High-Speed Power-Efficient Indoor Optical Wireless System

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1. INTRODUCTION

The need for easy, reliable and fast connectivity is a growing requirement of today's short-range indoor communication systems such as wireless local area networks (LANs). The requirement is for a communication medium that has high speed, low cost, and low power consumption. Optical wireless (Infrared) and radio are both viable solutions, but the promise of high un-regulated bandwidth at a low cost makes optical wireless an attractive technical alternative. The use of infrared (IR) technology in indoor optical wireless systems make them less costly, free of government regulation, immune to radio interference, and secure (cannot penetrate walls). Currently, directed beam infrared (DBIR) systems are the most widely used optical wireless systems which offer excellent transmission capacity, but with restricted mobility and severe shadowing problems. These restrictions can be reduced using diffuse infrared (DFIR) systems but at the cost of the reduced transmission capacity due to the increased path loss and multipath distortion. Tracked or quasi-diffuse infrared (QDIR) systems [1] can offer potentially high bit rates and combine the high power flux densities associated with line-of-site (LOS) or DBIR systems with the increased coverage enjoyed by wide-LOS or DFIR systems. Conventionally, tracked configuration is achieved by means of steerable optics which is not convenient and economical. For the proposed system, the tracking functionality can be realized using arrays of emitters and detectors.

Traditionally, IR technology is designed for operation at 850 nm wavelength[2], although the latest technology includes 1.5 ìm wavelength devices[3]. The use of 1.5 ìm wavelength devices for indoor communications is attractive due to the following reasons: Firstly, they are eye-safe up to the permissible emitted power of 10mW[1]. The higher level of permissible emitted power at this wavelength also helps in improving the available link power budget. Secondly, the optical environment becomes progressively quieter with increasing wavelength[2] as shown in Figure 1. Therefore, at these wavelengths, the system receivers are immune to strong ambient infrared radiation (except incandescent light sources).

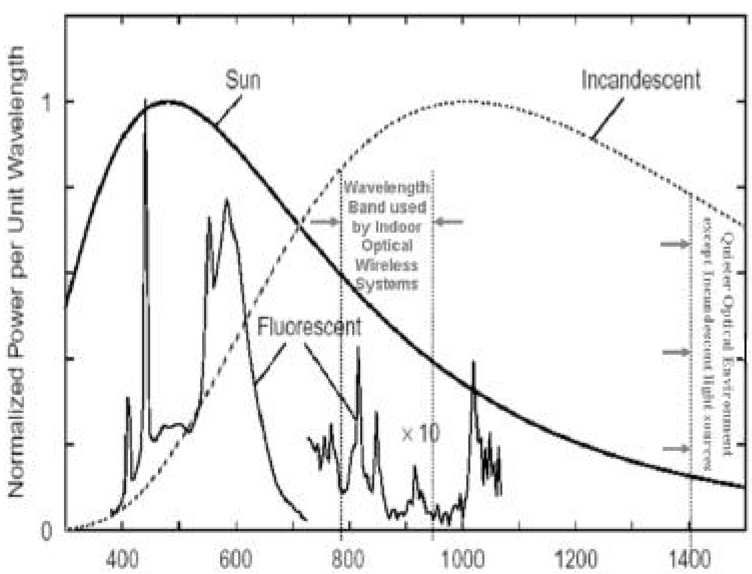

Figure 1: Spectral power densities of common ambient light sources

2. THE PROPOSED SYSTEM

We propose an architecture of an optical wireless system for local area networking. This system would provide high-speed, power-efficient and reliable wireless connectivity among the stationary and mobile wireless data terminals within a room to the terminals on backbone. Fig. 2 shows the schematic diagram of a bidirectional optical wireless system based on the star network topology. An active base station (BS) comprising of a transceiver is installed above the coverage area. To form a local area network, each terminal in the room is also equipped with an integrated transceiver.

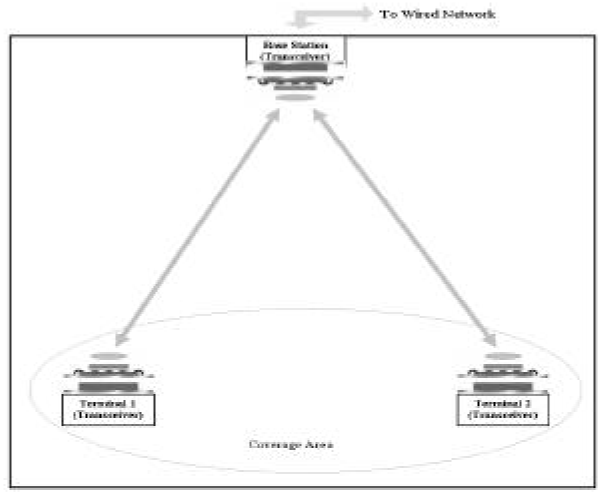

Figure 2: A high-speed power-efficient indoor optical wireless system

Figure 3 illustrates the working principle of the optical wireless link for the proposed system. The individual component of the transceiver might consist of a source, its paired detector and the necessary drive and control electronics. The tracking functionality of the transmitters for the proposed system can be realized using two-dimensional (2-D) arrays of vertical-cavity surface-emitting lasers (VCSELs) emitting beyond 1400nm[3] as shown in Figure 3a. VCSELs operating at these wavelengths have been demonstrated by R. Shau et al[2], and it is likely that arrays of sources will become available in the near future. VCSELs are advantageous due to well-controlled output beam properties, high modulation bandwidth, high efficiency, and high power. A matrix-type diffractive element (DE) can be used to shape and direct the beam of each individual VCSEL[4] as shown in the inset of Figure 3a. Each individual DE converts the Gaussian beam to a flat top beam and direct the beam to a desired solid angle. The field of view of the multi-beam transmitter can be set at ±50 degrees. When each element illuminates a 10-degree angle in one dimension, a 10×10 VCSEL matrix is needed. Light from each VCSEL, forms a narrow 'beam' of illumination at the receiver plane of the coverage area. The transmitters using this configuration are expected to reduce path loss compared to the diffuse transmitters, because the narrow beam experiences little path loss traveling from the transmitter to the destination receivers. The transmitted power from the array of sources is minimized by deactivating the VCSEL elements not emitting in directions of receiver hub.

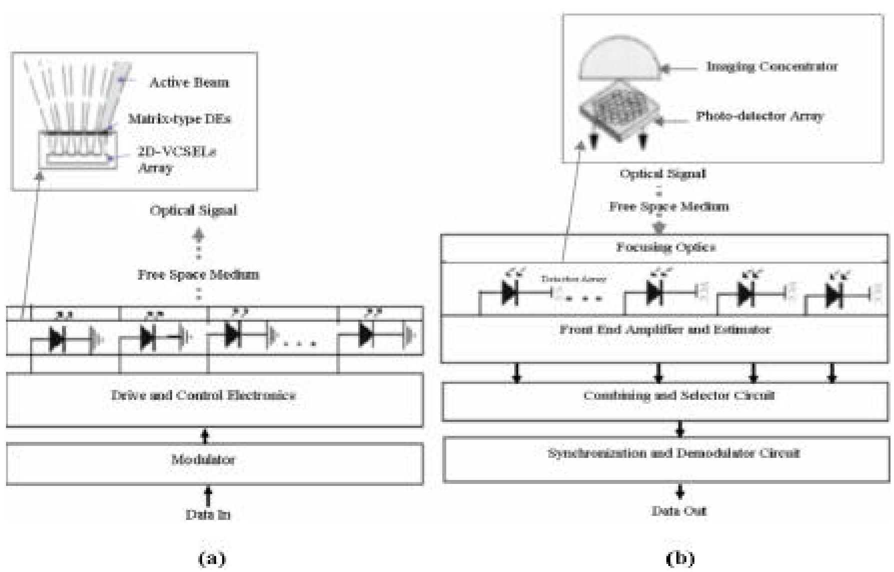

Figure 3: Working Principle of the proposed system (a) transmitter, (b) receiver

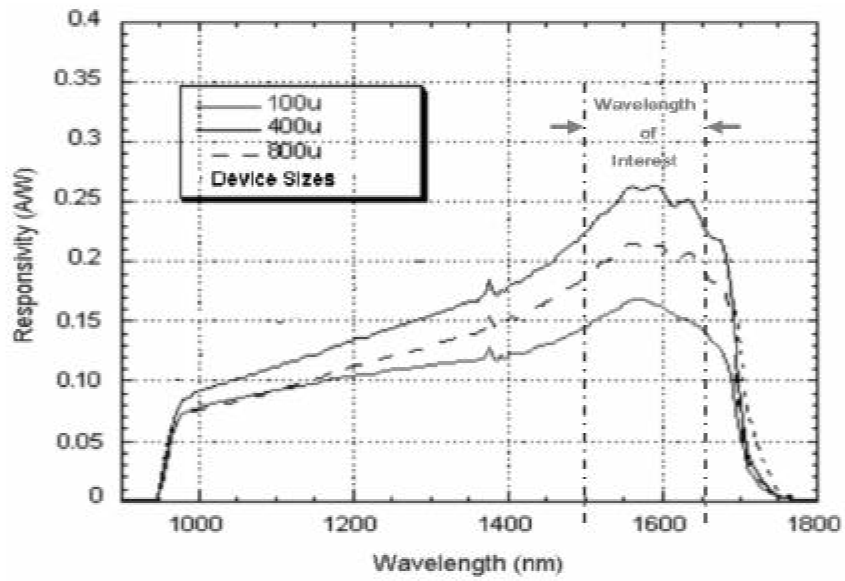

Figure 4: Responsivity of filtered detectors for various device sizes

The receivers of the system can use imaging mechanism[5] as shown in the inset of Figure 3b. It helps to detect the signals received from different directions. It consists of the focusing optics and the hexagonal closed-packed array of InGaAs detectors with a relatively small FOV grown on InP substrates. A thick InGaAsP optical filter layer can be integrated with InGaAs detector array layer to detect light and generate photocurrent for only a small wavelength range between 1500nm and the long wavelength cut-off for this material which is at 1650nm[6]. These devices offer excellent peak responsivity (Fig. 4) at higher wavelengths (beyond 1400nm). Each element of the array can use receiver electronics to track the direction from which the maximum radiation is received (Figure 3b). The photocurrents received by the various detectors can be separately amplified, and the resulting electrical signals can be processed and combined using select-best (SB) or any other suitable method. The combining circuit works as an analogue multiplexer that selects the signals with the highest SNR.

In wireless networks, the carrier sense multiple access/collision detection (CSMA/CD) protocol[7], which is used with great success in Ethemet, is not very efficient due to interference from neighboring cells, the relatively large amount of time taken to sense the channel, and the hidden node problem. However, the proposed system does not suffer from these problems and can use the CSMA/CD protocol. The transceiver of the base station routes signals to and from the active transceiver pairs of the machines within the coverage. Additionally, the BS can be modified to function as Ethernet switch, where narrow beams will act as ports of Ethernet switch. Now, multiple transceiver pairs can communicate simultaneously if they use non-overlapping narrow beams.

3. CONCLUSIONS

We have proposed the architecture of an optical wireless system for local area networking. The base station at the ceiling establishes a shared medium and due to the directed link, the channel properties are nearly ideal. Hence the Ethernet MAC protocol can be applied. Since the proposed system uses array of VCSELs emitting at 1.5ìm, it is eye-safe, nearly immune to ambient light noise and offers excellent power budget. Moreover, shot noise is reduced by the small field of view of receiver array elements and effects of multipath dispersion are minimized due to use of multiple detector arrays in the receiver. The proposed system is expected to achieve a bit error rate (BER) of the order of 10^{-9} at a transmission rate of more than 100 Mb/s.

4. REFERENCES

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