

Implementation of HFR/WLAN network

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Abstract: Integration of wireless and optical networks is a potential solution for increasing capacity and mobility as well as decreasing costs. By using Hybrid Fiber Radio (HFR) network, a method in integrating wireless and optical networks, the capacity of optical networks can be combined with the flexibility and mobility of WLANs. This paper presents a novel approach in deploying HFR/WLAN network. Proposed method is based on using Subcarrier Modulation (SCM) for multiplexing multiple WLAN signals in RF domain and modulation of a single optical carrier for simultaneous transmission of those signals in downstream direction. In upstream direction, a single photo detector and time division multiplexing (TDM) are employed. Usage of passive optical network (PON) as reliable and mature technology is also proposed for bidirectional duplex transport of optical signals between central site and remote antenna sites.

1. INTRODUCTION

In contemporary communication systems, the interconnection and interfacing of differing technologies are becoming commonplace. Therefore, gaining an understanding of how these interconnects and interfaces interact is critical to successful system design. Integration of fiber optics with the wireless local area network (WLAN) is an attractive option for high data rate, short-range links, where deploying optical fibers all the way to the customer premises is too expensive or otherwise impractical.

The advantages of using optical networks for delivering radio signals from a central location to many remote antenna sites have long been an area of researched [2], [3], [6]. However, the transmission of analog RF signals has been limited by the linearity constraints in modulating/demodulating devices, and by the distortion effects created by the optical link. Advances in fiber optic technology now allow modulating laser devices with RF signals beyond 10 GHz [4]. Utilizing optical devices that operate at high frequency to carry WLAN 802.11a, g (or even emerging 802.11n) signals in 2.4/5 GHz frequency band can provide very high-speed connections up to 54 Mb/s (or above 100Mb/s in case of 802.11n standard) to mobile users.

The primary objective of this paper is proposal of novel hybrid fiber radio (HFR) system using an integrated optical and wireless infrastructure capable of delivering broadband multimedia traffic to mobile users in remote areas. In such a scheme, the fiber is used to route the broadband modulated optical signals to remote access units (RAU) where the RF signals are detected and transmitted to client stations. By making use of the high bandwidth and low loss characteristics of optical fiber, all high frequency and signal processing can be performed centrally and transported over

the optical network directly at the carrier frequency. The remote site would then be very simple, requiring only optoelectronic conversion, filtering and amplification [3]. Such remote access units would also be cheap, small, lightweight, and easy to install with low power consumption. This proposed HFR system also provides an inexpensive method for system upgrades, since most of the signal processing and mobility functions would be done at the central office (CO) and not at each individual RAU. Thus, HFR technology has been suggested as cost-effective solution to meet modern ever increasing user bandwidth demands and mobility.

This paper is organized as follows: Section 2. emphasizes main application of proposed HFR/WLAN system and gives basic information's of its architecture. In Section 3., we briefly describe transport of HFR/WLAN signals in downstream direction, from central office unit to RAUs. Transport of HFR/WLAN signals in upstream directions with two technical solutions for reception of these signals is presented in Section 4. In Section 5., advantages of the proposed HFR/WLAN system and future developments are outlined.

2. HFR/WLAN ARCHITECTURE

The main application of HFR/WLAN is in wireless coverage of buildings. These locations share the common characteristics of high people concentration, existing coverage with fiber optics (mainly used for Gigabit-Ethernet), low mobility, and a requirement suitable for a high-speed technology like WLAN. IEEE 802.11 WLAN technologies tend to have small cell size (up to 300m or smaller for outdoor coverage), making it unsuitable for providing cellular size coverage. Instead, its coverage is mostly characterized by disjointed broadband hotspots. The HFR/WLAN network allow the RAUs to be fed by a common signal, were the sum coverage areas of many remote elements form a large single cell. Crossing between coverage boundaries will not result handover as it is still within the same cell of single CO unit (COU). It also allows radio capacities to be allocated to RAUs based on the number of users and traffic volume. Hence, unlike most WLAN implementations, HFR/WLAN cells are potentially dynamic in terms of its capacity and coverage area.

The proposed HFR architecture is suitable for integration of WLAN and passive optical network (PON) star topology as shown in fig.1. PON employs a passive device to split optical signal from one fiber into several fibers (splitter) and reciprocally, to combine optical signals from multiple fibers

into one (combiner) [1,7]. RAUs are connected to COU with two optical fibers, each for one direction using PON technology. RAUs communicate with several wireless terminals using the IEEE 802.11a,g air interface (fig. 1.). A complete system may consist of many cells. Adjacent cells operate on different frequencies with channel frequency reuse patterns defined by used IEEE WLAN technology. All signals from all RAUs are processed at COU, and the RF signals are transported back and forth between the RAUs and the COU on fiber optic links. Processing units for many cells are then gathered in the single device (COU) with multiple Tx/Rx optical connectors (fig.1.). Each of N Tx/Rx optical connectors are dedicated to predefined RAU.

In the downstream direction (from COU to RAUs), proposed HFR/WLAN is point-to-multipoint optical network where COU assigns to each RAU its own dedicated bandwidth. With dedicated bandwidth, each RAU can be guaranteed a certain quality of service. The downstream RF WLAN signal is broadcast by transmitter at the COU to all RAUs using optical subcarrier modulation (SCM) technique. The main motivation for using SCM is to multiplex in RF domain (FDM) multiple RF-WLAN signals onto a single optical carrier (wavelength). Reason for using SCM technique lies in fact that microwave (electronic) devices are more technologically mature than optical devices. Stability of a microwave oscillator and frequency selectivity of a microwave filter are much better than their optical counterpart. By combining multiple microwave carriers at different frequencies and modulating the optical transmitter with combined signal we need only one laser source for simultaneous transport of N RF-WLAN signals in downstream direction.

In the upstream direction (from RAUs to COU), proposed HFR/WLAN is multipoint-to-point optical network since multiple RAUs transmit all towards one COU. In that scenario, total bandwidth is shared by all the RAUs. Directional properties of PON elements like passive splitter/combiner are such that a RAUs transmission cannot be detected by other RAUs. However, data streams from different RAUs transmitted simultaneously still may collide at COU. Thus, in the upstream direction proposed HFR/WLAN architecture employs time division multiplexing (TDM) to avoid data collisions and fairly share trunk fiber channel capacity and resources. Each RAU must be synchronized with COU and transmit upstream optical signal in its own transmission window (time slot). One of the major advantages of proposed upstream signal transmission using TDM PON is that all RAUs operate on the same wavelength (dedicated only for downstream transmission) generated by a single laser source placed in COU. Thus, COU need only one optical laser source and single optical receiver for transmission and reception of upstream HFR/WLAN signals, without the need for employing optical light sources in every RAU.

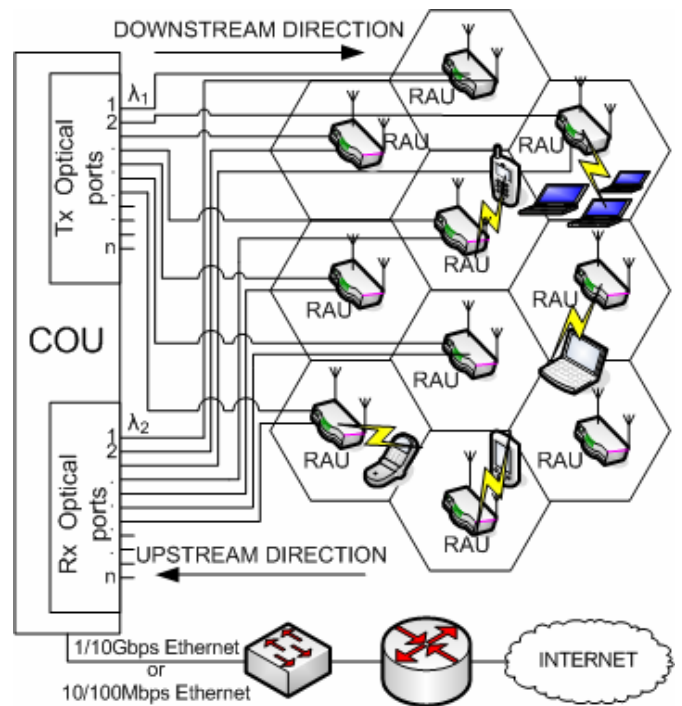


Figure 1. Basic architecture of proposed HFR network

In proposed HFR/WLAN architecture all signal processing, modulation and multiplexing are performed electronically. Only transmission of HFR/WLAN signals between COU and RAUs is done in optical domain. One of the main advantages of proposed HFR system is centralized network architecture, where most of the RAU functions of conventional WLAN APs are shifted to COU. Transferring complexity deeper in the network enables implementation of cheap and simple RAUs.

When the application of the proposed HFR/WLAN is in building wireless coverage, COU is placed in main/intermediate distribution facility (MDF/IDF) of the building. In that scenario, COU is connected with the rest of the local area network (LAN) by using one of few different Ethernet technologies (0.1/1/10 Gbps Ethernet). For outdoor coverage, COU can also be placed in MDF/IDF, but much likely it will be placed in central office (CO) or at optical line termination (OLT) of Internet Service Provider (ISP).

3. DOWNSTREAM TRANSPORT OF HFR/WLAN SIGNALS

Details of HFR/WLAN architecture are shown in Fig. 2. Separate electronic functions of many conventional access points (AP) are now concentrated in the single electronic device called AP unit (APU). The signals generated by APU correspond to signals generated by n conventional APs. Using SCM technique, each of n independent high-speed

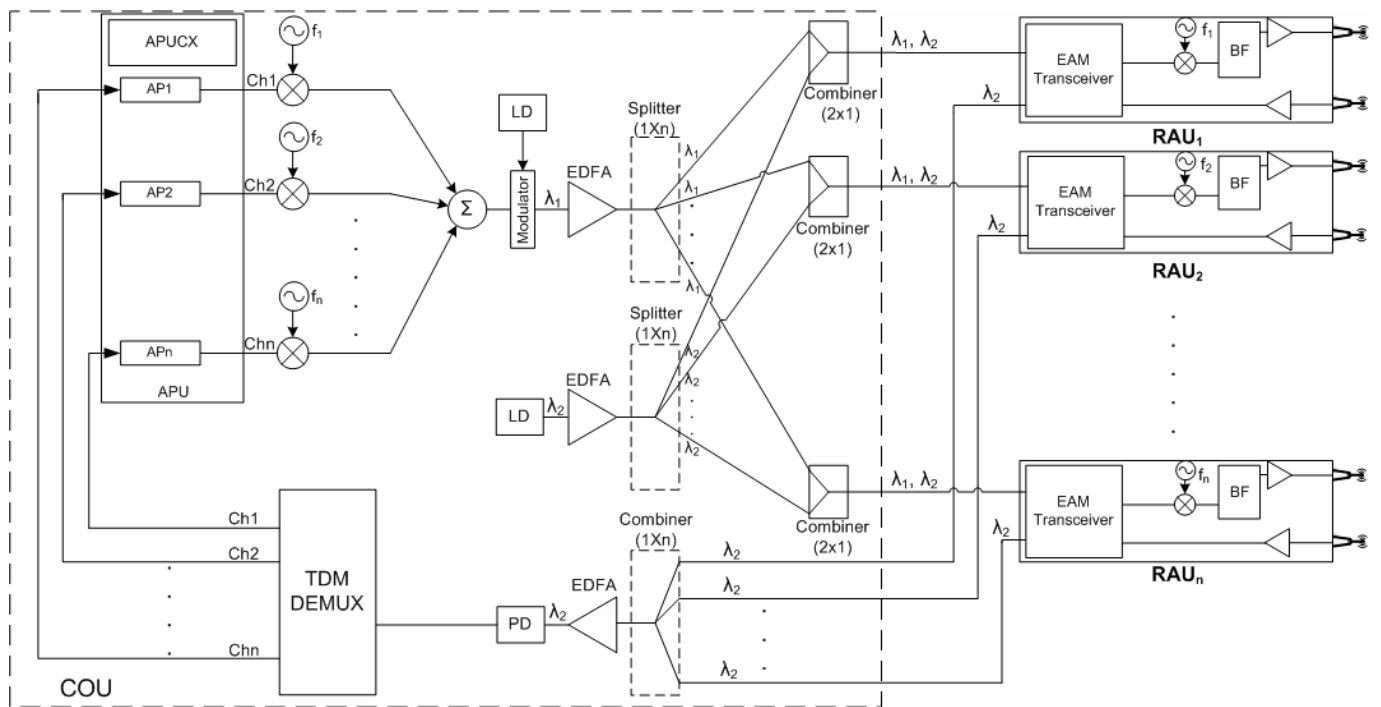


Figure 2. Architecture of the proposed HFR/WLAN system

WLAN signals are separately mixed with one microwave carrier frequency f_1 to f_n , respectively. These mixed RF signals are then combined and sent to the Mach-Zehnder modulator (MZM). In MZM combined signal modulates continuous laser light of wavelength λ_1 generated by Distributed Feedback (DFB) laser. Thus, multiple WLAN signals are transmitted using single optical carrier with wavelength λ_1 generated by only one DFB laser. Conventional SCM generally occupies a wide modulation bandwidth, because of its double-sideband spectrum structure and, therefore is susceptible to chromatic dispersion. In order to reduce chromatic dispersion penalty, and increase optical bandwidth efficiency, optical single-sideband (OSSB) modulation is used. Compared to conventional TDM systems, SCM is less sensitive to fiber dispersion, because the dispersion penalty is determined by the width of the baseband of each individual signal channel. That is the main reason for using of SCM instead of conventional TDM for downstream transmission of HFR/WLAN signals. Compared to conventional WDM systems, on the other hand, it has better optical spectral efficiency because much narrower channel spacing is allowed. Sophisticated microwave and RF technology enables the channel spacing to be comparable to baseband. This is the primary reason for using SCM system instead of n multiple optical carriers simultaneously transported in downstream direction by means of WDM system [5]. That architecture would also greatly increase the price of a system, because it will require n laser sources for every of n RAUs. Optical carrier of wavelength λ_1 is then amplified by erbium-doped fiber amplifier (EDFA). A combination of several advantages has made EDFA the

amplifier of choice in our proposal: the availability of compact and reliable high-power semiconductor pump lasers, the fact that it is an all-fiber device, making it polarization independent and easy to couple light in and out of it, and the simplicity of the device. After amplification of signals in optical domain, optical carrier is passed to the $1 \times n$ optical splitter. Passive optical ($1 \times n$) star splitter divides the downstream signal into multiple identical signals of wavelength λ_1 , in order to broadcast them to the subtending RAUs. The optical splitter alone has an optical insertion loss and without EDFA output power would not be acceptable. Therefore, inserting an EDFA before an optical splitter decreases the power, allows each of the n outputs power almost equal to the original transmitter power.

Another DFB laser generates continuous light of wavelength λ_2 which will be used for the upstream transmission of all HFR/WLAN traffic. This unmodulated optical carrier wavelength λ_2 is optically amplified by another EDFA and passed through another ($1 \times n$) passive star splitter. Both optical carriers with wavelengths λ_1 and λ_2 are combined at optical (2×1) coupler and transmitted over an optical fiber from COU to RAUs. The number of passive optical couplers corresponds to the number of RAUs. Thus, one wavelength for the down-link is modulated by user data and the other for the up-link is transmitted unmodulated. The unmodulated wavelength is modulated by up-link data at the RAUs and returns to the COU.

In order to be small, simple and cheap, RAU contains only microwave oscillator, baseband filter (BF), RF electronic

amplifier and an Electro Absorption Modulator (EAM) transceiver. The EAM is an optical waveguide device in which the optical intensity in the output fiber can be varied by application of an electric field across its contact. Light is absorbed inside the device depending on the magnitude of the electric field of the modulating signal. Since the light is absorbed, a photocurrent is generated inside the device. It can behave therefore as a conventional photo detector (PD) as well as optical modulator and furthermore can do so without an external bias voltage [2].

The downstream modulated optical carrier of wavelength λ_1 is detected by photo detection capability of EAM and converted into the electrical domain at each RAU. The downstream signal was then down-converted to each individual baseband by mixing the composite signal with microwave signal of corresponding frequency f_i , generated by local oscillator. Accordingly, each RAU operates with different microwave frequency f_i , defined by SCM system at COU. In order to suppress the unwanted harmonics of the microwave signal and to reduce noise, baseband signal is passed through BF filter. Thereby, RF coherent detection is used at the SCM level to separate the digital signal channels. Subsequently, WLAN signal is electrically amplified and fed to the antenna where RF signal carrying data is transmitted to the mobile terminals (MT). Thus, transparent transport of HFR/WLAN signals in downstream direction to MSs is accomplished.

4. UPSTREAM TRANSPORT OF HFR/WLAN SIGNALS

In the upstream direction (from MT through RAU to COU), RF signals from the MTs are used by EAM of each RAU to intensity modulate remaining unmodulated optical carrier wavelength λ_2 . Before usage for modulation of optical carrier, RF signal from MSs are received on RAU antenna and passed through electrical amplifier. This architecture avoids the need for any optical source at each RAU. Instead, each RAU has an EAM modulator working as photo detector in downstream direction and as external modulator in upstream direction. EAM modulator is used because of its many advantages including small size, small driving voltage, polarization insensitivities, and possibility of integration with laser diodes.

Modulated optical carrier wavelength λ_2 is propagated from each RAU to COU, and then optically redirect in an optical combiner ($n \times 1$) at COU to EDFA. Since optical carrier of upstream data travels from COU to RAU and again to COU without any amplification on the road, it must be optically amplified in order to reduce impact of chromatic dispersion. Therefore, upstream optical signal is amplified by EDFA at entrance of COU and transmitted to optical receiver. The optical receiver uses an avalanche photodiode (APD) to

receive the optical signal and convert it back into an electrical signal.

4.1. Reception of upstream HFR/WLAN signals with multiple optical receivers

To allow independent (non-arbitrated) transmission of each of n RAUs, the COU must have n EDFA amplifiers and optical receivers – one for each RAU. Price of that architecture will be higher compared to proposed, but it can be implemented as first step in reaching architecture proposed in this paper. Implementation of that architecture would not impose any significant changes in used IEEE 802.11(a,b,g) standard at any level. Especially if the fiber optical length is not limited by optical losses in the fiber network, but rather on the 802.11 specifications; where all stations must synchronizes its clocks with the servicing AP in few microseconds ($4\mu\text{s}$). Considering the group velocity within fiber is 2×10^8 m/s and the modulation/demodulation of laser does not incur significant delay, optical link length between COU and RAUs would be between 500m – 600m range. This highlights the possibility of fiber co-sharing with IEEE 802.3 gigabit Ethernet (which is widely used in building LAN) as it is limited to 550m on 50 μm multimode fiber. Not only optical propagation delay, but also optical equivalent of free-space multipath echo must be encountered, in order to preserve OFDM guard interval (for 802.11a or g standard). This ultimately results in ISI as the multipath, multi-copies of the same signal arriving at the receiver exceeding the OFDM guard interval. ISI can be prevented as long as time differences between RAUs, which are directly proportional with the path differences between co-neighbor RAUs, does not exceed the OFDM guard interval. Thus, the maximum path difference between co-located RAUs is defined by guard interval of IEEE 802.11 standard and equals to few hundred meters (160m for 802.11a with guard interval of $0.8\mu\text{s}$).

Optical network must not introduce significant delay into the wireless medium to cause stations to incorrectly determining an idle period has been detected. As we sad, maximum delay introduced by the optical network is defined by 802.11 standards and should be less than $4\mu\text{s}$, what is small comparison to the total DIFS period. Addition of random back off before transmission, and CTS/RTS mechanism, it is unlike that 802.11 MAC protocol would collapse in the HFR/WLAN network. For that architecture, IEEE 802.11 CSMA/CA and RTS/CTS mechanism provides access control for the wireless medium and could also simultaneously provide access control for the optical medium [3].

4.2. Reception of upstream HFR/WLAN signals with single optical receiver

Using only single optical receiver at the COU as shown in proposed architecture on fig. 2., data stream from only one

