Dynamic Access Point Association Using Software Defined Networking

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***Abstract*—Previous attempts in addressing Access Point (AP) association at overlapping zone of IEEE 802.11 networks have shown some issues. They work passively and estimate load from different network metrics such as frame delay, packet loss, number of users etc. that may not always true. Further the user behaviour is selfish i.e. illegitimate user consume high network resources. This adversely affect existing or new users which in turn motivates them to change locations. To alleviate these issues, we propose the use of a Software Defined Networking (SDN) enabled client side (wireless end user) solution. In this paper, we start by proposing a dynamic AP selection algorithm/framework in wireless user device. The device receive network resource related statistics from SDN Controller and guide the client device to associate itself with the best selected AP. We justify that the use of SDN discourage users to act selfishly. Further, a mathematical modelling of the proposed scheme is derived using Fuzzy membership function and the simulation is carried out. Results obtained from simulation necessitates to implement SDN enabled client side methods.**

Index Terms*— *Software Defined Wireless Networks (SDWN), Greedy algorithms, IEEE 802.11 Networks, SDN Use Case

I. Introduction

In Wireless Local Area Networks (WLAN) for example Wi-Fi hot spot areas including airports, hotels, coffee shops, retail locations etc. consists of multiple APs, the coverage area of adjacent APs may overlap. If a user is located in this overlapping area, a decision of selecting the best available AP which has the strongest signal strength and sufficient bandwidth, has to be made. This is very difficult because of the static algorithm in user device only considers Received Signal Strength Indicator (RSSI) parameter for AP association [1]. This approach has been widely adopted but has a critical disadvantage that it may cause imbalanced load among APs resulting in degrades to network performance, cause unfairness among the users and APs causing high collision rate [2]. For example, airport, where the number of users at different departure gates vary and depending on flight schedule. A situation arises where a high concentration of users may dramatically increases the load on AP thus reducing per share air bandwidth usage eventually resulting in end-to end delay. While APs in less crowded areas of other nearby departure gates on the same network may be (simultaneously) under-utilized or sitting ideal. Various other scenarios where the problem of AP association is still existing.

One possible solution for this problem (AP association in overlapping area) is to deploy multiple APs in local networks, so that each AP serve fewer users in order to balance load and to maintain network performance. However, this solution may have its own disadvantages. Firstly, frequent user handoffs may be required, which is very time consuming. Secondly, APs may need to exchange information about associated users to aid in associated scheduling, and lastly, it causes packets to be delayed or lost because such solution may have issues routing downlink data to users which perform reassociation [1] [2] .

As an alternative, numerous AP association algorithms have been proposed to avoid load imbalanced situations. Broadly these algorithms can be classified into two main categories: Client-side and Server or Network-side [3] . Server side load balanced algorithm in SDN can compete with commercial balancers. The Round Robin policy uses circular queue to determine where to send a request. The load based policy send request to the server with the lowest load, where the load is defined as the number of pending request [3] . Research efforts in [3] is server side solution. While at Client-side, previous attempts without SDN uses different metrics to solve this issue in wireless zone. The end user client device (mobile, laptop, tablet etc...) collects the load information passively from APs or estimated from the network metric such as frame delay [5] , retransmitted packets [6] etc. We argue that frame delay, retransmitted packets and collision rate can still be very high even if the load on APs are considerably low. Because such factors not only depends on load but also depends on environmental condition, interference from nearby devices operating on same frequency and device receiver sensitivity [7] . Kimaya et al. [8] uses game theory approach to analyse wireless access point selection by wireless users. They calculated load on AP based on number of associated users. Critically, in some cases this assumption is not valid. High bandwidth requirement application likely to consume resources disproportionately, hence few users running bandwidth sensitive application can create load imbalanced situations. Therefore load calculation based on such factors are not always true.

While deploying client side solutions it is also arguable and important to address the issue that the users are selfish, user selection may poorly impact other users and in turn motivate them to change the selection [8] [9] . The term selfish means that illegitimate users consuming high network resource for various reasons such as to knock down network services at particular AP, to add significant delay to other running applications and so. The static algorithm in user device allows them to do so. All previous attempts to solve the AP

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association problem in overlapping WLAN zone unfortunately do not address this issue. This long awaited problem still needs an effective solution.

The conceptual motivation behind the presented solution is to attain a satisfactory incentive compatible Access point and to design an architecture that prevents non-cooperative behaviour. In this research effort, our interest is to develop a SDN based load balancing client side solution for SDN enabled Wi-Fi hot spot areas. At wireless client side, with SDN, to the best of our knowledge, there is no effort reported till date. We emphasize that SDN has open new doors to address these issues. We propose that the logically centralized WLAN SDN controller, as shown in figure 1, monitor and design the statistics (number of available AP in area and load on respective AP) and forward these statistics to new user according to network requirements. Decisions are then deployed in the network by the client based on the received statistics that jointly consider the load in terms of AP bandwidth and RSSI value. Hence, global visibility of the status of network components i.e. APs is utilized to relinquish load imbalance in WLAN via programmability attained in SDNs.

We highlight our contributions as following.

- We research the opportunities to apply new concept of networks, SDN, for solving well known problem of load balancing. We propose that the SDN controller monitor the load related network statistics according to network demand and need, and then such statistics forwarded to new user or any user trying to associate in the network.
- We used multiple network parameters i.e. available AP bandwidth and RSSI value, in order to calculate the load on AP. Available bandwidth is calculated by SDN controller and the RSSI value is determined by the user device.

It is worth to claim that our contribution is designing a novel wireless client side load balancing framework, in SDN enabled WLAN network, which drives network clients to associate itself with the best available AP without acting selfishly.

The rest of the paper is organized as follows. In section II related work is presented. We discussed our proposed framework in section III. In section IV system analysis is conducted and in section V we have presented simulation results. Finally we have drawn conclusion in section VI.

II. Related Work

A typical SDN WLAN network architecture is shown in figure 1. Users associated with APs make Basis Service Set typically called BSS. The BSS is served by APs which are connected to SDN Controller via OpenFlow (OF) enabled Ethernet switch. The OF enabled AP switch which evaluates every incoming flow independently received from user and finds a matching flow against it and perform the associated action. If no match is found, the switch (OF enabled AP in wireless case and Ethernet Switch in wired communication) forward packet to controller for getting instruction on how to deal with packet. The SDN controller populates the switch with flow table entries. Typically controller updates switches (AP in our case) with new flow entries as new flow pattern are received. Wild card rules are also accepted. This technology is known as *Software Defined Networking*. It is important to note that this process of data forwarding occurs only after the user get association with AP. And our problem lies in the context where user is still trying to get association with AP.

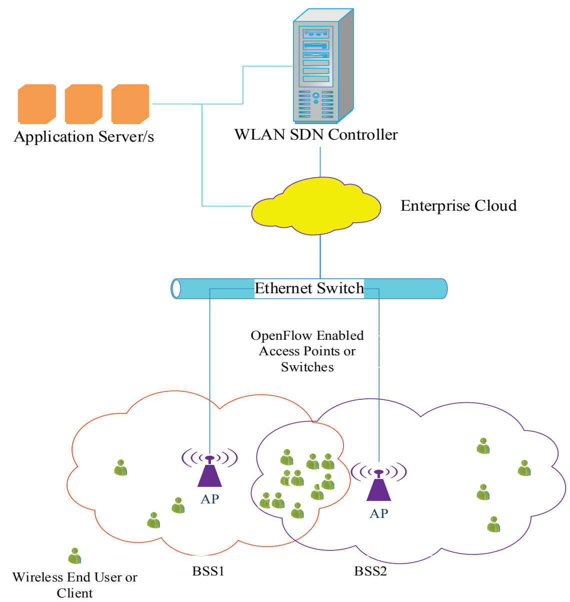

Fig. 1. Typical SDN enabled WLAN network architecture.

From the existing AP association research solutions available till date we recognize that they still encourage user to act selfishly and do not consider jointly the RSSI value and bandwidth as a load metric. Their effectiveness and stability is still questionable that makes Load Balancing issue more complicated. This motivate researchers to investigate effective solutions to tackle this issue. In [9] the sum of reciprocal of data rates from associated clients is used to estimate the load of an AP. In [10] AP association was formulated into non-cooperative games. Authors in [11] used Nash equilibrium approach. [12] Used estimated file download time to indicate the AP load. Furthermore, Traffic Intensity of clients was regarded as another metric of calculating load. However the greedy selection of the least loaded AP does not guarantee optimal AP selection. Authors in [13] propose cell-breathing approach where AP adjust the load by changing the transmitted power of beacon frames, but this scheme does not fits for some scenarios [2] . Joint AP selection and channel assignment (not RSSI) was first studied in [14] with the objective is to focus on the impact of channel bonding. However this scheme do not specify how to implement bandwidth allocation in WLANs to realize proportional fairness.

In the WLAN virtualization [15] scheme a controller allocates uplink time to clients fairly. In [16] airtime usage control mechanisms is based on Enhanced Distributed Channel Access (EDCA) where user associate to AP based on appropriate Arbitration of Inter-Frame Space (AIFS). These schemes somehow prevents anomaly [1] but hard to adopt. Moreover all these methods are without SDN.

With SDN, Odin prototype [17] designed by Suresh et al. is a novel design that introduces programmed, Lightweight Virtual AP (LVAP). The association and dissociation of client decisions in network were made by virtual AP in this design. It simplifies the client management and has demonstrated the reduction in delay while channel handoff on HTTP traffic. However failure in LVAP will disturb the network capabilities and no such immediate traffic offloading mechanism has discussed. It is important to argue that the reason of handoffs are many, and one of which is the load on AP. Unnecessarily handoffs have many disadvantages and causes network overhead. Rangisetti et al. has extended the Odins work. They proposed a novel load aware hand off scheduling algorithm [18] for SDN based WLAN networks. But all these efforts with SDN are at controller/server/network side.

III. Framework of SDN Enabled Cleint-Side AP Association Method

In this section, working description of client side proposed framework is described.

A. Working steps of the proposed framework

The following literature describes working procedure of our framework illustrated in figure 2. The elements used in this framework are available in production domain easily.

Step 1:- The Global controller (External SDN controller) via. AP contacts wireless clients local controller (a piece of software in kernel space) after every N beacon cycle intervals. Usually in IEEE 802.11 networks, AP send beacon frames after regular interval i.e. 0.1s. The global controller provides the statistics to local controller such as number of APs in a network and load in terms of available bandwidth on each AP, and Signal to Noise Ratio (SNR) of APs of the local network in which the client is currently located.

The Global controller can also be used to provide per user per application policy, scheduling actions and enforce policies to client device. It also collects QoS requirements of user application from local controller via SDN API (SDN Application Interface such as OpenFlow, python, java etc.).

Step 2:- The local controller in the client device receives that statistics and forward those to Wi-Fi driver to invoke scheduling algorithm in order to associate the client device with the least loaded AP provided it has the sufficient RSSI [3] .

Step 3:- The Wi-Fi driver/scheduler (Atheros cards such as ath5k, ath9k etc.) perform the scheduling action (refer green lines in figure). According to this solution, the user device will associate to the least loaded AP provided it has sufficient RSSI value to maintain Quality of Service (QoS) requirements. On another side if the RSSI value of the minimum loaded AP is not sufficient, the device will try to associate the next minimum loaded AP. The search cycle continuous until the both conditions matched. (First condition is load and second

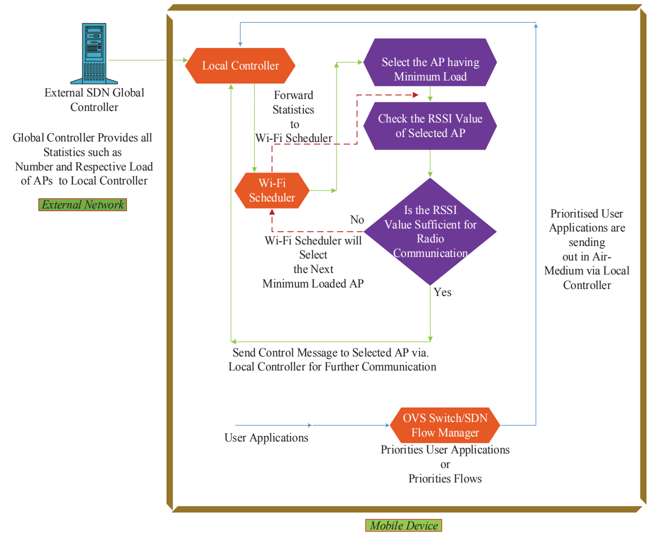

Fig. 2. Flow chart of the proposed solution.

is sufficient RSSI) This process is shown in figure 2 in red dotted lines.

Step 4:- The client device (wireless mobile user) send the control message back to the selected AP. It also send message to global controller via local controller to track the logs.

Step 5:- The SDN device manager (OVS software switch) priorities different applications running on the client device, received via secure connection such as TCP before sending them out to air medium.

Taking an example of VoIP flow over p2p flow. In this case the SDN manager introduce delay in p2p application and priorities the VoIP application. The Flow Manager measure per-flow statistics i.e. flow size and time duration of each flow. These statistics forwarded to the Global controller for achieving better air time scheduling via local controller in order to optimize the network and to obtain end to end node control in a network. The local controller has a full view about the application specific QoS requirements and the available bandwidth. The communication between different building blocks of proposed framework will be via SDN APIs.

The SDN controller can hide the identity of any AP (to new user or any existing user try to associate with AP) at any point of time depend on certain factors such as to exclude the user consuming high network bandwidth that acts selfishly and, if load or traffic volume on particular AP is continuously exceeding that mimicking Distributed Denial of Service (DDoS) Attack kind of situation. New users only received the statistics forwarded by the SDN controller therefore users have no choice to select AP of their own interest. This discourage users to select AP of his own choice to associate with, even if users try to change positions. Hence users cannot act selfishly to knock down particular AP because SDN Controller can detour and might omit that traffic flow (consuming high bandwidth) or user out of network even if they are trying to relocate or change location to select new AP. Therefore using SDNs opportunity to solve the problem of managing resources has potential to avoid users to act selfishly. This issue is commonly known as *mitigating selfish-attacks* in WLAN.

IV. System Analysis

Table 1 is notations and definitions used for system analysis. The parameters we used for evaluation, our proposed method, is based on IEEE 802.11n standard.

TABLE I
Notations and Definitions

Symbol	Semantics
P or S	AP transmitted power
B	Bandwidth for an AP
P_u	Received power by user u
R_u	Average transmitted power by user u
Γ_u	Path loss
ϵ	The maximum distance at which the full power P is received by user
α	Path loss exponent
ϕ	Data rate
AP_i	User linked to i^{th} AP
σ	AP load effect
Ld_i	Load on i^{th} AP
l	User distance from AP
γ	Signal to Noise Ratio
σ_j	Load level on j^{th} user

A. Average data rate calculation

Firstly we calculated the average data rate $R_u(l,\gamma)$ transmitted by the user which depends on the distance l or RSSI value of the device from AP and on the signal strength of channel denoted by γ.

AP transmit beacons continuously or transmit power at certain intervals therefore the power P_u received by the user u is equal to $P \times \Gamma_u$ where P is the transmission power of the AP and Γ_u denotes the path loss. In practice, path loss varies with respect to the user's location and device conditions such as receiver sensitivity and interference from surrounding devices. In this case, we adopt a simple propagation model where the path loss Γ_u is a function of the distance l from AP to user u only.

$$\Gamma_u(l) = \begin{cases} 1 & l \leq \epsilon \\ (\frac{\epsilon}{l})^{\alpha} & otherwise \end{cases} \quad (1)$$

where ϵ denotes the maximum distance at which the full wireless power P is received and α is the path loss exponent which characterizes the scenario environment (AP association problem at overlapping zone), (typical ranges from 2 to 5) [19]. The data rate is chosen from ϕ [20] .

$$\phi(\gamma) = bBlog2(1 + \frac{\gamma}{a}) \quad (2)$$

$$\gamma = \frac{S}{N_o B} \quad (3)$$

In above equation, B is the maximum allocated bandwidth for an AP, and N_o is the power spectral density of noise. S is the transmitted signal power of AP which is same as P, both are one and the same thing. To keep the equation in its standard form we are not writing S as P in equation 3. Signal to Noise ration is denoted by γ and $a \geqq 1, b \leqq 1$ are two constants in equation 2. For $a = 1, b = 1$ formula (2) is the Shannon's well known formula [21] . According to [20] $a = 1.25, b = 0.75$ provides the best fit for the associated adaptive curve in that paper for Long Term Evaluation (LTE) system. However, in this paper research on wireless connection, we choose $a = 1.25, b = 0.9$. We assume $D \subset R^2$ as the network area. The user that linked to AP is denoted by AP_i. The data rate of user attached to that AP located at $l \epsilon D$ is:

$$R_u(l,\gamma) = \frac{\Gamma_u(l) \cdot \phi(\gamma)}{AP_i} = \frac{\phi(\gamma)}{AP_i} \cdot \begin{cases} 1 & l \leq \epsilon \\ (\frac{\epsilon}{l})^{\alpha} & otherwise \end{cases} \quad (4)$$

B. Load calculation using using Fuzzy Membership function

Assume users attached to AP i have load effect σ on the access point, assume users in the overlap area follows Poison distribution with parameter λ, the load of AP i can be calculated as:

$$Ld_i = E[\sigma] \int_{D_i} \frac{\lambda}{R_u(l,\gamma)} dl \quad (5)$$

In our work, we use σ denotes the size of the file that users would like to download. However in practice it is difficult to identify the size of file that each user want to download or open, even few users just plan video games rather than downloading heavy files. In such case, users indeed added the load to the AP. To make it simple, we classify the load into different levels to run our experiment, which is $\sigma_j \epsilon [0, 1]$. For example, $\sigma_j = o$ means users get attached to AP but do nothing (no load), $\sigma_j = 0.5$ means that users surfing on the net using normal or moderate data driven activities., while $\sigma_j = 1$ indicates users may downloading heavy files such as playing video games, watching you-tube etc. which we treat as heavy load on AP.

To make our scenario more practical and close to true environment, we use the following fuzzy membership function to assume users adding different level of load to AP.

$$\sigma_j = f(x, s, t) = \frac{1}{1 + \exp^{-s(x-t)}} \quad (6)$$

Where s, t are constants $(s = 1, t = 5)$ are used in the proposed solution. x is supposed to be the value of each user load level to AP. In order to justify users load level, x is randomly generated from $N(\mu, \sigma)$. AP 1 for $(N(5, 1)$, AP2 for $(N(5, 1.5)$ and AP3 for $N(5, 2)$.

V. Performance Evaluation

In this section simulation results are presented. We assume that the overlapping area consisting three APs where AP1 has strongest RSSI. As it has mentioned previously that the load metrics used in previous attempts are, number of users associated with AP, frame delay, retransmitted packets, collision rate etc. To critically defeat this concept, we proved that even the less number of users can significantly increase the load on AP. Figure 3 indicates the evaluation result of this

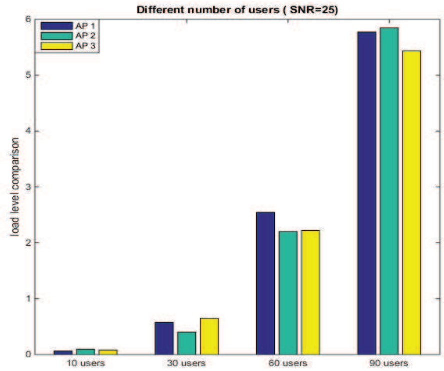

Fig. 3. The load level difference at fixed number of users.

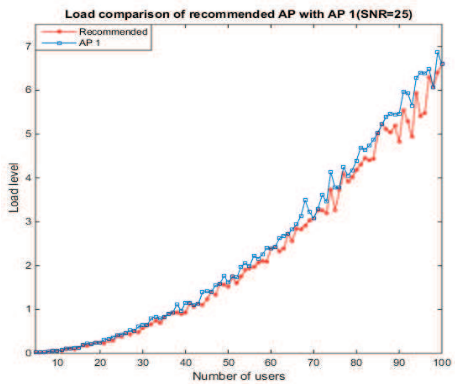

Fig. 4. Load level comparison using our proposed method.

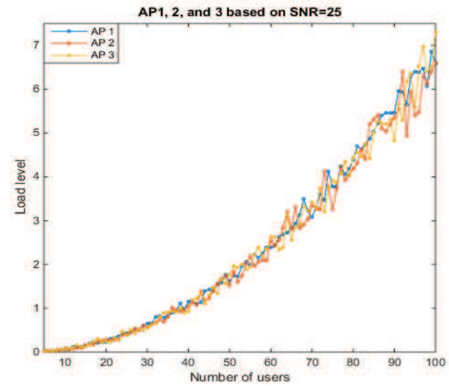

Fig. 5. Load level of Access Points at fixed SNR=25

argument. Consider a case at SNR = 25 and number of user = 30 associated to all APs. It reflects that the load level is not same on all APs even if the number of users are fixed to them.

Further we critically argue on various other load metrics such as frame delay, retransmitted packets and collision rate etc. used by researchers. Authors in [7] already proved that Quality of Service (QoS) depends on environmental conditions, interference from nearby devices operating on same frequency and device receiver sensitivity. Therefore it is arguable that calculation of load based on other mentioned factors are also not always true.

From our simulations, figure 4 and 5 depicts the real world trend. The word Recommended used in figure 4 indicates the result taken out from our proposed algorithm. This diagram clearly revels that the load distribution can be highly imbalanced even if the number of users and SNR is fixed for AP1 because of the static algorithm that allows user to attach with the strongest signal. Similar trend, for example at AP 2, number of users = 90 and SNR=25, can be seen in figure 5. It is because of the users unpredicted browsing behaviour. To solve this problem we use fuzzy membership function in equation 6.

Figure 6 illustrates the general trend of load level of AP1 and AP2 based on different SNR values. Unsurprisingly, the load level of both APs increase slightly with more users get associate with them. Comparatively, due to different users of each access point, we can see the load are more or less different even with the same users under each SNR. Interestingly, with higher SNR values (from both pictures) does not mean that it always has the lower load level. Take SNR = 25 for example, it can be seen for most of the times the load is higher than the other two, this may because more users are busy on network with that access point. Therefore knowing the bandwidth consumption related to load is true parameter to solve this issue. In above literature we have theoretically justified that the bandwidth metric is most suitable to calculate load at APs. In figure 7 we have shown the importance of considering RSSI value in order to prove that both parameters are important to consider while designing novel load balance mechanisms.

We have conducted wide comparison with different SNR values. Data rate at $\lambda \leq \epsilon$ means the users are not in overlapping area and getting higher bandwidth and so the higher data rate can be obtained. Whereas the users at $\lambda \leq \epsilon$ are getting lesser bandwidth in comparison to $\lambda \leq \epsilon$. From this comparison it is doubtless to claim that our algorithm is valid in other scenarios too. SDN controller design novel statistic based on network needs and requirement and populate such statistic to the every incoming user.

VI. Conclusion and Future Work

In this paper, we studied AP association problem for Wi-Fi networks with Software Defined Networks. We used SDNs potential to globally view each network element, their resource/s consumption etc. in order to design load statistics. We proposed a dynamic algorithm in client device that jointly consider the bandwidth of AP (defined by SDN Controller) and RSSI of receiver device to determine which AP to associate with, using fuzzy membership function. Finally we concluded that SDN has open new vistas to solve this well know problem. This discourage selfish attackers to knock down or consume network resources illegitimately. Further we have given a vision by highlighting SDN device manager (*OVS* software switch) that can priorities the different applications running

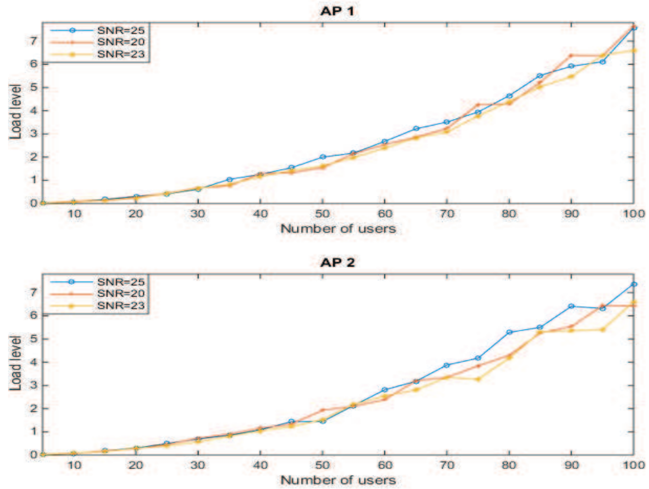

Fig. 6. General trend of load level with different SNR values.

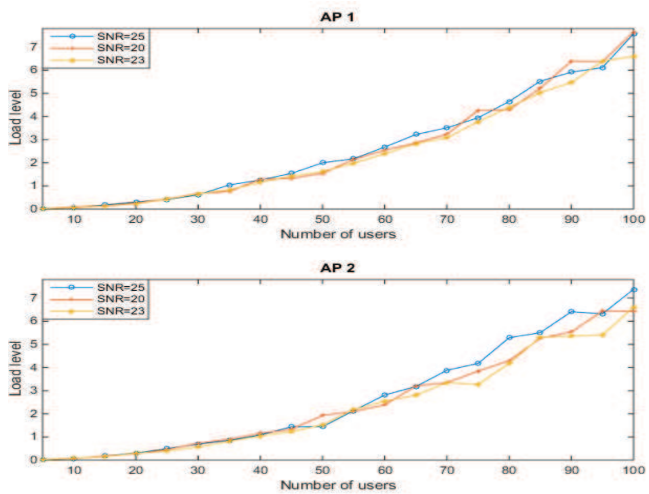

Fig. 7. Data rate comparison w.r.t distance and SNR value.

on client device.

The presented study can only be regarded as samples and not statistical guarantees. Therefore the proposed solution will be prototyped and tested on real SDN platform in future.

REFERENCES

[1] D. Gong, Y. Yang, "On-Line AP Association Algorithms for 802.11n WLANs with Heterogeneous Clients", *IEEE Transactions on Computers*, vol.63, no.11, pp.2772-2786, 2014.

[2] D. Gong, Y. Yang, "AP Association in 802.11n WLANs with Heterogeneous Clients", *INFOCOM, 2012 Proceedings IEEE*, pp.1440-1448, 2012.

[3] Y. Lee, H. Yu, X. Cheng, Y. Cui, M. A. AL-Rodhaaan, A. Al-Dhelaan, "Load Balancing Access Point Association Schemes for IEEE 802.11 Wireless Network", *Proceedings of 6th ACM International Conference of Wireless Algorithms, Systems, and Applications* , pp.271-279, 2011.

[4] A. Ghaffarinejad, V. R. Syrotiuk, "Load Balancing in a Campus Network Using Software Defined Networking", *Research and Educational Experiment Workshop (GREE)*, 2014 Third GENI , pp.75-76, 2014.

[5] S. Vasudevan, K. Papagiannaki, C. Diot, J. Kurose, D. Towsley,"Facilitating Access Point Selection in IEEE 802.11 Wireless Networks", *Proceedings of the 5th ACM SIGCOMM Conference on Internet Measurement, ser. IMC 2005*, pp.293-298. USENIX Association, Berkeley 2005.

[6] Y. Taenaka, S. Kashihara, K. Tsukamoto, S. Yamaguchi, Y. Oie,,"Terminal-centric AP Selection Algorithm based on Frame Retransmissions", *Proceedings of the 2nd ACM Workshop on Performance Monitoring and Measurement of Heterogeneous Wireless and Wired Networks, ser. PM2HW2N 2007*, pp. 128-131. ACM, 2007.

[7] A. J. F. Loureiro, D. Gallegos, G. Caldwell, "Substandard Cell Phones: Impact on Network Quality and a New Method to Identify an Unlicensed IMEI in the Network", *IEEE Communications Magazine*, vol.52, no.3, pp.90-96, 2014.

[8] K. Mittal, E. M. Belding, S. Suri, "A Game Theoretic Analysis of Wireless Access Point Selection by Mobile Users", *Proceeding of ACM Journal of Computer Communications*, Vol.31 issue 10, pp. 2049-2062, 2008.

[9] H. Gong, K. Nahm, J. W. Kim, "Distributed Fair Access Point Selection for Multi-Rate IEEE 802.11 WLANs", *Proceedings of 5th IEEE Consumer Communication Networking Conference*, pp.528-532, 2008.

[10] W. Xu, C. Hua, A. Huang, "A Game Theoretical Approach for Load Balancing User Associated in 802.11 Wireless Networks", *Proceedings of IEEE Global Telecomm Conference (GLOBECOM10)*, pp.1-5, 2010.

[11] O. Ercentin, "Association Games in IEEE 802.11 Wireless Local Area Network", *IEEE Transaction Wireless Communication*, vol.7, no.12, pp.5136-5143, 2008.

[12] B. K. Pradeepa, J. Kuri, "An Estimated Delay Based Association Policy for Web Browsing in a Multirate WLAN", *IEEE Trans. Network and Service Management*, vol.9, no.3, pp.1-13, June 2012.

[13] P. Bahl, M. T. Hajiaghayi, K. Jain, S. V. Mirrokni, L. Qiu, A. Saberi, "Cell Breathing in Wireless LANs: Algorithms and Evaluation", *IEEE Trans. Mobile Computing*, vol.6, no.2, pp.164-178, 2007.

[14] C. Huang, P. Ramanathan, "Joint Association and Power Adaption in WiFi Community Networks", *Proceedings of 45th Ann. Conf. Information Sciences and Systems*, pp.1-6, Mar. 2011.

[15] G. Bhanage, D. Vete, I. Seskar, D. Raychaudhuri, "SplitAP: Leveraging Wireless Network Virtualization for Flexible Sharing of WLANs", *Proceedings of IEEE Global Telecomm. Conf. (GLOBECOM10)*, pp.1-6, 2010.

[16] C. Chou, K. G. Shin, N. S. Shankar, "Contention-Based Airtime Usage Control in Multirate IEEE 802.11 Wireless LANs", *IEEE/ACM Trans. Networking*, vol.14, no.6, pp.1179-1192, Dec. 2006.

[17] L. Suresh, J. S. Zander, R. Merz, A. Feldmann, T. Vazao, "Towards Programmable Enterprise WLANs with Odin", *Proceedings of the 1st ACM SIGCOMM Workshop on Hot topics of Software Defined Networks (HotSDN12)*, pp.115-120, 2012.

[18] A. K. Rangisetti, H. B. Baldaniya, P. B. Kumar, B. R. Tamma, "Load-Aware Hand-offs in Software Defined Wireless LANs", *IEEE 10th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)*, pp.685-690, 2014.

[19] T. Bonald, A. Proutire, "Wireless Downlink Data Channels: User Performance and Cell Dimensioning", *Proceedings of the 9th Annual International Conference on Mobile Computing and Networking*, pp. 339-352, 2003.

[20] P. Mogensen, W. Na, I. Z. Kovcs, F. Frederiksen, A. Pokhariyal, K. I. Pedersen, et al., "LTE Capacity Compared to the Shannon Bound", *Proceedings of IEEE 65th Vehicular Technology Conference*, VTC2007-Spring. 2007, pp.1234-1238. 2007.

[21] B. Sklar, Digital communications vol. 2: *Prentice Hall NJ*, 2001.