Towards Trusted and Accountable Win-Win SDWN Platform for Trading Wi-Fi Network Access

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***Abstract*— Wi-Fi is still by far the most common and cheapest wireless technology to deliver Internet services to users and digital devices, which are dramatically increasing in terms of quantity and the quality of services they require. As a result, Wi-Fi networks are the most congested wireless technology. This issue incentivised many researchers to propose radio resource management solutions in unlicensed frequency bands to alleviate that problem. Nonetheless, these solutions lack coordination among the network operators who utilise wireless spectrum and hence, they do not efficiently solve the problem. In this work we propose a 'win-win' platform based on Software Defined Wireless Networking (SDWN) that facilitates a trusted and accountable Wi-Fi network access trading among networks operators, to solve the congestion problem in a collaborative manner that is beneficial for everyone. The platform enables Wi-Fi networks operators to both improve their users' satisfaction and earn incentives hence, achieving the 'win-win' equilibrium. Evaluation results in a dense Wi-Fi network environment show how the 'win-win' platform significantly improves satisfaction and achieved data rates for the cooperating networks operators' users in comparison to the standard approach.**

Keywords—Blockchain, Radio Access Network (RAN), Software Defined Network (SDN), Spectrum Sharing, Wi-Fi

I. INTRODUCTION

Wireless communications are witnessing a massive increase of devices connecting to the Internet that requires us to reshape the way services are provided to users. The proliferation of portable computing devices such as laptops, smartphones, tablets, and Internet of Things (IoT) is dramatically increasing. In addition, the emergence of novel mobile applications and online services is driving the demand for more efficient wireless Anything, Anyone, Anytime, Anyplace (4A) communication connectivity [1]. Therefore, wireless networks operators are challenged to define new solutions to optimise management of the radio resources and available spectrum while satisfying their users. For simplicity, in this paper, we will consider only the term Wi-Fi Networks Operators (NOs) to refer to any entity that manages a Wi-Fi network and its resources (e.g., Wi-Fi Access Points (APs) and radio resources). This includes operators of Wi-Fi networks deployed in apartments blocks, and public spaces such as airports and trains station.

Effective radio management solutions must be developed taking into consideration that Wi-Fi still represents the most convenient and used wireless network and, therefore, a highly congested wireless technology [2]. In this context, several radio resource management solutions have been developed to address the problem of wireless network congestion. However, although they each showed promising performance results, they lack coordination among wireless spectrum users and do not provide NOs with a simple, transparent, and fair mechanism to encourage their cooperation. Hence, they cannot efficiently solve the congestion problem.

The aim of this paper is to design a platform that addresses the problem of optimising Radio Access Network (RAN) resources, focusing on dense Wi-Fi networks, and advocating a transparent and 'win-win' cooperation that is managed collectively by different NOs. In principle, the platform will allow users to connect to any Wi-Fi network in range, which might belong to any NO that is involved in the cooperation platform, based on their needs. The term 'win-win' is used to emphasise, as will be explained throughout the paper, that the proposed approach would provide performance enhancements for all users and benefit the cooperating NOs in terms of users' satisfaction and further gains/incentives through cooperation.

To develop the desired platform, we exploit the centralised management nature and programmability that Software Defined Wireless Networking (SDWN) offers. These characteristics make SDWN a suitable technology to implement cooperative resource management policies that could operate from a central control and act in real-time via a smart controller, which has a global view of users' devices and profiles, APs, and ongoing applications. Moreover, it does not require the deployment of a specific vendor's APs. The main challenge, however, is that the deployment of the SDWN controller may fail due to the lack of trust, transparency, and accountability among Wi-Fi NOs and the SDWN controller. These operators do not necessarily trust each other and would not yet trust the unknown SDWN controller that would handle the operations of the proposed platform. To alleviate this issue, Blockchain technologies [3] are utilised to establish that trust and facilitate a transparent, accountable, and trusted way for NOs to cooperate without giving up control to any other entity.

In this paper, the proposed platform is a step towards enabling NOs to cooperate with the aim of providing high quality services to their subscribed users (i.e., customers) and achieving high satisfaction rates. Specifically, the customers 'win' is the high performance, connectivity, and availability of their subscribed Wi-Fi network service while the NOs 'win' is their customers' satisfaction with the level of services they provide. In the current deeply competitive market, high customers' satisfaction rates would undoubtedly help NOs safeguard their profits (e.g., improving their churn rate, which is the rate of customers leaving their NOs due to poor service [4]). In addition, the 'win-win' concept extends the cooperation among NOs to create a free market for sharing and trading Wi-Fi network access. NOs, through serving other NOs' customers with their available Wi-Fi network access, will gain incentives that can be used later to serve their own customers through other NOs. These incentives, which will be referred to as tokens hereafter, can also be sold and/or exchanged depending on different agreements among NOs. Hence, the token as a principle is just a placeholder for any exchange agreed up on by the cooperating NOs.

The main contributions in this work are as follows:

- A novel Blockchain-based 'win-win' platform is developed utilising an SDWN controller to facilitate a trusted, and accountable collaboration among NOs. Accountability and trust here mean that all actions by all parties who join the 'win-win' platform should be approved collectively and evidenced at any time. Note that the SDWN controller is only entrusted to execute the cooperation agreement among NOs in terms of managing connections to APs. Hence, all its actions can be scrutinised by the participating NOs since no single entity in this platform is fully trusted.
- A new algorithm is proposed in the SDWN controller allowing efficient AP allocation to the users' wireless devices served by the cooperating NOs. Thus, it is optimising the performance for users and, at the same time, allowing NOs to provide a better service alleviating the congestion problem in dense Wi-Fi environments through cooperation.

The rest of the paper is structured as follows. In Section II, related works in the literature are discussed. Section III explains the proposed platform architecture. Section IV presents the simulation setup, and performance results. Finally, the paper's conclusions and future works are presented in Section V.

II. Literature Review

Several papers in the literature have proposed strategies to allow coordination among wireless users through cooperation in unlicensed bands. Ali *et al.* [5] discussed the potential of Unlicensed Long-Term Evolution (LTE-U) and Wi-Fi cooperating in heterogeneous networks as key technologies for future beyond 5th Generation (5G) systems. Moreover, they proposed a Mesh Adaptive Direct Search (MADS)-based resource allocation approach for LTE-U and Wi-Fi to maximise the throughput. However, this solution still needs further optimisation for utilising spectrums efficiently.

Bouhafs *et al*. [2] proposed and evaluated a radio spectrum programming architecture based on SDWN that provides new possibilities for managing radio resources in unlicensed frequency bands focusing on cooperation among APs in Wi-Fi networks. In [6], Coronado *et al.* presented *5G-EmPOWER*, a novel, programmable, and open-source platform for heterogeneous 5G RANs, guaranteeing simultaneous control of Wi-Fi and cellular networks through SDN technology. Furthermore, they assessed the effectiveness of the platform through different reference use cases including active network slicing, mobility management, and load-balancing. While the results were promising, more work is still needed to introduce and enforce Service Level Agreement (SLA) policies such as admission control.

Candal-Ventureira *et al.* [7] introduced and evaluated two solutions for wireless network operators to dynamically divide the radio resources of a shared channel between Wi-Fi and cellular technologies to enhance spectrum efficiency without requiring modifications to current commercial off-the-shelf (COTS) end devices. Their approach avoids competition between technologies sharing the medium by allocating alternate time slots. However, it is not clear how wireless network operators are going to cooperate to achieve the goal of these solutions considering the lack of trust and competitiveness between them. Raschellà *et al*. [4] proposed a framework that addresses the radio access congestion problem in unlicensed bands, which simultaneously benefits the satisfaction of both Wi-Fi and 5G users through cooperation managed by centralised controllers. Moreover, their work demonstrated the benefits of the solution through the simulation of a smart Radio Access Technology (RAT) selection algorithm in a realistic scenario.

It is worth noting that the main challenges and issues with the works mentioned above are: 1) the assumption that the RAN infrastructure works under a single administrative control; and 2) the lack of a realistic strategy to guarantee trust, incentives, transparency, and accountability among the actors. To address these issues, Qin *et al.* [8] proposed a novel architecture including a slicing orchestrator, which coordinates multiple network and service providers to define a slicing allocation by negotiations in a heterogeneous RAN. The slicing orchestrator plays the role of a third-party entity helping service providers maximise their utility and network providers minimise their costs through an auction mechanism, which guarantees convergence to optimal social welfare in finite time. However, it does not guarantee a system with full transparency and trust, in fact, the optimal social welfare can be reached only if all the service providers and network providers give in time their bids needed by the orchestrator.

Ling *et al*. analysed the Hash Access protocol characteristics and performance in Blockchain RAN (B-RAN) [9]. They developed an analytical model, based on game theory, to evaluate the performance of B-RAN that uses a hash access protocol in terms of transmission success probability, access delay, and network throughput. However, their work was just an analytical model with no actual implementation. Zheng *et al*. [10] proposed a Multiple-Operators Spectrum Sharing (MOSS) platform based on the permissioned Blockchain platform Ethereum to implement spectrum trading among multiple operators (multi-OPs). They designed a smart contract to ensure that multi-OPs truthfully share the spectrum otherwise, they will be punished. Sharing spectrum is done via a spectrum auction between seller OPs and buyer OPs according to free-trading market rules. However, the cooperation benefits in terms of solving spectrum or network congestion are not evaluated. Moreover, there is no incentive mechanism for OPs to collaborate, which makes it difficult to realise such cooperation in real-world scenarios.

In comparison to the related works discussed above, the main differences proposed in this work are related to transparency, accountability, trust and the 'win-win' approach. Firstly, all the cooperation transactions (i.e., the execution of the cooperation agreement) are transparent and can be referred to for any dispute. This goes beyond secure record keeping which does not address all the trust issues among NOs. Transparency and trust require traceability of all operations' records satisfying the following two conditions: 1) they have been created if and only if consensus is reached according to the cooperation agreement terms and conditions; and 2) after being written, they have never been altered afterwards (i.e., the records are immutable). Secondly, the 'win-win' approach in this work aims to address the network congestion problem to improve the QoS for users thus, providing benefits for the cooperating NOs mainly in terms of users' satisfaction.

III. THE WIN-WIN PLATFORM ARCHITECTURE

A. *Platform Architecture*

The proposed architecture consists of the elements showed in Fig. 1 where, for illustration purposes, it shows five APs belonging to five different NOs who agreed to cooperate, and users' wireless stations (STAs) representing wireless devices in a specific area. The platform leverages the advantages offered by SDWN technology. In fact, the Wi-Fi SDWN Controller (WSC) has an overarching view and control over the five APs, and it can obtain a global view of the network through monitoring and measurements to support all the implemented applications.

The SDWN controller developed for the EU H2020 *What to do With the Wi-Fi Wild West* (Wi-5) project that addresses spectrum congestion in Wi-Fi networks is the basis for this platform architecture [2]. This controller guarantees the input needed for the developed algorithm presented in Section III-B, for efficient AP allocation to STAs based on the gathered information. Specifically, the controller gathers the Received Signal Strength Indicator (RSSI), available bandwidth, and bit rate requirements experienced for each STA connected to the controlled APs through the Southbound Application Programming Interface (API). After that, it executes Algorithm 1, which is explained below, thus contributing to the element of optimising available network access in the 'win-win' concept. Note that the SDWN controller can be managed by a 3rd party that is trusted and agreed upon by the NOs as they have the ultimate control in this architecture. The controller does not keep records nor controls anything without NOs agreement.

A permissioned Blockchain network is considered to develop the 'win-win' platform as it gives NOs control over who can join the network, manage the communication channels, setup relevant security and privacy policies, and establish a bare minimum of trust among each other. Each NO_i that is cooperating has a peer P_i in the Blockchain network to execute the Smart Contract (SC) functions. Here, the SC represents the implementation of the cooperation agreement among NOs, for instance, stating that STAs belonging to the cooperating NOs can connect to any AP that belongs to one of the cooperating NOs. Each connection will have a record including duration, served data rate, and cost, so NOs can transact these costs later. Cost here refers to the network access tokens that NOs exchange for each other's services as part of the 'win-win' concept. The implementation of this agreement is explained in the next section. All SCs are developed using Node.js in the Hyperledger Fabric (HLF) Blockchain network, which is an enterprise grade permissioned Blockchain platform [11].

A dedicated channel *WSC-Ch* is established that allows all peers on the Blockchain network to communicate and transact securely and privately. This way, the ledger records are kept private and only available for those who are admitted to *WSC-Ch*. Note that admitting a peer into the channel requires the endorsement of all peers (and their organisations) according to the channel administration policy in this architecture. This policy and its related security requirements are agreed during the system initialisation among NOs.

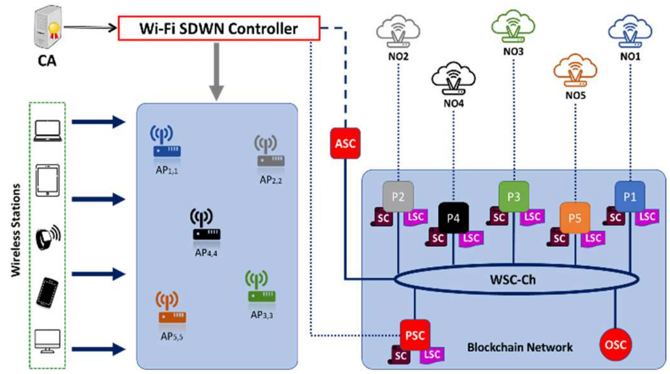

Fig. 1. The Win-Win Platform Architecture Model

A copy of the SDWN Controller Ledger (*LSC*) and the smart contract *SC* is provided for each peer P_i in the network. As the *SC* represents the implementation of the cooperation agreement, it must be approved by all peers before any transaction could take place. The ledger *LSC* holds the records of all connections between STAs and APs according to the cooperation agreement. The SDWN Controller Peer (*PSC*) is a peer on the network that is managed by the SDWN controller. It allows the controller to interact with the Blockchain network and keep a record of the ledger *LSC* and *SC*. The SDWN Controller Orderer (*OSC*) node also belongs to the controller and is managed by it. The orderer is a special node responsible for ordering transactions, creating a new block of ordered transactions, and distributing a newly created block to all peers on the *WSC-Ch* channel. Hence, it keeps the ledgers on all peers consistent.

The SDWN Controller Application (*ASC*) is used by the controller to interact with *SC* on the Blockchain network and its function is to update the ledger records. Note that only the controller is allowed to use *ASC* and invokes *SC* functions according to the system policy. This design keeps the responsibility of updating ledger records in the controller so NOs can only read these records. This is an essential element to facilitate trust and transparency in the 'win-win' platform. The Certificate Authority (CA) for the SDWN controller is responsible for managing the controller's public key certificate, and other security parameters such as hash algorithms that will be used in the platform.

B. *Access Point Connection Algorithm*

A *legal AP* is defined as an AP that belongs to a NO and provides services to an STA that is paying for these services (i.e., a subscriber). The algorithm implemented in the SDWN controller for an efficient AP allocation to STAs, is presented in Algorithm 1. This algorithm allows, for the first time to the best of the authors' knowledge, a trusted and transparent collaboration among NOs' APs relying on the 'win-win' platform in Fig.1 for sharing network access between STAs and APs regardless of their NO.

Algorithm 1. Access Point Connection

```
1:  if STA_i is not able to connect to its legal AP_j do
2:        Look for AP_{k, k≠i} with best RSSI
3:        all_good = 1;
4:        for each STA_x connected to AP_k do
5:              update R_{b,x} based on connection of STA_i
                 to AP_k for required R_{breq,i}
6:              if R_{breq,x} > updated R_{b,x} and x ≠ i do
7:                    all_good = 0;
8:              end if
9:        end for
10:       if all_good = 1 and R_{b,i} > 0 do
11:             connect STA_i to AP_k
12:       else do
13:       do not allow connection
14:       end if
15: else
16:     connect STA_i to AP_j
17: end if
```

Specifically, for each STA_i that tries to connect to its legal AP_j but is not able to because AP_j is either out of its coverage or congested, the algorithm first selects the best AP_k ($k \neq j$) for STA_i in terms of RSSI among the available APs (lines 1-2 of Algorithm 1). Note that the algorithm does not distinguish, now, between home users who are subscribed to their legal AP_j, greedy home users who are also subscribed to their legal AP_j, but wants to add more STAs than other users, and visitors who belong to other NOs but are utilising AP_j. This issue is identified as part of our future works since a balance between home users, greedy home users, and visitors should be established.

After that, for each STA_x that is already connected to AP_k, the algorithm computes the bit rate $R_{b,x}$ that each STA_x would obtain after a possible connection of STA_i, which is a visitor in AP_k, that requires a bit rate $R_{breq,i}$. If STA_i can achieve any bit rate from AP_k without downgrading $R_{b,x}$ for each STA_x to a bit rate lower than its requirement $R_{req,x}$, STA_i is allowed to connect to AP_k. Otherwise, its connection request is denied (lines 3-14 of Algorithm 1). The rationale behind this strategy is that it is more convenient trying to assign any available bit rate to STA_i rather than reject the connection to AP_k due to, for instance, congestion. However, this approach will be improved as part of our future work by including a threshold that would allow us to provide STA_i with a minimum acceptable bit rate in AP_k. The possibility of moving/transferring visitors' connections from AP_k to other APs, which could serve them, to give priority to home users at their legal AP is another direction for investigation.

Finally, note that this process is transparent to the STAs meaning that users will always believe they are connected to their legal AP. This aspect of the algorithm allows the extension of the potential coverage of the legal AP for its customers, making it more efficient for the corresponding NO.

C. Smart Contract Design & Functions

A simple "Connection" record is designed to store the necessary information about current connections between STAs and APs. In addition, this record reflects the outcome of Algorithm 1 when a connection is allocated to an AP or transferred from its legal AP to another AP. Table 1 explains the structure of a "Connection" record in the ledger.

Table 1. Connection Record Structure

Field	Type	Explanation
ID	String	Connection ID
ST_ID	String	User station ID $STA_{x,y}$ where x is the station ID and y is the legal AP ID
OAP_ID	String	Legal AP ID $AP_{x,y}$ where x is the AP ID and y is the NO ID which this AP belongs to
CAP_ID	String	Connected to AP ID $AP_{x,y}$ where x is the AP ID and y is the NO ID which this AP belongs to
ConnTime	Float	Connection time is seconds
ConsBand	Float	Consumed bandwidth (served data rate) in bps
UnitRate	Float	Charging rate (Mbps/¤) for connecting to another AP other than the legal AP.
ConnCost	Float	Connection cost, which will be zero if OAP_ID = CAP_ID

Note that every time a user connects to an AP whether it is their legal one or another AP, he/she must authenticate themselves to ensure they are allowed to connect to that AP (i.e., they are subscribed to a NO in the 'win-win' platform).

D. Application Design & Interaction with the Ledger

Interacting with the ledger *LSC* on the Blockchain network is done via the *ASC* application, which allows the SDWN controller to submit transactions to the network to be validated and committed. If the transaction is successful, a notification is sent back to the application. This process involves consensus whereby peers collaborate to ensure that every proposed transaction is acceptable and performed in an agreed and consistent order according to the 'win-win' cooperation agreement among NOs. To elaborate how the SDWN controller uses *ASC* to leverage the *SC* functions to effectively manage and keep records of all the connections in the network, Fig. 2 shows the core processes and inputs/outputs on the 'win-win' platform.

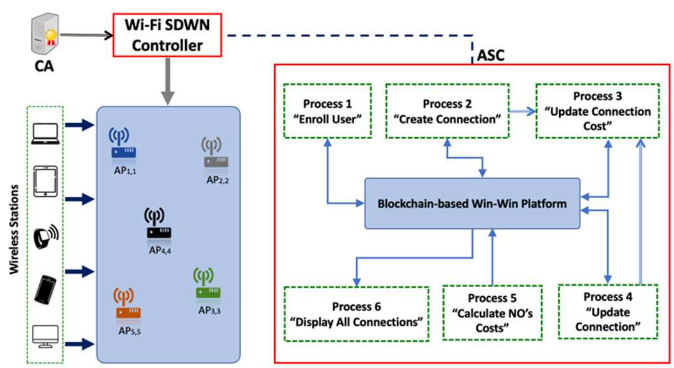

Fig. 2. The Core Processes of the Win-Win Platform

- **Process 1 – Enrol User**: before the SDWN controller can use the *ASC* application to interact with the *SC* functions on the platform, it needs to enrol an identity (i.e., *ASC* user) based on a certificate issued by the controller's CA for that identity.
- **Process 2 – Create Connection**: when a new STA wants to connect to an AP, the controller decides which AP the STA will connect to according to Algorithm 1. Once the connection is established, the controller invokes the *CreateConnection()* function to create a new record on the ledger LSC. In turn, *CreateConnection()* sends the information of the new connection to *Process 3* to update the cost if needed.

- **Process 3 – Update Connection Cost**: this process is either invoked by Process 2 – Create Connection or Process 4 –Update Connection. Either way, it checks whether the STA connects to its legal AP. If yes, the cost is zero. Otherwise, it calculates the cost, using *CostCalc()*, of this connection considering the connection time, served bandwidth, and unit rate of the other AP.
- **Process 4 – Update Connection**: the SDWN controller can move a connection from one AP to another depending on the conditions of the network. This happens when home users return to their legal AP and their requirements cannot be satisfied because the AP is congested with other connections. In this case, the controller invokes *UpdateConnection()* to reflect this change and updates the connection cost by invoking *Process 3* as explained above. This functionality is reserved to accommodate future works identified for Algorithm 1 above.
- **Process 5 – Calculate NO's Costs/Gains**: the SDWN controller can calculate the total cost/gain (i.e., number of tokens) for a particular NO for connections from its STAs (i.e., NO's customers) to other NOs' APs or vice versa. This is done via calling *CalcConnCost()* function.
- **Process 6 – Get All Connections**: by utilising either the *GetConnection()* or *GetAllConnections()* function, the controller can query the platform to get a specific or all connection records from the platform.

IV. Evaluation of the Win-Win Platform

A. Simulation Scenario & Performance Metrics

In this evaluation, the SDWN controller manages five APs that belong to different NOs as shown in Fig. 1, randomly distributed in an area of 100m^2 with a minimum distance of 7m between them, and 100 STAs distributed uniformly in the area. The APs are configured to work on the ISM 2.4 GHz radio band. Note that when the number of APs is more than 4 in this area, it represents the initial point of densification that becomes more significant when the number of STAs increases to 100 [12].

The evaluation of Algorithm 1 is done against the standard approach, which allows each STA_i to try connecting only to its legal AP_i even if there is another AP_j, which belongs to a different NO, available and could provide a better connection. The bit rate requirements of STAs have been randomly selected from a set varying between 64 kbps to 5 Mbps to consider the minimum bit rates needed for typical online applications such as Voice over IP (VoIP) and video streaming on YouTube or Netflix. Specifically, in the case of VoIP, we have considered 64 kbps and 128 kbps, which are the approximate bit rate requirements when the *G.726* and *G.722* codecs are used, respectively[1]. In the case of video streaming, the considered minimum bit rate requirement for watching videos on YouTube is 700 kbps with Standard Definition (SD) 360p, 1.1 Mbps in the case of SD 480p, and 5 Mbps for High Definition (HD) 1080p[2]. The considered minimum bit rate requirement for watching videos on Netflix is 1 Mbps and 5 Mbps for SD and HD, respectively[3]. Finally, 50 independent simulation runs were performed to obtain the results which have been analysed in the next subsections.

The assessment of the proposed 'win-win' platform focuses on the following performance parameters:

- **Satisfaction** – This is the average percentage of STAs that manage to connect to an AP getting at least their bit rate requirements.
- **Cost/Gain**: This is the cost/gain in tokens ¤ a particular NO might experience from participating in the 'win-win' platform. It represents the cost/gain of all connections made from this NO's users to other NOs' APs according to Algorithm 1 or vice versa. The connection cost/gain is calculated using the parameters *ConnTime*, *ConsBand*, and *UnitRate* in Table 1.

B. Performance Results

Fig. 3 shows the satisfaction rate obtained through the proposed 'win-win' platform by the STAs of each NO against the standard approach. The gains achieved in terms of satisfaction through the proposed 'win-win' platform in comparison to the standard approach are approximately 38%, 39%, 53%, 47% and 60% for NO1, NO2, NO3, NO4 and NO5, respectively.

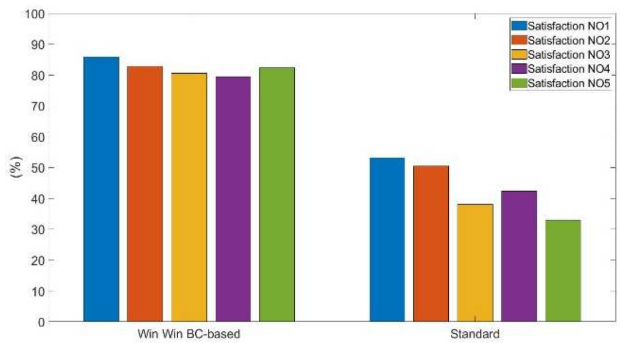

Fig. 3. Satisfaction Results

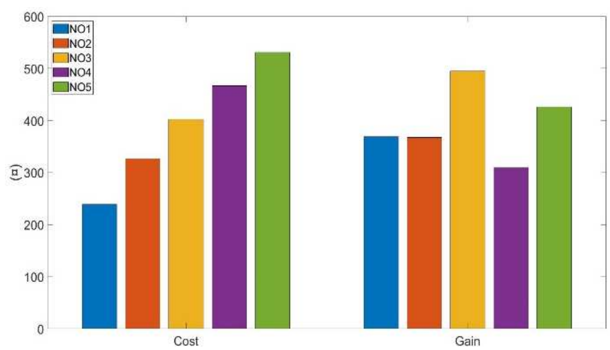

Fig. 4. Win-Win Results

To further elaborate the 'win-win' approach's benefits, Fig. 4 shows the average tokens cost and gain for each NO. It can be noted that NO1, NO2 and NO3 benefit from the proposed 'win-win' platform both ways (i.e., their users' satisfaction and net gains since their incurred costs are lower than their earned tokens). However, NO4 and NO5 incurred higher costs to service their users' connections than their gains from servicing

[1] https://www.cisco.com/c/en/us/support/docs/voice/voice-quality/7934-bwidth-consume.html (Accessed October 2022)

[2] https://support.google.com/youtube/answer/78358?hl=en-GB (Accessed October 2022)

[3] https://help.netflix.com/en/node/306 (Accessed October 2022)

other NOs users. However, their costs (i.e., paid tokens) are approximately 33% and 19%, respectively, more than their gains. These costs are a relatively low price to bear considering their gains in terms of users' satisfaction as shown in Fig. 3.

Furthermore, Fig. 5 and Fig. 6 expand on Fig 4 to show where the gains (i.e., tokens) are coming from and where the costs are going to for each NO, respectively. These details can be used to extract useful insights for NOs and their users. For instance, NO3 gained the most of its tokens from NO4's users connecting to NO3's AP as shown in Fig. 5. This is confirmed in Fig. 6 where the majority of NO4's cost came from servicing connections to NO3's AP.

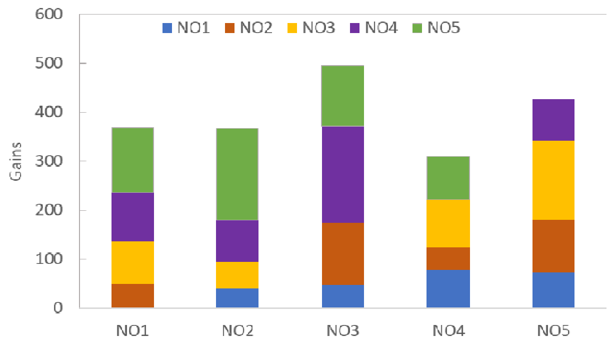

Fig. 5. Detailed Gains for each NO

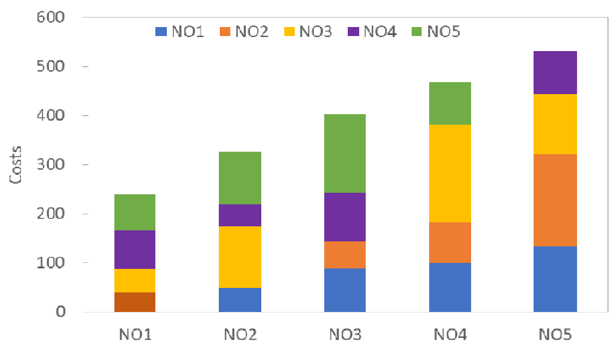

Fig. 6. Detailed Costs for each NO

These results would allow NO4 to consider options to improve its service regardless of the involvement of NO3 (i.e., NO4 is exchanging a high rate of tokens to other NOs to service its users). The improvements here can be related to APs' positioning, capacity, etc. as all APs are configured similarly.

In summary, based on our results reported in the figures above, all NOs and their users have gained considerably from the proposed 'win-win' cooperation platform. Moreover, some NOs have gained tokens for future exchange while others, based on their incurred costs, have gained insights to where service improvements are needed. In addition to the transparency of this cooperation, these results consolidate the benefits of the proposed 'win-win' approach in this paper. It also clarifies how this approach can facilitate and contributes to establishing a market of network access tokens where NOs can buy/sell these tokens to serve their users.

V. Conclusion & Future Work

In this work, we presented a SDWN-based 'win-win' platform that enables NOs to trade access in Wi-Fi networks using Blockchain. The platform is a step towards trusted, transparent, and accountable cooperation among NOs to alleviate the Wi-Fi congestion problem in dense areas. The platform utilised an SDWN controller that has an overview of users' requirements and APs' status to relay connections from STAs to suitable APs. The cooperation in the platform is governed by a smart contract that implements the cooperation agreement among NOs. In addition, every participating NO has full access to the cooperation records in the ledger, which are traceable and immutable. Evaluation results in a dense Wi-Fi network environment showed higher users' satisfaction in comparison to the standard approach. Additionally, all NOs transacted network access via the cooperation agreement where they gained tokens that can be used for future transactions.

For future works, in addition to the areas identified above, we will investigate introducing a threshold where an NO can be notified of specific improvements if it is incurring high costs in comparison to other NOs. Moreover, we will extend the platform to include mobile network access nodes.

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