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Radio over Fiber as a Cost Effective Technology for Transmission of WiMAX Signals

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***Abstract*—**In this paper, an overview of the radio over fiber (RoF) technology is provided. Obstacles for reducing the capital and operational expenses in the existing systems are discussed in various perspectives. Some possible RoF deployment scenarios for WiMAX data transmission are proposed as a means for capital and operational expenses reduction. IEEE 802.16a standard based end-to-end physical layer model is simulated including intensity modulated direct detection RoF technology. Finally the feasibility of RoF technology to carry WiMAX signals between the base station and the remote antenna units is demonstrated using the simulation results.

***Keywords*—**IMDD, Radio over Fiber, Remote Antenna Unit, WiMAX.

I. Introduction

WIRELESS operators are increasingly challenged to accommodate a great diversity of data oriented mobile services and the growing number of end users. To meet the higher data rate, WiMAX is a key and promising technology for the delivery of last mile wireless broadband access as an alternative to wired broadband like cable and DSL. WiMAX provides fixed, nomadic, portable and mobile wireless broadband connectivity. The technology provides up to 3 Mbps broadband speed without the need for cables which is sufficiently enough bandwidth to simultaneously support hundreds of businesses with T-1 speed connectivity and thousands of residences with DSL speed connectivity. Along with providing the ever-increasing traffic demands, the operators must find ways to reduce capital and operational expenses of the networks. In response to the cost issue, some major architectural trends such as distributed base station (BS) or BS hostelling are beginning to emerge as enablers for reduced-cost, next-generation wireless access networks. The expansion in broadband radio services like WiMAX, has also led to a renewed focus on the optimum network infrastructure capable of transmitting signals between BSs and antennas.

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The use of centrally located BS hostel that connect several remote antenna units (RAU) via lossless optical fiber link dramatically reduces costs associated with site acquisition, site leasing, and energy consumption. In addition, allowing several remote antenna sites to be controlled by one central BS offers more rapid and more scalable network deployment. As a result, interest has been grown on radio over fiber (RoF) systems, which employ analog fiber optic links to transport radio frequency (RF) signals between BSs and RAUs. These have potential advantages in allowing transmission of WiMAX signals in their raw form to antennas at which no RF signal processing beyond amplification is required, which leads to a simplification of the transmission equipment. Since laser diodes of bandwidth of 7 GHz are now readily available, directly modulated semiconductor lasers and single mode fiber (SMF) are preferred for most wireless standards (GSM, WiFi 802.11 a/b/g, UMTS, or WiMAX) due to low transmission losses, engineering simplicity and low cost. Research on transmission of radio signals for various standards has been carried out by several research groups and some significant results are reported in [1]-[3]. Our present study focuses on the aspects of the wireless broadband system deployment, where there are still some stones to be turned to reduce the capital and operational expenses. In the following sections, we discuss about some problems associated with the conventional BSs and potentiality of RoF technology to carry WiMAX broadband wireless data cost efficiently.

II. Radio over Fiber Technologies

The use of optical fiber links to distribute RF signals from a central BS to multiple RAUs is the basis of RoF technology. RF signal processing functions such as frequency up-conversion, carrier modulation, and multiplexing are performed at the BS, and immediately fed into the antenna. RoF makes it possible to centralize the RF signal processing functions in one shared location and then to use optical fiber to distribute the RF signals to the RAUs. In this way, the RAUs are simplified significantly, as they only need to perform optoelectronic conversion and amplification functions. The key advantages of analog optical links are the reduced complexity of the transmission equipment close to the antennas, a minimized visual impact of these equipments, and lower operational costs of the network due to infrastructure sharing among different BSs. The deployment of optical fiber technology in wireless networks provides great potential for increasing the capacity and QoS without largely occupying additional radio spectrum. By using RoF technology, the capacity of optical networks can be combined with the flexibility and mobility of wireless access networks.

Transportation of radio signals over fiber can be done in several ways. The simplest way is to modulate the light intensity of the optical source directly by the radio signal. At the remote antenna site, photodetector and bandpass amplifier converts the received optical signal to radio signal to be radiated by the antenna. This technique is termed as intensity modulated direct detection (IMDD). However, large bandwidth and linearity is required for the laser transmitter and the receiver. Also compensation techniques for fiber dispersion may be needed at higher RF frequencies and longer fiber lengths. Thus the intensity-modulation scheme is restricted to the low/medium RF range. Alternatively, optical frequency conversion can be done to generate the microwave signal at the remote antenna site. For the frequency conversion, two narrow-linewidth laser diodes can be deployed, one of which is intensity modulated with the data signal. The optical frequency spacing between these two lasers is carefully kept equal to the desired microwave frequency. After traveling through the fiber link, the heterodyning of the two optical signals in the photodiode generates the modulated microwave carrier. However, the linewidth of the microwave signal is equal to the sum of the linewidths of the two laser diodes, and may exceed the requirements for adequate detection of the usually multilevel signal modulation format (such as multi-level QAM). Hence the linewidth of the laser diodes needs to be very small, which is achievable by injection locking. A second option of optical frequency conversion method uses just a single laser followed by a Mach Zehnder Interferometer (MZI) modulator which is biased at its inflexion point (v_{π}) and is driven by a sinusoidal signal at half the desired microwave frequency [4]. At the MZI's output, a two-tone optical signal emerges with a tone spacing equal to the microwave frequency, and with suppressed optical carrier. When modulating the laser with the data signal, heterodyning in the photodiode at the receiver generates the modulated microwave signal. This method suppresses the phase noise of the laser diode, and hence creates a clean microwave. However, among the above optical transmission techniques, IMDD is the simplest design and lowest cost. In the next section, RoF deployment scenarios are discussed where WiMAX data are transmitted through the fiber using simple IMDD.

III. RoF Deployment Scenario

Rapidly increasing demand for broadband services like high speed internet access and mobile multimedia forcing towards smaller radio cell size. Smaller cells imply that more antennas are needed to cover a certain area. Such an area may include the rooms in a residential home, a hospital, an office building, an airport lounge, or a conference site, etc. When it needs so many antenna sites, it becomes economically attractive to locate the microwave signal generation and modulation at a central BS from where the radio signals will be transmitted to

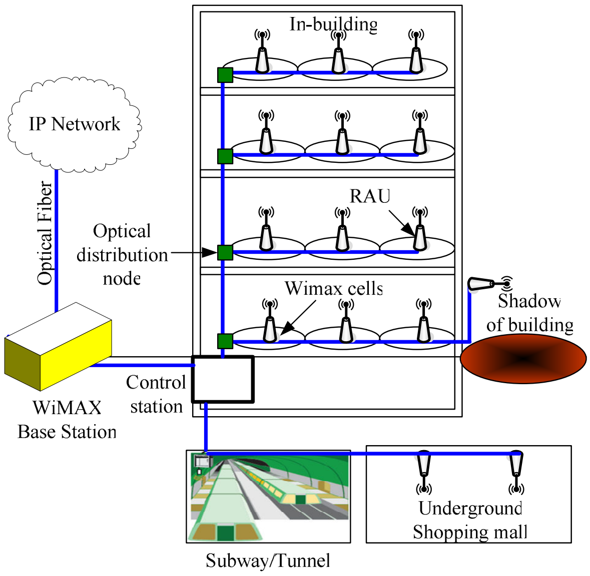

Fig. 1 In building deployment scenario of WiMAX over RoF

the RAUs using RoF. The antenna units have to do the simple optical-to-electrical conversion, and to emit and receive the wireless signal. Centralizing the sophisticated signal handling process can bring many advantages in operating, maintaining and upgrading wireless networks. In WiMAX service provisioning, several approaches can be taken to utilize the benefits of RoF. Two particular deployment scenarios are given in Fig. 1 and Fig. 2. Fig. 1 shows indoor WiMAX cells, inside the residential buildings, offices, underground subways, tunnels, or shadowed areas, are served by the distributed antenna systems, where the RAUs are fed by WiMAX over

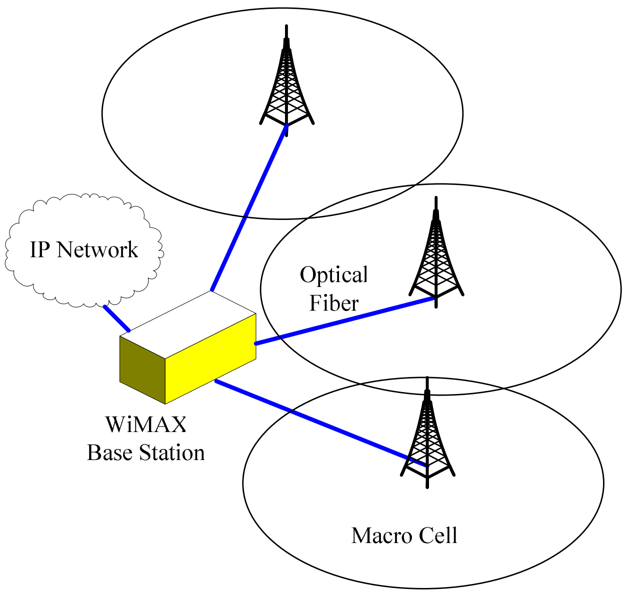

Fig. 2 Base station hostelling

fiber links from the WiMAX BS via a control station. BS hostelling can be another cost reducing deployment of RoF as shown in Fig. 2, where multiple macro cells are covered by a central BS and RoF links are used to feed the antenn in each cell. This type of deployment scenario results in lower capital and operational cost for the service providers.

IV. Cost Effectiveness of RoF

Conventional BS drives the antennas over lossy electrical cable which necessitates the location of the BS very close to the antennas. This can create problems with acquiring suitable sites for coverage extension. It also increases the capital and operational expenses due to site purchasing or leasing, new BS installation and maintenance. Utilizing the idea of RoF and BS hostelling, one BS can control several RAUs and new BS is not required for coverage extension. The additional antennas can be served from the existing BS close to the cell tower. This dramatically reduces the requirements for cell site footprint and the cost of site acquisition.

The electrical cables that drive the antenna are responsible for large amount power loss of the BS. The loss in these cables and their associated connectors can range from a typical value of 3db to as much as 10dB in extreme cases which means 50% to 90% of the radio transceiver's output power is dissipated in cable transmission [5]. All this extra power required to drive the electrical feeder cables means that higher output power amplifiers must be deployed. These high power amplifiers are more expensive and have poor operating efficiencies of around 10%, further compounding the problem of high energy consumption by BS. By feeding the RAUs with optical fiber, transmission to the antenna location can be made virtually almost loss-free except some small amount of loss in the short electrical cable connections between the RAUs and the antennas.

In the conventional BS, the power dissipated as heat by the low-efficiency amplifiers requires the BS enclosure to have sophisticated metal enclosures with climate control facilities such as air conditioning, which also increases the expenses. RoF offers large reduction in the amount of thermal energy dissipated by the system. This means that the RAU can be designed without the need for any expensive climate control facilities at the remote site. In addition, the BS hostel can be installed in the more benign environmental conditions of an indoor facility. From the above discussion, it is clear that RoF technology has lots of possibilities to reduce the capital and operational expenses. In order to check the feasibility of transmission of IEEE 802.16a based WiMAX data through optical fiber link, we have done the simulation study.

V. IEEE802.16a Physical Layer Simulation Model

Fig. 3 below depicts the Physical layer of 802.16a and a classical IMDD optical link model for transmitting the signal to RAU. The laser diode is modulated by the RF signal in the downlink path. The resulting intensity modulated optical signal is then transmitted through the single mode fiber towards a RAU. At the RAU end, the received optical signal is converted to RF signal by direct detection through a PIN photodetector. The signal is then amplified and radiated by the antenna. The Uplink signal is transmitted from the RAU to the BS in a similar way.

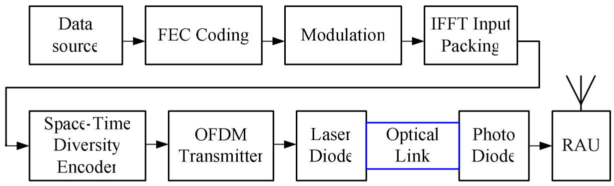

Fig. 3 IEEE 802.16a model with RoF implemented using Simulink

VI. Laser and Photodiode Model

The laser is usually a significant source of noise and distortion in an ROF link, and laser diode normally exhibits nonlinear behavior. When it is driven well above its threshold current, its input/output relationship can be modeled by a Volterra series of order 3 [6]. However, if the signal current dynamic range is within the linear region of the laser diode, it obviously will show linear response. In our present simulation we assume ideal linear characteristic of the laser diode. Output optical power versus current can be given as:

$$P_{opt}(I) = (hf / e)\eta_L (I(t) - I_{th}) \qquad (1)$$

where $I(t)$ is input current of the microwave signal including the dc bias, I_{th} is diode threshold current, h is Planck constant, f is frequency in hertz, e is charge of an electron, and η_L is laser quantum efficiency [6]. The detection of transmitted lightwaves is performed primarily by the photodetector. In most cases the received optical signal is quite weak and thus electronic amplification circuitry is used, following the photodiode, to ensure that an optimized power signal-to-noise (SNR) is achieved. The PIN photodiode and receiver total noise are calculated and superimposed over the ideal photodiode signal current. To evaluate the effect of noise added during the amplification process, a mathematical model explained in [7] has been used in our simulation. The noise in photodiode includes quantum shot noise i_{sh}, dark current noise i_{dk}, and the thermal noise i_{th}. The total current generated by the photodiode when optical power falls on it is expressed by:

$$i_{total} = i_{sig} + \sqrt{\left\langle i_{noise}^{2} \right\rangle} \qquad (2)$$

where mean squared noise $\left\langle i_{noise}^{2} \right\rangle = \left\langle i_{sh}^{2} \right\rangle + \left\langle i_{dk}^{2} \right\rangle + \left\langle i_{th}^{2} \right\rangle$.

It has been demonstrated that both the shot noise and dark current noise contributions from the bulk material of the photodiode follow a Poisson process, and is thus random. For that reason the mean squared of these noise sources are considered for the calculations. The noise sources can be expressed mathematically as follows:

$$\left\langle i_{sh}^{2} \right\rangle = 2qI_{sig}B,\ \left\langle i_{dk}^{2} \right\rangle = 2qI_{dk}B,\ \left\langle i_{th}^{2} \right\rangle = (4K_B TB / R)$$

where I_{dk} = 25nA, is assumed to be dark current obtained from the DSC10H PIN photodiode datasheet of

Semiconductor.Inc, B is the photodiode 3dB bandwidth, K_B is Boltzmann's constant, T is the absolute temperature (ºK), and R is the photodiode load resistor assumed to be 50 ohm for ultra wideband receiver.

A total normalized mean squared noise is found to be 4.44×10^{-4}. In order to ensure the accurate recovery of data, amplification of photodiode current is essential which incorporates additional noise. For this amplification, a noise gain of 11% of the maximum current is added to the current waveform. This amplifier also contributes a 33dB gain which translates to a power gain of 44.67.

VII. Simulation Results

In order to study the feasibility of transmission of WiMAX signals through single mode fiber by IMDD, the simulation was carried out using Simulink model. The simulink model consisted of IEEE 802.16a end-to-end physical layer. More specifically, it modeled the OFDM-based physical layer for downlink, supporting all of the mandatory coding and modulation options. It also consisted the option of using space time block coding (STBC) for providing transmit diversity. The laser and photodiode are modeled using (1) and (2), respectively. The parameters and configurations of the IEEE 802.16a physical layer that are used for the simulation, are listed in Table I.

TABLE I
SIMULATION PARAMETERS AND CONFIGURATIONS

Parameter/Configuration	Value
Channel bandwidth	3.5 MHz
Number of OFDM symbols per burst	2
Cyclix prefix factor	1/8
Forward error correction code	Convolutional at rates ½ and ¾
Modulation	QPSK, 16-QAM, 64-QAM
OFDM	192 sub carriers, 8 pilots, and 256 point FFT
Space time block coding	Alamouti's scheme
Channel	AWGN
Fading	Rayleigh

Fig. 4 show the simulation results for bit error rate Vs different SNR values. Result for 64-QAM with ¾ coding rate is shown here only. Transmit diversity was also provided. It is seen from the figure that BER is decreased with increasing the SNR. At SNR value of 21, BER is found to be 6.018×10^{-5}.

BER Vs SNR results for 64-QAM and ¾ coding rate and without transmit diversity are show in Fig. 5. Here, similar behavior is obtained as before. However, BER performance is found to be better in case of transmit diversity is added. These results imply that RoF can be a successful enabling technology for transmitting WiMAX data.

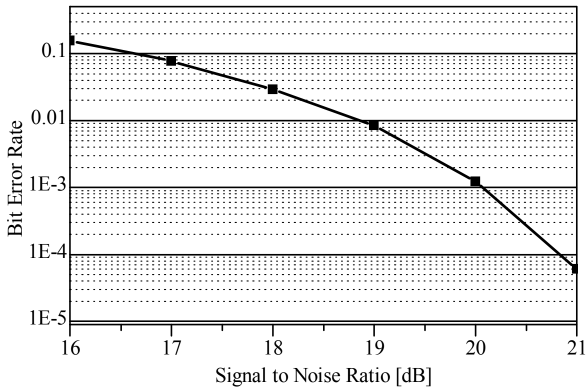

Fig. 4 Bit error rate Vs signal to noise ratio with 64QAM modulation and ¾ coding with transmit diversity

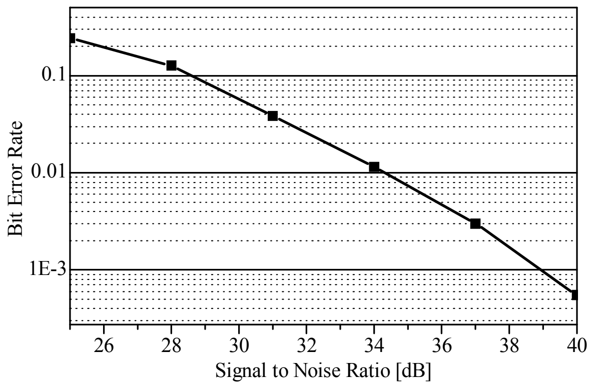

Fig. 5 Bit error rate Vs signal to noise ratio with 64 QAM modulation and ¾ coding without transmission diversity

VIII. Conclusion

Objective of this study was to investigate RoF technology for the transmission of WiMAX signals to the RAUs and hence to suggest feasible RoF deployment scenarios to reduce the capital and operational expenses of the service providers. After detailed study, some factors responsible for increasing the cost such as installation of large number of BSs, loss in electrical cables, climate control in BSs etc. are identified. In order to solve these problems, RoF can be a promising technology. With the concept of BS hostelling and indoor WiMAX cells, RoF can be a cost efficient enabling technology for WiMAX broadband service.

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