Radio over Fiber Technology – A Review

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ABSTRACT: Wireless network based on Radio over Fiber (RoF) technology has been proposed as a promising cost effective solution to meet ever increasing user bandwidth and wireless demands in broadband, interactive, and multimedia wireless services. In recent years, considerable attention has been devoted to the merging of radio frequency and optical fiber technologies aiming to increase the capacity and mobility of the access network. Since, it was first demonstrated for cordless or mobile telephone service in 1990, a lot of research has been carried out to investigate its limitations and develop new and high performance RoF technologies. This paper gives the comprehensive review of radio over fiber technology used in communication system. Architecture, applications, advantages and limitations of RoF technology are also discussed in this paper.

KEYWORDS: Radio-over-fiber (RoF); Base Station (BS); Central Office (CO); Intensity Modulation and Direct Detection (IM-DD); Mobile Unit (MU); Remote Antenna Unit (RAU).

I. INTRODUCTION

Optical communication is a form of communication that uses light as the transmission medium. The RF spectrum is congested, and the provision of broadband services in new bands is increasingly more difficult. Radio over fiber is an analog optical link to transport information over optical fiber by transmitting modulated RF signals to and from central station to base station [1]. This modulation can be done directly with the radio signal or at an intermediate frequency. RoF systems are used basically because of their low loss and extremely wide bandwidth and robustness. Radio over fiber can use millimeter waves and serve as a high speed wireless local or personal area network. RoF systems are now being used for enhanced cellular coverage inside buildings. RoF reduces radio system costs because it simplifies the remote antenna sites and enhances the sharing of expensive radio equipment located at central stations. The frequencies of the radio signals distributed by RoF systems span a wide range (usually in the GHz region) and depend on the nature of the applications.

Nowadays, due to the various demands of system users, data capacity for wireless communication has been radically expanded from voices and simple messages to multimedia with evolutionary future services. Radio over Fiber (RoF) systems could be the answer to many urgent needs of the telecommunication networks, as they could provide the necessary bandwidth for the transmission of broadband data to end-users, other benefits are low attenuation loss, and immunity to radio frequency interference [2 - 3]. In a RoF system, most of the signal processing processes (including coding, Multiplexing, and RF generation and modulation) are carried out by the Central Office (CO), which makes the Base Station (BS) cost-effective. Therefore, RoF will become a key technology in the next generation of mobile communication system [4].

RoF finds applications in optical signal processing and for applications such as broadband wireless access networks, electronic warfare and RADAR processing, imaging and spectroscopy or radio-astronomy. In these applications, a radio signal typically in the millimetre-wave band is transmitted through optical fiber employing laser sources and electro-optical devices [5].

Radio over Fiber technology (RoF), an integration of wireless and fiber optic networks, is an essential technology for the provision of untethered access to broadband wireless communications in a range of applications including last mile

solutions, extension of existing radio coverage and capacity, and backhaul [6]. This paper gives the brief introduction of radio over fiber technology used in communication system. In this paper, concept, architecture, features, applications and limitation of the radio over fiber technology are discussed.

II. CONCEPT OF ROF

Radio-over-Fiber technology uses optical fiber links to distribute modulated RF signals from BS to Remote Antenna Unit (RAU). In narrowband communication systems, RF signal processing functions such as frequency up-conversion, carrier modulation, and multiplexing are performed at the BS and then fed into the antenna. RoF makes it possible to centralize the RF signal processing functions in one shared location (headend), and then use optical fiber, which offers low signal loss (0.3 dB/km for 1550 nm, and 0.5 dB/km for 1310 nm wavelengths) to distribute the RF signals to the RAUs, as shown in Figure 1 [7].

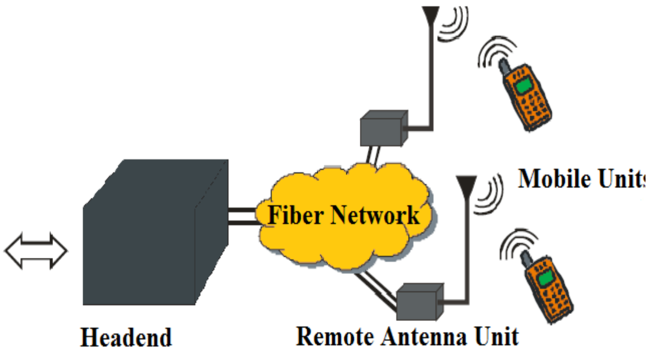

Fig. 1 The Radio over Fiber System Concept

By doing so, RAUs are simplified significantly, as they only need to perform optoelectronic conversion and amplification functions. The centralization of RF signal processing functions enables equipment sharing, dynamic allocation of resources, and simplified system operation and maintenance. These benefits can translate into major system installation and operational savings, especially in wide-coverage broadband wireless communication systems, where a high density of BS/RAPs is necessary as discussed above.

III. ARCHITECTURE OF ROF

RoF transmission system are usually classified into two main categories depending on the frequency range of the radio signal to be transported

1. RF-over-Fiber (Radio Frequency over Fiber)

2. IF-over-Fiber (Intermediate Frequency over Fiber)

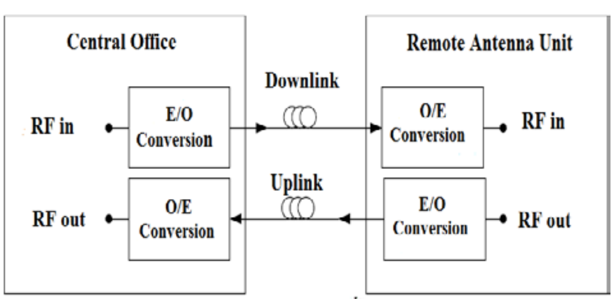

Fig. 2 The Radio over Fiber System Architecture

1) In RF-over-fiber architecture, a data-carrying RF (radio frequency) signal with a high frequency (greater than 10 GHz) is imposed on a lightwave signal before transmission over the optical link. Therefore, wireless signals are optically distributed to base stations directly at high frequencies and converted from the optical to electrical domain at the base stations before being amplified and radiated by an antenna. As a result, no frequency up–down conversion is required at the various base stations, thereby resulting in simple and rather cost-effective implementation is enabled at the base stations [8].

2) In IF-over-fiber architecture, an IF (intermediate frequency) radio signal with a lower frequency (less than 10GHz) is used for modulating light before being transported over the optical link. Therefore, before radiation through the air, the signal must be up-converted to RF at the base station [9].

IV. APPLICATIONS

1) **Cellular network:** Radio-over-Fiber (ROF) technology could be a best option to use in cellular system for cell optimization method since it will simply be utilized in millimeter wave band and additionally it will scale back the system overall price. Mobile traffic is relayed between base station and central station via ROF system [10].

2) **Wireless LANs:** As portable devices and computers have become more and more powerful as well as widespread, RoF can be used to distribute wireless LAN signals operating at 2.4 GHz to 5 GHz [11].

3) **Vehicle communication and control:** ROF can be used for intelligent transport system and road- to-vehicle communication system. In order to achieve the required coverage of the road network, numerous base stations are required. These can be made simple and of low cost by feeding them through RoF systems, thereby making the complete system cost effective and manageable.

4) **OFDM-RoF Systems:** The OFDM through RoF system is to increase modulation technique and it overcomes various limitation of the wireless transmission such as electrical power attenuation, chromatic dispersion and phase modulation through the optical link. The combination of system has many advantages for future high speed data transmission system.

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5) **Military Application:** For security reasons, the broadband microwave or RF signals received by the radar are transmitted through the optical fiber in the mode of RoF communication to the remote end. This will cause fewer casualties in the event of radar strikes.

6) **High-Speed Sensing**: The RoF communication can be used for fast transfer of video monitoring signals on the highspeed trains and jumbo jets, as broadband transmission can be satisfied and also less electromagnetic pollution will be produced.

7) **Millimeter Fiber Transmission**: The millimeter wave at 60 GHz and higher generates fast attenuation and less electromagnetic interference thus is quite suitable for indoor coverage. Together with the RoF communication, the problems of electromagnetic interference and electromagnetic pollution will be addressed in a better way.

8) **Satellite Communication:** One of the applications involves the remoting of antennas to suitable locations at satellite earth stations. In this case, small optical fiber links of less than 1km and operating at frequencies between 1 GHz and 15 GHz are used. By so doing, high frequency equipment can be centralized. The second application involves the remoting of earth stations themselves. With the use of Radio over Fiber technology the antennae can be positioned many kilometers away for the purpose of improved satellite visibility or reduction in interference from other terrestrial systems [12].

V. ADVANTAGES

Low attenuation

It is a well known fact that signals transmitted on optical fiber attenuate much less than through other media, especially when compared to wireless medium. By using optical fiber, the signal will travel further, reducing the need of repeaters.

Low complexity

RoF makes use of the concept of a remote station (RS). This station only consists of an optical-to-electrical (O/E) (and an optional frequency up or down converter), amplifiers, and the antenna [13]. This means that the resource management and signal generation circuitry of the base station can be moved to a centralized location and shared between several remote stations, thus simplifying the architecture.

Lower cost

Simpler structure of remote base station means lower cost of infrastructure, lower power consumption by devices and simpler maintenance that contribute to lower the overall installation and maintenance cost. Further reduction can also be made by use of low-cost graded index polymer optical fiber [13].

Future-proof

Fiber optics are designed to handle gigabits/second speeds which means they will be able to handle speeds offered by future generations of networks for years to come. RoF technology is also protocol and bit-rate transparent, hence, can be employed to use any current and future technologies.

Easy Installation and Maintenance

In RoF systems, complex and expensive equipment is kept at the headend, thereby making the RAUs simpler. Modulation and switching equipment is kept in the headend and is shared by several RAUs. This arrangement leads to smaller and lighter RAUs, effectively reducing system installation and maintenance costs [14].

Multi-Operator and Multi-Service Operation

RoF offers system operational flexibility. Depending on the microwave generation technique, the RoF distribution system can be made signal-format transparent. For instance the Intensity Modulation and Direct Detection (IM-DD) technique can be made to operate as a linear system and therefore as a transparent system [14].

Large Bandwidth

Optical fibers offer enormous bandwidth. There are three main transmission windows, which offer low attenuation, namely the 850 nm, 1310 nm, and 1550 nm wavelengths. For a single SMF optical fiber, the combined bandwidth of the three windows is in the excess of 50 THz. The enormous bandwidth offered by optical fibers has other benefits apart from the high capacity for transmitting microwave signals. The high optical bandwidth enables high speed signal processing that may be more difficult or impossible to do in electronic systems.

Immunity to Radio Frequency Interference

Immunity to Electromagnetic Interference (EMI) is a very attractive property of optical fiber communications, especially for microwave transmission. This is so because signals are transmitted in the form of light through the fiber. Because of this

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immunity, fiber cables are preferred even for short connections at mm waves.

Reduced Power Consumption

Due to having simple Radio Stations, reduced power consumption is achieved. Most of the complex equipment is kept at the central Station. In some applications, the antenna sites are operated in inactive mode. For instance, some 5 GHz Fiber-Radio systems having pico-cells (small radio cells) can have the Base Stations to operate in inactive mode [15].

VI. LIMITATIONS

Since RoF involves analogue modulation, and detection of light, it is fundamentally an analogue transmission system. Therefore, signal impairments such as noise and distortion, which are important in analogue communication systems, are important in RoF systems as well [16]. These impairments tend to limit the Noise Figure (NF) and Dynamic Range (DR) of the RoF links. DR is a very important parameter for mobile (cellular) communication systems such as GSM because the power received at the BS from the MUs varies widely. That is, the RF power received from a MU which is close to the BS can be much higher than the RF power received from a MU which is several kilometers away, but within the same cell. The noise sources in analogue optical fiber links include the laser's Relative Intensity Noise (RIN), the laser's phase noise, the photodiode's shot noise, the amplifier's thermal noise, and the fiber's dispersion. In Single Mode Fiber (SMF) based RoF, systems, chromatic dispersion may limit the fiber link lengths and may also cause phase de-correlation leading to increased RF carrier phase noise [6]. In Multi-Mode Fiber based RoF systems, modal dispersion severely limits the available link bandwidth and distance. It must be stated that although the RoF transmission system itself is analogue, the radio system being distributed need not be analogue as well, but it may be digital (e.g. WLAN, UMTS), using comprehensive multi-level signal modulation formats such as xQAM, or Orthogonal Frequency Division Multiplexing (OFDM).

VII. CONCLUSION

In this paper, review of the ROF technology has been done. Radio over fiber is an essential technology for the integration of broadband wireless and optical access networks and enables a flexible access network infrastructure capable of offering broadband wireless connectivity to a variety of services and applications. RoF technologies can provide a range of benefits including the realization of a future proof architecture with the ability to support multiple radio services and standards. It provides a flexible, reliable and cost effective approach for remotely interfacing with multiple remotely located antennas by reducing system complexity with a centralized architecture that incorporates a simplified BS located closer to the customer.

The main advantages of the ROF technology are low attenuation loss, large bandwidth and easy installation and maintenance. The main drawback of the ROF technology is signal impairments such as noise and distortion which should be eliminated in the future.

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