A SDN-based WiFi-VLC Coupled System for Optimised Service Provision in 5G Networks

Harilaos Koumaras
Institute of Informatics and Telecommunications
NCSR Demokritos
Agia Paraskevi, Greece
koumaras@iit.demokritos.gr

Andreas Foteas
Institute of Informatics and Telecommunications
NCSR Demokritos
Agia Paraskevi, Greece
afoteas@iit.demokritos.gr

Michael-Alexandros Kourtis
Institute of Informatics and Telecommunications
NCSR Demokritos
Agia Paraskevi, Greece
akis.kourtis@iit.demokritos.gr

Dimitris Makris
Institute of Informatics and Telecommunications
NCSR Demokritos
Agia Paraskevi, Greece
dmakris@iit.demokritos.gr

George Xilouris
Institute of Informatics and Telecommunications
NCSR Demokritos
Agia Paraskevi, Greece
xilouris@iit.demokritos.gr

Vaios Koumaras
Institute of Informatics and Telecommunications
NCSR Demokritos
Agia Paraskevi, Greece
vaios@iit.demokritos.gr

John Cosmas
College of Engineering
Design and Physical Sciences
Brunel University
United Kingdom
john.cosmas@brunel.ac.uk

***Abstract*— Visible Light Communication (VLC) is a powerful supplement, which has gained tremendous attention recently and has become a favorable technology in short-range communication scenarios for the Fifth Generation (5G) networks. VLC possesses a number of prominent features to address the highly demanding 5G system requirements for high capacity, high data rate, high spectral efficiency, high energy efficiency, low battery consumption, and low latency. However, this prominent performance is limited by the imperfect reception, since line of sight channel condition may not always exist in practice. This paper presents and experimentally validates a SDN-assisted VLC system, which is coupled with WiFi access technology in order to improve the reliability of VLC system, reassuring zero packet loss reception quality due to misalignment or path obstructions or when the user is moving between two consecutive VLC transmitters and experience "dead coverage zones".**

Keywords—VLC, WiFi, SDN, 5G, QoS, video

I. INTRODUCTION

The Fifth Generation (5G) wireless systems is the next wave in mobile telecommunications beyond the current 4G standards. Compared to the existing 4G systems, 5G is planning to achieve higher capacity, data rate, spectral and energy efficiency, as well as improved user experience. At the same time, lower battery consumption and lower implementation costs are also deemed to be a must [1]. In order to meet these demands, 5G networks are expected to incorporate smaller cells in higher densities, additional spectrum, energy efficient communication, mobile convergence, heterogeneous network (HetNet) integration and cognition at both the device and network level.

In this integrated ecosystem, Visible Light Communication (VLC) is a prominent candidate and has the potential to be an integral part of 5G networks. VLC systems employ visible light for communication that occupy the spectrum from 380 nm to 750 nm corresponding to a frequency spectrum of 430 THz to 790 THz. Due to a number of prominent features that VLC systems possess [2] and successfully address the 5G requirements, such as the massive non-licensed channels in the visible light band and the high bandwidth density, the low power consumption and broad adoption of LED-based devices for use in the lighting infrastructure, VLC becomes very promising for the 5G market.

Keeping in view the above advantages, VLC is one of the promising 5G technologies. However, a number of constraints limit the marketability of VLC systems, mainly due to the susceptibility to blocking due to misalignment or path obstructions, which result in significant QoS degradation in comparison to the 5G expectations. Moreover, the necessary cooperation between the lighting industry and the communications industry is another challenge that should be considered, where Software Defined Networking (SDN) is expected to play a major role [3].

This paper presents and experimentally validates a SDN-assisted VLC system, which is coupled with WiFi access technology in order to improve the provided QoS, reassuring good reception quality due to misalignment or path obstructions or when the user is moving between two consecutive VLC transmitters and experience "dead coverage zones".

The rest of the paper is organized as follows: Section II presents briefly the motivation of this paper. Then, Section III describes the experimental topology. Section IV discusses the proposed SDN architecture and the SDN-app use in the SDN controller. Section V discusses the experimental findings, while Section VI concludes this paper.

II. MOTIVATION OF THIS WORK

The motivation of this paper is to experimentally evaluate how the WiFi access network with the assistance of SDN can efficiently couple the VLC connectivity across two LED lamps, facing loss of connectivity at the dead zones, which are created between the two coverage areas.

Such as a topology has been reconstructed in lab environment and depicted on Fig. 1, where two LED lamps have been placed indoor at distance D=4m, which is a typical set up of VLC lamps for indoor use. The scope of the experiment was to identify the impact of the dead reception zones (denoted as d) at the service continuation, especially the ones that require constant data rate and high QoS, such as the video services.

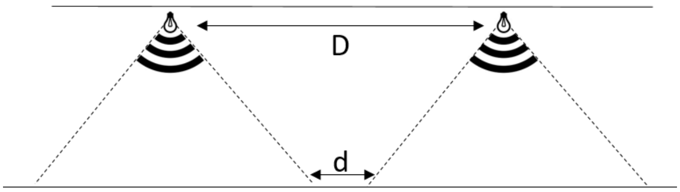

Fig. 1. Dead reception zones between two VLC lamps

In the described topology, as the user is moving away from the center of the LED light, the SNR value is decreasing, which means that the reception quality drops [4]. This problem is more usual at indoor spaces, where VLC systems have been installed and the user is moving across different VLC/LED lamps, where it is observed the SNR value to fluctuates from the maximum value down to the minimum and then back to maximum. Depending on the distance that each VLC unit has been installed, the user may experience not only drop in the SNR quality, but even dead zones, such as Fig. 1 depicts.

This is exactly the problem that this paper researches. More specifically, the paper setups an experiment with the topology described in Fig. 1, where D=4m and d=10cm and examines how the fluctuation in the reception quality can be reduced by i) making the network SDN-assisted and ii) by dynamically coupling via an SDN-app the VLC channel with WiFi access.

III. EXPERIMENTAL TOPOLOGY

The experimental setup of this paper is depicted on Fig. 2, which was used to evaluate the service continuation for a moving user across different VLC transceivers and how SDN can contribute towards its reception performance enhancement.

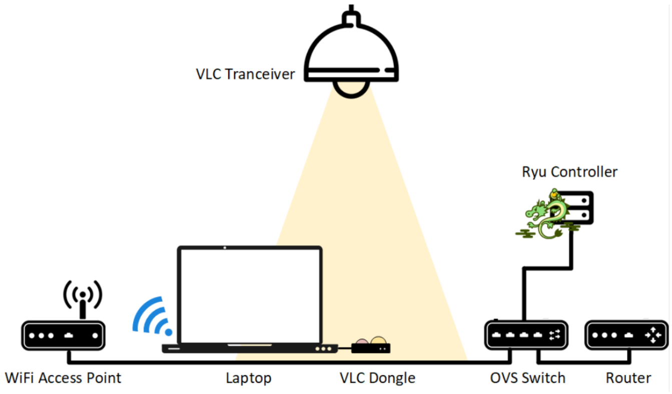

Fig. 2. Experimental Setup

The experimental setup includes an SDN network domain, which is controlled by Ryu controller [5] that is capable of executing python-based SDN apps. The CPE is a laptop equipped with a USB VLC receiver and an Arduino-based luminance detector, placed next to the VLC dongle. Fig.3 depicts the CPE that was used for the execution of the experiment.

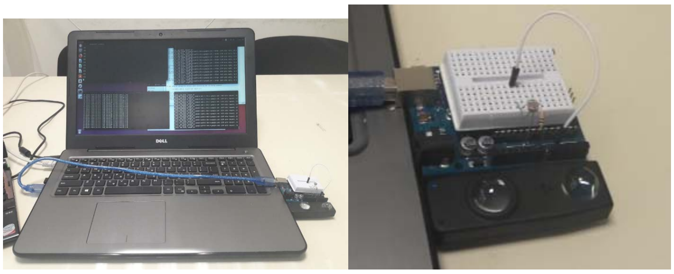

Fig. 3. Experimental CPE with VLC receiver and Arduino photodetector

The experimental topology complements the VLC technology with a 2.4GHz WiFi 802.11g access point, which was used in the experiment as a dynamically coupled access technology for the zones that the user has poor reception quality, such as the dead reception zones between two successive VLC transceivers. An SDN app was developed in order to handle the seamless switching of the access technology (i.e. WiFi or VLC) used each time in order to maintain good reception quality.

IV. THE PROPOSED SDN ARCHITECTURE AND SDN-APP

An SDN domain, as the one used for the execution of the proposed experiment, follows a three tier structure, which is briefly described as follows.

The first tier in the SDN architecture is the physical infrastructure, which includes all the network devices required to support the network, which are compatible with the Openflow protocol (the protocol used by the SDN controllers). Network control is decoupled from network devices and is given to a software application, which for the case of an SDN domain is the SDN controller.

SDN Controllers in a SDN domain is the application that acts as a strategic control point in the SDN network, manage flow control to the switches/routers of the domain (via southbound APIs) and the applications and business logic 'above' (via northbound APIs) to deploy intelligent networks. Controllers, which initiate and terminate traffic, make up the second tier of the architecture.

The third tier is the SDN applications, which direct specific functions through the controller. An SDN application is a software program designed to perform a task in a software-defined networking (SDN) environment. Types of SDN apps include programs for network virtualization, network monitoring, intrusion detection (IDS) and flow balancing (the SDN equivalent of load balancing), among a great number of other possibilities.

In this paper, we developed an SDN-app, which acts as a hand-over controller for the end-user by coupling the VLC access channel with WiFi, reassuring that the QoS is maintained at acceptable levels as the user is consuming data-rate demanding services, such as video, when he/she is passing through a dead reception zone of two successive VLC transceivers.

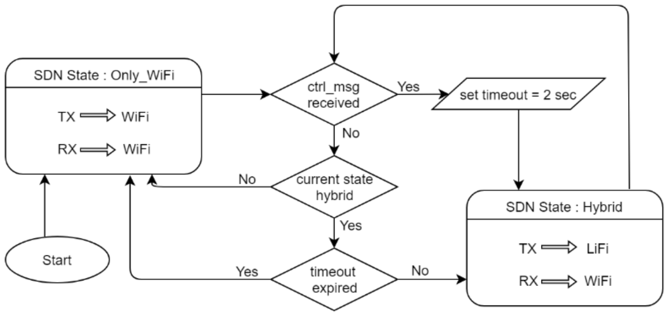

Fig. 4. The flow diagram of the developed SDN-app

The flow diagram of the developed SDN-app is depicted on Fig. 4, which describes the FSM diagram of the algorithm. The proposed SDN-app supports two modes of operation: The "WiFi only" and the "Hybrid" mode. More specifically, the initial state of the SDN app starts at gaining connectivity via the WiFi access technology (i.e. WiFi only). Then the SDN-app continuously monitors if a VLC control message is captured via the VLC receiver, which means that the user is located at a coverage area of a VLC transceiver. Then, the SDN app mandates the SDN controller to apply the appropriate OpenFlow commands at the SDN devices of the domain (in our experimental topology an Open Virtual Switch is used) in order the end-user terminal to start receiving the download link via the VLC and the return link via the WiFi (i.e. Hybrid mode). More specifically, in the hybrid mode the user receives service data from the VLC access technology and uses the WiFi channel only for requests and ACKs (as a return channel). The system remains at the hybrid state, according to the SDN app, for at least 2 seconds before performing a check loop for moving to the next state. If at the check, the system identifies that the user remains at a coverage area of VLC lamp, then the system remains at the "hybrid mode" state for additionally two seconds. Otherwise, the system returns to "WiFi only" state.

V. EXPERIMENTAL RESULTS

A. LED lamp power distribution

As an initial step in the experimental process, we measured the LED power distribution between two successive VLC transceivers in order to verify the existence of dead coverage zones. In our experimental setup, the VLC lamps are located at a height of 2 meters from the luminance sensor and the VLC receiver at the CPE. The measurements of luminance intensity and packet loss where taken by measuring at the CPE when the user had requested an HTTP streaming video service, with the buffer at the client side to have been configured to 1 second only. The measurements were taken by placing the CPE with the VLC and luminance sensors at specific distances from the conceptual vertical line, which is defined between the LED lamp and the floor (as Fig. 5 defines), following a step of approx. 30 cm.

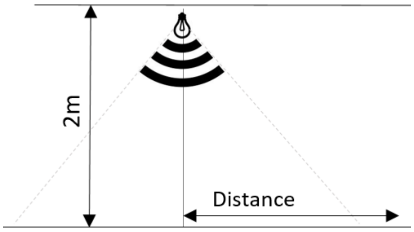

Fig. 5. Distance definition in the experimental measurements

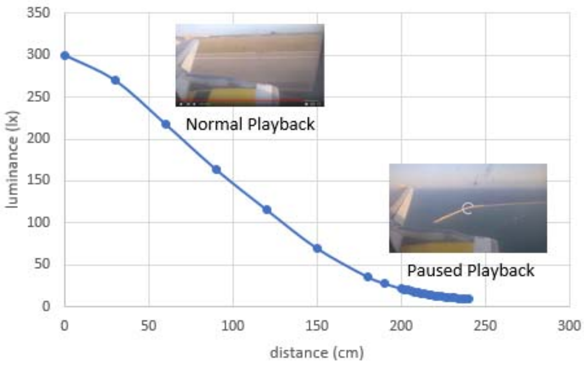

Fig. 6. Luminance power (lx) vs. distance in relation to video playback status

As it was expected, while the user is moving away from the center of the LED light, the *lx* value (and respectively the *SNR* value) is decreasing, which means that the reception quality drops and the http-streaming video service from normal playback is starting to appear occasional pauses. Gradually the *lx* value reaches to zero as the users is located in a dead reception zone between two successive lamps, where the video service provision is paused/interrupted.

The video service playback re-initiates when the user reaches the coverage area of the next VLC transmitter, since all the lamps are broadcasting the same content, and therefore the distance from the next light source is decreasing and therefore the *lm* value and the *SNR* value are gradually increasing.

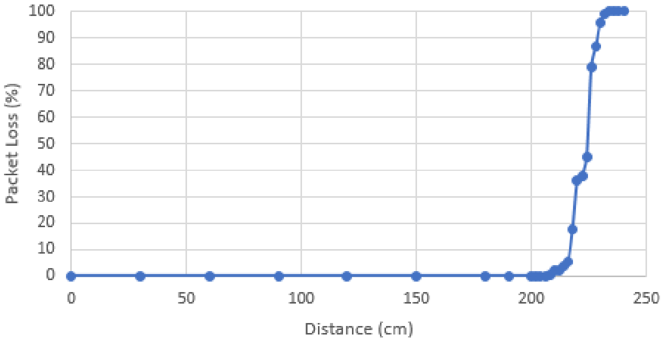

Fig. 7. Packet loss vs. distance

Thus, in such a VLC setup, a moving user between two successive LED lamps, experiences fluctuations in the reception quality due to the existence of coverage dead zones, where the luminance value drops and the *SNR* value is decreasing as well.

B. SDN-enabled hybrid VLC-WiFi access network

The experiment was repeated placing the CPE at the same distances, but with the SDN controller enabled and the proposed SDN-app active and properly configured. The user requested the HTTP streaming video service and once the service started, she/he started to move from distance equal to zero with step of 30cm, towards the next VLC lamp. When she/he covered a distance of two meters (i.e. at the dead coverage zone between the two lamps), then the packet loss started to increase (as is it observed in Fig. 8). Then the SDN-app detected the loss of the ctrl_messages via the VLC channel and once the window of 2 seconds had been completed, the SDN-app instructed via the SDN Controller appropriate Openflow commands to be applied on the OVS switch for diverting the downloading flow to WiFi. The switching process performed seamlessly to the end-user, which resulted in maintaining the video service delivery intact, without any service interruption or quality degradation.

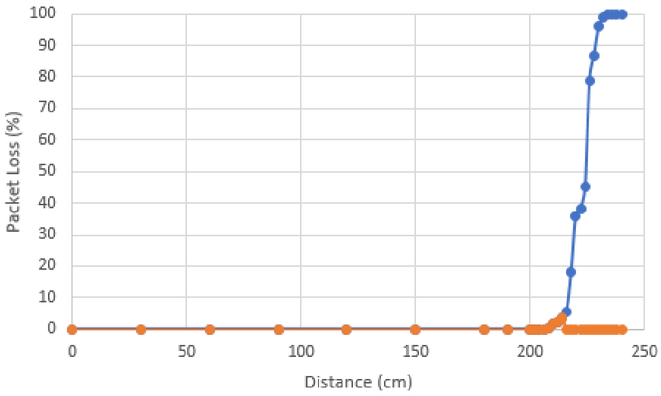

Fig. 8. Packet loss vs. distance for VLC only (blue line) and VLC-WiFi coupled scenario (orange line)

As Fig. 8 shows, the proposed SDN-enabled VLC-WiFi coupled topology achieves to maintain the packet loss of the downloading link to 0% for a moving user across subsequent LED lamps, reassuring flawless service continuation, without any quality degradation artefacts or service interruptions.

VI. CONCLUSIONS

This paper has described and experimentally validated an SDN-enabled VLC-WiFi coupled architecture, which enhances the performance of the VLC system in the areas where the reception coverage is not good. The paper has shown that the proposed coupling can achieve seamless switching between the two access technologies, while service continuation is achieved.

ACKNOWLEDGMENT

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