Uncompressed HD and Ultra-HD Video Streaming Using Terahertz Wireless Communications

Kathirvel Nallappan
Dept. of Electrical Engineering
and Dept. of Engineering Physics
Ecole Polytechnique de Montréal
Montréal, Canada
kathirvel.nallappan@polymtl.ca

Hichem Guerboukha
Dept. of Engineering Physics
Ecole Polytechnique de Montréal
Montréal, Canada
hichem.guerboukha@polymtl.ca

Chahé Nerguizian
Dept. of Electrical Engineering
Ecole Polytechnique de Montréal
Montréal, Canada
chahe.nerguizian@polymtl.ca

Maksim Skorobogatiy
Dept. of Engineering Physics
Ecole Polytechnique de Montréal
Montréal, Canada
maksim.skorobogatiy@polymtl.ca

Abstract— **Taming the Terahertz waves (100 GHz-10 THz) is considered the next frontier in wireless communications. While components for the ultra-high bandwidth Terahertz wireless communications were in rapid development over the past several years, however, their commercial availability is still lacking. Nevertheless, as we demonstrate in this work, due to recent advances in the microwave and infrared photonics hardware, it is now possible to assemble high performance hybrid THz communication systems for real-life applications. We present design and performance evaluation of the photonics-based Terahertz wireless communication system for the transmission of uncompressed 4K video feed that is built using all commercially available system components. The Terahertz carrier frequency is fixed at 138 GHz and the system is characterized by measuring the bit error rate for the pseudo random bit sequences at 5.5 Gbps. By optimizing the link geometry and decision parameters, an error-free (BER<10^{-10}) transmission at a link distance of 1m is achieved. Finally, we detail integration of a professional 4K camera into the THz communication link and demonstrate live streaming of the uncompressed HD and 4K video followed by analysis of the link quality.**

Index Terms—**4K video, Digital multimedia broadcasting, High definition video, Streaming media, Terahertz communications**

I. Introduction

The internet protocol data traffic is continuing its exponential increase and is expected to reach over 278 Exabytes per month by 2021 [1]. Similarly, the ever-increasing wireless communications data rate in the commercial markets is expected to be 100 Gbps within the next 10 years [2]. To meet the bandwidth demand, a shift towards higher carrier frequencies has been considered as a solution [3, 4]. The terahertz (THz) frequency band (Frequency:100 GHz to 10 THz) is seen by many as the next frontier in wireless communications [5]. At the same time, maturing the THz wireless communication technologies from laboratories into commercial applications is facing multiple challenges. Two major technologies exist in establishing THz wireless communication links: electronics-based frequency multiplier chains and photonics-based frequency difference generation . Electronics-based approaches offer high powers (thus longer link distances), but at lower carrier-wave frequencies (<100 GHz), thus limiting the communication data rates. On the other hand, photonics systems suffer from lower power budgets due to inefficiency in optical to THz conversion, but offer potentially higher data rates at much higher carrier frequencies (>100GHz) [6]. One of the key advantages offered by infrared (IR) photonics is its ability to interface directly with the already existing fiber-based network equipment [7]. Additionally, high tunability of the THz carrier frequency (between 20 GHz - 3.8 THz [8, 9]) is easily achievable using photomixing, thus higher carrier frequencies and, hence, higher data rates are readily achievable in optics-based THz systems. Recent advances in the uni-traveling carrier photodiodes (UTC-PD)–based THz photomixers give a new hope for commercial applications of photonics-based THz communication systems [10]. Such devices offer relatively high powers (~1 mW) even at higher THz frequencies (~300 GHz) [11]. By using a hybrid approach incorporating both UTC-PD as the emitter and solid-state devices such as Schottky diodes as receivers, several high-speed THz communication links have been demonstrated in recent years.

With ever increasing wireless data rate, mobile backhaul for transferring large bandwidth signals between base stations and end users is one of the primary goals using THz band. Thus, enabling photonics based wireless links (millimeter to THz frequency band) offers high efficiency and cost-effective solution to the mobile backhauling and 'last mile' connections [12]. Similarly, the THz communication systems can be used to establish short range high-speed wireless links for applications such as chip-to-chip communications, high-speed indoor wireless LAN to name a few . Among several bandwidth hungry applications, wireless transmission of uncompressed HD, 4K and 8K video finds importance in applications such as education, entertainment, telemedicine, security, video conferencing to name a few. It is reported that the market value of 4K technology will reach $102.1 billion by 2020 [13]. We believe that the transmission of uncompressed 4K videos can be one of the immediate real-world applications using THz wireless communication systems.

In this article, we show the possibility of assembling a high-performance THz communication system by borrowing off-the-shelf commercial components from various communication technologies. We present the design and the performance evaluation of the photonics-based THz communication. As a practical application, we detail the integration of a 4K camera into the THz communication link and demonstrate the live streaming and recording of the uncompressed HD and 4K videos, followed by analysis of the link quality.

II. EXPERIMENTAL SET UP

The schematic of the Photonics based THz wireless communication system is shown in Fig.1. One of the two laser beams is intensity modulated and then amplified using the Erbium doped fiber amplifier (EDFA). The laser beams are then combined using the 3 dB coupler and injected in to the photomixer for THz generation. A zero-bias schottky diode (ZBD) is used to detect the incoming THz signal and to directly demodulate the baseband signal.

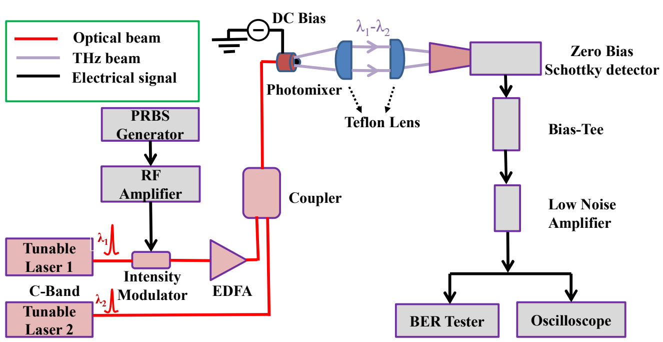

Fig. 1. Schematic of the Photonic based THz wireless communication system.

The choice of THz carrier frequency is determined from the output power of the THz emitter and the Responsivity of ZBD's that is commercially available. The THz emitter has higher power below 200 GHz and hence two ZBD's (Virginia diodes-WR8.0ZBD-F & WR6.5ZBD-F) with the working range below 200 GHz is used for the analysis. The maximal voltages at the output of the two ZBDs are estimated by multiplying the emitted THz power by the responsivity of a corresponding ZBD.

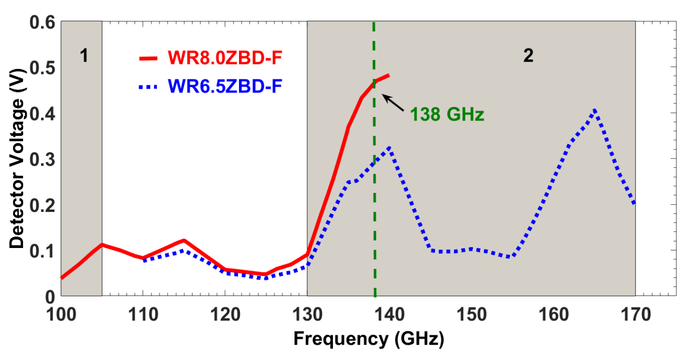

Fig.2. Estimate of the maximal voltage at the ZBD's output when used with Toptica THz photomixer. Grey areas correspond to the THz atmospheric transmission windows as identified in [14].

In Fig. 2, we plot such voltages as a function of the THz frequency and conclude that WR8.0ZBD-F ZBD with the conical horn antenna (Virginia diodes WR8.0CH) operating at 138 GHz results in the maximal detected signal amplitude for a back-to-back emitter/detector arrangement. Furthermore, this frequency lies in the second atmospheric transmission window above 100 GHz [14] (grey area in Fig. 2), making it a natural choice as a carrier frequency for THz communications. The Bias-Tee Tee (Minicircuits-ZFBT-6GW+) is connected in sequence to block the DC voltage and let only the AC signal above 100MHz pass to the next stage. Followed by the Bias-Tee a high gain low noise amplifier (LNA) (Fairview Microwave-SLNA-030-32-30-SMA) is used to amplify the demodulated baseband signal.

III. BIT ERROR RATE MEASUREMENTS AND UNCOMPRESSED VIDEO TRANSMISSION

The performance of the THz communication system is characterized using Bit Error Rate (BER) analyzer (Anritsu-MP2100B). The BER is first measured as a function of link distance. By varying the link distance and optimizing the decision threshold, the BER is measured after the LNA as shown in Fig.3. The lowest BER of $\sim 10^{-10}$ was achieved for the photomixer bias voltage of -1.9 V at 100 cm. By gradually increasing the link distance, it is found that the BER increased exponentially fast.

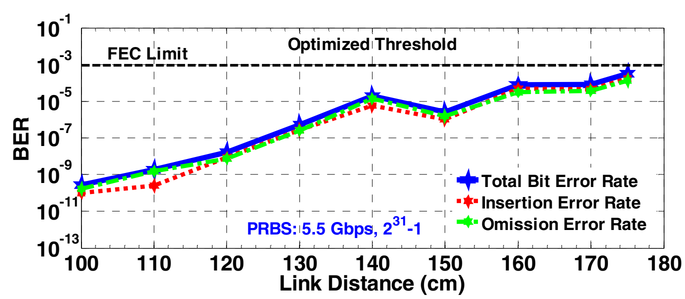

Fig.3. Measured BER for the test signal (5.5 Gbps, 2^{31}-1) by varying the link distance.

In what follows, we present the integration of the professional 4K camera into the THz communication system as shown in Fig.4. and then demonstrate successful transmission of the uncompressed HD and 4K videos at 60 frames per second (fps) and 30 fps respectively.

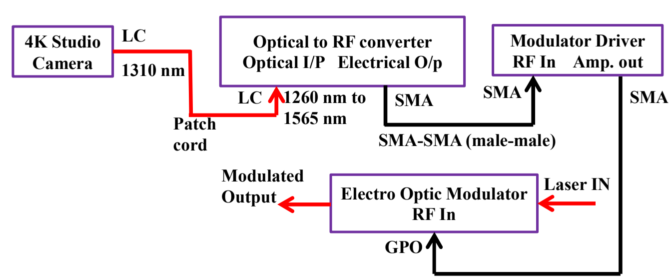

Fig.4. Block diagram for the integration of 4K video camera with the Transmitter of the THz communication system

The optical output signal from the 4K camera (Blackmagic) is converted to electrical signal using the optical transceiver module in the test equipment (Anritsu-MP2100B), where the electrical output port has SMA connector with 50Ω impedance (Impedance matching with the THz transmitter). The electrical signal is then amplified, and the laser beam is modulated. Similarly, in the receiver side, the demodulated electrical baseband signal is converted to optical as shown in Fig.5. and the video is recorded using a high-speed capture card (Blackmagic- Decklink 4K Extreme 12G) for further analysis.

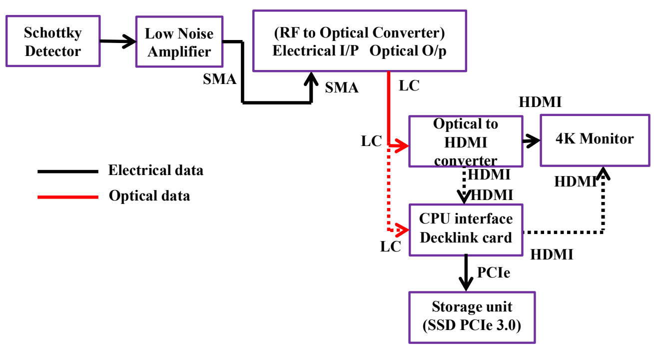

Fig.5. Block diagram for the reception and recording of the transmitted uncompressed HD and 4K video

For the ease of analysis, each frame of the received video is recorded as image format and the black frames are identified. The video is recorded for a duration of 30 minutes and the black frame is identified by analyzing the RGB value by taking the small portion (5x5 pixels) of each frame.

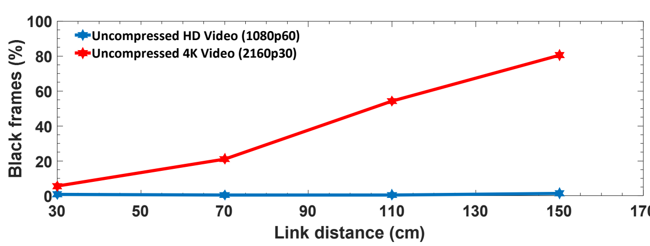

Fig.6. Detected black frames in percentage as a function of link distance for HD video at 60 fps and 4K video at 30 fps

Fig.6, presents the identified percentage of black frames as a function of link distance. About ~0.5% and 5% of the frames are identified as black frames for HD and 4K video respectively at the link distance of 30 cm. The percentage of black frames increases as the link distance increases for 4K video but remains almost constant for HD video.

IV. CONCLUSION

To conclude, a Photonics based THz wireless communication system has been built using all commercially available system components and characterized by measuring the BER. An error free data transmission at the rate of 5.5Gbps is achieved over the link distance of 1 m. Finally, we showed the design for the integration of 4K camera and the recorder with the THz transmitter and receiver respectively. We also demonstrated the transmission of uncompressed HD and 4K video and the percentage of black frames were calculated. It is observed that the percentage of black frames is higher for the uncompressed 4K video when compared with HD video. The obtained results confirm that it is now possible to realize a short-range THz wireless communication system for commercial applications. Such system can also be used in the characterization of integrated THz components for real-time signal processing in wireless communication applications.

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