Integration of Hybrid Fibre Radio and IEEE 802.11 WLAN network

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Abstract: By using hybrid fibre radio (HFR), a method in integrating wireless and optical networks, large part of the radio complexity can be transferred to a central office deeper in the network. This paper presents a novel approach in deploying IEEE 802.11 wireless local access network (WLAN) through integration with HFR. We will discuss its applications, a brief review of the individual technologies, and investigate the networking issues involve to make such integration feasible.

1. Introduction

The advantages of using analogue optical networks for delivering radio signals from a central location to many remote antenna sites have long been an area of researched [1]. By making use of the high bandwidth, low loss characteristics of optical fibre, 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. Such remote access units (RAU) would also be cheap, small, lightweight, and easy to install with low power consumption.

In-building coverage: The main application of HFR-WLAN is in building wireless coverage. Examples include corporate offices, shopping malls, indoor stadiums, swimming pools, campuses, and airport lounges. These spaces share the common characteristics of high people concentration, existing coverage with fibre optics (mainly used for Gigabit-Ethernet), low mobility, and a requirement suitable for a high-speed technology like WLAN.

Outdoor hotspots: IEEE 802.11 WLAN tends to have small cell size (50m – 150m), making it unsuitable for providing cellular size coverage. Instead, its coverage is mostly characterised 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.) It also allows radio capacities to be allocated to remote antennas base 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.

2. IEEE 802.11 Wireless LAN

The first release of the IEEE 802.11 standard [2 - 4] in 1997 operates at 2.4 GHz with the basic rate of 1 and 2 Mbit/s. Subsequently enhances with IEEE 802.11a and IEEE 802.11b was introduced to support higher transmission rates. Table 1 shows the characteristics of the different WLAN standards.

Table 1: Approved standards (valid only in US per FCC regulations).

	802.11a [4]	**802.11b [3]**	**802.11 [2]**
Frequency Band	5.150 - 5.350 GHz, 5.725 - 5.825 GHz	2.4 - 2.4835 GHz	2.4 – 2.4835 GHz
Number of Non-Overlapping Channels	12 (Indoor/Outdoor)	3 (Indoor/Outdoor)	3 (Indoor/Outdoor)
Data Rate per Channel	6, 9, 12, 18, 24, 36, 48, 54 Mbit/s	1, 2, 5.5, 11Mbit/s	1, 2 Mbit/s
Modulation Type	OFDM	DSSS	FHSS, DSSS

IEEE 802.11 Medium Access Control (MAC): IEEE 802.11 employs a carrier sense multiple access with collision avoidance (CSMA/CA) MAC protocol with binary exponential back-off, called Distributed Coordination Function (DCF) and an optional Point Coordination Function (PCF). The DCF allows for medium reservation through request-to-send (RTS), clear-to-send (CTS) and acknowledgement (ACK) frames. The function of CSMA/CA and CTS/RTS mechanism is illustrated in *fig 1*. The basic coverage area in 802.11 is called a *Basic Service Set* (BSS). Any station with packets to send is required to monitor the medium for activities until a period equivalent to a *distributed inter-frame space* (DIFS).

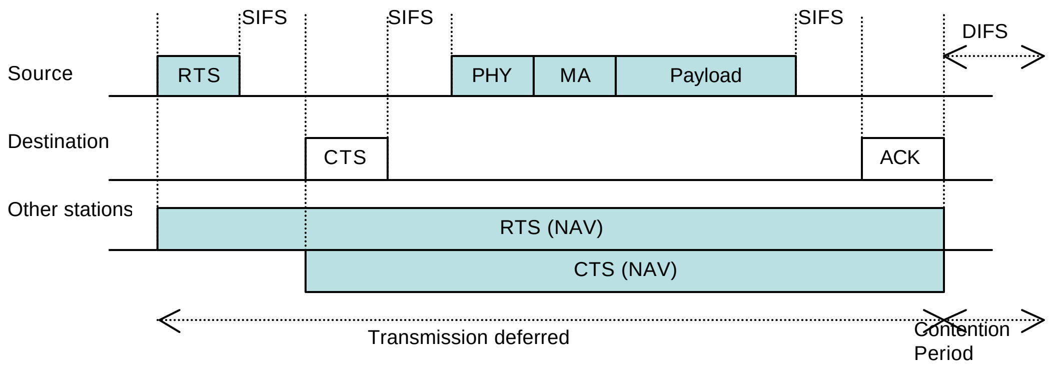

Figure 1. RTS/CTS access mechanism

802.11a system which uses an *Orthogonal Frequency Division Multiplexing* (OFDM) scheme is robust against *inter-symbol interference* (ISI) caused by multipath effect, as compared to other 802.11 systems. OFDM divides and transmits the data simultaneously over a large number of subcarriers, and at a lower rate; this is oppose to transmitting at a high rate over a single frequency. Error correction coding ensures the corruption of any single subcarrier will not result the loss of the whole data frame. A further enhancement is the use of a *guard interval*. The total transmitted symbol period is the sum of the active symbol period and a period called the guard interval. This means the receiver will not encounter ISI provided any echoes present in the received signal have a delay which does not exceed the guard interval.

3. HFR Architecture

The techniques of transporting radio waves on optical fibre are well documented [1]. Instead, we propose an HFR architecture that is more suitable for WLAN and its applications, as shown in *fig 2*.

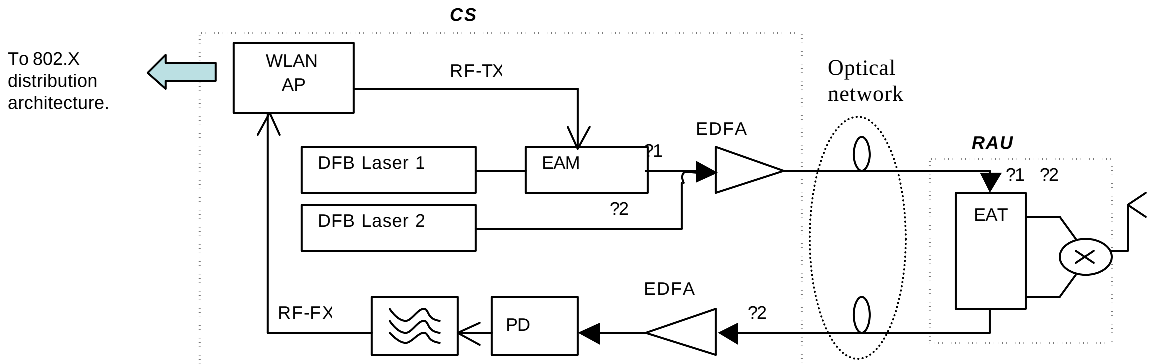

Figure 2. Architecture of a HFR-WLAN system with indirect optical modulations and passive RAU with electro-absorption transistor.

The downstream optical/radio signal at the *central station* (CS) can be external modulated, which allows the laser to work at a constant current' and the laser's output is modulated by an *electro-absorption modulator* (EAM). A novel technique of remotely feeding separate optical signals for both the downlink and uplink, from the CS is introduced in [5]. RAU design is further simplify by the use of an *EAM transistor* (EAT) [6], which serves as a photodetector for the downstream path, and as a modulator on the upstream path.

4. HFR-WLAN Network Investigation

We have considered aspects of wireless technology and HFR modulation technique. Now we investigated the issues that shape any HFR/WLAN network.

Network topology: The above described system would have a logical star topology, *fig 3(a)*, because of the point-to-point nature of the fibre-optic link technology. Such architecture provides high reliability and easy maintenance due to its topology; however, it requires an enormous investment for the optical fibre infrastructure. This cost can be reduced by an alternative topology, the star/tree hybrid, employing passive optical splitters, as illustrated by *fig 3(b)*. Yet the cost saving might be offset by additional complexity to the network as the CS wouldn't be able to distinguish between the signals coming from different RAUs.

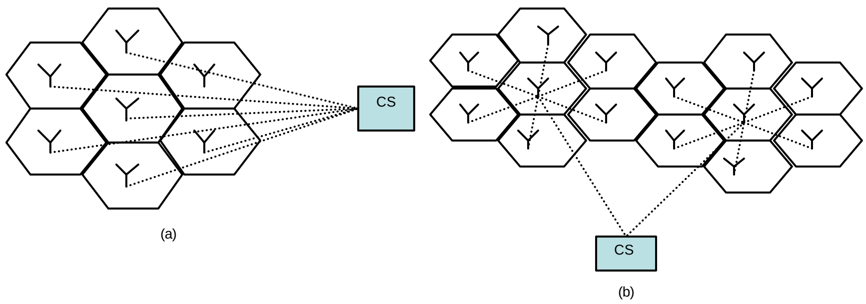

Figure 3. Wireless LAN network topology using optical fibre. (a) Star. (b) Hybrid star/tree.

Optical length: Most of the time, the HFR size and topology are limited by the optical losses in the fibre infrastructure. This is true for the HFR architecture proposed (fig 3) where the upstream signal is especially sensitive to optical loss as the total length consists of the distance between CS and RAU, and back again (where the downstream loss reduces the optical power available for modulation.) Instead we propose that the optical length is limited not by optical losses in the fibre network, but rather on the 802.11 specifications; where all stations must synchronises its clocks with the servicing *access points* (AP). This involves the AP periodically generating beacon frames containing clocking information, and the receiving client stations will adjust its internal clock base on the information within the beacons. It also specifies the synchronisation process should be completed within 4 µs, excluding air propagation delay. In the HFR/WLAN environment, not only there is propagation delay in the air, but also in the optical layer. Hence care must be taken to ensure the optical propagation delay does not exceed the synchronising timing. Considering the group velocity within fibre is $2x10^8$ m/s and the modulation/demodulation of laser does not incur significant delay. Using the simple calculation where length is the product of velocity against time; the maximum link length is 800m. The more realistic length would rather be at the 500m – 600m range, after taking into account of processing delay across physical layer (PHY) of the devices. This highlights the possibility of fibre co-sharing with IEEE 802.3 gigabit Ethernet (which is widely used in building LAN) as it is limited to 550m [8] on 50 µm *multimode fibre* (MMF). Hence we have shown the optical link length is not limited by losses in the fibre, but rather by the wireless standard. Where HFR normally would allow optical links to reach tens of kilometres, IEEE 802.11 has limited it to less than 800 meters.

Preserving OFDM guard interval: Another issue relevant to the network is preserving the OFDM guard interval in the optical medium. We suggest that HFR/WLAN not only introduces optical propagation delay, but also optical equivalent of free-space multipath echo. This ultimately results in ISI as the multipath, multi-copies of the same signal arriving at the receiver exceeding the OFDM guard interval. This would result from a transmitting station on the coverage edges of a few RAUs with different optical path to the CS. The receiving AP will thus be presented with copies of the same signal, but arriving at different time (or the other way round where the receiving stations receiving multiple copies of the same transmission, but from different RAUs.) These differences in time between RAUs we term as t_{RAU}, which is also directly proportional with the path differences between co-neighbour RAUs. Thus ISI can be prevented as long as t_{RAU} does not exceed the guard interval. 802.11a specifies its guard interval to be 0.8 µs and this is the maximum value of t_{RAU}. Again assuming the group velocity within fibre is $2x10^8$ m/s and the modulation/demodulation of laser does not incur significant delay. Using the simple calculation where length is the product of velocity against time; the maximum path difference between co-located RAUs is 160m.

Optical MAC: Let us now discuss about medium access control for the optical network. Here we are proposing as much as the IEEE 802.11 CSMA/CA and RTS/CTS mechanism provides access control for the wireless medium; it could also simultaneously provide access control for the optical medium. Since collisions are equally undetectable in the optical, as in the wireless medium. Monitoring of both mediums for activities, and correctly determining the idle period is absolutely essential to ensure proper access to the network. This means the optical network must not introduce significant delay into the wireless medium to cause stations to incorrectly determining an idle period has been detected. We mentioned the maximum delayed introduced by the optical network should be less than 4µs, and this is small comparison to the total DIFS period. Addition of random back off before transmission, and CTS/RTS mechanism, it is unlike 802.11 MAC would collapse in the HFR-WLAN network.

5. Conclusion

This paper has presented an approach to provisioning wireless LAN services over an optical network layer. We propose a HFR/WLAN network with optical signal generation by external modulations at the CS, and simplify RAU employing EAT as the detector and modulator simultaneously. It is characterise by the wireless specification being the dominating factor on optical transport topology. This means the size of the optical network is limited by IEEE 802.11 devices need for clock synchronisation, and preservation of OFDM guard interval. We have also argued that IEEE 802.11 MAC provides medium access control for both wireless and optical medium, as long as the optical layer does not contribute distortion to wireless medium.

References

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