Sending wireless signals over wired fiber

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Microwave photonics enables the transfer of radio frequency signals over optical fibers for mobility and high bandwidth, bridging the gap between wireless applications and photonic technology.

We regard wireless mobile Internet access as essential to daily life, yet this ubiquitous technology is vulnerable to bandwidth limitations and electromagnetic interference (EMI). To overcome these challenges, we considered microwave photonics (MWP), an interdisciplinary area that exploits the interaction between microwaves and optical waves, potentially bridging the gap between wireless applications and photonic technology.

Because MWP has the intrinsic advantages of broad bandwidth and immunity to EMI, it is a promising technique for use in avionics, modern electronic warfare, and phase array radar.

One key application of MWP is the transport and distribution of radio or wireless signals over optical fiber (see Figure 1). In a typical configuration, distributed and remote antennas gather various wireless-based services (mobile units or wireless sensor nodes, for example) and transmit their radio frequency (RF) signals to the central office through optical fiber links. The office processes all the received signals and performs related management services, such as security monitoring and control, signal switching, and routing. This setup has the dual advantages of wireless (mobility) and optical fiber (high bandwidth), but it is not perfect. The transmitted signals are mostly analog, so it is essential to minimize their distortion to maximize the linearity of the link. As shown in Figure 1, there are embedded physical obstacles along the fiber, including chromatic dispersion (CD) and polarization mode dispersion (PMD), such that the various frequency or polarization components of the signal travel at different speeds. The system is also susceptible to nonlinear effects in the fiber (Kerr effects), and in the RF signal itself. CD and PMD lead to periodic power fading, while fiber Kerr effects may induce different signal degradations (self-phase and cross-phase modulation, for example), and RF nonlinearity produces serious third-order intermodulation distortions (IMD3). Collectively, all these effects limit the spurious-free dynamic range (SFDR), the strength ratio of the fundamental signal to the strongest spurious signal in the output. Without a high SFDR, we are unable to effectively manipulate the signal along the fiber, and therefore cannot guarantee the functionality of all connected services.

Various studies have sought to address these degradations by enhancing the SFDR of the link, and consequently the quality of the transmitted signals. Examples include using pre-distortion or post-compensation, multiple-wavelength architecture, and different combinations of modulated signals. Others have investigated coherent detection with enhanced sensitivities, carrier modulation in optical single sidebands (SSBs), and manipulation of polarization.

Here, we describe two compensation approaches for CD and RF nonlinearity (see Figure 2). In the first, we considered that the phase difference between the optical carrier and the two sidebands of double-sideband (DSB) signals changes along the link because of fiber dispersion, which would induce destructive interference power fading after certain distances. Therefore, we generated and transmitted SSB signals: see Figure 2(a).

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Figure 2. Typical compensation approaches for (a) chromatic dispersion (CD) and (b) RF nonlinearity. OC: Optical carrier. DSB: Double sideband. LSB: Lower sideband. USB: Upper sideband. θ: Phase difference (PD) between OC and first-order sidebands. Ω: Transmitted frequency of the signal. USB+C: Frequency component overcome by USB and OC. LSB+C: Frequency component overcome by LSB and OC. ω₁, ω₂: Frequency-closed RF signals. IMD3: Third-order intermodulation distortions. DSP: Digital signal processing.

The inherent nonlinearity of the optical modulator leads to two frequency-closed RF signals (ω₁ and ω₂) interacting with each other to generate two new idlers (2ω₁ − ω₂ and 2ω₂ − ω₁), defined as IMD3 by photodetector signal detection. To compensate the RF nonlinearity, in our second approach we used the inverse transformation for the detected signal in the receiver side, using either photonic or electrical digital signal processing: see Figure 2(b).

The advantages of these techniques are their simplicity and broadband operation window. In our latest experiment, we increased the SFDR to ~124dB-Hz⁴¹⁄₂ using the inverse transformation approach along conventional intensity modulated links. Transmitting wireless signals over optical fiber seems a promising concept, and is already starting to be deployed. In the future we will focus on mitigating PMD effects and on compensation of multiple degrading effects simultaneously. Meeting these challenges requires a more detailed understanding of analog signal evolution along the fiber link, as well as reconfigurable function blocks to deal with dynamic degradations.

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Lianshan Yan has published more than 350 papers, including six invited journal review submissions, and has given more than 20 invited talks. He received the IEEE Photonics Society Distinguished Lecturer Award (2011–2013) and is an associate editor of IEEE Photonics Journal. He has been the co-chair or technical program committee member of more than 20 international conferences.

References