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Hybrid Fiber/Millimeter-wave Wireless for Broadband Last Mile Access

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Demand for broadband last-mile wireless connectivity is leading to the development of millimeter-wave fixed cellular wireless services such as the Local Multipoint Distribution Service (LMDS) at 28 GHz in the U.S. At these frequencies, practical propagation limits lead to cell sizes that are as small as 1 mile in diameter. The small cell size promotes both efficient frequency reuse for commercial applications and signal security for military applications.

In a fixed wireless system, such as LMDS, each subscriber is assigned customer premise equipment (CPE) consisting of a fixed high-gain antenna, a block down-converter and a broadband digital modem. The CPE communicates with a nearby base-station via a fixed wireless link. Each base-station is then connected to a central office (CO) via either fiber or a point-to-point millimeter-wave link. Fiber backhaul is more advantageous, allowing the allocated wireless bandwidth to be dedicated to multipoint service.

A variety of architectures have been developed for the distribution of modulated millimeter-wave wireless radio signals over fiber [1] using either intensity modulation at millimeter wave frequencies or heterodyne techniques. Each of these approaches involves a cost/performance tradeoff.

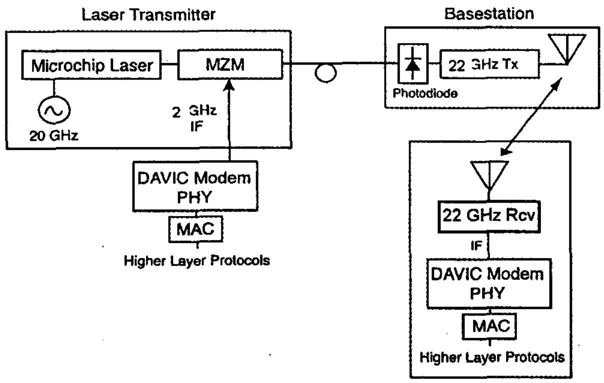
As an example of a typical performance analysis, we treat the downlink of a mode-locked chip laser [2] fiber radio architecture as shown in Fig. 1. For the purpose of demonstration, this link operates at a 22 GHz RF/wireless frequency.

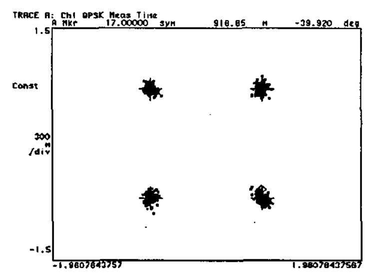
As shown in Fig. 1, the laser is actively mode-locked with an external reference, producing an optical comb spectrum with optical modes spaced at f_L= 20 GHz. A broadband modem [3] generates a 6 MHz bandwidth, QPSK modulated signal with Reed-Solomon (204, 188) coding at an IF frequency of f_{IF} = 2 GHz. The modem drives a Mach-Zehnder modulator at the IF frequency, adding upper and lower modulation sidebands to each of the mode-locked optical frequencies. At the base-station photodiode, the optical frequencies mix with each other to generate microwave signals of interest at, $f_{RF} = f_L \pm f_{IF}$ and f_L. The sum frequency (at f_{RF} = 22 GHz) is retained and amplified for transmission, while the other frequencies are filtered out. This self-heterodyne approach is resistant to the carrier suppression effect [4]; the first null does not occur until a fiber length of 580 km.

The energy per bit to noise ratio, E_b/N_0, required to achieve a fixed bit error rate (BER) is a key system performance parameter. The impairment due to the fiber link can be isolated from other system impairments by noting the increase in required E_b when the optical link is added into the system. Assuming an additive white Gaussian noise wireless channel, the error corrected BER is bounded below $<10^{-10}$ with a carrier to noise ratio (CNR) of 11 dB [5]. Adding in measured sources of optical layer impairment yields a required CNR of 11.5 dB on the wireless link as shown in Table 1. This implies an acceptable power penalty of only 0.5 dB. The optical link impairment results from amplitude and phase noise appearing on the self-heterodyned signals as well as thermal noise in the receiver. Both error vector magnitude (EVM) [6] measurements of the modulated QPSK signal (Fig. 2) and independent measurement of integrated amplitude, phase, and thermal noise of the un-modulated carrier yield identical amplitude and phase noise levels.

While the measurements discussed above qualify the system for single-channel operation, two-tone measurements are used for multi-channel qualification. The measured two-tone spur free dynamic range of the optical link was 79 dB-Hz$^{2/3}$. By permitting up to 1 dB of power penalty, we predict that we can operate up to 68 equal power incoherent subcarrier multiplexed channels with an acceptable level of composite triple beat (CTB) [7]. We note that the distortion performance with QPSK modulation will likely be better than the predicted un-modulated CTB.

In summary we have analyzed many of the technical issues involved in the development of a base-station to central office fiber link for last-mile wireless service. A power penalty due to the insertion of the fiber link has been determined for a chip laser based fiber radio downlink. Measurements have been performed to predict system performance, both for single channel and multi-channel operation.





(a)

Fig. 2. Measured 5 MBaud QPSK Constellation: EVM= 7% rms, 6% rms magnitude

Fig. 1. Layout of fiber radio link with microchip laser.

TABLE I

SINGLE CHANNEL OPTICAL LINK POWER PENALTY

Noise Source	Level
Integrated Amplitude Noise (laser)	-27 dBc
Laser Relaxation Oscillation (tone)	-35 dBc
Integrated Absolute Phase Noise (laser)	-38 dBc
Integrated Thermal Noise (photoreceiver)	-26 dBc
SUM OPTICAL LINK NOISE	-23 dBc
Wireless Link Noise (budgeted)	-11.5 dBc
TOTAL NOISE LEVEL (<10^{-10} BER)	-11 dBc
Power Penalty (Wireless Link Noise less Total Noise)	0.5 dB

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