FIBER RADIO: FROM LINKS TO NETWORKS

W. D. Jemison[a], E. Funk[b], M. Bystrom[c], P. R. Herczfeld[c], I. Frigyes[d], T. Berceli[d]

[a]Department of ECE
Lafayette College
Easton, PA 18042
610-330-5425
610-330-5059 FAX
w.d.jemison@ieee.org

[b]SFA, Inc.
Largo, MD

[c]Center for
Microwave/Lightwave
Engineering
Drexel University
Philadelphia, PA

[d]Budapest University of
Technology and
Economics
Department of Microwave
Telecommunications
Budapest, Hungary

Abstract - ***Various fiber radio link architectures have been developed to transmit modulated microwave or mm-wave signals over fiber. However, the issue of how to integrate these links into a network topology remains an open issue. This paper will address one method that can be used to develop a transparent fiber radio network.***

I. Introduction

The demand for broadband wireless communications is currently driving wireless networks to higher frequencies, including millimeter waves (mm-waves). The considerable path loss at these frequencies has led to either fixed cellular architectures with high directivity antennas or picocell architectures with short wireless path lengths. In the picocell approach basestations should be compact and inexpensive. A significant cost, complexity, and network management savings may be realized if signals are distributed via fiber at mm-wave frequencies.

This type of mm-wave fiber distribution can be regarded as the addition of an optical transport layer within the network hierarchy. Ideally, the optical layer would be a *transparent* layer positioned below the wireless physical (PHY) layer. As such it would operate transparently with both current and future wireless standards. This could include an array of wireless modulation and multiple access schemes.

We note that while various methods of transmitting a wireless signal on an optical carrier have been proposed [1-6], few have considered how this approach would fit in to an overall network topology.

In this paper, we consider a network topology where the optical layer connects a *multitude* of basestations to a central station or head end. The development of this type of network consists of two principal challenges:

1) The development of an optical layer that is transparent to the wireless PHY layer.
2) The development of a multi-cell distribution architecture that is transparent to wireless PHY, Media Access (MAC), and higher layers.

The primary purpose of this paper is to address the second challenge, that is, distribution of signals in a network of many picocells. In Section II, our previously reported work on a transparent fiber radio link for a single cell based on a mode-locked microchip laser will be briefly reviewed. This will be followed by a description of some of the issues associated with the interconnection of these links into development of a network in section III.

II. Overview of the Transparent Fiber Radio Link

Recently, Jemison, *et. al.* reported on the development of a transparent fiber radio link based on a mode-locked microchip laser [7-8]. The link is intended to provide transparent transport of the wireless PHY. The down-link consists of a laser transmitter that is located at the central station or head-end, a mm-wave basestation, and a mm-wave mobile transceiver as shown in Figure 1. The laser transmitter consists of an Nd: LiNbO3 microchip laser that is actively mode-locked using an external 20 GHz reference.

The output of the laser is externally modulated with the wireless signal at a 2.45 GHz intermediate frequency (IF). When wireless frequency division multiplexing (FDM) is used, the IF signal further consists of many modulated RF carriers.

Self-heterodyne in a high speed photodiode at the basestation, results in an upconverted wireless PHY signal at 22.45 GHz and a 20 GHz continuous wave (CW) signal. The wireless PHY signal is amplified, filtered, and transmitted wirelessly. The 20 GHz CW signal is used in the basestation as a local oscillator signal for the up-link (not discussed here).

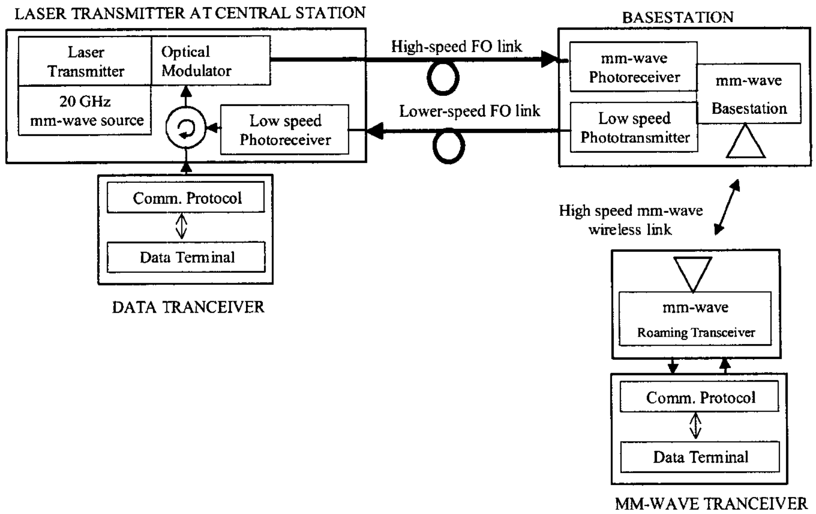

Figure 1. A Fiber Radio Link based on a mode-locked microchip laser

Funk, *et. al.* have analyzed and tested the performance limits of this system and determined it to be acceptable for demanding high speed mm-wave wireless communications [9]. Tests that were performed on the laser transmitter/photodetector combination included amplitude and phase noise characterization, error vector magnitude (EVM) and spur-free dynamic range measurements. Figure 2 shows a typical EVM result for a 22 GHz 10 Mb/s (channel rate) quadrature phase-shift keyed (QPSK) signal. The total measured EVM was 7% rms. We note that while these measurements were made at 22 GHz, our current fiber radio link work is moving to the 28 GHz LMDS band.

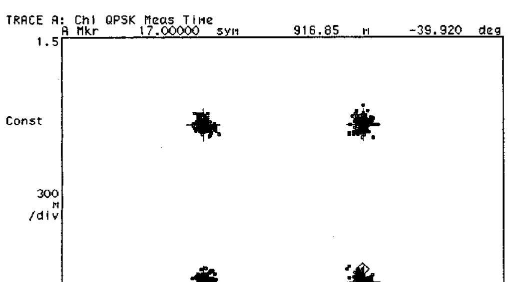

Figure 2. QPSK EVM Measurement

III. Transparent Fiber Radio Network

A block diagram of a typical fiber radio network is shown in Figure 3. It consists of a many picocells, each having its own wireless basestation. The picocell radius may be on the order of tens of meters. Each picocell is connected to the central station or head end by a fiber radio link.

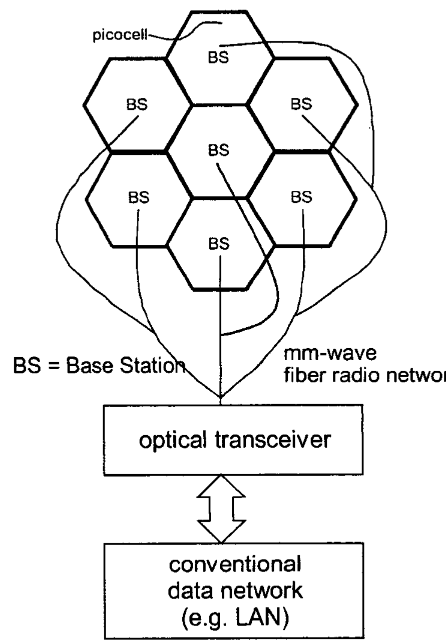

Figure 3. Fiber Radio Network

It is readily apparent that the development of a transparent fiber radio network is in many ways more challenging than developing a traditional wireless cellular network due to the addition of the optical transport layer. Conceptually, we consider the optical transport layer to be a transparent layer, positioned below the wireless physical layer as shown in Figure 4.

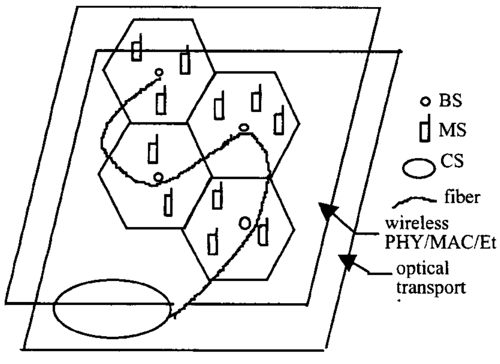

Fig. 4 layered structure of a fiber radio network (BS = Basestation, MS = mobile station, CS = Central station)

Thus, the two primary challenges associated with the optical layer are:

1) Passive routing of the signals from the central station to the proper picocell basestation.
2) Passive routing of the signals from multiple basestations to the central station.

The first challenge is considered more difficult of the two, and will be addressed in greater detail.

Multiplexing Options for Signal Distrubution to Picocells

Several multiplexing schemes are possible to transparently distribute the optical signals from the optical transmitter to the correct picocell.

The simplest and most obvious one is Optical Space Division Multiplexing (OSDM) where a separate fiber is provided to each basestation (the "optical" descriptor will be used to avoid confusion with media access schemes that may be applied at the wireless layer). This method is ruled out for a variety of reasons including the need for excessive replication of fiber runs and optical transmitter hardware. Likewise, time division multiplexing at the optical layer could not be accomplished passively without causing disruption to the wireless PHY and MAC layers.

Therefore, the remaining optical layer multiplexing options include wavelength division multiplexing (WDM), and subcarrier multiplexing (SCM) of the mm-wave signal on the optical carrier. Each of these will be briefly considered under the constraint of keeping the basestation complexity and cost low; a requirement for a pico-cellular approach employing a large number of basestations.

WDM, while suitable for long-haul optical communications, is not currently viable for fiber radio networks due to the additional complexity and cost associated with the optical filters that would be required in each basestation. Crosstalk between WDM channels has also proven to be a significant limitation in WDM CATV architectures [10].

SCM appears to be the logical solution [11]. In this approach, RF signals intended for each cell are multiplexed into a *block* of channels covering the full wireless bandwidth as used in an individual cell. The block bandwidth can be up to several hundred megahertz. This multiplexing occurs at the wireless network layer and is subject to the rules of spectrum usage and wireless multiple access. Then, each channel *block*, as intended for a given base-station, is further modulated onto a unique optical sub-carrier.

In our mode-locked optical transmitter, this would be accomplished as follows. A separate microwave IF frequency is assigned to each basestation channel block. Each of the IF signals are then modulated onto the optical signal at the MZM input. After detection in an individual basestation, self-heterodyning in the photodetector directly up-converts each individual channel block to a unique mm-wave frequency. Figure 5 illustrates this approach as applied to the 28 GHz LMDS band. Note that the frequencies used serve to illustrate the approach, however, a more detailed trade-off study would be required to finalize the frequency selection due to cross modulation of the IF signals in the photodetector.

It is important to note that the basestation utilizes a cell-specific LO frequency to upconvert the relevant block to 28 GHz. A carefully designed filter would follow the upconverter, ensuring that only the intended block of channels is radiated. A block spacing on the order of 1 GHz would be required to ensure rejection of adjacent channel blocks by the filter. Similarly, double up-conversion architectures could be envisioned in order to further reduce the block spacing.

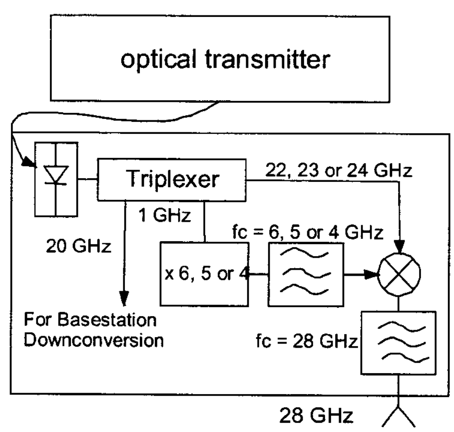

Figure 5. Simplified basestation architecture for the SCM network approach

In Figure 5, note that the channel block intended for the *n*th picocell is modulated onto the *n*th mm-wave sub-carrier, with all carriers appearing on the fiber simultaneously. The optical transmitter also delivers an unmodulated 1 GHz tone across the fiber. This tone is multiplied up to the correct LO frequency. Note that subcarriers are widely spaced at 2, 3, and 4 GHz. Each basestation has a triplexer designed to extract three signals: 1) the 20 GHz local oscillator signal, 2) the 1 GHz local oscillator signal, 3) and the upconverted (due to photodetector self-heterodyning) sub-carriers at 22, 23, and 24 GHz. The 1 GHz tone is then multiplied by a factor of 6, 5, or 4 to be used as an LO to mix the 22, 23, or 24 GHz, respectively, up to the desired transmit frequency of 28 GHz. The filter following the upconverter/mixer passes only the intended channel block at 28 GHz.

From a cost and complexity perspective, note that the basestation is easily configurable. The architecture allows the same triplexer and filters to be used in all basestations. The basestation can easily be configured to select an arbitrary channel block by simply changing the multiplication factor used to generate the LO.

IV. Conclusions

Significant progress has been made in the realization of mm-wave fiber radio links employing a mode-locked microchip laser. These links have been shown to possess performance characteristics necessary to meet demanding high-speed communications and are transparent to the type of digital modulation used to modulate the wireless signal. This paper discusses one approach to migrate these fiber radio links to transparent fiber radio networks. In order to practically implement this approach, a modification to the basestation architecture is necessary. This modification involves using a conventional electrical up-conversion. This simple approach allows a transparent fiber radio network consisting of a small to moderate number of picocells to be practically developed. There are several variants to this approach that are currently being investigated.

Acknowledgements

This work was supported by the Office of Naval Research (ONR) under the following grants: # N00014-00-1-0781, #N0014-99-1-0865

References

[1] H. Ogawa, D. Polifiko, and S. Banba, "Millimeter-wave fiber optic system for personal radio-communication," *IEEE Trans. Microwave Theory Tech.*, Vol. 40, pp. 2285-2293, 1992.

[2] Z. Ahmed, D. Novak, Rod B. Waterhouse, and Hai-Feng Liu, "37 GHz fiber-wireless system for distribution of broad-band signals," *IEEE Trans. Microwave Theory Tech.*, Vol. 45, pp.1431-1435, 1997.

[3] G. H. Smith, D. Novak, C. Lim, and K. Wu, "Full-duplex broadband millimeter-wave optical transport system for fibre-wireless access," *Electron. Lett.*, Vol. 33, pp. 1159-1160, 1999.

[4] D. Wake, I. C. Smith, N. G. Walker, I. D. Hamming, and R. D. Carver, "Video Transmission over a 40 GHz radio-fiber link," *Electron. Lett.*, Vol. 28, pp. 2024-20250, 1992.

[5] J. O'Reilly and P. Lane, "Remote delivery of video services using mm-waves and optics," *J. Lightwave Technol.*, Vol. 12, pp. 369-375, 1994.

[6] J. Park, and K. Y. Lau, "Millimeter–wave (39 GHz) fiber-wireless transmission of broadband multi-channel compressed digital video," Electron. Lett., Vol. 32 pp. 474-476, 1996.

[7] W. D. Jemison, P. R. Herczfeld, W. Rosen, A. Vieira, A. Rosen, A. Paolella, A. Joshi, "Hybrid Fiberoptic-Millimeter-Wave Links," *IEEE Microwave Magazine*, Vol. 1, June 2000, pp. 44-51.

[8] W. D. Jemison, P. R. Herczfeld, E. Funk, K Williams, A. Paolella, A. Vieira, J. SooHoo, W. Rosen, J. Adams, A. Rosen, A. Joshi, D. Novak, R. B. Waterhouse," Fiber Radio – System Considerations and Performance Evaluation," submitted to *IEEE Transactions on Microwave Theory and Techniques.*

[9] E. Funk, P. R. Herczfeld, W. D. Jemison, A. Vieira, and K. Williams, "Performance Limits of a Hybrid Fiber/Millimeter Wave Wireless System," to be presented at *2001 International Microwave Optoelectronics Conference*, Belim, Brazil, August 6-10, 2001.

[10] Mary R. Phillips, and Daniel M. Ott, "Crosstalk due to fiber nonlinearities in WDM CATV lightwave systems," *J. Lightwave Technol.*, Vol. 17, pp. 1782-1792, 1999.

[11] T. Berceli, G. Járó, T. Marozsák, S. Mihály, E. Udvary, Z. Varga, A. Zólomy: "A Novel Optical Cellular Millimeter Wave Radio System", Proceedings of the 29th European Microwave Conference, pp. 230-233, München, Germany, October, 1999.