# Radio over Fiber Technology for Wireless Access

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**Abstract - 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. The well known advantages of optical fiber as a transmission medium such as low loss, light weight, large bandwidth characteristics, small size and low cable cost make it the ideal and most flexible solution for efficiently transporting radio signals to remotely located antenna sites in a wireless network. In addition to its transmission properties, the insensitivity of fiber optic cables to electromagnetic radiation is a key benefit in their implementation as the backbone of a wireless network.**

**The traditional link between the radio base station (RBS) and the antenna has previously been a copper coaxial cable. To use an optical fiber cable instead, makes both design of new sites, as well as the physical deployment of the hardware, much easier.**

## I. Introduction

Optical wireless networking connectivity can typically be achieved using radiofrequency (RF) or optical wireless approaches at the physical level. The RF spectrum is congested, and the provision of broadband services in new bands is increasingly more difficult. Optical wireless networking offers a vast unregulated bandwidth that can be exploited by mobile terminals within an indoor environment to set up high speed multimedia services. Optical signal transmission and detection offers immunity from fading and security at the physical level where the optical signal is typically contained within the indoor communication environment. The same communication equipment and wavelengths can be reused in other parts of a building, thus offering wavelength diversity. The optical medium is, however, far from ideal. Diffuse optical wireless networking systems offer user mobility and are robust in the presence of shadowing, but they can be significantly impaired by multipath propagation, which results in pulse dispersion and inter symbol interference.

Fiber optic LANs will be carrying traffic at data rates of tens of gigabits per second in the near future, whereas data rates of tens of megabits per second are difficult to provide to mobile users. In this regime, optical channels, offering terahertz of bandwidth, have many advantages.

First RoF systems were mainly used to transport microwave signals, and to achieve mobility functions in the central office or exchange (CO). That is, modulated microwave signals had to be available at the input end of the RoF system, which subsequently transported them over a distance to the RS (Remote Site) in the form of optical signals. At the RS the microwave signals are regenerated and radiated by antennas. The system was used to distribute GSM 900 network traffic. The added value in using such a system lay in the capability to dynamically allocate capacity based on traffic demands.

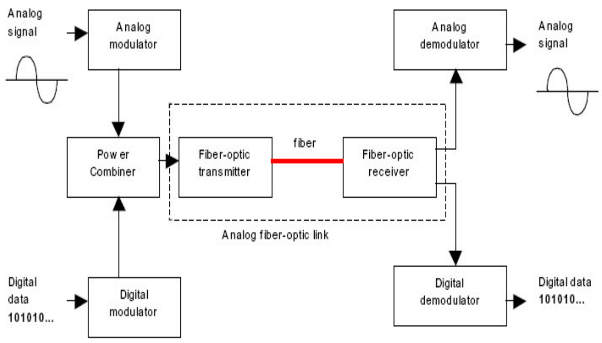


Figure 1. Basic ROF architecture

Today RoF systems, are designed to perform added radio system functionalities besides transportation and mobility functions. These functions include data modulation, signal processing, and frequency conversion (up and down). For a multifunctional RoF system, the required radio signal at the input of the RoF system depends on the RoF technology and the functionality desired. Figure 1. shows a typical RF signal (modulated by analog or digital modulation techniques) being transported by an analog fiber optic link. The RF signal may be baseband data, modulated IF, or the actual modulated RF signal to be distributed. The RF signal is used to modulate the optical source in transmitter. The resulting optical signal is launched into an optical fiber. At the other end of the fiber, we need an optical receiver that converts the optical signal to RF again. The generated electrical signal must meet the specifications required by the wireless application be it GSM, UMTS, wireless LAN, WiMax or other. By delivering the radio signals directly, the optical fiber link avoids the necessity to generate high frequency radio carriers at the antenna site. Since antenna sites are usually remote from easy access, there is a lot to gain from such an arrangement. Usually a single fiber can carry information in one direction only (simplex) which means that we usually require two fibers for bi-directional (duplex) communication. However, recent progress in wavelength division multiplexing make it possible to use the same fiber for duplex communication using different wavelengths. WDM can be use to combine several wavelengths together to send them through a fiber optic network, greatly increasing the use of the available fiber bandwidth and maximizing total data throughput that in order to meet future wireless bandwidth requirements.

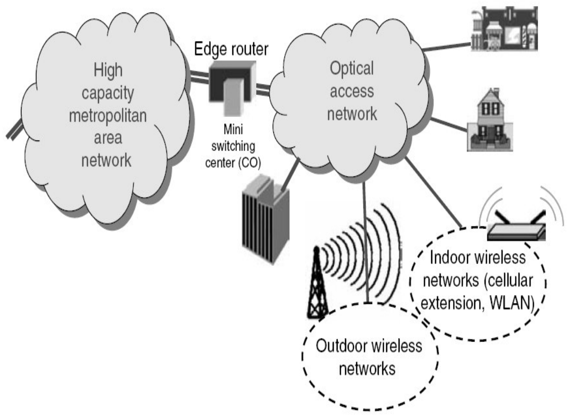


Figure 2. The integration of optical fiber and wireless networks

Figure 2. shows that the CO provides the interface between an external network (typically a Metropolitan Area Network (MAN) or Local Area Network (LAN)) and a wireless network in which multiple BSs provide wireless coverage to Mobile Units (MUs). A fiber radio network differs from a traditional fiber to the home (FTTH) access network in that the transported data is at a wireless frequency.

The paper is organized as follows. Section II describes the proposed network architecture, then III section demonstrates basic configuration of radio link. Section IV deals with introduction of WDM technology in wireless networks.

## II. Network architecture

RoF network architectures vary according to the planned service application. The basically RoF system consists of a Central Office (CO) and a Remote Site (RS) connected by an optical fiber link or network. If the application area is in a GSM network, then the CO could be the Mobile Switching Centre (MSC) and the RS the base station (BS). For Wireless Local Area Networks (WLANs), the CO would be the head end while the Radio Access Point (RAP) would act as the RS.

For example, the dominant market for ROF technology today is the distribution of radio signals over fiber to extend the range and capacity of radio systems indoors; so called fiber Distributed Antenna Systems (DAS), figure 3. At moment fiber based DAS installations are being increasingly used in a variety of locations including public buildings, airports, stadiums and subways. In these in building wireless systems a Base Station includes the centralized equipment where the radio signals are converted to optical signals, which are then transmitted via optical fiber to specific Remote Node (RN) locations. Then at each RN, the optical signal is converted back into the RF domain, which is then directed to an antenna for wireless coverage.

Mainly all other applications of RoF technology can use architecture shown in Figure 4. Current wireless network architectures are often characterized by centralized switching nodes that are interconnected to geographically distributed BSs via microwave links. In future broadband pico cellular network architectures, due to the large capacity and large number of BSs, radio networks may be dimensioned in such a way that there will be a number of clusters of BSs serviced by a switching node.

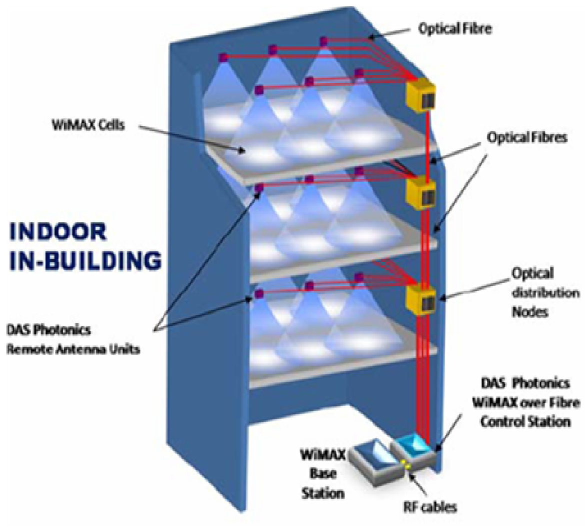


Figure 3. .ROF solution for DAS architecture

For a large metropolitan area, a number of such switching nodes will be required to interconnected via an optical MAN ring architecture, as shown in Figure 4.

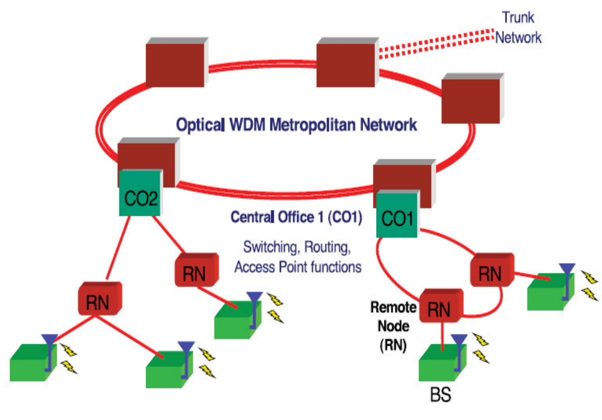


Figure 4. Architecture of ROF with an optical WDM MAN

In the ROF architecture shown in Figure 4. , WDM channels could be dropped or added into the optical WDM MAN via the switching center. As depicted in this diagram, CO1 is connected to several remote nodes via an optical ring while the second central office (CO2) feeds its RNs via a star tree arrangement. In either arrangement individual wavelengths would be demultiplexed from the WDM signal by being dropped from the optical WDM MAN via the remote nodes, which direct the optical signals to the remote antenna BSs for signal detection and radio distribution. In the upstream direction, radio signals generated at the customer site are upconverted in frequency and radiated to the BS where an electrical to optical conversion process takes place before the radio signals are directed to the CO for further processing.

## III. RoF link configurations

We have several possible approaches to transporting radio signals over optical fiber in RoF systems, which is classified based on the kinds of frequency bands (RF bands, IF baseband (BB)) transmitted over an optical fiber link. The three fundamental techniques as shown in Figure 5. RoF analog photonic links are typically multichannel in nature and require high power compared to digital schemes because of the increased carrier to noise ratio (CNR) requirements. The performance, including CNR and capacity, of RoF systems employing analog optical links is limited by the noise of the various optical and electrical components in the link as well as by device nonlinearities, which introduce intermodulation and distortion products that create interference with other radio channels [1].

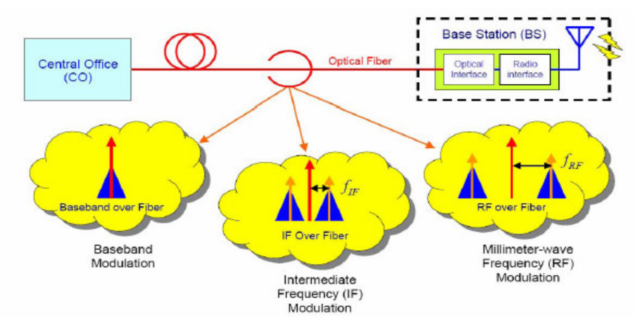


Figure 5. Radio signal transport schemes for RoF systems

Momentarily Rof is probably the most straightforward radio signal distribution technology because the wireless signals are transported directly over the fiber at the radio carrier transmission frequency without the need for any subsequent frequency up or down conversion at the remote antenna BSs. The key optical and RF devices required at the CO and the BS for downstream signal transmission in an RoF system based on RF over fiber is shown in figure 6.

This configuration enables centralized control and remote monitoring of the radio signal distribution via the fiber backbone network and reduces the complexity of the BS implementation, but is susceptible to fiber chromatic dispersion that seriously limits the transmission distance [2]. The wireless data obtained from the trunk network are modulated onto a number of lower intermediate frequency (IF) carriers, which are then combined to form a subcarrier multiplexed (SCM) signal.

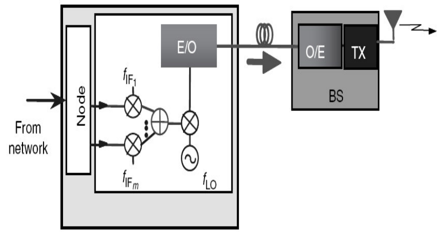


Figure 6. Downstream signal transmission via RF over fiber

This SCM signal is up converted to the radio transmission frequency using a local oscillator (LO) source located at the CO and then modulated onto an optical carrier. At the remote BS, the analog optical signal is detected, amplified, filtered, and directed to an antenna for free space transmission. Upstream radio transmission to the BS and subsequently back to the CO will require a mechanism for modulating an optical source located at the BS at the radio carrier frequency, and photo detection of this signal back at the CO.

Figure 7. shows a scheme of the basic hardware required for downstream signal transmission in an RoF system based on the distribution of the radio signal at a lower IF, the so called ‘‘IF over fiber’’. IF signal transport schemes offer the advantage that the readily available mature microwave hardware can be utilized at the BS, although the requirement for frequency conversion at the BS increases the complexity of the BS architecture particularly as the frequency of the wireless application moves into the millimeter wave frequency region. The BS hardware now requires LOs and mixers for the frequency conversion processes, which may limit the ability to upgrade or reconfigure the radio network with the provision of additional radio channels or the implementation of required changes in RF frequency. IF radio signal transport allow transmission over low cost multimode fiber (MMF) and several commercial RoF products are based on the distribution of radio signals over MMF since many buildings have legacy optical fiber infrastructure networks based on multimode fibers.

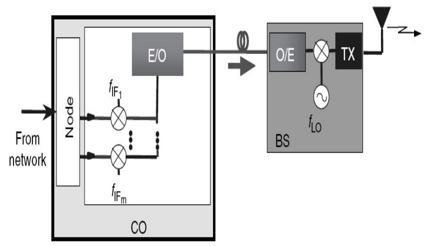


Figure 7. Downstream signal transmission via IF over fiber

The third technique that can be used to transport data carrying radio signals between the CO and the remote antenna BS in RoF systems is via a baseband over fiber approach as depicted in Figure 8. The radio information for the radio carriers is transported to the BS as a time division multiplexed (TDM) digital data stream. The individual data channels are then demultiplexed, up converted to IFs, before undergoing an additional frequency up conversion to the required radio frequency band via an LO located at the BS. Upstream signal transport via baseband over fiber can also be accomplished by down converting the received wireless carriers at the BS to the baseband before transmission back to the CO. As with IF over fiber, RoF systems based on baseband over fiber transport schemes can readily exploit the use of mature and reliable RF and digital hardware for signal processing at the CO and BS as well as low cost optoelectronic interfaces. The need for frequency conversion at the BS complicates the BS architecture design as the air interface frequency increases. The additional LO source and extensive signal processing hardware (frequency conversion and multiplexing and de-multiplexing (MUX–DEMUX) of signals from many users) in the antenna BS may also limit the upgradeability of the overall fiber radio system.

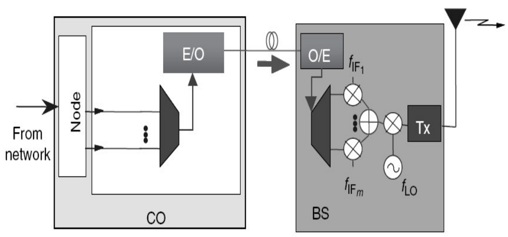


Figure 8. Downstream signal transmission via BB over fiber

## IV. WDM and optical effects

### 1) *Limiting optical factors*

The optical technologies has some limitations like amplified spontaneous emission (ASE), noise, distortions, dispersion and nonlinearities.

Therefore, signal impairments such as noise and distortion, which are important in analogue communication systems, tend to limit the Noise Figure (NF) and Dynamic Range (DR) of the RoF links [2]. 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 (e.g. 80 dB). 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 kilometres 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 and the amplifier's thermal noise.

Dispersion is the widening of a pulse duration as it travels through a fiber. As the pulse widens, it can broaden enough to interfere with neighboring pulses (bits) on the fiber, leading to intersymbol interference. Dispersion thus limits the bit spacing and the maximum transmission rate on a fiber optic channel. One form of the dispersion is an intermodal dispersion. This is caused when multiple modes of the same signal propagate at different velocities along the fiber. Intermodal dispersion does not occur in a single mode fiber. Another form of dispersion is material or chromatic dispersion. In a dispersive medium, the index of refraction is a function of the wavelength. Thus, if the transmitted signal consists of more than one wavelength, certain wavelengths will propagate faster than other wavelengths. Since no laser can create a signal consisting of an exact single wavelength, chromatic dispersion will occur in most systems. A third type of dispersion is waveguide dispersion. Waveguide dispersion is caused as the propagation of different wavelengths depends on waveguide characteristics such as the indices and shape of the fiber core and cladding. At 1300 nm, chromatic dispersion in a conventional single mode fiber is nearly zero. Luckily, this is also a low attenuation window (although loss is higher than 1550 nm). Through advanced techniques such as dispersion shifting, fibers with zero dispersion at a 1300-1700 nm can be manufactured [3].

Nonlinear effects in fiber may potentially have a significant impact on the performance of WDM optical communications systems. Nonlinearities in fiber may lead to attenuation, distortion, and cross channel interference. In a WDM system, these effects place constraints on the spacing between adjacent wavelength channels, limit the maximum power on any channel, and may also limit the maximum bit rate. The details of the optical nonlinearities are very complex and beyond the scope of the paper. It should be emphasized that they are the major limiting factors in the available number of channels in a WDM system.

The another main phenomenon limiting the network transmission performances is crosstalk. Crosstalk can be classified as either heterodyne, between signals at different wavelengths, or homodyne, between signals at the same nominal wavelength. Homodyne crosstalk can be further subdivided into coherent crosstalk, between phase correlated signals, and incoherent crosstalk, between signals which are not phase correlated. The results shown in [4] revealed that when the crosstalk power exceeds a critical value, the error rate due to this mechanism can dominate all other effects inducing errors, and lead to a bit error rate (BER) floor. Heterodyne coherent crosstalk is important in WDM photonic switch networks where channels with nominally the same wavelength are routed in the same photonic switch fabric.

### 2) *SCM over WDM*

SCM transmission over WDM wavelengths has been investigated with the goal of increasing transmission capacity and providing multiple services. A system for transmission between a wireless center office and remote stations for mobile communications, optical routing of amplitude multilevel modulated SCM signals in a WDM access network, and multimodulation format signal integration, including SCM transmission by WDM [5].

These approaches use CWDM/wide passband WDM to assign the SCM signal. To reduce the system cost by sharing the transmitting and processing equipment and to simplify the architecture, a full duplex WDM/SCM fiber radio access network has been developed [5], featuring three WDM carriers for downstream transmission and a single carrier for upstream transmission.

This is shown in Figure 9. Each downstream wavelength carries three 155 Mb/s BPSK SCM channels, and the upstream wavelength carries a 20 Mb/s BPSK RF channel.

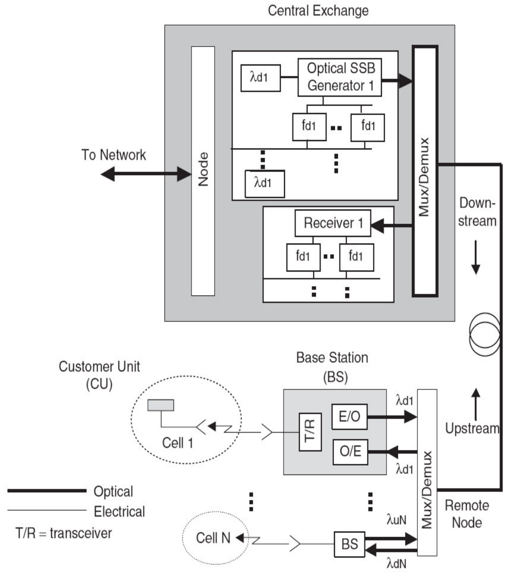


Figure 9. Full duplex SCM/WDM fiber radio access network

The mm-wave signals in the down and upstream fiber links are unaffected by chromatic dispersion. The network demonstration incorporates a 40 km SMF and 5 m radio cells. In the downstream direction, three lasers operating at 1537.5, 1541.5, and 1549.5 nm are used, each wavelength is externally modulated by three SCM mm-wave signals, and dispersion effects are overcome by optical single side band (SSB) modulation.

### *3) OCDMA over WDM*

The large gap between the user requirement and the capacity of a wavelength has forced the need for wavelength sharing mechanisms that would allow more then one user to share the wavelength channel capacity. Wavelength sharing, similar to sharing a fiber using multiple wavelengths, can be done in several ways. One approach to sharing a wavelength is to divide the wavelength bandwidth into frames containing a certain number of time slots. A time slot on successive frames would then form a channel. Other approaches such as phase modulation and optical code division multiple access (OCDMA) can also be employed to share the capacity on a wavelength.

Optical code division multiple access (OCDMA) is a spread spectrum technique similar to that which has been implemented with great success in wireless communication systems. Its techniques allow a large pool of users to share the same transmission bandwidth. Each individual user, or subgroup of users, is allocated a specific address that can be used to label bits that are either to be transmitted to the user, or to be transmitted by the user. The WDM/OCDMA system could be one promising solution to the symmetric high capacity access network with high spectral efficiency, cost effective, good flexibility and enhanced security, is an attractive candidate for next generation broadband access networks.

The design of optical communication systems is usually very different from that of wireless or radio communication systems. An optical communication system based on CDMA will also be very different from a CDMA wireless communication system. As a matter of fact, optical CDMA communication systems have not received enough attention due largely to the fact that there is enough bandwidth available to optical communication systems, which use optical fiber cables with great capacity to support many more users than wireless or radio communication systems. But, there are some major issues in OCDMA communication system design:

- the design of spreading codes with good correlation properties. An optical communication system is not able to send binary data streams using -1 and +1 signal levels. Instead, it will send binary information using directly 0 and 1 states. This is because it is extremely difficult for an optical system to distinguish the phases of the optical signal. Thus, only amplitude will be the medium used to carry information data. The correlation properties of the spreading codes used in an OCDMA system can directly influence the system bit error rate (BER). It is obviously impossible to completely eliminate autocorrelation function side lobes and cross-correlation functions of the spreading codes used in any OCDMA system.
- the number of users/channels which can be supported by the OCDMA system. The number of users will affect the system capacity. It is extremely difficult to achieve a low BER when a large number of users are present.
- most optical systems use different wavelengths to divide different signal channels, (namely wavelength division multiple access or WDMA), while wireless systems often use frequencies to divide different signal channels. It should also be noted that the application of OTDMA is not common as WDMA in optical communications.

They include an approach designed to suppress the optical beat interference in a WDMA network using subscriber based common wavelength signaling or PON [6], the use of the OCDM channels within an access node assigned a specific WDM wavelength [7], and the use of photonic IP routing for optical codes [8], with both electric and optical CDM techniques. CWDM is used to combine the four OCDM signals with other optical signals in DWDM channels of the metro ring. The wavelength channel is first added/dropped at the node (ADM), and thus, only the OCDM access protocol with tee and go capacity can be exploited without using complicated WDM access protocol.

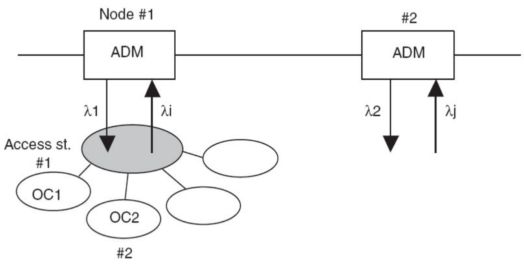


Figure 10. The OCDM/WDM access network

Access station #1, which is connected to the added/dropped node (ADM #1), is assigned an optical code (OC1), so that it can communicate with the other stations on the assigned wavelength ($\lambda 1$) via OCDM access protocol. To communicate with an access station on a different wavelength, the message must be on the destination wavelength. This approach makes it possible to take advantage of the asynchronous access of OCDM without using WDM access protocols. Figure 10. shows the OCDM/WDM access network.

## V. Conclusion

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.

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