ANALYSIS OF DELAY BOUND IN IEEE 802.11g WLAN OVER FIBER NETWORKS

Erna Sri Sugesti[1], Purnomo Sidi Priambodo[2], Kalamullah Ramli[2], Bagio Budiardjo[2]

[1] Faculty of Electrical Engineering Department, Telkom Institute of Engineering, Bandung 40257, Indonesia
[2]Faculty of Engineering, University of Indonesia, Depok 16424, Indonesia
[1] ern@ittelkom.ac.id, erna.sri@ui.ac.id, [2]{pspriambodo, bbudi, k.ramli}@ee.ui.ac.id

Abstract

In this paper, we elaborate a new delay calculation on IEEE 802.11g-over-Fiber networks theoretically. It is found that delays generated by optical fiber and optical transceiver are more dominant than the air propagation. In this case, by inserting optical transceiver delay made the fiber length difference of 100 m.

Keywords: WLAN, IEEE 802.11, optical fiber, delay,

1. Introduction

The technology of Radio over Fiber (RoF) has been developed since in the mid of '90s. In the beginning, the development of this technology is mainly to support wireless cellular networks as a backhaul or an access network. This technology is accepted by the market rapidly, it can be by the following factors: the migration of cell coverage from macrocells into microcells, the enabling unified operation of multicarrier frequency system from multioperator, the simplicity of the RoF realization with better performance than coaxial networks, and the ease of increasing capacity by using wavelength division multiplexing (WDM) techniques [8][3][1].

Recently the tremendous rapid growth of internet users brings onto last-mile network traffic problems, especially for wireless-LAN (WLAN) applications. The success implementation of RoF networks has motivated to explore another hybrid network between IEEE 802.11 Wireless-LAN (WLAN) and the optical fiber, which is called Fi-Wi (Fiber-Wireless) network. Intuitively there is no doubt that the hybrid network will perform better to some extent. In fact, however, the throughput of the hybrid network demonstrates worse than the WLAN [5]. One of the reasons is the make use of a carrier sense multiple access with collision avoidance (CSMA/CA) without any modification.

There are some kinds of WLAN technologies; in this case we decide to employ the utmost technology applied in the world is IEEE 802.11g [1]. The main characteristics of IEEE 802.11g are shown on Table 1 [11]. This technology applies adaptive modulations which depend on the traffic situation and the distance between an Access Point (AP) and Mobile Units (MU), Table 2. From both tables, it can be seen that if the MU location closer to the AP it will obtain higher bit rate and vice versa. However, the maximum range is only 100 m. It means that other APs should be installed in order to extend the coverage area.

Table 1. Resume of IEEE 802.11g technology [11]

Freq.	Physical	Access	Max range	Power
2,4 GHz	OFDM	CSMA/CA	50-100 m	Medium
Throughput				
Physical	Effective			Region
54 Mbps	=< 22 Mbps			Worlwide

Tabel 2. Modulation systems in IEEE 802.11g[9]

User Rate (Mbps)	*FEC Coding*	*Line Rate (Mbps)*	*∑Bits per SC*	*Mod. BW*	*Eff. (bps/Hz)*
54	3/4	72	1.5 Mbps	64-QAM	2.7
24	1/2	48	1 Mbps	16-QAM	1.2
12	1/2	24	500 kbps	QPSK	0.6
6	1/2	12	250 kbps	BPSK	0.3

The standard of IEEE 802.11g WLAN deploys a license-free frequency 2.4 GHz. It definitely becomes a crowded-usage bandwidth and high-density traffic where anyone can use it as a propagation medium. With a very short range of 100 m, overlapping cells or co-channel interference may occur easily if the wireless network design unconsiders a site survey in advance. Moreover, some products of this standard are equipped with Power Level (PoE) management. This denotes that the coverage areas may vary that depend on power setting of the AP.

To avoid such complex problems, the Fi-Wi network seem to give a proper solution. By using the optical fiber for extending the wireless coverage area to make a new WLAN cluster, we can penetrate that overlapping coverage area without doubting that the wireless electromagnetic disturbance may deteriorate the information signals.

In this paper, we investigate the delay mechanism in propagation media, especially on optical fiber and optoelectronic transceiver delay factors which can affect the network performance.

The main purpose is to obtain the propagation delay of IEEE 802.11g WLAN over fibers numerically, which then we could have the maximum length of fiber in order to enlarge the coverage area and to increase the network throughput, as well. This preliminary study is based on theoretical approach.

2. Theoretical Background

2.1. Medium Access Control Structure

The family of IEEE 802.11 standard applies a carrier sense multiple access with collision avoidance (CSMA/CA) medium access protocol (MAC) with binary exponential, which called Distributed Coordination Function (DCF) and Point Coordination Function (PCF). DCF is a class of coordination function where the same coordination function logic is active in *every station* (STA) in the basic service set (BSS) whenever the network is in operation [13]. Meanwhile, PCF is similar to DCF but *only one STA* in a BSS at any given time. The relationship of both in MAC is shown in Fig. 1.

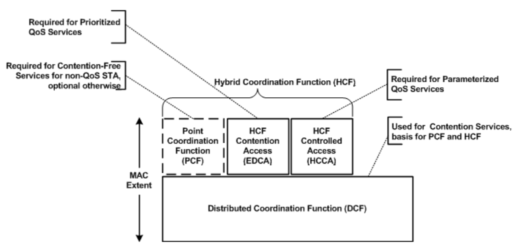

Fig. 1. MAC architecture [13]

The DCF creates two mechanisms, basic access and Request-to-Send/Clear-to-Send (RTS/CTS). Shortly, both mechanisms are depicted in Fig 2 and 3, respectively. Among those timing procedures, we concern to Short Interframe Space (SIFS) one since this is a basic timing and it plays key role in frame exchanges. The SIFS is constructed by several different timings as stated in Eq. (1) [13]. For this time being, this is not our concern now. Every standard has its determination values. For example, the SIFS of 802.11g is 10 μs [13]. Subsequently, the total round trip delay between frames must be less than this value. Unless, the loss frames will take place and it should be retransmitted. Next, the effect of this occurrence is decreasing network throughput.

$$SIFSTime = aRxRFDelay + aRxPLCPDelay + aMACProcessingDelay + aRxTxTurnaroundTime \qquad (1)$$

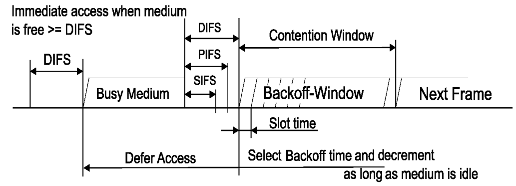

Fig. 2. Basic access method [6]

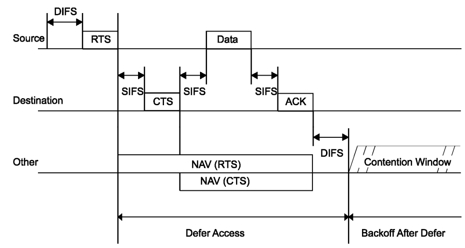

Fig. 3. RTS/CTS/data/ACK and NAV setting [6]

2.2. Optical Fiber and Optical Transceiver

The optical fiber is made of isolator materials, such as glass or plastics, that makes it immune to electromagnetic wave disturbance. Based on the index profile of the core, the optical fiber types are step index (SI) fiber and graded index (GI) fiber, meanwhile based on the number of modes propagate in the core are single mode fiber (SMF) and multimode (MM).

The optical fiber materials are classified into dispersive substance. Besides, optical sources such as a light emitting diode (LED) and a light amplification by stimulated emission of radiation (LASER) may produce multi optical frequencies. Therefore, the optical signals propagate along the fiber delivered into several refractive indices distributed inhomogeneously in the core. With this phenomenon, we may use the effective refractive index parameter (n_{eff}) in spite of an absolute value. Some methods to determine the effective refractive indices have been analyzed by Chiang [4]. In physics, it may be defined that refractive index describe as the comparison between velocity of light in vacuum (c) and velocity of light in a medium (v), Eq. (2). Meanwhile v is also define as the optical waves travel during a time of t_f (s) and at distance of L (m), Eq. (3). By substituting Eq. (3) into (2) and eliminating v, the one-trip delay of optical fiber can be derived as the result in Eq.(4).

$$n_{eff} = \frac{c}{v} \qquad (2)$$

$$v = \frac{L}{t_f} \qquad (3)$$

$$t_f = \frac{n_{eff} L}{c} \qquad (4)$$

The MAC protocol requires one round trip delay.

An optical transmitter comprises of the optical source and a driver circuitry. The delays in the optical transmitter are due to the conversion process from electronic state into photonic state in the converter components. The accumulation transient time of the components are usually stated in rise/fall time characteristic of the driving circuit. The output light of LED is photons generated by spontaneous recombination. The modulation speeds of LED are restricted by two main factors, extrinsic and intrinsic [2]. The extrinsic factor is the junction capacitance of the diode. Together with resistance, it affects to a characteristic RC time constant. While the intrinsic factor stems from the charge storage and diffusion capacitance of a p-n junction under forward bias. The recombination lifetime in junction materials plays a key role in affecting the modulation bandwidth. In general, the modulation bandwidth of an LED relies on the device configuration, doping level in the active layer, the lifetime of the injected carriers, and parasitic capacitance and resistance in the circuit. The bandwidth more than 1 GHz can be achieved now.

The semiconductor laser type which uncooled, low cost, and popular used for application in short distance network such as local area network (LAN), storage area network (SAN) is the vertical-cavity surface-emitting laser (VCSEL). The VCSEL is characterized by a complex interplay between optical, electrical, and thermal effects [14]. The maximum modulation bandwidth of the laser is limited by damping effects. The capability of modulation speed is up to 20 GHz. The VCSEL is suitable for outdoor usage for its heat resistance environment. A demonstration has been carried out at wavelength of 850 nm and the temperature of 85^{o}C for 2-km MMF shows full WLAN operation at 3,85 Mbps, with no observable degradation [10].

The optoeletronic device at receiver which is assigned to reconverts the photons into the electrons is a photodetector. Commonly, two types of photodetector that suitable for optical fiber communication, *p-i-n* (positive-intrinsic negative) photodiode and avalanche photodiode (APD). They operate at a certain wavelength region, such as around 850 nm, or 1300-1600 nm. The pin photodiode is constructed by pn junction diode in which an undoped *i*-region is inserted between p^+ and n^+ regions. A trade off must be taken for certain purpose design, for example for high response speed the depletion layer should be small and for high quantum efficiency, or responsivity, the depletion layer width should be large. There is no internal optical gain. By careful choice material parameter and device design, very large bandwidth can be obtained. The response speed depends on the carrier diffusion time in which creates a long tail pulse for ~1-10 ns. Therefore, this type is fit for low speed and short-distance link. On the other hand, the APD is built by many different type layers with specific purposes to generate the internal gain. For example, the separate absorption and multiplication (SAM) APD [9]. These configurations combine low leakage with sensitivity at long wavelengths. Due to some weakness arised from this type, further development construction created into next generation, called separate-absorption graded-multiplication (SAGM)-APD. For high-speed operation, usually the rise time of 100-200 ps and fall time ~10-100 ns can be achieved. Therefore, the APD makes it more suitable applied for high-speed operation and long-distance link.

3. Analysis of Delay-Bound

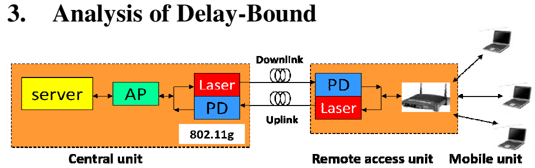

Fig. 4. Model of hybrid link IEEE802.11g WLAN-over-Fiber [5].

Table 3. Parameters of Delays

Transceiver Delay (µs)		Air Propagation Delay (µs)	
OPT1[6]	1.6	A	1
OPT2[7]	1.25	B	0.1
		C	0.01

We use a hybrid link model as in Fig. 4 with MAC protocol of IEEE 802.11g, focusing on the optical segment that is a laser, an optical fiber and a photodiode (PD), and the direction of signal flow may downlink or uplink is similar. The total delays are the contribution of optical transceiver D_{opt}, optical fiber (t_f) and air propagation (D_{air}). The optical transceiver delay data can be found in Table 3. These data are based on the equipment data sheet. The optical fiber delay uses Eq. (4) with the setting of n_{eff} = 1.5, as an example. This equation may valid for SM or MM fiber type. The air propagation delays are varied, since the distance between AP and MU are varied as well. Next, the roundtrip total delay can be expressed as

$$D_T = 2\left(D_{opt} + t_f + D_{air}\right) \qquad (5)$$

Fig. 5 shows the results of the delay calculation.

From Fig. 5, it can be seen that the delay increase linearly as the distance longer. As stated that the delay limit based on 802.11g is 10 µs. To fulfill this requirement, we cut off the fiber length that resulting allowable delay. The shortest fiber length is 400 m meanwhile the longest fiber used is around 700 m only. For all the case, choosing shorter delay on optical transceiver shows a significant difference for the air delay, about 100 m. The closeness lines between (OPT1,B) and (OPT1,C) and between (OPT2,B) and (OPT2,C) indicate that the air propagation delay change of 0,1 µs give very small contribution to the total delay. Therefore, we can abandon the air propagation delay in this network.

4. Discussion

Our calculation on the delays are confirmed with the results of [5] but not for [12]. However, both papers did not concern with the optical transceiver. This made the length of fiber longer than our calculation. Those papers are published by an intensive research group specialized on Radio or WLAN over Fiber which has never consider the optical transceiver take into account. Therefore, this paper is the first attempt inserting the optical transceiver into the total delay calculation. For different transceiver specification, in this case the fiber length difference is around 100 m.

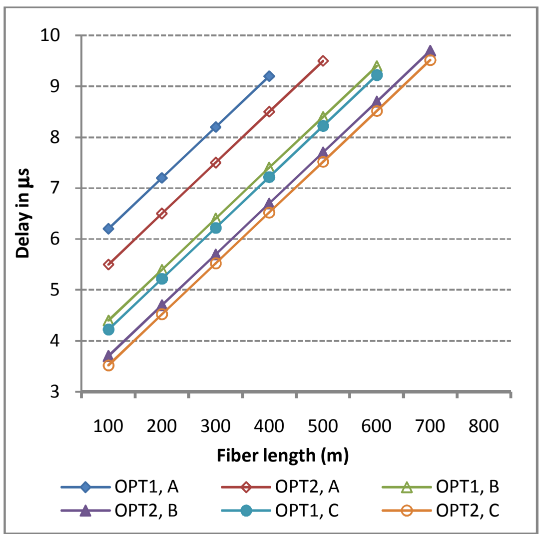

Fig. 5. The length of fiber under SIFS

Comparing the hybrid network with an optical access network (OAN) in the term of fiber length, there will be the unbalance situation since the optical signal may travel tens of kilometer and can carry information in the order of hundreds Mbps in the later network. In my opinion, it seems due to the usage of different protocols. The OAN usually applies synchronous digital hierarchy (SDH) protocol, meanwhile the hybrid network utilizes CSMA/CA which the procedure is very tight constraint in timing. If we want to extend the coverage area of the hybrid network with maintaining the network throughput, we may not rely on the physical layer re-engineering any longer.

Some alternative solutions offered are re-engineering the data link logic layer MAC or to combine with a free space optical communication (FSOC) system which the refractive index of the air is smaller than the optical fiber to enable the longer distance coverage.

5. Conclusion

The insertion of optical transceiver, introducing new precision delay bound calculation, in this case the result show around 100 m of fiber length difference. The delay bounds are affected dominantly by the optical transceiver and the optical fiber.

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