Implementation of Machine Learning-based Emergency Communication Using RoFSO-VLC/RF Convergence link

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Abstract: This paper firstly experimentally demonstrates an ease of deployment integrated system to provide communication services for emergency responders, which employs machine-learning-based Radio-over-FSO system for outdoor fronthaul network and hybrid VLC/RF system for indoor access network.

1. Introduction

Recently, the explosive growth of network devices and traffic puts pressure on existing radio frequency (RF) networks [1]. To meet the demand for capacity and scarce spectrum resource, wired-wireless convergence technique such as radio over fiber (RoF) is considered as a promising solution [2]. Nevertheless, there are still many areas where fiber is inaccessible or set-up costs are too high [3]. Especially for disaster recovery and other emergency communication scenarios, traditional RF system is not able to ensure the need for fast and inexpensive recovery of communications. Thus, radio-over-free space optics (RoFSO) scheme deployed outdoors has been actively discussed owing to inherent high security, ease of deployment, large bandwidth and robustness. As for indoor access networks, in addition to employing traditional RF communication, we also introduce visible light communication (VLC) technique to cope with strong electromagnetic interference and other cases that cause RF link interruptions [4]. Therefore, we adopt a hybrid VLC/RF system in the indoor access network. It is well known that FSO link is sensitive to weather conditions and atmospheric turbulence and thus ensuring FSO link transmission reliability is the top priority of the above system [5]. It is a feasible way to improve the reliability of FSO link by obtaining the fading information in advance to provide active transmission control. Therefore, this paper further enhances the stability of emergency communication system (ECS) through machine learning (ML)-based channel estimation technique. In this paper, we aim to implement ML-assisted ECS combining RoFSO and hybrid VLC/RF technologies for the first time. The put forward ECS includes four components. i) *Outdoor Fronthaul Links*: We implement a RoFSO system with M-Quadrature Amplitude Modulation (QAM) and 2×1 Multiple Input Single Output (MISO) FSO links to combat turbulence. ii) *Indoor Access links*: We divide the access links into two subsystems, which are fixed network link via wired communication and mobile network link using hybrid VLC/RF communication, respectively. iii) *Mobile Application for Emergency Communication*: According to hybrid VLC/RF link for indoor mobile network, we further develop a mobile application at the mobile receiver side to receive emergency information. iv) *ML-based Channel Estimation and Power Compensation*: In this paper, received signal strength indicator (RSSI) is analyzed as the indicator to evaluate channel quality. We build a Gated Recurrent Unit (GRU) neural network (NN) model considering time attention mechanism (TAM) to perform the estimation of RSSI and then power compensation can be implemented based on the estimation results.

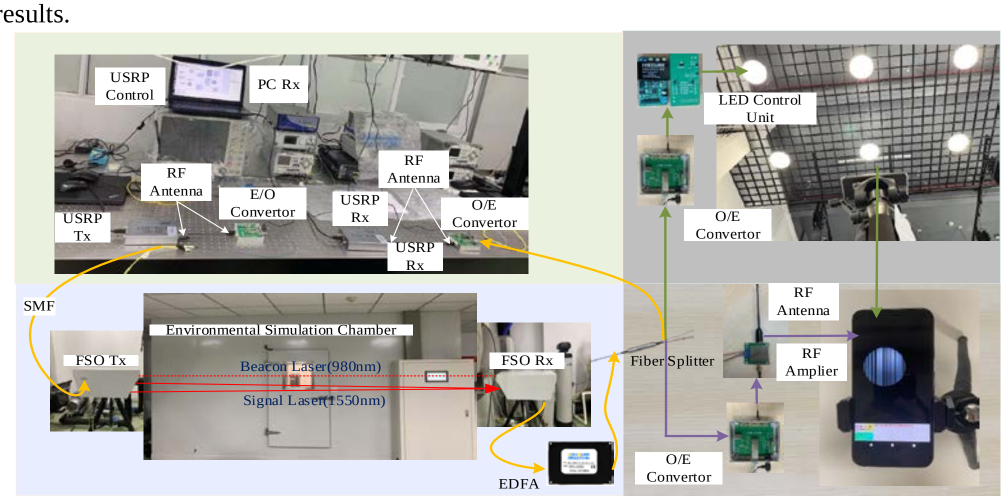

Fig. 1 Experimental setup of the real-time emergency communication system

2. Experimental Setup

Figure 1 shows the experimental setup of our proposed real-time ECS. For a clearer explanation, a detailed schematic is shown in Fig. 2(a).

Outdoor Fronthaul Links: To facilitate the construction of the experimental link, this part is built indoors to verify the relevant performance based on personal computer (PC) and universal software radio peripheral (USRP) by software radio technique. The RF transmitter includes information source, packet encoder, 16-QAM modulation, RF amplifier and RF antenna. And then the RF signal with 2.4GHz can be received by the RF antenna of the Electrical/Optical (E/O) convertor integrated by an 10cm×9cm printed circuit board (PCB). The converted optical signal is further amplified by Erbium-Doped Fiber Amplifier (EDFA). After passing through an optical splitter in a ratio of 1 to 1, the optical signal is transmitted by two FSO antennas and 2×1 links with 1550nm wavelength in order to combat turbulence by spatial diversity. At the FSO receiver side, the optical signals of both links can be received by the same lens of FSO antenna. Finally, the signal is coupled into the fiber and passes through Optical/Electrical (O/E) convertor.

Indoor Access links: The indoor access links are composed of two subsystems, which are fixed network with wired communication technique and mobile network with hybrid VLC/RF technique, respectively. In fixed network subsystem, the converted electrical signal passes through 16-QAM modulation and packet decoder to the client shown as PC via wired cable. In mobile network subsystem, one-way electrical signal is sent to RF amplifier and emitted by RF transmitter. The other way electrical signal is sent to light-emitting diode (LED) control unit implemented by an 8cm×4cm PCB where the control circuit of the LED is integrated. The control unit consists of inverse proportional amplifier, follower and LED control chip. Then the electrical signal drives the LED for data transmission while illuminating.

Mobile Application for Emergency Communication: We develop a mobile application based on Google Pixel 2 Series for data receiving. The RF signal can be received by the smartphone antenna, after which 16-QAM demodulation and packet decoder of mobile application are carried out to complete the recovery of data. When the channel is under strong electromagnetic interference conditions and traditional RF communication fails, the smartphone can still ensure data transmission through VLC link. The smartphone opens the front camera and sets the exposure rate and International Organization for Standardization (ISO) value to 1/86347s and 50, respectively. Then the camera takes successive images and performs image processing including grayscale, Gaussian blurring, contour extraction, and sub-picture segmentation on each image in turn. By the above operations, we can obtain the bright and dark striped images shown in Fig. 2. Next, the data is extracted and identified by the width ratio of light and dark stripes. Finally, data recovery is also accomplished through 16-QAM demodulation and packet decoder.

ML-based Channel Estimation and Power Compensation: Based on real-world environmental parameters by national meteorological information center (NMIC), we use the environmental simulation chamber (ESC) to generate different channel conditions and collect RSSI datasets. RSSI has strong correlation for part of a continuous period of time and hidden states of parameters at these moments also have a high correlation. Thus, we improved the traditional GRU cell structure using TAM by adopting score function based on Spearman's rank correlation coefficient to analyze the correlation between different hidden states and the proposed structure is shown in Fig. 2(a). The complete TAM-based GRU NN structure with encoder and decoder is presented in Fig. 2(b). With the sliding window prediction, we can predict the change of RSSI in the future m moments. If the RSSI values within m moments are continuously below the set threshold, the system will boost the transmitting power. If the RSSI value is higher than the set threshold, the transmit power will remain the same. Channel estimation and power compensation are implemented in the upper computer of FSO transceivers.

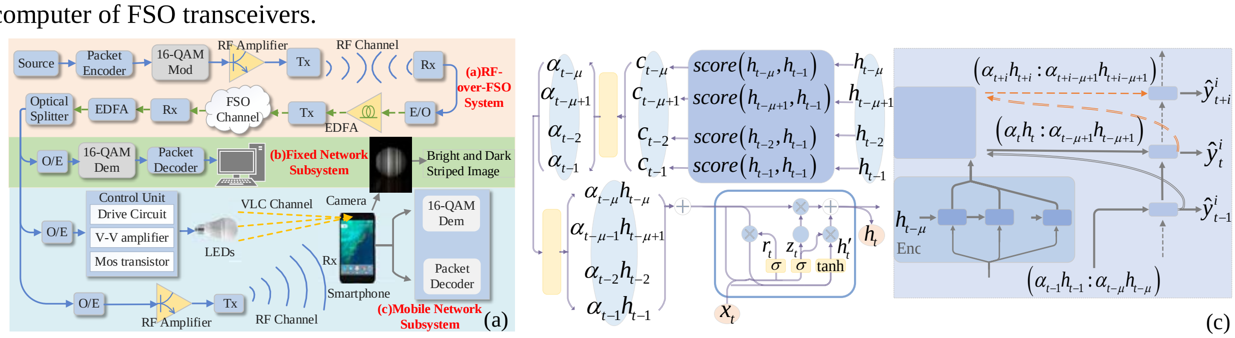

Fig. 2. (a)Schematic of ECS. (b) The improved structure of TAM-based GRU cell. (c) The complete structure of TAM-based GRU NN with encoder and decoder.

3. Results and Discussions

We build a four-layer NN structure of [1, 128, 128, 1] where there is an input layer, two TAM-based GRU layer with 128 neurons and an output layer. Based on the ten-step prediction by sliding window prediction, we select ten cycles with a total of 100 predicted points. In order to verify the effectiveness of the proposed NN model, we first compare the absolute error (AE) and absolute percentage error (APE) between traditional GRU NN and TAM-based GRU NN. The error distribution and cumulative distribution function (CDF) are presented in the same figure. In traditional GRU NN shown in Fig. 3(a), we can observe that the AE values lower than 0.275 and 0.525 account for fifty percent and ninety percent, respectively. In TAM-based GRU NN shown in Fig. 3(b), we can observe that the AE values lower than 0.125 and 0.295 account for fifty percent and ninety percent, respectively. In traditional GRU NN shown in Fig. 3(c), the APE values lower than 2.5% and 6.5% account for fifty percent and ninety percent, respectively. In TAM-based GRU NN shown in Fig. 3(s), the APE values lower than 0.5% and 3% account for fifty percent and ninety percent, respectively. The results show that the proposed TAM-based GRU NN can significantly improve the prediction accuracy of RSSI. When 5 values of 10 continuously predicted RSSI values in one cycle are consistently below the set threshold of -15dBm, the system will perform power compensation. Figure 3(e) presents the constellation diagram of RF signal at RoFSO transmitter side. After the RoFSO system, Figure 3(f) shows the constellation diagram at PC receiver side in fixed network subsystem. Figure 3(g) shows the constellation diagram at PC receiver side after power compensation. It can be seen from the Fig. 3(e), (f) and (g), constellation diagram becomes clearer and more focused benefiting from power compensation, which means that the quality of signal transmission is improved. To further demonstrate the mobile network communication performance of the ECS, we send text message "Test for FSO-VLC/RF system" at the source of RoFSO link. As we can see in Fig. 3(h), the smartphone is in VLC communication mode and the text message is displayed on the phone screen, which proves that the signal is correctly received and the proposed ECS can quickly establish an effective communication.

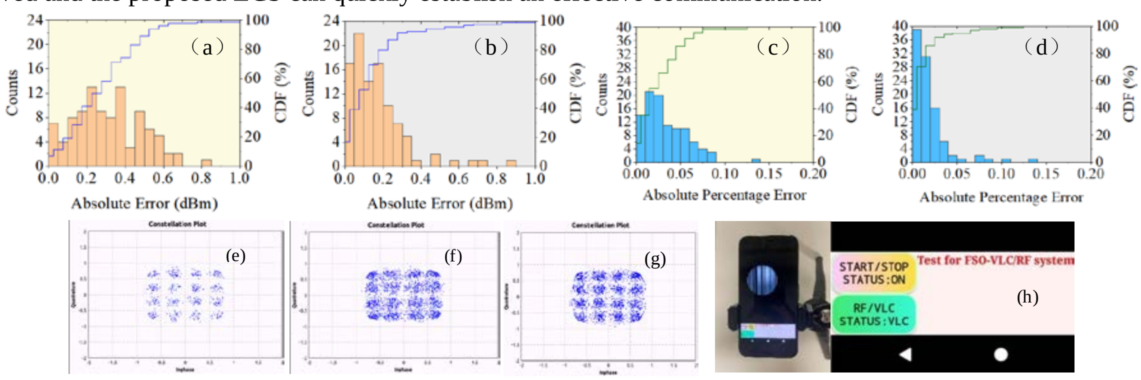

Fig. 3 (a) Counts and CDF vs. AE of GRU. (b) Counts and CDF vs. AE of TAM-based GRU. (c) Counts and CDF vs. APE of GRU. (d) Counts and CDF vs. APE of TAM-based GRU. (e) Constellation diagram of RF signal at RoFSO transmitter side. (f) Constellation diagram at PC receiver side. (g) Constellation diagram at PC receiver side after power compensation. (h) Smartphone receiving information in VLC mode.

4. Conclusion

We have experimentally demonstrated an easy set-up ECS employing wired-wireless convergence technique. For the ECS, outdoor fronthaul links are implemented using a RoFSO system and indoor access links are further completed based on hybrid VLC/RF system. Then we developed a mobile application for receiving information sent by hybrid VLC/RF system. Finally, to ensure the stability of the RoFSO system transmission, we proposed TAM-based GRU NN model to perform channel estimation and power compensation. The experimental results show that the put forward ECS can be set up effectively and complete correct information reception through smart phones or PC. ML-based channel estimation and power compensation can effectively predict FSO channel variations and provide new opportunities for improving system stability.

5. Acknowledgment

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6. References

[1] D. Wu, X. Sun and N. Ansari, "An FSO-based drone assisted mobile access network for emergency communications," in *IEEE Transactions on Network Science and Engineering*, 7(3), pp. 1597-1606 (2019).

[2] P. Zhu P, Y. Yoshid and K. Kitayama, "< 500ns Latency Overhead Analog-to-digital-compression Radio-over-fiber (ADX-RoF) Transport of 16-channel MIMO, 1024QAM Signals with 5G NR Bandwidth," in *Optical Fiber Communication Conference* (OFC) 2020, M2F. 7.

[3] Y. S. Heo, J. H. Ryu, C. I. Yeo, S. Park and H. S. Kang, "Implementation and evaluation of 2.5 Gbps mobile FSO communication system based on 2.5 GBASE-T standard," in *Optical Fiber Communication Conference* (OFC), 2021, W7E. 8.

[4] P. Pesek, S. Zvánovec, P. Chvojka, Z. Ghassemlooy and P. A. Haigh, "Demonstration of a hybrid FSO/VLC link for the last mile and last meter networks," in *IEEE Photonics Journal*, 11(1), pp. 1-7 (2018).

[5] W. M. R. Shakir, "Performance evaluation of a selection combining scheme for the hybrid FSO/RF system," in *IEEE Photonics Journal*, 10(1), pp. 1–10 (2018).