LCoS-based Access Node for Bidirectional Optical Wireless Communications

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Abstract: An LCoS-based access node using optical fibers as the transmitter and receiver to extend the high-speed data transmission from NG-PON 2 to indoor home area network through optical wireless communications without O/E/O conversions is reported.
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1. Introduction

With the increasing bandwidth requirement from home multimedia services such as online game and video on demands, Next-Generation Passive Optical Network Stage 2 (NG-PON2) [01] has been proposed to deliver a high-speed data transmission rate over 10 Gbps and above for consumer use in home area networks (HANs). However, the bottleneck problem of consumer use from accessing *Internet* service directly through a high-speed data transmission approach in HANs remain exists due to the difficulties in using and installing optical fibers arbitrary. Although wireless access technologies such as WiFi and WiMax based on the use of radio frequencies (RF) at microwave range have become a popular access approach in the modern world, a high-speed data transmission service delivered from NG-PON2 cannot be well transferred for consumer use efficiently due to the limited modulation bandwidth of microwave frequencies. Optical wireless solutions based on free-space transmission medium, are emergence as an alternative solution to RF communications [02] for NG-PON2 extension to indoor wireless access due to its variety of advantages such as unregulated free optical spectrum with a higher modulation bandwidth and the immunity of electromagnetic interference.

In this research, we have proposed and for the proof of concept, experimentally demonstrate an Liquid Crystal on Silicon (LCoS)-based access node (AN) for home access network application. The presented work is distinguished from conventional optical wireless communication system [02] which were based on a fixed point to point communication link and several times of optical/electrical (O/E) and E/O conversions were required before signal emitting/coupling from/into an optical fiber. The proposed AN uses optical fibers as the transmitter and receiver for downlink and uplink transmission directly. An LCoS-based spatial light modulator (SLM) which acts as a beam steering and wavelength selection element was used to dynamically establish communication links between an AN and terminal users (TUs).

A bidirectional optical wireless communication system, for the proof of concept, using eight typical WDM wavelengths (channel spacing by 100 GHz) modulated at a data speed of 2.5 Gbps at a transmission distance of 2.5 meters was established to evaluate the performance of the proposed node architecture. The results shown that in the downlink transmission, multi-wavelengths delivered from optical fiber can be arbitrary transmitted directly to the terminal users through the proposed node without any O/E/O conversion. In the uplink transmission, all the wavelengths received at the AN can be arbitrary switched to a desired output fiber port of the node to the external fiber network without any O/E/O conversion. The estimated bit error ratios (BERs) of all the transmitted wavelengths in the uplink and downlink transmission scenarios were all less than 10^{-12}.

2. Node Architecture Design

Fig. 1 shows a geometric room model [03] that is targeted for the proposed AN application. This room model contains 4 ANs which are connected directly to the external fiber network (i.e. NG-PON2) and several TUs which were composed of identical physical components. Each AN is responsible for a specific coverage area within the room. The fundamental role of the AN is to exchange optical wavelengths between external fiber network and indoor TUs without O/E/O conversions. As illustrated in Fig. 2, each TU was assumed to have identical physical layer components which include a transmitter module composed by a GRIN lens fiber, and a keplerian beam expander [04] for uplink transmission and a receiver module composed by a collimating lens and a photo-detector to receive downlink wavelengths. The node architecture is composed by six major components: a single GRIN lensed fiber for downlink transmission (TX_N), a fiber ribbon for uplink receiver (RX_N) which includes a row of 12 multimode fibers (62.5um) based on a mechanically transferable (MT) connector and the spacing between the centers of adjacent fibers is 250um, a lens for collimation (L3), a half-wave plate to adjust polarization property of the incident light, a static diffraction grating element for wavelength de-multiplexing and an LCoS-based SLM that acts as a beam steering element.

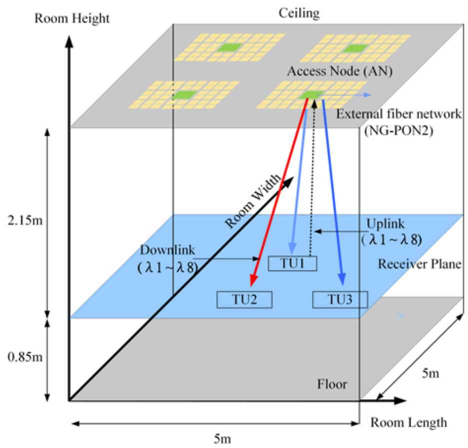


Fig. 1. LCoS-based access node in home area network

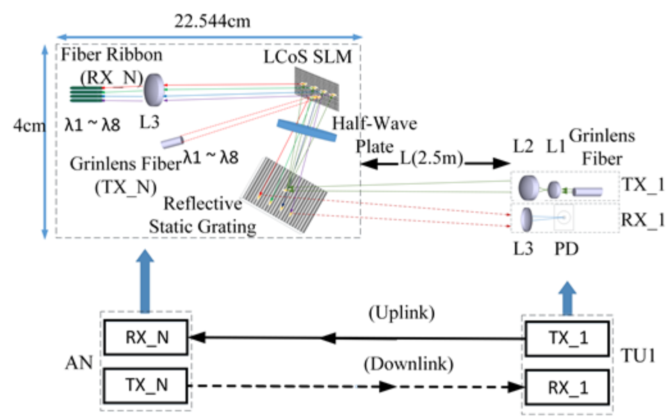


Fig. 2. Ray tracing of proposed node architecture in up/down link

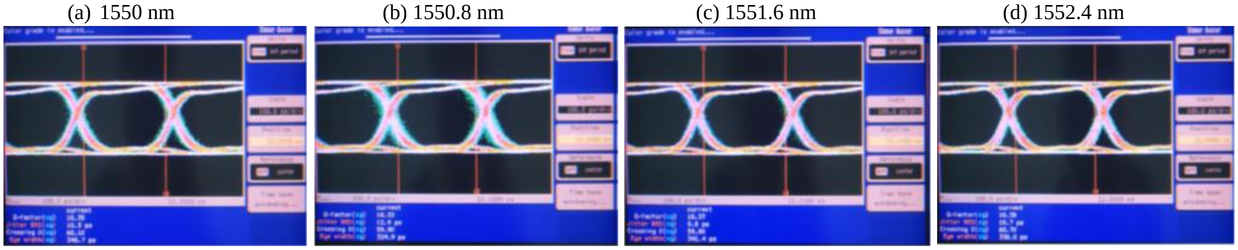
The operation principle of the node architecture is as follows: In the uplink transmission, eight WDM wavelengths (channel spacing by 0.8 nm) ranged from 1550 nm to 1555.6 nm in C band were transmitted from TUs. These optical wavelengths from TUs in uplink after transmitting a distance of 2.5 m were firstly diffracted by a static grating element, which converted the eight individual wavelengths into a different spatial separation, and thus each wavelength emerges from the static grating element at slightly different angle. The diffraction beam from the static grating element is then incident on the LCoS surface where a typical phase hologram pattern is shown. The LCoS device then converts these wavelengths into a spatial separation according to the period of the hologram pattern used. Since each wavelength will be deflected at a slightly different angle when different period of hologram was used on LCoS device, we can therefore arbitrary control the period of each hologram on LCoS device to route each wavelength to any desired output fiber port. In the downlink transmission, the same eight multiple optical wavelengths with a channel spacing of 0.8 nm ranged from 1550 nm to 1555.6 nm in C band representing optical signals delivered from external fiber network were launched down to the input fiber (GRIN lensed fiber) of the node and transmitted directly onto the LCoS device. The LCoS now acts as a high dispersion reflective holographic phase grating element with a tunable period and pattern, which de-multiplexes the eight individual wavelengths, and each wavelength emerges from the LCoS device at slightly different angle. Each diffracted beam from LCoS is incident onto the different position of a high dispersion static reflective phase grating element which then converts these wavelengths into a spatial separation. By controlling the deflection angle of reflected beams from LCoS, the reflected beam from the static grating element can be routed to a chosen terminal user.

3. Experimental Setup and Results

In order to explore the characteristics of the proposed AN architecture, the performance evaluations of the node architecture were conducted at two communication scenarios: downlink transmission in which multiple wavelengths from external fiber network were transmitted through AN to TUs and uplink transmission in which multiple wavelengths from TUs were received by AN and then switched to output ports to external fiber network. In the setup of the digital data transmission test, a pulse pattern generator (Keysight N4970A) was used to generate a data rate of 2.5 Gbit/sec. These electrical signals were converted to optical signals through tunable laser module that were used as the light source of the transmitter either in the uplink or downlink communication scenarios. The bit error rates (BERs) of the digital transmission test were estimated directly through the measured Q factors given by [05] according to the measured eye diagrams.

In the uplink transmission test, multiple wavelengths transmitted from TUs were received by the node and can be switched to any of the output fiber port. The resulting eye diagrams for eight wavelengths switched sequentially to the same output fiber port 1 are illustrated in Fig. 3 as a representative performance. The measured Q-factors were ranged between 10.15 and 10.39. The BERs were all estimated to be less than 10^{-12}. Moreover, each wavelength transmitted from TUs can also be arbitrary switched to any of the output fiber port of the node. The measured eye diagrams for single wavelength switched to output fiber ports 1, 2, 3, and 4 sequentially are illustrated in Fig. 4 as a representative performance. The measured Q-factors were ranged between 10.2 and 10.3. The BERs were all estimated to be less than 10^{-12}.

(a) 1550 nm (b) 1550.8 nm (c) 1551.6 nm (d) 1552.4 nm

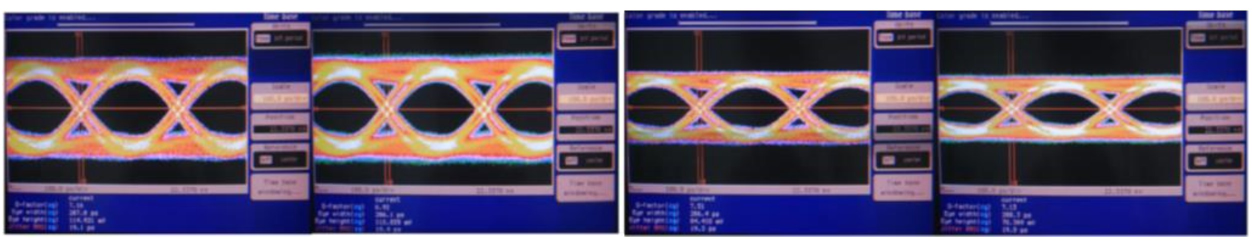


(e) 1553.2 nm (f) 1554 nm (g) 1554.8 nm (h) 1555.6 nm

Fig. 3. Eight WDM wavelengths switched sequentially to the same output port of the node. (Port1)

(a) Port 1 (b) Port 2 (c) Port 3 (d) Port 4

Fig. 4. Eye diagrams of a single wavelength transmitted from a TU is switched sequentially to four output ports of the node. (λ =1555.6 nm)



(a) 131 *um* (b) 107 *um* (c) 51 *um* (d) 43 *um*

Fig. 5. Eye diagrams taken when the spot size focused at TU in downlink was expanded from 43 *um* to 131 *um* (λ =1550 nm)

In the downlink transmission test, multiple wavelengths delivered from optical input fiber (as representative optical signals from external fiber network) were transmitted through AN to TUs. During this test, the spot sizes focused at a chosen TU expanded from 43 *um* to 131 *um* corresponding to the setup of the LCoS were also investigated in order to improve the alignment difficulty at the TU. According to the measured eye diagrams of a single wavelength as a representative illustration of performance shown in Fig. 5, the Q-factors were at a range of between 6.92 and 7.53. The BERs were all estimated to be less than 10^{-12}.

4. References

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