5.8 GHz Photonic Antenna for Point to Point Applications

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Abstract – Due to its low propagation loss, large bandwidth, and competitive cost, optical fiber become one of the best solution for the backhaul. However, new fiber network deployment is still very expensive in outdoor and rural environment. This paper proposes and evaluates design of 5.8 GHz photonic antenna in a radio over fiber system for point-to-point applications. Simulation result shows that the proposed system can support 540 Mbps, 16-QAM, at 5.8 GHz for optical fiber length of 30 km, and extended with wireless distance of 10 km.

Keywords: photonic antenna, point to point, backhaul, radio over fiber, 5.8 GHz.

1. Introduction

Migration to broadband services is needed to facilitate aggressive growth of internet access. In order to deliver expected bandwidth to customers, backhaul become major contributor to overall network performance and cost [1, 2]. Optical fiber is one of the best solutions of transmission media due to its huge bandwidth, low loss, and competitive cost.

However, new fiber optic and cable deployment is still very expensive in outdoor, backhaul, and sparse-and-large campus/rural environment. Nevertheless, some areas of campus may be have been covered by optical fiber network to provide backbone for campus network. These existing optical fiber networks can be used to provide and extend the backhaul network using WiMAX and WLAN signal.

The wireless backhaul extension of fiber network requires conversion from baseband optical Gigabit Ethernet (GbE) or Fast Ethernet to baseband electrical signal, format it with WiMAX and WLAN protocol to form the RF wireless signal, and then radiate it using antenna. However, the optical switch needed to do the conversion is expensive. Photonic antenna can potentially solve this problem, by bypassing the switch, i.e. transmitting radio/microwave signals directly through optical fiber and radiated the RF wave using RF antenna that is integrated with optoelectronics.

Successful transmission of WLAN signal over optical fiber has been reported. IEEE 802.11a/b transmitted with 1.3um VCSEL and 4180 MHz.km multimode fiber (MMF) can reach over 1.1 km, and using single mode fiber (SMF) over 30 km [3]. As optical fiber backhaul network extension, WLAN signal has been proven capable to coexist with Gigabit Ethernet, Fast Ethernet, and UWB signal in optical fiber [4]. Therefore, photonic antenna does not need dedicated optical fiber.

However, current photonic antennas [5-9] are low gain, therefore not suitable for high performance, point-to-point, and long distance wireless link. This paper proposes and evaluates design of 5.8 GHz photonic antenna in a RoF system, for point-to-point applications.

2. Photonic Antenna Design

General RoF system is described in Figure 1. A central station (CS) can serve many radio access units (RAU). The RAUs are located near to intended customer location, and acting as air interface to user premises. RAU consist of antenna, filter, RF amplifier, and optoelectronics. Photonic antennas are to replace RAU function, but commonly designed and fabricated without RF amplifier.

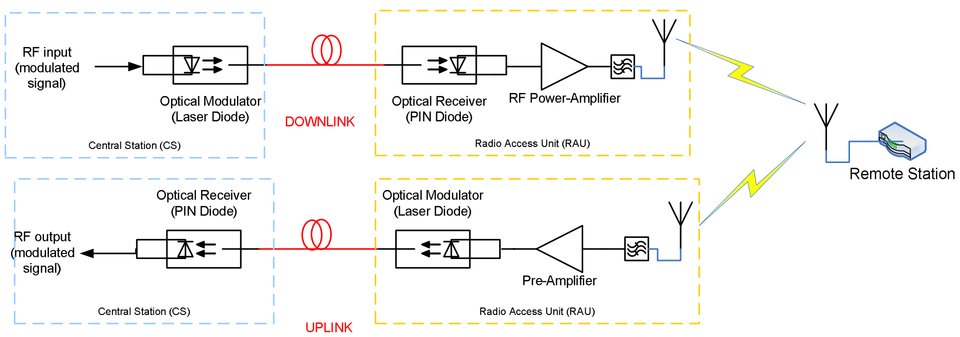


Figure 1: Block diagram of radio over fiber system.

A photonic antenna integrates PIN diode, band pass filter (BPF), and antenna in downlink, and laser diode, BPF and antenna in uplink as depicted in Figure 2. In our design, a high gain microstrip antenna (Figure 3) is used. The antenna is array of two antennas, which Figure 3a shows the individual antenna and Figure 3b shows the antenna array. From electromagnetic simulation result, the radiation pattern of the antenna is shown in Figure 4, and the maximum gain is 11.83 dBi. The antenna gain (G) and return-loss $|S_{11}|$ at 5 – 6.5 GHz are described in Figure 5. These results are also from electromagnetic simulation. BPF is used to reject out-of-band emission, needed especially if the RF signal coexists with GbE or Fast Ethernet. For long distance fiber, SMF based RoF with working optical frequency around 1300 nm and 1550 nm is used. Consequently, laser diode and photodiode employed in this design work on 1300 nm or 1550 nm.

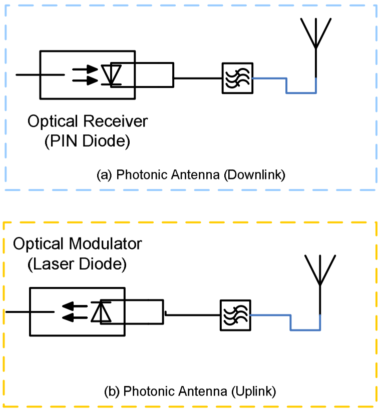
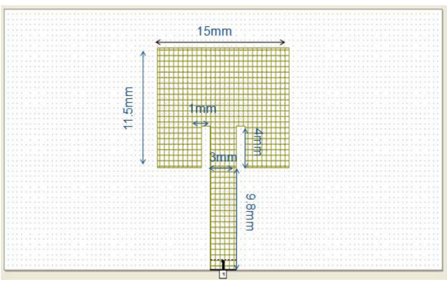
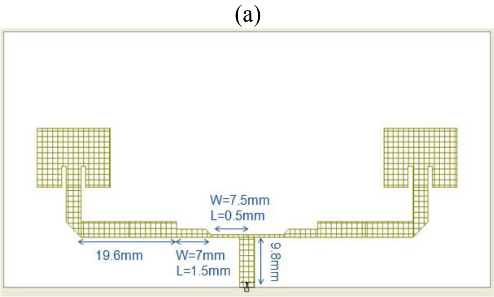


Figure 2: Block diagram of photonic antenna for (a) downlink and (b) uplink.



(a)



(b)

Figure 3: Microstrip antenna (b) is array of two individual antennas (a).

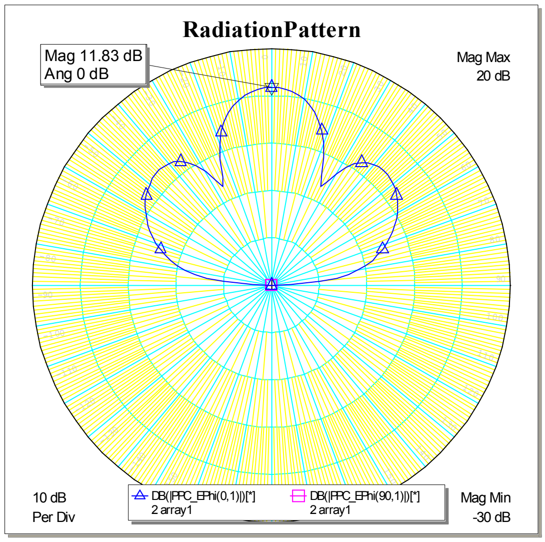
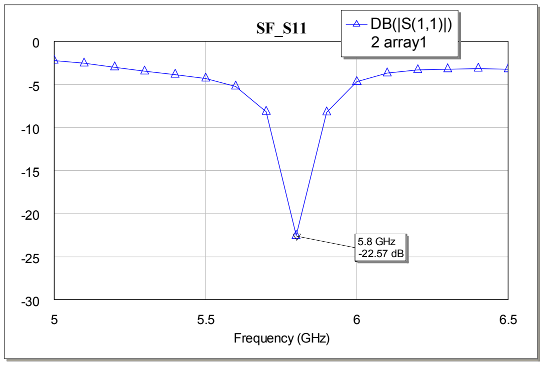
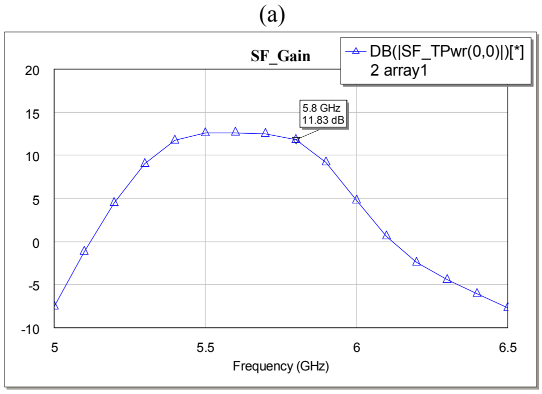


Figure 4: Radiation pattern of the antenna at 5.8 GHz.



(a)



(b)

Figure 5: Return loss (a) and gain (b) of the antenna.

3. Simulation Setup

The antenna has gain (G_P) and return-loss $|S_{11}|$ as described in Figure 4 and 5 then transformed to S2P using formula in Table 1 and 2. Operation of the photonic antenna in downlink uses S2P transformation for antenna in transmitting mode. The remote station uses the same antenna, but operating in receiving mode. Link between photonic antenna and remote station is free-space and distanced at 10 km, resulting propagation loss of 127.7 dB. System simulation uses

540 Mbps 16-QAM, and evaluated in terms of bit error rate (BER) as function of optical fiber length. The simulation uses Optisystem v7, an optical communication system simulation software.

Table 1: S2P values for antenna in transmitting mode.

$\lvert S_{11}\rvert$	$\angle S_{11}$	$\lvert S_{21}\rvert$	$\angle S_{21}$
$\lvert S_{11}\rvert$ of the antenna	$\angle S_{11}$ of the antenna	$\lvert S_{21}\rvert = \sqrt{G_P\left(1-\lvert S_{11}\rvert^2\right)}$	0
$\lvert S_{12}\rvert$	$\angle S_{12}$	$\lvert S_{22}\rvert$	$\angle S_{22}$
arbitrary	arbitrary	arbitrary	arbitrary

Table 2: S2P values for antenna in receiving mode.

$\lvert S_{11}\rvert$	$\angle S_{11}$	$\lvert S_{21}\rvert$	$\angle S_{21}$
0	0	$\lvert S_{21}\rvert = \sqrt{G_P\left(1-\lvert S_{22}\rvert^2\right)}$	0
$\lvert S_{12}\rvert$	$\angle S_{12}$	$\lvert S_{22}\rvert$	$\angle S_{22}$
0	0	$\lvert S_{11}\rvert$ of the antenna	$\angle S_{11}$ of the antenna

Figure 6 model the CS in Optisystem v7. The function of CS in this simulation is as source of RF signal with operating frequency of 5.8 GHz, modulated with 540 Mbps 16-QAM, and then modulate the RF signal into laser diode. To do this task, CS model in Optisystem consists of "Pseudo-random bit sequence generator" as source of information with data rate of 540 Mbps, "16-QAM sequence generator" that maps the binary bits into 16-QAM sequence, "M-ary pulse generator" that change the number (16-QAM sequence) into electrical signal, and "Quadrature modulator" that produce RF modulated signal at center frequency of 5.8 GHz. The modulated RF signal is then fed to "Directly modulated laser" that works on 1550 nm.

Model of photonic antenna is described in Figure 7. The "Photodetector PIN" works on 1550 nm, optically demodulate the optical signal into RF signal. BPF used is Bessel type with center frequency of 5.8 GHz and bandwidth of 3x540 MHz. The filtered RF signal is then radiated with high gain microstrip antenna that is represented with "2 Port S Parameters" block. The value in the block follows formula in Table 1. The electrical attenuator represents free space path loss at 5.8 GHz with distance of 10 km.

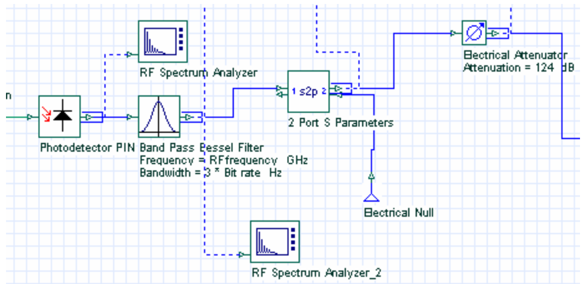


Figure 7: Model of photonic antenna as RAU and electrical attenuator and free-space path loss.

After attenuated by free space path loss, signal radiated by photonic antenna is received by remote station. Optisystem model for the remote station is shown in Figure 8. The "2 Port S Parameters" block represents antenna in receiving mode, which converts antenna gain (G_P) and return-loss $\lvert S_{11}\rvert$ as described in Figure 5 into S2P values based on formula in Table 2. The RF signal from the antenna then demodulated by "Quadrature demodulator" resulting a weak continues signal. Therefore, an automatic gain control (AGC amplifier) is inserted in front of decision device ("M-ary threshold detector"). The binary bits is decoded from 16-QAM sequence by the "QAM sequence decoder."

The "NRZ pulse generator" in CS and remote station model convert binary number into electrical signal. BER meter compares NRZ pulses from CS and remote stations to calculate bit error rate of the system.

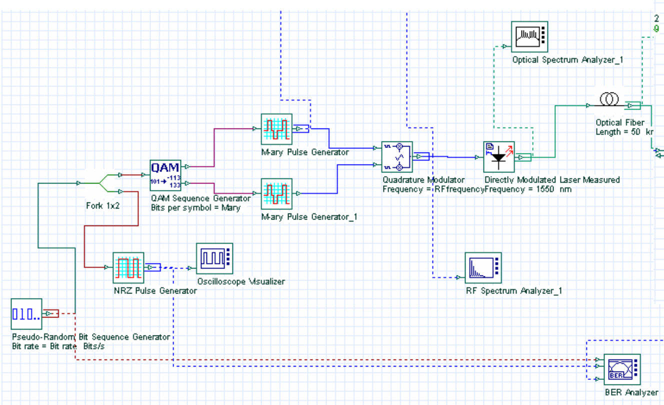


Figure 6: Model of Central Station and optical fiber.

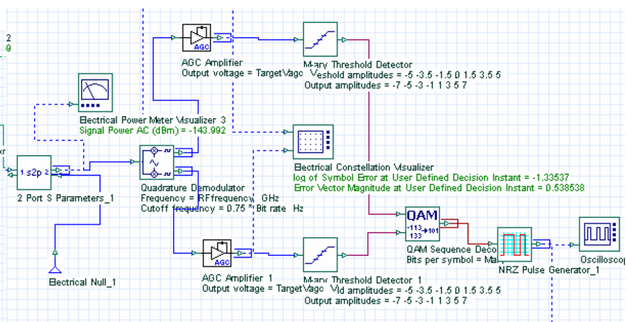


Figure 8: Model of remote station, with S2P block representing receiving antenna.

4. Simulation Result and Discussion

The system produces very low BER at optical fiber length up to 30 km (6 x 5 km) as shown in Figure 9. Compared with [3], the simulation in this paper involved much higher bit rate (54 Mbps vs. 540 Mbps). Added with wireless distance of 10 km, the backhaul network can serve 40 km. High gain photonic antenna plays significant role in extending the wireless distance.

Example of power level comparison at input and output of photonic antenna, as well as at input and output of remote station's antenna is depicted in Figure 10. Those are the power level at 5 km optical fiber. Power level at input of photonic antenna is -20.46 dBm, and EIRP of the photonic antenna is -9.24 dBm. The difference is 11.22 dB, lower than maximum gain of 11.83 dBi. This is result of non-zero return loss of antenna at 5.8 GHz.

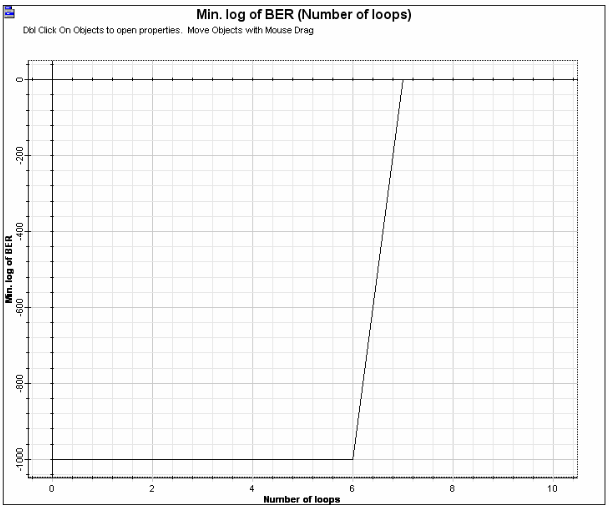


Figure 9: BER as function of multiple 5 km optical fiber.

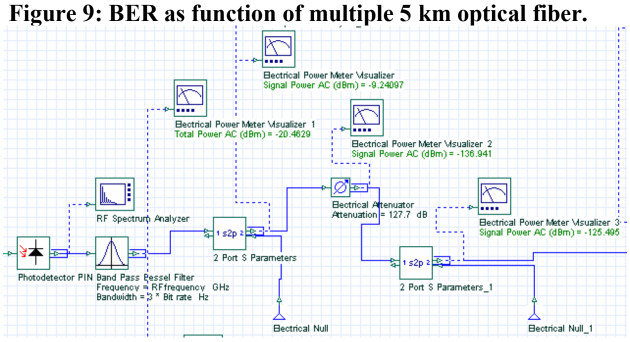


Figure 10: Comparison of power level at input and output of photonic antenna, and input and output of remote station's antenna.

5. Conclusion

It has been shown that the proposed system can support 540 Mbps, 16-QAM, at 5.8 GHz for optical fiber length of 30 km, and extended with wireless distance of 10 km. The proposed high gain photonic antenna works well in the system, capable to extend the backhaul distance and therefore suitable for longer distance, point-to-point application.

Acknowledgment

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