Fuzzy Logic-Based Access Point Selection in Multi-Technology RF-LiFi Networks with NOMA

Aryanaz Attarpour*, Dorsa Moadeli*, Francesco Musumeci, and Massimo Tornatore
Department of Electronics, Information and Bioengineering, Politecnico di Milano, Milan, Italy
*Corresponding authors: aryanaz.attarpour@polimi.it, dorsa.moadeli@mail.polimi.it

***Abstract*—As wireless applications grow, Radio Frequency (RF) bands are increasingly congested, and the spectrum is struggling to keep pace with increasing demands. The introduction of new services further boosts pressure on the limited RF resources. In recent years, Light Fidelity (LiFi) has attracted significant attention as a timely technology for 5G-and-beyond networks due to its ability to address the limitations of the RF spectrum, its cost-effectiveness, and low power consumption. However, a stand-alone LiFi network has some drawbacks, such as poor Non-Line-of-Sight (NLoS) transmission performance due to the inherent properties of Visible Light (VL), interference from sunlight in outdoor environments, and short-range coverage due to high attenuation in the VL band. Therefore, a hybrid RF-LiFi network is required to ensure reliability while offloading the RF spectrum as much as possible. In this paper, we propose a new fuzzy-logic-based algorithm for Access Point (AP) selection in hybrid multi-technology RF (including WiFi, 4G, and 5G) and LiFi access network. Fuzzy logic is a decision making mechanism that is able to jointly account multiple input factors (such as current load, QoS requirements, available capacity) in the access selection problem without relying on hard thresholds. Furthermore, we consider two multi-access scenarios: for RF, Orthogonal Multi-access (OMA), and for LiFi, Non-orthogonal Multi-access (NOMA). Illustrative numerical results based on realistic indoor settings show that, compared to a set of baseline approaches, our proposed fuzzy logic solution can achieve up to 22% more throughput, by selecting a more balanced and effective users' distribution across RF to LiFi APs.**

***Index Terms*—Hybrid RF-LiFi, Access Point Selection, Multi-technology RF, NOMA**

I. Introduction

The new services enabled by 5G-and-beyond networks, such as Artificial Intelligence (AI) applications and the Internet of Things (IoT), require high-bandwidth, fast, and reliable communications. Radio Frequency (RF) technologies, including WiFi, 4G, and 5G networks, have an important role in supporting these new services, but are increasingly facing congestion, and spectrum allocation and utilization are become critical challenges in the design and deployment of advanced multi-technology RF communication systems. To overcome the exhaustion of spectrum in RF technologies, a prominent solution is using Light-Fidelity (LiFi). LiFi systems, as part of Visible Light Communications (VLCs), is introduced as a complementary technology for communications, due to their ability to address RF spectrum limitations by using light as a communication medium and providing high bandwidth [1]. LiFi systems are cost-effective and feature low power consumption, since they use an LED and a photodetector as transmitter and receiver, respectively [2]. However, a stand-alone LiFi network has some drawbacks, such as a poor Non-Line-of-Sight (NLoS) transmission performance due to the inherent behavior of Visible Light (VL), interference with sunlight in outdoor environment, and short-range coverage due to the high attenuation in the VL band. These challenges make LiFi a suitable technology to complement RF systems rather than a stand-alone technology. While a hybrid RF-LiFi network can meet the physical requirements for high data rates and capacity demands through multiple-technology AP support, in practical scenarios, multiple users might attempt to simultaneously transmit data to the AP with the best signal. However, selecting APs based solely on signal strength is not effective, as the AP with the strongest signal will become congested, and users should be assigned among the APs appropriately considering multiple factors, such as signal strength, Quality-of-Service (QoS), and AP load. Thus, the AP selection is a critical resource allocation problem aimed at selecting the best AP for the users. As a solving method for this problem, we consider *fuzzy logic*, which is a decision making mechanism that is able to jointly account multiple input factors (such as current load, QoS requirements, available capacity) in the access selection problem without relying on hard thresholds.

Moreover, different multi-access scenarios can be employed to allow multiple users to access the same communication medium. Among them, in this study we consider two multi-access schemes: Orthogonal Multiple-Access (OMA) and Non-Orthogonal Multiple-Access (NOMA). More precisely, the OMA, in which users are separated via orthogonal resource allocation, is preferred for RF systems since OMA can effectively avoid multi-user interference while maintaining low receiver complexity [3]. Conversely, NOMA, in which users share the same resources by exploiting power-domain multiplexing and Successive Interference Cancellation (SIC), is a well-suited solution for LiFi systems, where the optical wireless channel is mainly LoS, and shows significant channel-gain differences among users due to spatial positioning [4]–[6]. In this study, we propose a novel fuzzy-logic-based solution for Access Point (AP) selection in hybrid multi-technology RF and LiFi networks. The basic fuzzy-based model used in this study is derived from Ref. [7], which considers only WiFi and LiFi APs. More precisely, with respect to [7], we extend the model by incorporating the joint deployment of 4G, 5G, and WiFi APs in the RF band in addition to the LiFi APs, and we employ fuzzy logic across all technologies. We also added QoS as a new input to the fuzzy logic model, which categorizes users based on their traffic type, i.e., video, voice, gaming, download, IoT, etc., to account for their latency and priority. Moreover, we incorporate two multiple-access schemes, *i)* OMA for RF users, and *ii)* NOMA for LiFi users. Finally, to evaluate the performance of our fuzzy logic model, we proposed a load-aware heuristic baseline and a theoretical LP upper bound.

II. Related works

Some early studies have already modeled hybrid WiFi-LiFi networks in which both LiFi and WiFi APs coexist to accommodate users. In [7], the authors proposed a fuzzy logic algorithm for determining and assigning users to WiFi APs, and the remaining users are assigned to the LiFi APs. Recently, some works have investigated the implementation of 5G-LiFi [8] and a general RF-LiFi architecture using NOMA [9]. In addition, some studies consider the impact of various multi-access schemes, such as OMA, NOMA, and coexistence of them to minimize user intervention in LiFi APs [5]. The aforementioned studies typically consider networks as stand-alone LiFi, hybrid WiFi-LiFi, 5G-LiFi, or hybrid RF-LiFi without explicitly specifying the different RF technologies and access points. In contrast, we consider a hybrid RF-LiFi network that accounts for multiple RF access points, i.e., WiFi, 4G, and 5G, along with their corresponding accurate channel models. Furthermore, we consider the multi-access scheme for RF with OMA and for LiFi with NOMA.

III. Problem statement and system model

*1) **Problem Statement**:* The problem of AP selection in hybrid RF-LiFi networks, as a decision-making problem, can be stated as follows: **Given** a hybrid indoor network in a defined room size, locations of WiFi, 4G, 5G, ceiling-mounted LiFi APs, and N static users in random positions with defined height, **decide** the allocation of users to different APs, using NOMA for LiFi and OMA for RF with **objective** of maximizing total system throughput. The problem is **constrained by** RF channel models (path loss and fading), LiFi channel model (LoS/NLoS and interference), capacity limits of each AP, and individual user QoS requirements.

*2) **LiFi Channel Model with NOMA**:* The LiFi channel model is based on the optical channel gain (H) between an LED AP and the photodetector at the user-receiver, which has LoS and NLoS components [7]. We assume the LoS component follows the Lambertian radiation pattern, and the NLoS component is approximated as in Eq. 1:

$$H_{\text{NLOS}} = \frac{\rho A_{pd}}{4\pi d^2} \tag{1}$$

where ρ is the wall reflectivity (set to 0.3 for painted walls), and A_{pd} is the photodetector area [7].

To deploy NOMA with LiFi, we consider that multiple users share a LiFi AP with power-domain multiplexing [6]. Thus, users with weaker channels receive more power, and power allocation coefficients follow the Fractional Transmit Power Allocation (FTPA) method [4]. In our implementation, we also model imperfect SIC so that stronger users can decode and remove weaker users' signals before decoding their own [6]. Specifically, we consider efficiency parameter $\eta = 0.95$, where residual interference from incompletely canceled signals is calculated as $(1-\eta)$ times the original signal power [6]. Additionally, we account for Inter-Cell Interference (ICI) from neighboring LiFi APs [7]. The ICI power is computed as in Eq. 2 while calculating SINR for a user served by APi:

$$I_{\text{ICI}} = \sum_{j\neq i, j\in\mathcal{L}_{\text{room}}} \alpha_j (R_{pd} P_{opt} H_j)^2 \tag{2}$$

In Eq. 2, $\mathcal{L}_{\text{room}}$ is the set of LiFi APs in a room, α_j is the power allocation coefficient of interfering APj, and H_j is the channel gain from AP j to the user.

*3) **RF Technology-Specific Channel Model with OMA**:* We implement technology-specific channel models for WiFi (2.4 GHz), 4G LTE (2.6 GHz), and 5G NR (3.5 GHz). Each technology is characterized by distinct propagation characteristics, bandwidth availability, and capacity constraints, enabling our fuzzy logic algorithm to make technology-aware access point selection decisions based on channel quality, user demand, and network load. For all RF technologies, as shown in Eq. 3, we employ a dual-slope path loss model following 3GPP guidelines [3]:

$$\text{PL}(d) = \begin{cases} \text{PL}(d_0) + 10n_1\log_{10}(d/d_0) + X_\sigma, & d \leq d_{BP} \\ \text{PL}(d_{BP}) + 10n_2\log_{10}(d/d_{BP}) + X_\sigma, & d > d_{BP} \end{cases} \tag{3}$$

where d_0 is the reference distance for indoor scenarios, n_1, n_2 are path loss exponents for LoS/NLoS regions, d_{BP} is the breakpoint distance, and $X_\sigma \sim \mathcal{N}(0,\sigma^2)$ represents log-normal shadow fading with standard deviation σ specified in Table I. To consider RF with OMA, each user is assigned orthogonal resources, and users experience ICI from neighboring APs of the same technology operating in the same frequency band [3]. The achievable rate is computed using Shannon capacity [3], as in Eq. 4, where B is bandwidth from Table I.:

$$R = B\log_2(1+\text{SINR}) \tag{4}$$

TABLE I: Technology-Specific RF Parameters

Parameter	WiFi	4G LTE	5G NR
Carrier Frequency	2.4 GHz	2.6 GHz	3.5 GHz
Transmit Power	20 dBm	20 dBm	27 dBm
Bandwidth	20 MHz	10 MHz	100 MHz
Breakpoint Distance d_{BP}	15 m	20 m	20 m
Path Loss Exp. n_1 (LOS)	1.8	2.2	2.4
Path Loss Exp. n_2 (NLOS)	3.0	4.2	4.5
Shadow Fading σ (LOS)	4 dB	4 dB	4 dB
Shadow Fading σ (NLOS)	6 dB	6 dB	7 dB
Noise Figure	7 dB	7 dB	7 dB

IV. Proposed Approach for Access Point Selection

*1) **Fuzzy Logic AP selection Algorithm**:* Fuzzy logic, first introduced in [10], is a method of making decisions based on degrees of truth as opposed to binary Boolean logic. It maps continuous input variables to linguistic terms through membership functions, allowing partial membership across multiple categories. The first step in fuzzy inference is fuzzification, which converts numerical inputs into degrees of membership. A series of *IF-THEN* rules that encode the system's inference logic are then used to process these memberships. Finally, defuzzification is used to convert the fuzzy output into a single representative value. Our proposed fuzzy logic solution extends the work in [7], which applied fuzzy logic to WiFi-LiFi selection, to support multi-technology RF-LiFi networks. The algorithm takes five inputs as follows: *1) User Demand (D):* shows quantitative required rate. *2) QoS Type (Q):* traffic class category (video, voice, gaming, download, IoT), which establishes throughput priority and latency for technology selection. *3) SNR:* signal quality for each technology (SNR_{LiFi}, SNR_{WiFi}, SNR_{4G}, SNR_{5G}). *4) LiFi Load (L):* AP congestion metric computed as the SNR-weighted sum of users within the coverage of each LiFi AP, normalized across all APs. *5) LiFi Variance (V):* Channel stability metric computed as the variance of the top-4 LiFi SNR values for each user. The algorithm uses over 40 technology-specific rules evaluated using Mamdani max-min composition [7]. The centroid method is used to defuzzify the aggregated output and obtain suitability scores $S_t \in [0, 1]$ for technology $t \in \{\text{LiFi, WiFi, 4G, 5G}\}$. Then, for technology assignment, each user selects a technology with the highest suitability score. To prevent ping-pong effects, hysteresis is applied: a user switches from current technology t_c to new technology t_n only if $S_{t_n} > S_{t_c} + \Delta_h$ where $\Delta_h = 0.05$. After assignment, capacity limits apply when demand exceeds AP capacity.

*2) **Baseline**:* We compare our proposed fuzzy logic approach against a load-aware heuristic baseline and a theoretical upper bound. Although it lacks QoS awareness, the *Load-Aware heuristic* improves load balancing by penalizing congested technologies and APs using load factors. In addition, we consider a theoretical *LP Upper Bound* on system performance that allows fractional assignments and maximizes total throughput under capacity and user assignment constraints.

V. Illustrative numerical Results

We consider a room with the size of 50×50 m^2, equipped with four WiFi APs mounted at wall corners, one 4G base station in the center, two 5G base stations, and 300 LiFi APs uniformly distributed on the ceiling. We evaluate the system with 500 randomly positioned static users, and each user has height $h_u = 0.85$ m. We evaluate the performance of the proposed fuzzy logic algorithm in terms of system throughput, user distribution, and per-technology throughput contribution, and compare it with Load-aware baseline. Figure 1 shows system throughput comparison, demonstrating that our proposed fuzzy achieves 21.3 Gbps, outperforming the load-aware heuristic baseline by 22%. Compared to the fuzzy RF-only scenario (which uses the same fuzzy logic but disables LiFi infrastructure), our proposed fuzzy framework achieves 63% higher throughput, highlighting the significant contribution of LiFi integration. Moreover, Fig. 1 indicates throughput contribution by technology and show that LiFi-NOMA contributes 38% of total throughput, demonstrating effective spectrum utilization. Figure 2 illustrates user distribution across technologies, showing that fuzzy successfully offloads 95 users

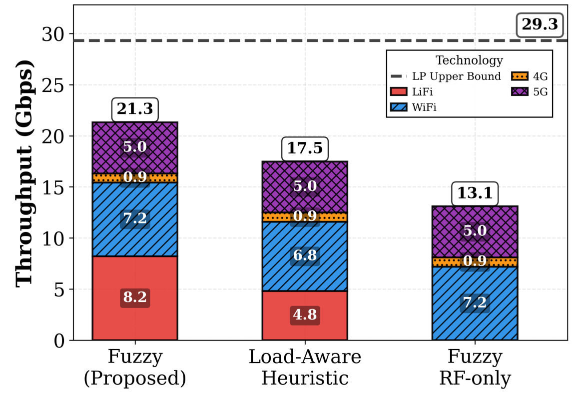

Fig. 1: System throughput by technology

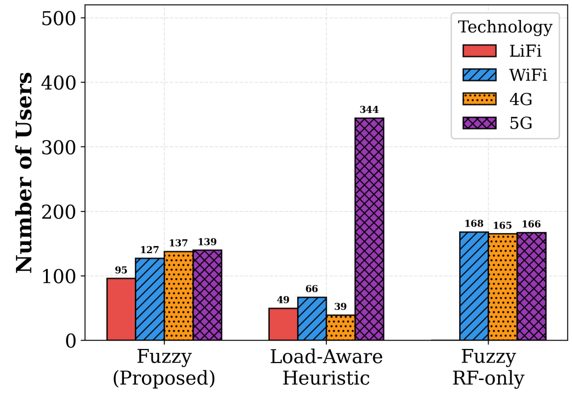

Fig. 2: User distribution

(19%) to LiFi while maintaining balanced load across RF technologies. In conclusion, our numerical results show that in a hybrid RF-LiFi network, our proposed fuzzy algorithm can achieve up to 22% and 63% throughput increase compared to baseline and only RF fuzzy, respectively. We plan to extend this work so that the solution can be applicable to dynamic users and consider the handover procedures.

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