A flexible transport layer protocol architecture for handover in a vehicular VLC network

Elnaz Alizadeh Jarchlo
OSRAM GmbH
E.Alizadeh@osram.com

Bernhard Siessegger
OSRAM GmbH
B.Siesseggerg@osram.com

Zabih Ghassemlooy
Northumbria University
z.ghassemlooy@northumbria.ac.uk

Piotr Gawłowicz Technische
technische universität berlin
Gawlowicz@tkn.tu-berlin.de

Markus Jung
OSRAM GmbH
M.Jung@osram.com

Hossein Doroud
Universidad Carlos III de Madrid
Hossein.Doroud@alumnos.uc3m.es

Giuseppe Caire
technische universität berlin
Caire@tu-berlin.de

Anatolij Zubow
technische universität berlin
Anatolij.Zubow@tu-berlin.de

***Abstract*—Recent research works have focused on feasibility of using the multipath-transmission control protocol (MPTCP) in order to optimize the network throughput and latency. In this work, we propose a novel architecture using MPTCP for a vehicular visible light communications (VLC) network to improve the performance in terms of network outage duration and throughout. Two relevant MPTCP schedulers and an MPTCP tool is selected to analyze VLC performance during the handover. The results show that the proposed system offers low-outage duration handover of 24 ms and a high data throughput of 125 Mbps using "Redundant" and "Default" schedulers, respectively.**

Keywords—Visible light communication, MPTCP, Outage duration, Handover, Mobility, VLC throughout

I. INTRODUCTION

The main challenges in vehicular visible light communication (VVLC) networks are to achieve a reduced network outage duration, faster detection of links failure and establishing new connections during the handover process. In addition, achieving a high network throughput in VVLC is also critical for specific case scenarios. These challenges are investigated in the physical [1] and upper layers [2] of VLC systems. However, not many research works have been reported on the upper layers and more specifically in the transport layer for VLC network. MPTCP is a protocol designed to achieve improved throughput and resource utilization by means of simultaneous use of several sub flows. MPTCP scheduler allows transmission of packet on specific sub-flow [3]. Default and Redundant schedulers are highly attractive in addressing both mobility and handover issues in mobile networks.

The MPTCP Default scheduler is the default option, where at the beginning it transmits data on sub-flows with the lowest round trip time (RTT) value until the congestion-window is full. Following this transmission on the other sub-flows with the highest RTT values is initialized. Note that, the use of Default scheduler leads to the increment in the network throughput by using several sub flows capacity, simultaneously. In the MPTCP Redundant scheduler the data is transmitted on all available sub-flows, thus offering reduced latency since one link is always available for transmission during blocking [4].

In VVLC networks handover is needed due to both mobility and shadowing. Let's consider automated guided vehicle (AGV) travelling along a given path. Initially, a vehicle is connected to the first light access point (LAP). While moving and entering the overlapping coverage area between two cells, handover is initiated and a new VLC link is established with the second LAP. In case of shadowing or existence of obstacles, handover initiates when there is no line of sight (LOS) path, and therefore a new connection link is established via the next available LAP. In both cases, the VVLC network will experience decrease in the network outage during the handover. The remainder of this paper is organized as follows: Section II summarizes related research works for the use of MPTCP in various types of networks. Section III presents the motivation behind this research. Section IV describes the proposed architecture to use MPTCP in a VLC network. Section V presents the implementation results for mobility and shadowing use case scenarios in a VVLC network. Finally, Section VI concludes the paper.

II. RELATED WORK

Different approaches have been proposed to use MPTCP in various networks such as millimetre Wave (mmW), long term evolution (LTE), WiFi and hybrid networks (VLC-WiFi and WiFi-cellular). In [5], it was shown that how mmW-based mobile networks could be effected by the most widely used transport protocols and demonstrated the throughput-latency trade-off when MPTCP is used across various links, such as LTE. In [6], an experimental investigation of MPTCP in dual-band 60 GHz/5 GHz WLAN was reported, where uncoupled and different coupled congestion control algorithms were considered and compared with the aim of improving the throughput over a single path TCP. The results showed that, a significant throughput improvement for the case of uncoupled congestion control, achieving a throughput roughly equal to the sum of the SPTCP throughputs over WiFi and 60 GHz cellular links. Besides, in the case of coupled congestion control, the throughput was lower as the algorithms fail to fully utilize the capacity of both paths simultaneous. In [3,] the use of MPTCP in WiFi and cellular networks using a smart-phone interfaces was reported, where the device used more than one interface simultaneously. They evaluated the performance internet protocol (IP) reachability over real world networks and conducted experimental tests over multiple paths with differing loss rates and round trip latencies in order to assess the effect of primary path selection and issues related to selecting the under-performing paths.

Finally, in [7] and [8] MPTCP in hybrid networks including VLC were investigated. In [7], a novel decoupled TCP extension protocol for a VLC hybrid network was proposed, where decoupling operation to TCP transmission overcomes the limitation of regular TCP by allowing the users full utilization of network resources by the users. Based on Linux-kernel, they showed higher throughputs for multipath decoupled TCP (MP-DETCP) compared with DETCP for different downlink packet loss ratios. Moreover, in [8], a practical hybrid WiFi-VLC system was proposed, there was no need for a separate VLC uplink with aggregated WiFi and VLC downlinks and sharing the WiFi uplink. The link aggregation was achieved using Linux bonding and media access control (MAC) address redirection. The system throughput for the WiFi only (i.e., one WiFi downlink) and asymmetric (i.e., one VLC downlink) links were compared under a congested WiFi environment. The results demonstrated that, the proposed system offered an aggregated downlink bandwidth, which is approximately the sum of the downlink capacities of the WiFi-only and asymmetric systems. In addition, a tradeoff between bandwidth utilization and latency was outlined.

In this paper, we propose a novel transport layer architecture, which uses MPTCP in a VLC network, for the first time, which is flexible, robust and offers seamless handover between a vehicle and a server. We provide both uplink and downlink using VLC networks. Moreover, the proposed architecture offers lower latency of 0.024 seconds and higher throughput of 125 Mbps, respectively. The next section describes the use of MPTCP in a VLC network in detail.

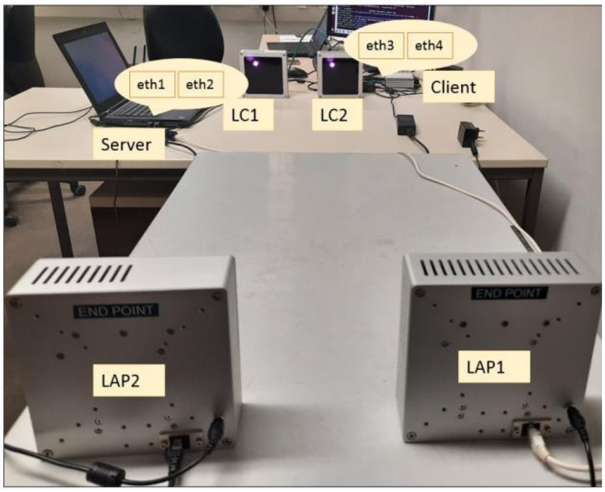


FIG. 2: MPTCP architectural design prototype in VLC

TABLE 1: Experimental parameters

Parameter	Value
LC1 and LAP1 frequency range (f_1)	4-52 MHz
LC2 and LAP2 frequency range (f_2)	52-96 MHz
Distance between LCs and LAPs	2 m
Link blockage duration time for shadowing/obstacle	3 s
Field of view (FoV) of photodiodes	60 degree
Average throughput between LAP1 and LC1	90 Mbps
Average throughput between LAP2 and LC2	110 Mbps
eth1 IP address	192.168.10.25
eth2 IP address	192.168.20.24
eth3 IP address	192.168.10.52
eth4 IP address	192.168.20.42
Room dimension	5 x 4 x 2.7 m^3
Distance between LAPs	1 m
Bandwidth	100 MHz
Transmission power of LED	630 mW
Effective active area of photodiod	150 mm^2
Number of LEDs in a VLC COTS	5
Number of LEDs in a VLC COTS	4

III. MOTIVATIONS

The main motivation behind this work is to address existing challenges in a VVLC network including mobility, shadowing or obstacles, which will block the LOS path

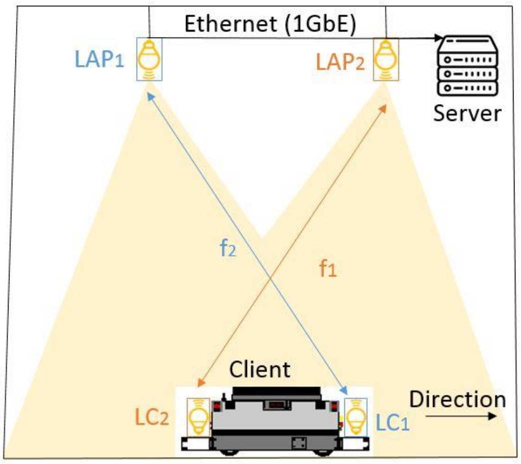


Fig. 1: VLC with MPTCP

between the transmitter and receiver, thus leading to increased packet losses and reduced network reliability. In addition, the network throughput is critical. In order to offer a reliable VVLC network with the required throughput, the outage duration during handover needs to be reduced. In this paper, we consider the transport layer of VLC with two different MPTCP schedulers and an MPTCP tool to investigate their impact on the VLC performance by considering Mobility (i.e., handover) and shadowing/obstacle.

IV. VLC WITH MPTCP

In this section, we present the proposed architecture to use in VLC with MPTCP . Fig. 1 shows the schematic system diagram for the proposed system. A vehicle with two optical transceivers acting as a light clients (LC) is connected to the two LAPs, which are mounted on the ceiling of the room, via

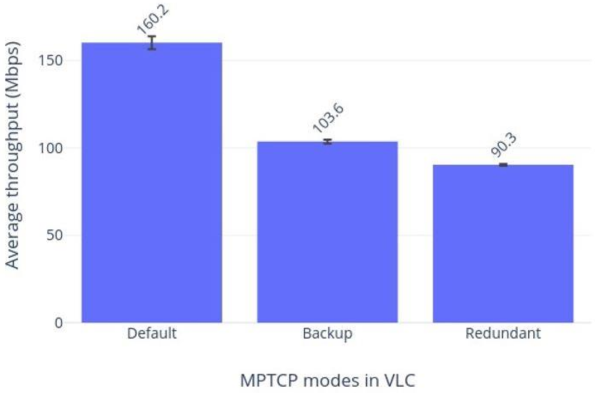


FIG. 3: Average throughput of MPTCP in VLC links using "Default", "Redundant" and backup-mode MPTCP tool.

full duplex VLC links. The client on the vehicle supports two Ethernet interfaces for connecting to two LCs. LAPs are connected via Ethernet to the server.

A. *MPTCP*

MPTCP is a Linux kernel, which is installed on Ubuntu 18.04 both on server and client systems. Here, MPTCP version 0.95 with full mesh path manager is adopted, which creates a full mesh of sub-flows among all available VLC network interfaces [4]. A TCP connection is established over two sub-flows as shown in blue and orange colors in Fig. 1 using Default and Redundant schedulers. In addition, we use an MPTCP tool called the backup mode with a TCP sub-flow for each interfaces and with one of the interfaces being configured in the backup mode. By doing this, if the current sub-flow experiences a failure, then the backup interface is selected as the backup for establishing TCP. Fig. 2 shows the experimental prototype for the proposed system as a proof of concept. Two pairs of LAPs and LCs, which are configured using two different frequency ranges of 4-52 MHz and 52-96 MHz for MC1-LAP1 and MC2-LAP2, respectively. Note, (i) there are two parallel active and non-overlapping VLC links between the client and the server; and (ii) VLC transceivers are connected to the clients and server using Ethernet links. In this work, we analyze the performance of VLC with MPTCP under the handover, which is initiated by or shadowing and temporary link blockage. For initialization, first we established TCP over two VLC links, see Fig. 3, in order to evaluate the performance of VLC links in a network environment with no link blockage. Table I shows the key experimental parameters adopted in this work.

Fig. 3 presents the average throughput for VLC with MPTCP links for the three cases of Default and Redundant schedulers and backup tool with no handover. As shown, using Default offers the highest possible throughput of 160.2 Mbps. Fig. 4 depicted the throughput for the three cases. As can be seen, for Default a higher throughput (i.e., an average of 160 Mbps) is achieved for the TCP link between client and server, this is because data is transmitted over both VLC links. For the Redundant scheduler, see Fig. 4(b), the throughput is lower (i.e., an average of 90 Mbps) with reduced variability. Fig. 4c presents the impact of this method on TCP established over VLC network. As it is shown, For the backup scheduler, the achieved average throughput is marginally higher than Redundant. And shows a smooth flow over only a single sub-flow since the second sub flow is configured as the backup only in case of the primary sub flow's failure.

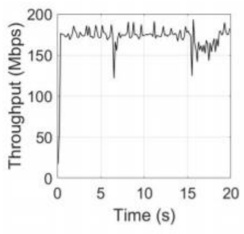
B. *VLC links*

We have used commercial off-the-shelf (COTS) VLC devices (OSRAM), with real-time bidirectional communications capability at a data rate of100 Mbit/s over a transmission distance of 10 m. The modulation is orthogonal frequency-division multiplex (OFDM) with the G.hn standard [9]. The analog board is customized to provide a high transmit optical power using off-the-shelf high-power LEDs (OSRAM SFH 4715 AS), 4 LEDs per unit with a total average optical power of 2.5 W in this case. In addition, optical receivers composed of large-area silicon photodiodes (PD) (Hamamatsu S6968), 5 in total, and transimpedance amplifier (TIAs) with equal gain combining are used to capture sufficient lights from all direction.

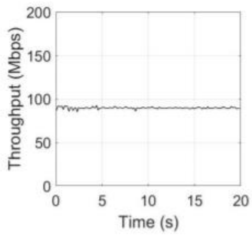
V. RESULTS

The proposed transport layer VLC architecture is experimentally implemented using the VLC prototype in order to validate the performance of MPTCP. To emulate the mobility, we introduced a permanent link blocking on the simplex link between a client and the server. To emulate shadowing/obstacle, a temporary link blockage on the single VLC link was introduced for about 3 s. As given in Table I, the VLC links were configured as two different subnets as in 192.168.10.x and 192.168.20.y. The client and the server machine with Ethernet interfaces are configured to use Ubuntu 18.04. The VLC COTS operating at two different transmission frequency bands of 4-52 MHz and 52-96 MHz are connected to both sides via Ethernet cables.

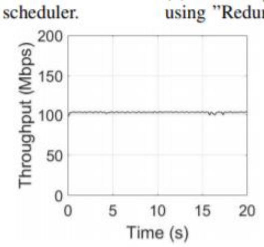
We have carried out experimental investigation for the two schedulers and a MPTCP tool, where each measurement is carried out for 10 times to ensure consistency. In the Default scheduler, the scheduler transmits the traffic data considering the RTT and congestion control window size, whereas in the Redundant schedulerthe traffic is broadcasted



(a) MPTCP performance in VLC using "Default" scheduler.

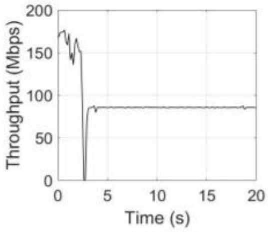


(b) MPTCP performance in VLC using "Redundant" scheduler.

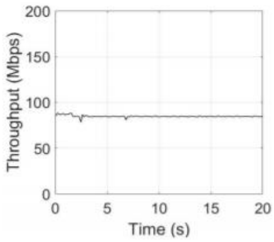


(c) MPTCP performance in VLC using Backup mode tool.

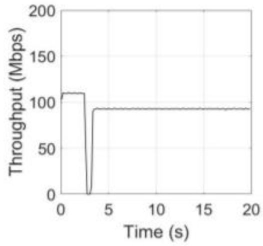
FIG. 4: MPTCP performance in VLC without any link blockage



(a) Mobility usecase using "Default" scheduler.



(b) Mobility usecase using "Redundant" scheduler.



(c) Mobility usecase using Backup mode tool.

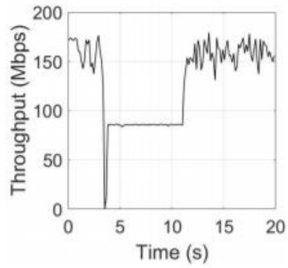
FIG. 5: MPTCP performance in VLC with link blockage due to mobility in "Default","Redundant" and Backup modes

over all available sub-flows regardless of path's characteristics. As was stated before, the latter reduced latency. In the backup mode, a single VLC link is configured as the backup to ensure connectivity during link failure.

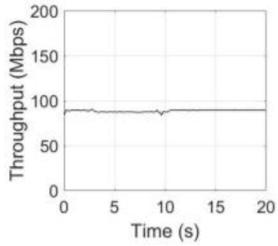
Experiment 1 - The Default scheduler: To evaluate and measure the network throughput via the uplink between the client and the server, we have used iperf tools both on server and client systems. For the mobility use case, the initial throughput is 170 Mbps and is reduced to 85 Mbps due to mobility induced link blockage. On receiving no acknowledgment back from the receiver the data traffic will be transmit over the second link with an average throughput of 90 Mbps. In the case of throughput dropping to zero, the data packet is buffered in a queue (i.e., packets in flight) for re-transmission over the first available sub-flow. Experiment 2 - The Redundant scheduler: Here the redundant mode is used with no latency during the handover and packet transmission continues seamlessly with a low throughput of 85 Mbps, see Fig. 5(b). Experiment 3 – The Backup-mode: As shown in Fig. 5(c) maximum latency is achieved during the handover while the traffic transmission changes the paths between the primary and backup links. However, the throughput achieved can be higher than the Redundant mode depending on the link being blocked. In this specific experiment, the link with the highest average throughput is blocked, therefore, the traffic is transmitted over the second link with lower average throughput.

The following set of experiments are based on the link failure due to shadow/obstacle.

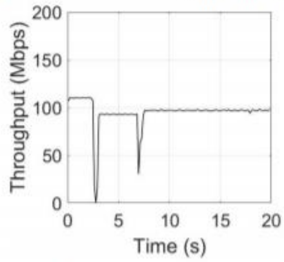
Experiment 4 – The Default scheduler: Using the iperf tools we could achieve results shown in Fig. 6a. Fig. 6(a) shows the data throughput for the link with shadowing, where the throughput dropped from as 173 Mbps to around 80 Mbps due to handover. The link is back to its maximum through level following the availability of the link with no shadowing/blocking. Experiment 5 – The Redundant mode": The achieved throughput, see Fig. 6(b), is similar to the experiment 2, where the same number of packets are being



(a) Shadow usecase using "Default" scheduler.



(b) Shadow usecase using "Redundant" scheduler.



(c) Shadow usecase using Backup mode tool.

FIG. 6: MPTCP performance in VLC with link blockage due to shadow/obstacle in "Default","Redundant" and Backup modes.

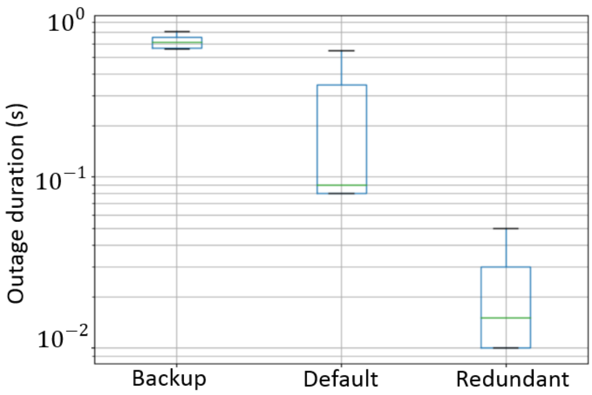


FIG.7: Outage duration for mobility usecase scenario in a VVLC network.

transmitted over both links simultaneously. Note, link failure (permanent or temporary) does not impact the latency during handover, but the average throughput is lower compared with other use cases.

Experiment 6 – The Backup-mode: Fig. 6(c) shows the throughput with handover for a single VLC link experiencing temporary blocking. Note, the link with the lowest average throughput fails temporarily (i.e., a few seconds), see the notches in Fig. 6(c). Using this mode, we achieve the highest outage duration rate during the handover.

Decreasing the outage duration during handover in a VVLC network is considered as one the significant challenges for this type of network. Here we investigate the outage duration of TCP transmission over VLC links for Default and Redundant schedulers and backup-mode tool with handover. Fig. 7 presents the outage duration for the three cases, with Redundant and Back-up offering the lowest and highest values of 2.4 and 620 ms, respectively.

VI. CONCLUSION

This paper proposed a novel architecture to tackle the handover issues in the upper layer (i.e., the transport layer) in a VLC network in order to to decrease the outage duration and increase the throughput during handover caused by mobility and shadow/obstacle. The architecture includes the use of frequency division on COTS of VLC and MPTCP on both client and server. We presented a real-world experiments using COTS VLC devices to demonstrate the network performance and showed that the improvement in the network throughput and outage duration depends on the user case scenarios, where there is a high chance of frequent handover caused by mobility and shadowing

Future work will include a novel MPTCP scheduler which can be designed specifically for VLC performance improvement both in terms of reliability and robustness.

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