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Radio over Fiber (RoF) Technology

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Abstract- Present trends for future provision of broadband and communication services over wireless media in both mobile and fixed cellular networks are to reduce cell size to accommodate more users and to operate in the microwave/millimeter wave (mm-wave) frequency bands to avoid spectral jamming in the lower frequency bands. Radio-over-fiber (RoF) technology is a favorable solution to the problem. Radio over fiber (ROF) is an essential technology in which light is modulated with radio frequency signals and transmitted over the optical fiber to attain wireless access. This paper gives the brief introduction of radio over fibre technology used in a communication system. In this paper architecture, benefits, applications and limitations of the radio over fibre technology are discussed in detail.

Index Terms- RoF; Base Station (BS); Radio Access Unit (RAU);Intensity Modulation with Direct Detection(IM-DD)

1. INTRODUCTION

In today's world, users demand for services that provide fast transmission and flexible solutions. Ways to increase capacity of wireless communication systems may include deploying smaller cells or increasing the carrier frequencies. But a smaller cell size leads to a huge number of Base Stations(BS) or Radio Access Points(RAP) to attain the wide coverage required for pervasive communication systems.[1] Therefore, the installation and maintenance costs of such systems are very high. Higher carrier frequencies may also lead to increase in costs of radio front-ends in the BSs. Radio-over-fibre (RoF) technology presents itself as a promising solution. Since it's validation for cordless or mobile telephone service in 1990[2], extensive research has been carried out to examine its limitation and cultivate new and high performance RoF technologies.

RoF (Radio over Fiber) Technology is the integration of microwave and optical networks (Fig.1)[3]. It develops into a broadband access network using an integrated intelligent system of radio-over-fibre and distributed antennas. Its working principle uses light to modulate electrical signal (radio signal) and transmit it over an optical fiber link to distribute radio signals from a central location to the remote stations. RoF encrypts different types of wireless signals into a beam

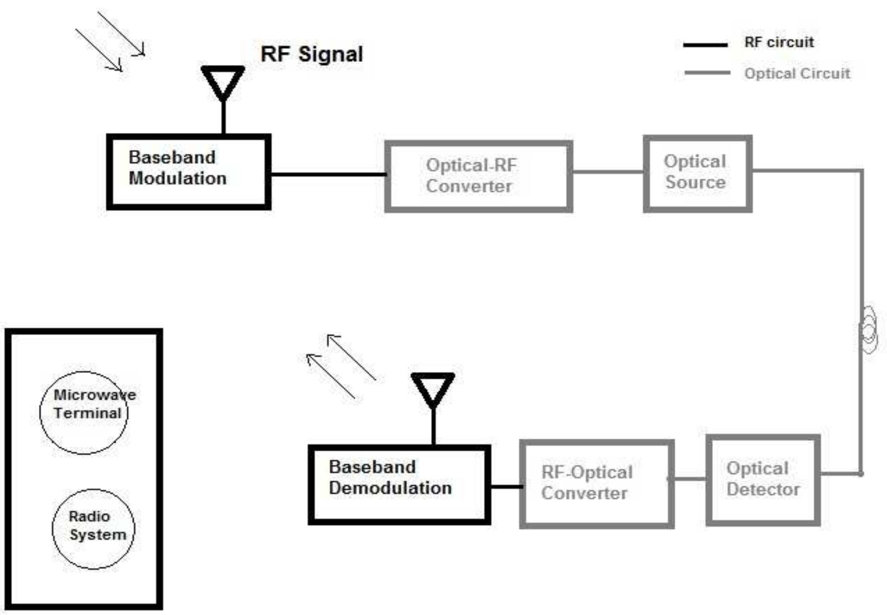

Fig. 1. Basic diagram of Radio over Fiber Technology

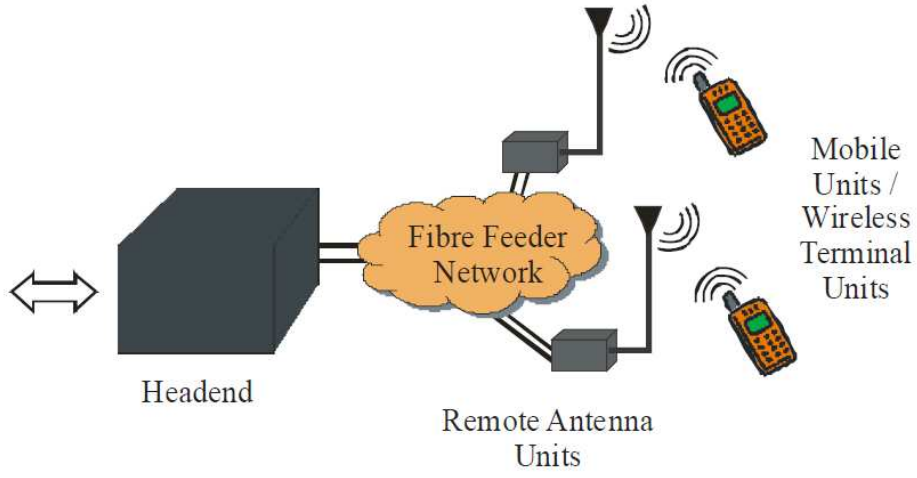

Fig. 2. The Radio over Fibre System Concept

of light and sends them down a fibre-optic cable. At the end of the fibre, these signals are aired using a radio antenna, thus facilitating wireless access. For instance, 3G and Wi-Fi are accessed simultaneously from the same antenna. Radio-over-Fibre (RoF) technology demands the use of optical fibre links to distribute RF signals from a central location (head-end) to Remote Antenna Units (RAUs). Hence, RoF centralize the RF signal processing functions in one shared location (head-end), and then to use optical fibre to distribute the RF signals to the RAUs, as shown in Figure 1. Optical fibre offers low signal loss (0.3dB/km for 1550 nm, and 0.5dB/km for 1310 nm wavelengths). Low signal loss leads to a significant simplification in RAUs, as they are needed only to perform optoelectronic conversion and amplification functions. This centralization of RF signal processing functions allows dynamic allocation of resources, equipment sharing, and simplified system operation and maintenance. Such benefits will eventually result in ease and speed of installation as well as operational savings [4].

The rest of the paper is organized as follows: Section II describes the basic RoF system architecture. Section III discusses the benefits associated with this technology, and section IV lists the limitations. Section V presents the conclusion.

2. BASIC ROF SYSTEM ARCHITECTURE

A basic RoF system is shown in Figure 3. In the downlink transmission, RF signal directly modulates the laser diode in the Central Site (CS), and the

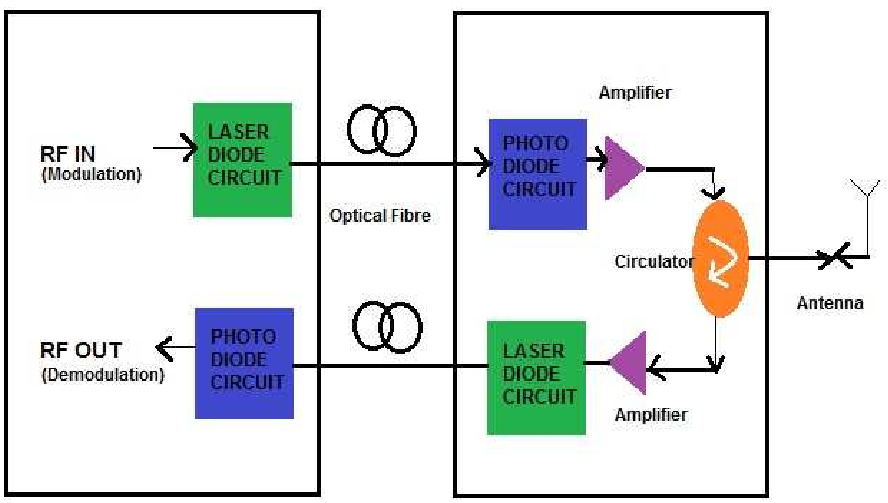

Fig. 3. Radio over fiber system architecture

resulting intensity modulated optical signal is subsequently transmitted through an optical fiber to the base station (BS). At the BS, the signals are demodulated directly by using a PIN photo detector or any other photodiode and thus the RF signals are recovered. Moreover, they are then amplified and radiated by an antenna. The uplink signal from the MU is transmitted from the RAU to the head-end in the same way. This technique of transporting RF signals over the fibre is called **Intensity Modulation with Direct Detection (IM-DD)[1]**, and is the simplest form of the RoF link. The reverse process is carried out at the BS, where the RF signals from the antenna directly modulate the laser diode and then the resultant optical signals are transferred through an optical fiber to the CS. At the CS, the intensity modulated optical signals are directly demodulated by employing a photodiode and thus the RF signals are recovered. Then the signals are amplified and further processed. The optical carrier's wavelength is usually selected to match with either the 1.3 µm window, in which a standard single-mode fibre has least dispersion, or the 1.55 µm window, when its attenuation is the smallest. The basic configuration of RoF link system consists of a central station and a remote access unit (RAU) connected by a single mode fiber[5].

3. BENEFITS

Some of the advantages and benefits of the RoF technology are discussed follow:

3.1. *Less signal attenuation:*

Electrical distribution of high-frequency microwave signals lines is challenging and expensive either in free space or through transmission [6]. Hence, expensive regenerating equipment is required in bestowing high frequency radio signals electrically over elongated distances. Their distribution via the transmission lines is not feasible even for short distances in the case of mm-waves. The substitute solution to this problem is to distribute signals at low intermediate frequencies (IF) or baseband signals from the switching center to the BS. These are then up-converted to the preconditioned microwave or mm-wave frequency at each base station, later amplified and then radiated. This system outline is the identical to the one used in the distribution of narrowband mobile communication systems. Since, high performance Local Oscillators (LOs) would be required for up conversion at each base station, it complicates the base stations with constricted performance requirements. Nevertheless, since we know optical fibre offers very low loss, RoF technology can be used to achieve both low-loss distribution of mm-waves, and simplification of RAUs takes place at the same time A signal doesn't need a repeater for a distance of almost 50km.

3.2. *Higher Bandwidth*

Optical fibre can support dramatically huge bandwidth. The three main transmission windows which offer low attenuation are namely the 850 nm, 1310 nm, and 1550 nm wavelengths. Apart from low attenuation, the huge bandwidth provided by optical fibers has other benefits too. Signal processing at high speed that may be more difficult or impossible to do in electronic systems can be done because we are provided with high optical bandwidth. Or we can say that some of the demanding microwave functions such as filtering, mixing, up- and down-conversion, can be realized in the optical domain [7]. For example, mm-wave filtering can be attained by first converting the electrical signal to be filtered into an optical signal, then carrying out the filtering by using optical components such as the Mach Zehnder Interferometer (MZI) or Fibre Bragg Gratings (FBG), and then transforming the filtered signal back into electrical form [8].

3.3. *Immunity to electromagnetic interference*

Electromagnetic Noise does not affect fiber optic cables. This is very important property of optical fibre, especially for microwave transmission. Signals are transmitted in the form of light through the fibre [9] and thus, since there is no involvement of copper fibers. It makes it immune to electromagnetic interferences. Because of this immunity, fibre cables are favored even for short networks at mm-waves.

3.4. *Easy installation and maintenance*

In RoF systems, complicated and costly equipment is kept at the headend, thereby making the RAUs simpler. For example, most RoF techniques doen not need a LO and related equipment at the RAU. In such cases RAU is made up of a photo detector, an RF amplifier, and an antenna. Modulation and switching equipment is kept at the headend and is shared by several RAUs. This structure, therefore, leads to smaller and lighter RAUs, and thus reduces system installation and maintenance costs[4][10].

3.5. *Dynamic resource allocation*

It is possible to allocate capacity dynamically, since the switching, modulation, and other RF functions are executed at a centralized headend. For example, in a RoF distribution system for GSM traffic, more capacity can be allocated to an area (e.g. market or office area) during peak times and then re-allocated to other areas when off-peak (e.g. to populated residential areas in the evenings. Since, most of the people will return home till evenings). This can be achieved by assigning optical wavelengths through Wavelength Division Multiplexing (WDM) according to need[11].

3.6. *Reduced power consumption*

Reduced power consumption is a result of having simple RAUs with reduced equipment. Most of the complex equipment is placed at the centralised headend. In some applications, the RAUs are operated in passive mode [12].

4. LIMITATIONS

As RoF includes analogue modulation and detection of light, it is primarily an analogue transmission system. Therefore, signal impairments such as noise and distortion that are prevalent in analogue communication systems, are significant in RoF systems as well. These impairments limit the Noise Figure (NF) and Dynamic Range (DR) of the RoF links[5]. DR is an essential parameter for mobile (cellular) communication systems such as GSM. The power received at the BS from the MUs varies widely [4]. This means that, the RF power received from a MU which is near to the BS can be much higher than the RF power received from a MU that is several kilometres away, though within the same cell. This phenomenon occurs due to the effect of noise and distortion over a large transmission distance. The noise sources in analogue optical fibre links comprises the laser's Relative Intensity Noise (RIN), the laser's phase noise, the photodiode's shot noise, the amplifier's thermal noise, and the fibre's dispersion. In Single Mode Fibre (SMF) based RoF, systems, chromatic dispersion occurs which may limit the fibre link lengths leading to increased RF carrier phase noise [13]]. In Multi-Mode Fibre based RoF systems, modal dispersion occurs which limits the available link bandwidth and distance. The radio system being distributed may be digital (e.g. WLAN, UMTS), using widespread multi-level signal modulation formats such as xQAM(Quadrature Amplitude Modulation), or Orthogonal Frequency Division Multiplexing (OFDM).

5. CONCLUSION

In this paper, the analysis of ROF technology has been elucidated and the basic architecture of radio over fiber technology has been explained. The main benefits of ROF technology are low attenuation losses, ease of installation and maintenance, a large bandwidth and greatly reduced power consumption. The drawbacks include signal impairments such as noise and distortion. With a high bandwidth and flexible considerations

RoF indeed has a great potential for further research.

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