Radio over Fiber for Broadband Wireless Access

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ABSTRACT - Fiber based wireless access systems support high-speed multimedia in real-time by combining the capacity of optical fiber with the flexibility of wireless networks. For example, single sub-carrier multiplexed radio-over-fiber (ROF) link can support wireless LAN, cellular radio, and CATV simultaneously. We investigate various issues in this scenario in order to provide a cost-effective, high performance solution for high-speed fiber based wireless access. We devised a system identification technique for a concatenated fiber-wireless channel (for single and multiuser), and have proposed various compensation schemes to equalize the time varying linear plus static nonlinear channel. We have also done various experimental studies on the performance of an ROF link.

1. INTRODUCTION

Wireless communications is entering a new phase where the focus is shifting from voice to multimedia services. Present consumers are no longer interested in the underlying technology; they simply need reliable and cost effective communication systems that can support anytime, anywhere, any media they want. Furthermore, new wireless subscribers are signing up at an increasing rate demanding more capacity while the radio spectrum is limited. As a result, wideband radio links will become more prevalent in today's communication systems. To satisfy this increasing demand, the high capacity of optical networks should be integrated with the flexibility of radio networks. This is the focus of the Advanced Radio and Optics Integrated Technology (ADROIT) group.

The aforementioned wideband demands can be met with micro/pico cellular architectures. Specifically, by using fiber based wireless access schemes such as radio-over-fiber (ROF), high-speed multimedia can be easily supported. ROF refers to a fiber optic link where the optical signal is modulated at radio frequencies and transmitted via the optical fiber.

The focus of our group ADROIT is to investigate various signal processing strategies to provide a cost-effective, high performance solution for high-speed fiber based wireless access. We have researched key aspects of the ROF such as: estimation and equalization strategies of the concatenated fiber-wireless channel in both single and multiuser environments [1], [2], [3], nonlinearity compensation by predistortion and asymmetric linearization of the ROF link [6]. Currently, we focus on the different issues of supporting both IS-95 cellular and IEEE 802.11 type Wi-Fi signals over the fiber-wireless (Fi-Wi) system. This can be done either in a sub-carrier multiplexed or baseband plus ROF manner. Although the fiber has several GHz of bandwidth, the cross coupling due to nonlinearity impairs the system performance and our focus is to quantify it and to come up with solutions. In this paper we provide an overview of the ROF research done by ADROIT.

2. METHODOLOGY

The ADROIT Fi-Wi solution is shown in Fig. 1. Our solution increases the frequency reuse and enables wideband access by providing a micro/pico cell scenario.

![Figure 1. ADROIT fiber-wireless solution for wideband multimedia access.](image-url)
for cost considerations. Therefore, the compensation should be done at the portable unit or at the central base station. The concatenated fiber-wireless channel should be handled jointly either way. This is a challenging task because of the time varying multipath wireless channel and nonlinear optical channel. Furthermore, the uplink and downlink require different solutions. Secondly, due to the ROF link, it is desirable not to modify the portable units in order to allow for seamless roaming. Thirdly, by performing most of the signal processing at the central base station, or by asymmetric distribution of the complexity, the cost can be shared among many users and helps reduce overall system cost.

2.1 Estimation

ROF provides an excellent link allowing for high bandwidth communication of several channels. However, when the wireless link is in series with the ROF link—especially in a multiuser environment—nonlinear distortion of the ROF link, due mainly to the laser diode (and partly to the high-gain RF amplifier at the optical receiver), becomes the primary concern. Also, the dynamic range of the input signal is adversely affected in the uplink where the received signal first travels through the wireless channel (resulting in path losses, fading and shadowing) before entering the ROF link. In order to limit the effect of these distortions, estimation, and subsequently equalization, of the concatenated fiber-wireless system should be done.

We have performed a complete identification of the ROF uplink in [1] and [2] in a single and multiuser environment, respectively. The uplink is a Wiener system, which consists of a linear part (wireless channel) followed by a mildly nonlinear part (ROF link). The wireless channel is identified using correlation analysis and the nonlinear link is identified using a least squares polynomial fit.

2.2 Equalization

Once the channel is estimated, an appropriate equalizer must be devised for the compensation of the linear and nonlinear parts. We have proposed an efficient Hammerstein type decision feedback equalizer (DFE) for the Wiener type uplink in [3]. This equalizer compensates for the linear and nonlinear distortions separately. This modular architecture is attractive for commercial implementation. The receiver consists of a polynomial filter, which inverse models the optical link, and a linear DFE arrangement that compensates for the wireless channel dispersion. The filter parameters have been optimized and performance analysis has been carried out in [3]. Currently, the Hammerstein type equalizer is implemented for a single user; however, we are working on expanding the equalization to a multiuser environment. In addition, innovative polynomial compensation methods are also being investigated.

2.3 Predistortion and asymmetric linearization

Several approaches have been proposed to characterize and solve the problem of nonlinear distortion. Some of these approaches attempt to use a post nonlinearity recovery block as in [4] or try to mitigate the nonlinear distortion in the network layer as in [5]. However, we developed an adaptive baseband model for the ROF link, and proposed two different predistortion schemes for the nonlinearity. One is being implemented now in an FPGA platform. Our proposed baseband predistortion scheme trains higher order adaptive filters to inverse model the ROF link [6]. Simulation results show very good performance improvement for the phase compensation. For the amplitude compensation, however, some backoff is required to protect the laser diode from excessive input power.

2.4 Relative intensity noise (RIN)

We came up with a new expression for the RIN noise in ROF links. This is a fundamental contribution and will most likely change the way people analyze ROF links.

Figure 2. ROF experimental setup. In this photo we have a Rohde & Schwarz signal generator sending a 1.5 GHz WCDMA signal through the ROF link and into the Tektronix WCA380 wireless communication analyzer.
3. RESULTS

For brevity's sake, we can only discuss some of our relevant research results. Regarding the estimation of the Wiener type fiber-wireless channel, we show our simulation results in Fig. 3. Here we see a good estimation of the linear wireless channel when using an input of 16 independent PN sequences and an SNR of 22 dB.

![Figure 3. Estimated (top) and actual (bottom) impulse response of the wireless channel using 16 independent PN sequences and an SNR of 22 dB.](image)

Our proposed correlation analysis algorithm is efficient in identifying the Wiener type system. The nonlinear link is also successfully estimated in the presence of noise (not shown here, refer to [2]).

Figure 4 shows relationships between fiber length, BER, RF bandwidth and radio cell size. It can be seen that for IS-95 systems (1.25 MHz RF bandwidth), when the fiber is short (< 5 km) relatively large radio cell size is possible. However, this cell size significantly decreases with fiber length and RF bandwidth.

4. CONCLUSIONS

The projected impact of implementing ROF schemes is substantial. The deployment of optical fiber technology in wireless networks provides great potential for increasing the capacity and QoS without largely occupying additional radio spectrum. From the aforementioned benefits, it is obvious that ROF technology will become ubiquitous in today's communication industry. The research performed by ADROIT will definitely help to provide a cost-effective, high performance solution for present and future high-speed fiber based wireless access systems.

REFERENCES