DynaVLC 13 Towards Dynamic GTS Allocation in VLC Networks

Harrison Kurunathan
Miguel Gutiérrez Gaitán
Ramiro Robles
Eduardo Tovar

CISTER-TR-240403

2024/03/04

DynaVLC 13 Towards Dynamic GTS Allocation in VLC Networks

Harrison Kurunathan, Miguel Gutiérrez Gaitán, Ramiro Robles, Eduardo Tovar

CISTER Research Centre

Polytechnic Institute of Porto (ISEP P.Porto)

Rua Dr. António Bernardino de Almeida, 431

4200-072 Porto

Portugal

Tel.: +351.22.8340509, Fax: +351.22.8321159

E-mail: jhk@isep.ipp.pt, mjggt@isep.ipp.pt, rsr@isep.ipp.pt, emt@isep.ipp.pt

https://www.cister-labs.pt

Abstract

Envisioned to deliver superior Quality of Service (QoS) by offering faster data rates and reduced latency in 6G communication scenarios, pioneering communication protocols like the IEEE 802.15.7 are poised to facilitate emerging application trends (e.g. metaverse). The IEEE 802.15.7 standard that supports visible light communication (VLC) provides determinism for time-critical reliable communication through its guaranteed time-slots mechanism of the contention-free period (CFP) while supporting non-time-critical communication through contention-access period (CAP). Nevertheless, the IEEE 802.15.7 MAC structure is fixed and statically defined at the beginning of the network creation. This rigid definition of the network can be detrimental when the traffic characteristics evolve dynamically, for example, due to environmental or user-driven workload conditions. To this purpose, this paper proposes a resource-aware dynamic architecture for IEEE 802.15.7 networks that efficiently adapts the superframe structure to traffic dynamics. Notably, this technique was shown to reduce the overall delay and throughput by up to 45% and 30%, respectively, when compared to the traditional IEEE 802.15.7 protocol performance under the same network conditions.

DynaVLC – Towards Dynamic GTS Allocation in VLC Networks

Harrison Kurunathan
CISTER/ISEP, Polytechnic Institute of Porto, Portugal

Miguel Gutiérrez Gaitán[1]
Department of Electrical Engineering, Pontificia Universidad Católica de Chile, Santiago, Chile
Faculty of Engineering, Universidad Andres Bello, Santiago, Chile
CISTER/ISEP, Polytechnic Institute of Porto, Portugal

Ramiro Sámano-Robles
CISTER/ISEP, Polytechnic Institute of Porto, Portugal

Eduardo Tovar
CISTER/ISEP, Polytechnic Institute of Porto, Portugal

Abstract

Envisioned to deliver superior Quality of Service (QoS) by offering faster data rates and reduced latency in 6G communication scenarios, pioneering communication protocols like the IEEE 802.15.7 are poised to facilitate emerging application trends (e.g. metaverse). The IEEE 802.15.7 standard that supports visible light communication (VLC) provides determinism for time-critical reliable communication through its guaranteed time-slots mechanism of the contention-free period (CFP) while supporting non-time-critical communication through contention-access period (CAP). Nevertheless, the IEEE 802.15.7 MAC structure is fixed and statically defined at the beginning of the network creation. This rigid definition of the network can be detrimental when the traffic characteristics evolve dynamically, for example, due to environmental or user-driven workload conditions. To this purpose, this paper proposes a resource-aware dynamic architecture for IEEE 802.15.7 networks that efficiently adapts the superframe structure to traffic dynamics. Notably, this technique was shown to reduce the overall delay and throughput by up to 45% and 30%, respectively, when compared to the traditional IEEE 802.15.7 protocol performance under the same network conditions.

2012 ACM Subject Classification Computer systems organization → Real-time systems; Networks → Network protocols; Theory of computation → Design and analysis of algorithms

Keywords and phrases IEEE 802.15.7, VLC networks, network tuning

Digital Object Identifier 10.4230/OASIcs.NG-RES.2024.3

Category Invited Paper

Funding This work was partially supported by National Funds through FCT/MCTES (Portuguese Foundation for Science and Technology) within the CISTER Research Unit (UIDB/04234/2020).

1 Introduction

With 6G expected on the horizon by 2025, new technologies must be adopted to ensure the flawless usage of 6G [5]. Likewise, with the ever-growing network traffic demand and the need to support high bandwidth applications, researchers are venturing into new communication possibilities, including Visible Light Communication (VLC) and the Terahertz (THz) band. VLC, particularly, is deemed to be well-suited to meet the criteria of emerging applications toward 6G, including Virtual Reality (VR) and augmented Reality (AR), among others.

---

[1] Corresponding author

Fifth Workshop on Next Generation Real-Time Embedded Systems (NG-RES 2024).
Editors: Patrick Meumeu Yomsi and Stefan Wildermann; Article No. 3; pp. 3:1–3:11
OpenAccess Series in Informatics
Schloss Dagstuhl – Leibniz-Zentrum für Informatik, Dagstuhl Publishing, Germany

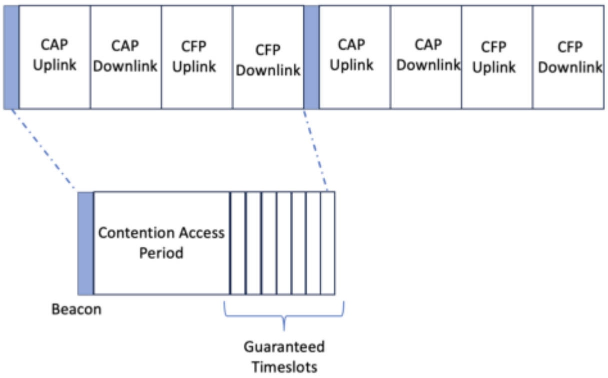


Figure 1 The superframe structure of IEEE 802.15.7 with the contention-free period of guaranteed time-slots enabling time-critical communication for VLC applications.

VLC's distinctive features such as its immunity to electromagnetic interference, high data rates, and the capability to operate in unlicensed bands [7], have placed it among the potential candidates to be included in the competitive arsenal of 6G communication technologies.

IEEE 802.15.7 [13] is a communication protocol poised to realize communication in VLC networks. The architecture of this standard supports high data rates of up to 96 Mbps with almost 300 THz of unlicensed spectrum. This makes it ideal to support bandwidth-hungry applications, potentially using existing illumination infrastructure. The standard also offers predictable protocol features enabling the support of critical and demand strict timeliness requirements through its Guaranteed Time Slot (GTS) mechanism, which operates in a periodically synchronized superframe structure (Fig. 1).

Among the key parameters of the protocol is the *superframe order* (SO) which defines the duration of the active period of the superframe, a.k.a. the *superframe duration* (SD). Within this scheme, beacons are transmitted between subsequent superframes enabling time synchronization and MAC management. The time interval between beacons is known as the *beacon interval* (BI). All these parameters can be properly set statically at the beginning of the network to govern overall communication performance. This approach, although suitable in the case of highly stationary network scenarios, prevents achieving adequate Quality of Service (QoS) when traffic characteristics evolve dynamically, for example, due to environmental or user-driven workload conditions.

In fact, in several potential VLC scenarios for 6G, such as healthcare monitoring [9], underwater networks [1] or vehicular communication, to name a few, the data traffic and/or the number of nodes that connect (or disconnect) to a central coordinator can vary frequently, e.g., based on local environmental circumstances [2], mobility of the nodes from one area to another [9], and/or due to multiple nodes reaching the same area and creating a bottleneck, which implies more traffic to be accommodated. The aforementioned static settings are just examples of how a dynamic traffic behavior can lead to inevitable compromises on QoS on metrics such as (worst-case) delay or throughput. This raises a need for a novel VLC network architecture that can adapt protocol features on the fly to varying conditions.

In this paper, we propose an adaptive MAC architecture called the DynaVLC that will dynamically toggle the network parameters and make them suitable to the underlying traffic behavior. This method can adapt efficiently to scenarios where the data traffic demand grow either higher or lower while satisfying QoS requirements such as latency or throughput. This tuning technique can be facilitated by managing entities such as the network coordinators typically set to be aware of the network demand requirements to be served by the GTS. More concretely, making the network coordinators demand-aware can be done, for example, by integrating an RPL (Routing Protocol for Lossy Networks) layer over the VLC MAC layer.

We summarize the main contributions presented in this paper as follows:

- We provide a novel dynamic MAC structure tuning architecture called DynaVLC for IEEE 802.15.7 networks that yields better QoS performance.
- We introduce the so-called CAP reduction and modeling of the GTS under the DynaVLC architecture for several scenarios involving varying network demand.
- We derive the worst-case bounds and perform an in-depth performance analysis of the proposed structure covering both throughput and delay analysis.

The rest of the paper is organized as follows: Section 2 provides related works on some of the adaptive techniques devised for VLC networks and general communication protocols. Section 3 presents the CAP reduction technique as one of the key elements of the DynaVLC architecture to increase the number of GTS in the superframe. Section 4 introduces the system model and discusses the topologies and scenarios taken to demonstrate this architecture. Section 5 presents our novel DynaVLC architecture, and Section 6 analyzes its performance. Conclusions and a wrap-up with some discussion of future scope are presented in Section 7.

2 Related Works

The research work in [3] proposes a flexible superframe structure that enables sleep modes for priority data handling in IEEE 802.15.7-based real-time sensor networks. This method enables a hybrid mode in the contention access period and contention-free period (CFP) adaptively. The method works by shifting periods and sending priority data with lower bandwidth and delay. While the method holds promise in static/stationary conditions, the improvements do not show to be suitable for evolving traffic conditions.

A different approach is proposed by researchers in [17] who propose a priority MAC based on a multi-parameter for IEEE 802.15.7 VLC networks. They make use of common parameters such as the backoff times (NB), backoff exponent (BE), and contention window (CW) to enable priority-driven multilevel differentiated service. Moreover, using a discrete-time Markov chain model, the authors analyzed the impact of their multi-parameter traffic differentiation on throughput. More recently, a comparison between the traditional IEEE 802.15.7 frame and a novel energy-efficient superframe was done in [4]. This work also considered different inputs such as the biosensors' battery life as well as adaptive data requirements to vary MAC parameters accordingly. However, in both of these works variations in traffic data were not considered. The data traffic was set as a constant and only the impact of the variation of the MAC parameters such as the BO and SO were considered.

In one of our previous works, we presented the worst-case bounds delay of IEEE 802.15.7 using network calculus [13]. In this work, we explored the possibility of a technique called CAP reduction functionality from IEEE 802.15.4 and carried out a detailed performance analysis. This technique increases the number of GTS slots in the traditional IEEE 802.15.7 MAC frame, thus increasing the scalability for critical communication nodes in the network. Based on these results, we recently presented in [14] the possibility of having a multichannel structure to enhance the allocation for GTS in IEEE 802.15.7 frames. While both of these works focused on increasing the number of GTS timeslots, both the methods are statically defined, and thus cannot adapt to traffic dynamics in evolving network scenarios.

Adaptive superframe is a concept that has been researched for several network protocols like the IEEE 802.15.4 and IEEE 802.15.6. The underlying idea is that superframes are flexible to support GTS requirements [8, 11] where the active period or the CFP is adapted as per the requested data. They also can be adapted to support priority data [15, 6] and support specific QoS like the energy efficiency [16]. Along this line of thought, in this work, we propose a novel technique called DynaVLC for IEEE 802.15.7 VLC networks where the superframe structure can be adjusted based on the oncoming traffic needs. The end goal is to significantly improve network throughput and reduce the overall worst-case delay toward deterministic 6G application scenarios.

3 Background to the CAP reduction architecture

CAP reduction is a technique where two or more superframes can be joined together as a multi-superframe and the CAP period between them can be removed and replaced with a CFP period. This technique was first introduced for the IEEE 802.15.4e - DSME network protocol [10] and then extended to the IEEE 802.15.7 protocol in [13].

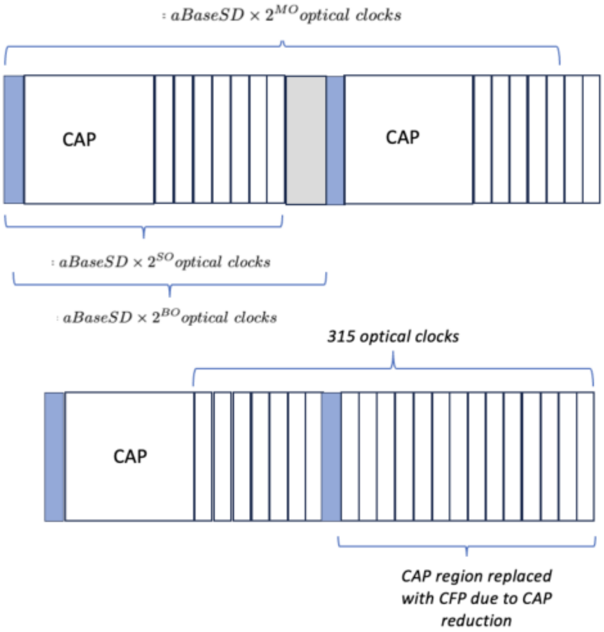


Figure 2 The superframe structure representation where BO=3, MO=3 and SO=2, also showing the structure with CAP reduction comprising of 21 GTS timeslots to support critical deterministic communication.

To have CAP reduction in the classes IEEE 802.15.7 protocols, we must introduce first a concept called multi-superframes that can be enabled through multi-superframe order (MO) and multi-superframe duration (MD). These parameters define the length of all the individual superframes within the multi-superframe. The aforementioned parameters can be formally represented as follows:

$$BI = aBaseSD \times 2^{BO} optical\ clocks \qquad for\ 0 \le BO \le 14 \tag{1}$$

$$SD = aBaseSD \times 2^{SO} optical\ clocks \qquad for\ 0 \le SO \le BO \le 14 \tag{2}$$

$$MD = aBaseSD \times 2^{MO} optical\ clocks \qquad for\ 0 \le SO \le MO \le BO \le 14. \tag{3}$$

Table 1 Network configurations and their respective application scenarios.

Application	BO	SO	MO	CAP reduction	SD size
Delay sensitive	6	0	2	enabled	60
Large scale	10	1	8	enabled	128
Energy critical	6	1	1	disabled	128
Reliability	8	2	2	disabled	240

The number of multi-superframes within a beacon interval is given by $2^{(BO-MO)}$, and the number of superframes within the multi-superframe by $2^{(MO-SO)}$. To illustrate this scheme we can take the configuration presented in Figure 2, which is a network infrastructure representation where BO=3, MO=3 and SO=2. This is a case where two superframes are stacked within a single multi-superframe. Note that after the network is initiated with these parameters the infrastructure remains unchanged and the setup repeats periodically. For clarity, we briefly describe the most relevant parameters as follows:

$aBaseSD$ is defined as the minimum duration of a superframe and is set to 60 optical clocks at the initial order of the superframe (i.e., SO=0). Formally, this value is defined as:

$$aBaseSD = Slot\ Duration \times T_s \tag{4}$$

where T_s is the size of the timeslot in the superframe. Note that T_s in a superframe is made up of the data frames and idle frames. Data frames encompass the data transmissions and the idle frames encompass acknowledgments, long interframe spacing ($LIFS$), short interframe spacing ($SIFS$), and reduced interframe spacing ($RIFS$). Then, to develop the worst-case bounds analysis, we must include the GTS transmission, its respective acknowledgments and the CAP region within the multi-superframe. As every VLC superframe comprises 16 timeslots, the size of a single timeslot is denoted as:

$$T_s = \frac{SD}{16} = aBaseSD \times 2^{SO-4}. \tag{5}$$

For the parameters that define the multi-superframe architecture of Figure 2, the size of every single timeslot will be 15 optical cycles, the superframe duration will be 240 optical cycles and the entire multi-superframe will be 480 optical cycles. Among these optical cycles 210 optical cycles that correspond to 14 GTS timeslots across the multi-superframe support critical deterministic communication. Now for the same structure when we employ CAP reduction, the CAP region of the second superframe is replaced with a CFP and the inactive period is removed, thus drastically increasing the number of GTS timeslots in the network. In such a case, there will be 315 optical cycles corresponding to 21 GTS timeslots to support critical deterministic communication. Now when multichannel communication can exist over this architecture, i.e., over three multi-channels, there will be a total of 63 GTS timeslots over 315 optical cycles.

The setting of the network parameters and the CAP reduction can also be made application-specific. For instance, in a delay-sensitive network that carries priority traffic, we need an architecture with minimal SD size so that the next packet can be sent with minimal latency. With CAP enabled, the delay due to waiting for the inactive period and the adjacent CAP region can be avoided. In the case of a large-scale network, more nodes must be accommodated within a short period. In such cases, there is a need for a short SD duration but a larger number of superframes within a single multi-superframe. As an illustrative example, different network configurations and their respective application scenarios are shown in Table 1.

4 System Model

With the possibility of having multiple channels, enabling multi-channel mesh networks would be feasible in VLC scenarios. Having this in mind, we assume a mesh network as shown in Figure 3. To emulate real networking scenarios, we consider dynamic nodes that join and leave the network. A mesh network consists of a PAN coordinator (node PAN-C in Figure 3), which can transceive messages and beacons. Then there will be Fully Functional Nodes (FFN) that facilitate routing and send beacons for association and timing synchronization. Finally, the Reduced Functional Nodes (RFN) are capable of only receiving messages. Such a network is facilitated with the aid of routing using protocols like the RPL by which a point-to-many-points (P2MP) tree-like network can be devised.

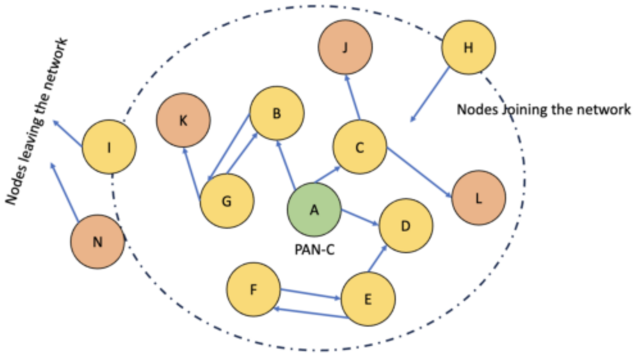
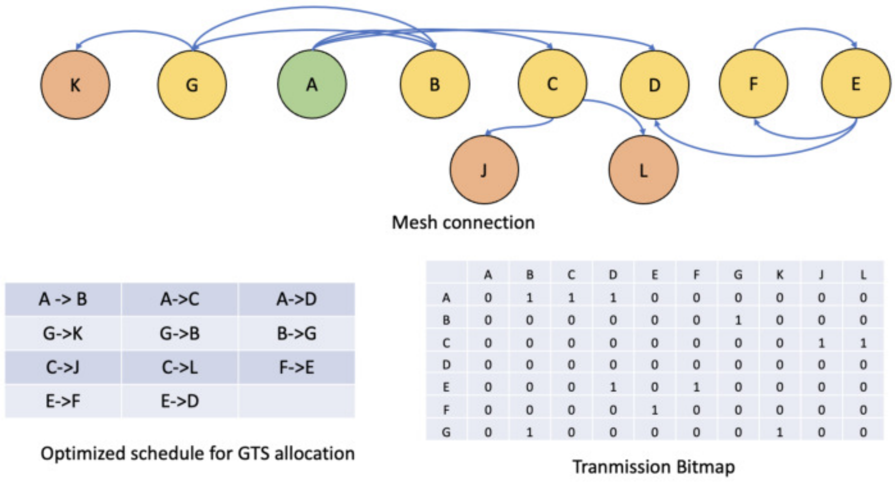


Figure 3 A mesh network comprising of the PAN-C, FFNs (green nodes) and RFNs (orange nodes) that dynamically join and leave the network.

Node association is done through the PAN coordinator. At the inception of the network formation, new FFNs advertise their respective superframe through periodic beacons. Association to an FFN, RFN or a PAN-C is done through an association request.

The nodes in the association process are assumed to be RPL-enabled routing nodes. The PAN-C acts as the sink in the Destination-Oriented Directed Acyclic Graph (DODAG). PAN-C is responsible for transmitting DODAG messages. In the RPL overlay network, all routers (FFNs) continuously broadcast DAG Information Object (DIO) messages to announce the DODAG. A node listens to the DIO messages when it joins the network through the association process. Upon receiving a DIO message from the FFN, the joining node adds the sender's DIO address to its parent list and calculates its rank based on the specified Objective Function (OF). The Objective Function for the DODAG can be QoS-defining factors such as Link Quality Indicator, Packet Delivery Ratio, or Power Consumption. Finally, the DIO message is updated with the newly computed ranks. The client node then selects its preferred parent from the list of FFNs as the default node through which inbound traffic is directed.

Figure 4 presents the mesh connection network for the network defined in the system model (Figure 3). An optimal schedule that utilizes the minimal number of time slots and channels can be defined using optimization methods like the Symphony [12] (adapted to IEEE 802.15.7 structure). Still, it must follow the mandate that the transmitting nodes do not overlap in time amongst themselves. By using Symphony, we provide a (near) optimal solution that uses 12 GTSs spanning over four channels and three timeslots. A transmission bitmap (Figure 4) will be created based on the transmissions of the mesh network and will be passed on to the underlying link layers using the RPL backbone periodically at every beacon interval.



A -> B	A->C	A->D
G->K	G->B	B->G
C->J	C->L	F->E
E->F	E->D	

Optimized schedule for GTS allocation

	A	B	C	D	E	F	G	K	J	L
A	0	1	1	1	0	0	0	0	0	0
B	0	0	0	0	0	0	1	0	0	0
C	0	0	0	0	0	0	0	0	1	1
D	0	0	0	0	0	0	0	0	0	0
E	0	0	0	1	0	1	0	0	0	0
F	0	0	0	0	1	0	0	0	0	0
G	0	1	0	0	0	0	0	1	0	0

Tranmission Bitmap

Figure 4 mesh formation of the network, its optimized schedule and its respective transmission bitmap that will be transmitted through the RPL-enabled routing nodes.

The proposed solution in this work aids in tackling two major network issues caused by the static assignment of the network parameters at the inception of the network formation. The first problem is a requisite when there is *a need for a more guaranteed bandwidth than what is available*. More bandwidth will be provided if a smaller SO is defined at the beginning of the network definition. By setting a smaller SO more superframes can be affixed within the multi-superframe duration, further with CAP reduction the total number of guaranteed bandwidth to be serviced can also be drastically increased. However, in the case of a small SO with a large amount of bandwidth available, it could be a negative factor when *there is a need for less bandwidth compared to what is available*. The more suitable solution for these aforementioned problems is a tunable network architecture that can adjust its network parameters when the network demand changes.

5 DynaVLC architecture

The PAN-C establishes the multi-channel GTS allocation based on the number of channels, the number of GTS time slots and the total available GTS resources N_{CFP}. When the CAP reduction primitive is enabled the total number of GTS timeslots N_{TS} augments to $7 + N_{CR}$, where N_{CR} is the number of timeslots added through CAP reduction. In a system with C channels, the total resources available can be computed as $C \times N_{TS}$.

The duration of timeslot in the multi-superframe T_{MS} with N_η symbols that encompasses the size of the CAP (T_{CAP}) and the CFP created through CAP reduction T_{CFP} can be calculated as:

$$T_{MS} = \frac{N_\eta}{T_{CAP} + T_{CFP}}. \tag{6}$$

Let GTS_{min} be the minimum number of superframe slots a single GTS can extend over. We present this constraint such that there is a limit for the GTS not to span over multi-superframe duration for a maximum forward delay of D_{max}.

$$GTS_{min} = \left\lceil \frac{D_{max}}{T_{MS}} \right\rceil \tag{7}$$

For n timeslots with a burst rate b and a data rate D, the maximum forward delay D_{max} can be obtained as:

$$D_{max} = \frac{b \times BI}{D \times T_{data}} + (BI - n(T_{MS})). \tag{8}$$

Then, since the maximum number of the GTS varies based on the CAP reduction technique, with C number of channels spanning across the CFP timeslots, the max GTS can be defined as:

$$GTS_{max} = min\left(\left\lceil\frac{(T_{CAP}+T_{CFP})\left(1-\frac{T_{CAP}}{T_{MS}}\right)}{GTS_{min}}\right\rceil, C \times N_{CFP}\right). \tag{9}$$

Following the availability of the transmission bitmap from the optimal schedule through the RPL backbone, the amount of the required resources R is known to the PAN-C. Based on the requirement of resources, if needed more, the PAN-C adds/removes CAP reduction primitive and increments/decrements the value of MO in the subsequent beacon intervals as shown in Algorithm 1.

Algorithm 1 DynaVLC algorithm to dynamically tune the superframe to the network demand.

```
Input: BO, SO, MO
optimal schedule from the RPL backbone
Number of channels ($C$) and Number of GTS available ($N_{CFP}$)
Initialization
repeat
    Schedule R = Required number of resources to accommodate the network
    Resource test: check $N_{CFP} \geq R$ in a multi-superframe

    Problem 1: Minimal resources and high demand
    while $N_{CFP} \leq R$ do
        CAP Reduction = ON;
        if resource test true then
            Print: DynaVLC is successful,
        else
            MO = MO + 1;
        end if
    end while

    Problem 2: abundant resources and less demand
    while $N_{CFP} \geq R$ do
        CAP Reduction = OFF;
        if Resource test true then
            Print: DynaVLC is successful,
        else
            MO = MO - 1;
        end if
    end while
until Every multi-superframe duration
```

In a multi-superframe duration (MD) of N superframes, and for a data rate of D over C channels, the maximum throughput for a single multi-superframe duration can be given as:

$$TH_{max} = \left(\frac{(N \times T_{MS}) - T_{idle}}{GTS_{max}}\right) \times D * C. \tag{10}$$

6 Numerical Analysis

To analyze the impact of DynaVLC, we consider an evolving network with the number of GTS transmissions increasing over time and analyze the delay. Let us consider a multi-superframe architecture with BO =6, MO = 1, SO = 1, such that there will be two superframes within a multi-superframe that repeats for every beacon interval. For this test let us consider three channels spanning over the 7 GTS in the classic IEEE 802.15.7 structure. In the classic VLC structure with 3 channels, there will be a total of 21 GTS slots, which will not be capable of accommodating more than 21 pairs of transmissions. However, when CAP reduction is added to the multi-superframe the number of available GTS increases to 63 individual GTS slots. However, in the case of static CAP reduction, after the 63 timeslots are filled, it waits for the entire CAP duration until the subsequent superframe starts allocating the GTSs.

In the case of DynaVLC, when the number of resources is minimal, initially the CAP reduction kicks in and we get almost the same performance as that of the static CAP reduction. When the entire CFP is full, the resource test R fails and the value of MO is increased adding another superframe to the multi-superframe. Now with CAP reduction on all of the superframes, we will have a total of 102 GTS slots for deterministic communication resulting in a decrease in delay by up to 45 %.

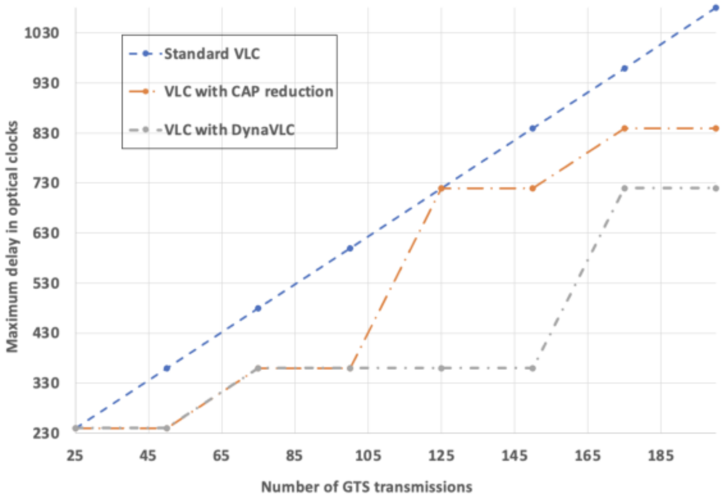


Figure 5 Impact of DynaVLC on the overall delay of the network - with the increment of MO as the number of GTS transmissions increase more superframes are added into the multi-superframe duration to accommodate the GTSs.

In the second part of our numerical analysis, we study the throughput of the network, comparing the static settings against the DynaVLC. Under static CAP reduction, we switch it "ON" at the beginning of the network, hence it has enough amount of GTS to accommodate the traffic. Yer, as the number of GTS increases, the non-allocated slots will have to wait for an entire CAP period to get served in the subsequent superframe. This results in a decrease in the network throughput, but still, it is higher than the standard VLC by 20–30 %.

In the case of DynaVLC, we initially have the CAP reduction setting “ON” to support the network demand, hence, it provides an identical throughput as the example with CAP reduction. However, as the number of GTS increases, the value of MO is incremented resulting in the addition of more superframes into the multisuperframe. Around 125 GTS requirement with the addition of more superframes into the MD, we witness an increase of throughput and it slowly reduces with the increase of the GTS slots. The throughput will eventually converge when the values of BO and MO become equal and all the GTS slots are occupied.

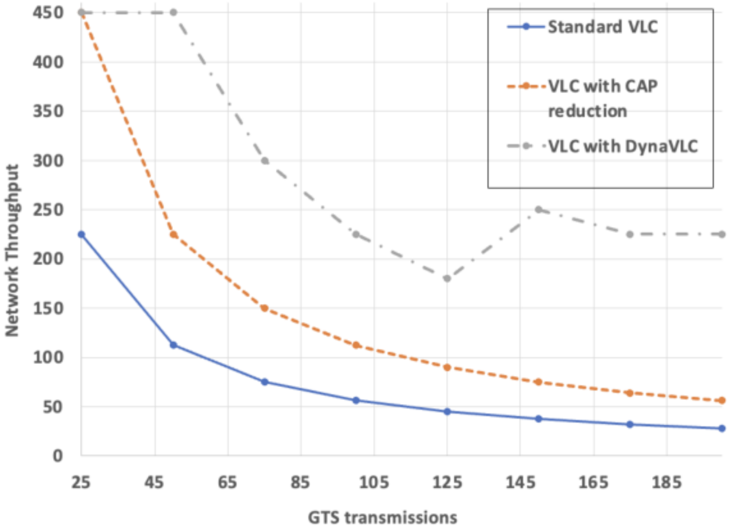


Figure 6 Impact of DynaVLC on the overall throughput of the network - with the increment of MO as the number of GTS transmissions increase more superframes are added into the multi-superframe duration to accommodate the GTSs.

7 Conclusion

In current VLC network deployments QoS defining MAC parameters such as MO, SO, BI are statically defined. This is an impediment to constantly evolving networks with varying workload conditions. To address the compromises of these static networks, in this research work, we propose a dynamic tuning mechanism called DynaVLC that can adjust the value of MO and CAP reduction to increase the resources available based on the changes in network demand. With DynaVLC, we were able to witness a decrease of 15-45% in delay when compared to the network in static settings, as well as an improvement of 20-30% in terms of the overall throughput. As a future work, we intend to create an open-source implementation of the IEEE 802.15.7 protocol adaptations here introduced with further enhancements towards the existing VLC architecture.

References

1 Mohammad Furqan Ali, Dushantha Nalin K Jayakody, and Yonghui Li. Recent trends in underwater visible light communication (UVLC) systems. *IEEE Access*, 10:22169–22225, 2022.

2 Lucas Almonacid, Pablo Palacios Játiva, Cesar A Azurdia-Meza, Diego Dujovne, Ismael Soto, Ali Dehghan Firoozabadi, and Miguel Gutierrez Gaitan. On the path loss performance of underwater visible light communication schemes evaluated in several water environments. In *2023 South American Conference On Visible Light Communications (SACVLC)*, pages 12–16. IEEE, 2023.

3 Monica Bhutani, Brejesh Lall, and Monika Agrawal. An efficient and adaptive superframe structure for IEEE 802.15.7-based real-time sensor networks. Research Square (Preprint), 2023.

4 Monica Bhutani, Brejesh Lall, and Monika Agrawal. A novel energy-efficient adaptive superframe structure for OWC-based real-time bio-sensor networks. Research Square (Preprint), 2023.

5 Wanshi Chen, Xingqin Lin, Juho Lee, Antti Toskala, Shu Sun, Carla Fabiana Chiasserini, and Lingjia Liu. 5G-advanced toward 6G: Past, present, and future. *IEEE Journal on Selected Areas in Communications*, 41(6):1592–1619, 2023.

6 Yuanming Ding, Yang Liu, and Jianxin Feng. Multi-priority MAC protocol for terahertz wireless local area network. In *2022 34th Chinese Control and Decision Conference (CCDC)*, pages 3427–3432. IEEE, 2022.

7 Prashant Dwivedy, Vipul Dixit, and Atul Kumar. A survey on visible light communication for 6G: Architecture, application and challenges. In *2023 International Conference on Computer, Electronics & Electrical Engineering & their Applications (IC2E3)*, pages 1–6. IEEE, 2023.

8 Sangrez Khan, A Naseem Alvi, M Awais Javed, and Safdar H Bouk. An enhanced superframe structure of IEEE 802.15. 4 standard for adaptive data requirement. *Computer Communications*, 169:59–70, 2021.

9 Harrison Kurunathan, R Indhumathi, Miguel Gutiérrez Gaitán, Carla Taramasco, and Eduardo Tovar. VLC-enabled monitoring in a healthcare setting: Overview and challenges. In *2023 South American Conference On Visible Light Communications (SACVLC)*, pages 135–140. IEEE, 2023.

10 Harrison Kurunathan, Ricardo Severino, Anis Koubaa, and Eduardo Tovar. IEEE 802.15. 4e in a nutshell: Survey and performance evaluation. *IEEE Communications Surveys & Tutorials*, 20(3):1989–2010, 2018.

11 Harrison Kurunathan, Ricardo Severino, Anis Koubaa, and Eduardo Tovar. DynaMO – Dynamic multisuperframe tuning for adaptive IEEE 802.15. 4e DSME Networks. *IEEE Access*, 7:122522–122535, 2019.

12 Harrison Kurunathan, Ricardo Severino, Anis Koubâa, and Eduardo Tovar. Symphony: routing aware scheduling for DSME networks. *ACM Sigbed Review*, 16(4):26–31, 2020.

13 Harrison Kurunathan, Ricardo Severino, and Eduardo Tovar. A comprehensive worst case bounds analysis of IEEE 802.15. 7. *Journal of Sensor and Actuator Networks*, 10(2):23, 2021.

14 Harrison Kurunathan, Ramiro Sámano-Robles, Miguel Gutiérrez Gaitán, R. Indhumathi, and Eduardo Tovar. Towards multi-channel GTS allocation in visible light communication. In *2023 South American Conference On Visible Light Communications (SACVLC)*, pages 130–134, 2023. `doi:10.1109/SACVLC59022.2023.10347865`.

15 Bih-Hwang Lee, Huai-Kuei Wu, and Neng-Chun Yu. A priority based algorithm for adaptive superframe adjustment and GTS allocation (PASAGA) in IEEE 802.15. 4 LR-WAN. In *2018 IEEE International Conference on Applied System Invention (ICASI)*, pages 318–320. IEEE, 2018.

16 Uma Shankar Pandey, Gulshan Soni, and Saroj Kumar Chandra. The impact of alteration of superframe duration on the consumption of energy in the IEEE 802.15. 4 MAC. In *2023 5th International Conference on Smart Systems and Inventive Technology (ICSSIT)*, pages 254–260. IEEE, 2023.

17 Vu Van Huynh, Yeong Min Jang, et al. Priority MAC based on multi-parameter for IEEE 802.15. 7 VLC. In *ICTC 2011*, pages 257–260. IEEE, 2011.