows a typical hybrid radio-on-fiber (RoF) network layout. The CO of the RoF network acts as a gateway to the optical wavelength-division-multiplexed (WDM) backbone while serving a large number of widely distributed antenna BSs. It has been shown that transporting the radio signals at the designated mm-wave frequency over fiber (RF-over-fiber transport) has the potential to reduce the BS complexity by enabling a centralized control architecture.

Although an RF-over-fiber transport scheme potentially simplifies the antenna BS design, there are optical impairments associated with this approach that need to be addressed. Fig. 2 illustrates a point-to-point link connecting a CO to a BS that incorporates RF-over-fiber transport and summarizes all the optical impairments that exist. The conversion of the radio signals to optical signals and vice versa in both the CO and BS is a non-linear process that introduces intermodulation distortion (IMD) when multiple carriers are present. In addition to the nonlinear optical interface, the transport of the radio signals at mm-wave frequencies significantly compromises the overall link budget and performance. The transport of mm-wave modulated optical signals also suffers from severe fiber chromatic dispersion penalties [1] and inefficient use of optical bandwidth.

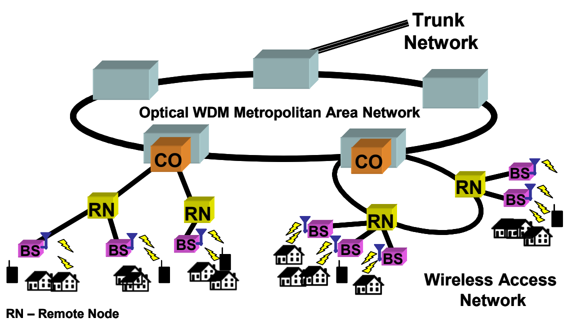

Fig. 1 Radio-on-Fiber network architecture

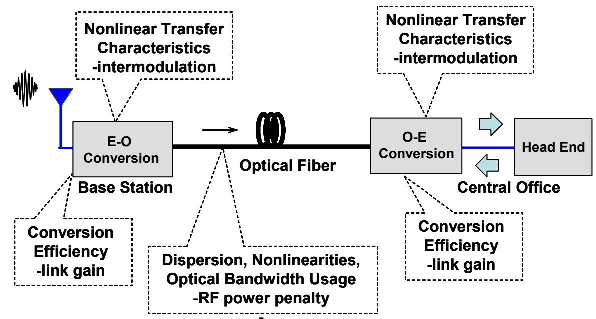

Fig. 2 Optical impairments within a RoF link

In this paper, we review and discuss some of our research activities focused on addressing these optical impairments. We have previously proposed and demonstrated techniques to improve optical spectral efficiency and link budget, as well as a linearization technique to reduce third-order IMD for RF-over-fiber transport.

Wavelength-Interleaving Technique

It has been well-established that optical single sideband with carrier (OSSB+C) modulation overcomes the penalty associated with fiber dispersion

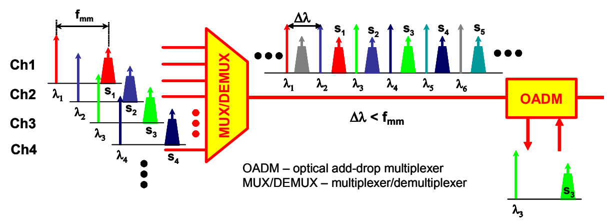

Fig. 3 Wavelength-interleaving for OSSB+C signals

for the distribution of mm-wave modulated optical signals [2]. It also improves the optical spectral usage by 50%. To further improve the spectral usage, a wavelength-interleaving technique was introduced [3,4] where it was shown that a potential threefold improvement in optical bandwidth usage using OSSB+C could be achieved [5]. This technique enables multiple mm-wave radio signals to be multiplexed in such a way that the optical channel spacing between adjacent channels is less than the mm-wave radio frequency as shown in the schematic in Fig. 3. We have successfully demonstrated this technique and have also implemented the essential optical interfaces for the interleaved channels (multiplexer and demultiplexer) using arrayed-waveguide gratings, optical circulators and fiber Bragg gratings (FBGs) [6].

Improvement in Link Performance

The OSSB+C signal is generated using a dual-electrode Mach-Zehnder modulator (DE-MZM), however due to the poor modulation efficiency at these frequencies the optical modulation depth (OMD) is typically very low. As a result, the modulated mm-wave optical sideband power can be more than 20 dB below that of the optical carrier. To improve the link performance, the optical power of the signals can be increased by using a high power optical source or an optical amplifier, however this may lead to increased IMD at the receiver (or even damage the receiver) due to too large an optical power incident on the detector. We have presented experimental, analytical and numerical studies on the impact of optical modulation efficiency of the mm-wave signals on the overall fiber-radio link performance [7]. The OMD of the mm-wave modulated signals was varied by removing a portion (via a FBG) of the optical carrier from the OSSB+C signal before detection. Shown in Fig 4a is a measured optical spectrum of an OSSB+C signal with and without an 80% reflective FBG that reduces the optical carrier by ~7.5 dB. The corresponding BER curves are shown in Fig. 4b with a 3 dB improvement in the sensitivity at a BER = 10^{-9} when the optical carrier was decreased by 7.5 dB (with 80% reflectivity FBG). We have also shown that the sensitivity performance of the RoF link is dependent on the optical carrier-to-sideband ratio (CSR) of the OSSB+C with an optimal performance occurring at CSR of 0 dB [7].

Linearization Technique

In a multi-carrier environment, system linearity is vital to maintaining the required dynamic range. It has been shown that the nonlinearity of the optical frontend of a RoF link limits the overall system dynamic range [8]. Recently we have proposed a linearization technique for dispersion-tolerant OSSB+C signals to reduce the third-order IMD contributions. We have quantified the IMD generation with respect to the optical components generated due to the nonlinear characteristics of the OSSB+C modulator and have shown that the major contributor to the overall IMD are the optical components located in the vicinity of the optical carrier, i.e. components at $\omega_c - \omega_1 + \omega_2$ and $\omega_c + \omega_1 - \omega_2$ if the OSSB+C were driven by two RF tones (f_1 and f_2) [9]. Our proposed linearization technique was based on the removal of these components. We have experimentally demonstrated the technique and have shown an improvement of 9 dB in the resulting carrier-to-interference ratio [9].

Conclusions

We have presented a brief overview of some of our research work in the area of RoF. The main focus of these research activities has been to overcome the impairments for transporting mm-wave modulated optical signals. We have introduced wavelength-interleaving the technique to improve optical spectral usage, quantified RoF link performance and demonstrated a linearization technique to combat these impairments.

Acknowledgement

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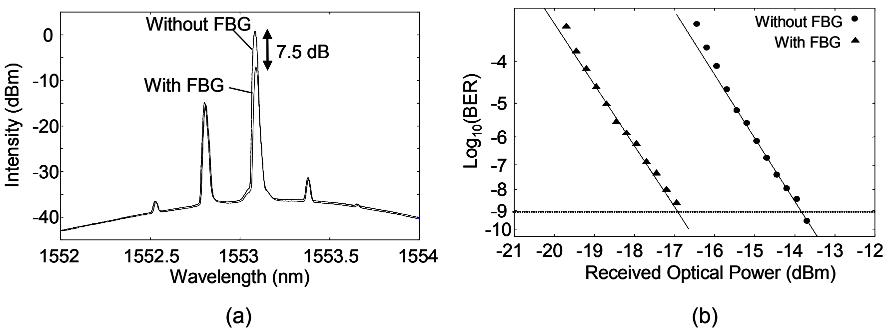

Fig. 4 (a) Measured optical spectra and (b) measured BER for OSSB+C with and without FBG