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SDN-Assisted Efficient LTE-WiFi Aggregation in Next Generation IoT Networks

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Abstract

Currently, the increasing demands of user terminals has surged drastically and pulling up the global data traffic along. According to 3GPP, offloading is one of the most beneficial and advantageous options to handle this critical traffic bottleneck, however, both Long Term Evolution (LTE) and Wireless Local Area Network (WLAN) are loosely coupled. To mitigate the User Equipment (UE) from latency issues during offloading and for tighter integration of LTE and WLAN radio networks, LTE-WLAN Aggregation (LWA) was introduced by 3GPP which is apparently suitable for Internet of Things (IoT) devices. However, LWA is not suitable for high mobility scenarios as UEs' information need to be updated for every new environment because of the frequent aggregation triggers which are mostly non-optimal and demands for a high-level controller. To resolve the disadvantage of non-optimal aggregation triggers, in this paper, we proposed Software Defined Networking (SDN) based approach for LWA, named as LWA under SDN Assistance (LWA-SA). In this approach, SDN initiates aggregation appropriately between LTE and an optimal WLAN Access Point (AP) which avoids frequent reconnections and deprived services. As multiple parameters are required for selection of an optimal WLAN AP, so we use Genetic Algorithm (GA) that considers each parameter as fitness value for the selection of optimal WLAN AP. This maximizes the throughput of UE and reduces the traffic pressure over licensed spectrum. Further, mathematical model is formulated that uses Karush-Kuhn-Tucker (KKT) to find the maximum attainable throughput of a UE. Using NS-3, we compared our approach with offloading scenarios and LWA. The simulation results clearly depict that LWA-SA outperforms existing schemes and achieves higher throughput.

Keywords: IoT, SDN, LTE, WiFi, Aggregation, Throughput maximization.

1. Introduction

In next generation networks, macro cells, small cells of same technology or different technologies like Wireless Local Area Network (WLAN), WiMAX, etc., are integrated to work simultaneously for providing better service and quality to User Equipment (UE) as shown in Fig. 1. They serve as a backbone for Internet of Things (IoT) and involve Device to Device (D2D) and vehicular communication. These heterogeneous networks improve network coverage and enhance user experience. By 2020; growth of cellular networks and IoT devices is expected to be three times of the population [1]. According to Cisco Virtual Networking Index (VNI) [2], the usage of smartphones has increased 38% on the average and surged to three-fifths of the total connected devices, thus contributing four-fifths of the mobile data traffic by 2020. This impacts the global mobile data traffic which grew 74% in 2015, 63% in 2016 and 18-fold over the past 5 years. Cisco also predicts that the monthly global mobile data traffic would increase 30.6 exabytes by the year 2020. Serving this huge traffic at low cost while meeting the Quality of Service (QoS) has become a major concern for networks. Among this enormous traffic, 4G caters six times more traffic compared to non-4G networks as it is intended for high end devices supporting high speed and high bandwidth.

To handle Long Term Evolution (LTE) data traffic, remedial measures like WiFi offloading, coexistence mechanisms, proximity services e.g., D2D communications etc., are essential as it is impossible for a single platform to handle such a massive traffic coming from smartphones, sensors, actuators and IoT devices. Unlike small cells, integration of LTE with WiFi supports operation under unlicensed frequency bands whose deployment does not promote backhaul stress, capital and operational expenditure. In addition to this, according to Cisco, deployment of WiFi hotspots is expected to increase seven-fold through 2020. Therefore, the volume of traffic offloaded will continue moving on to WiFi. Deploying new generation of fittest WiFi Access Point (which is referred as AP) using Genetic Algorithm (GA) would increase the UE's throughput. Without offloading, the Compound Annual Growth Rate (CAGR) of mobile data traffic will reach up to 62% instead of 57%. With maturity of next generation networks, heavy traffic is also being contributed from wireless sensor networks and IoT, Therefore, the offloading will attain prime importance to cope up with user's service expectations. Thus, in this paper, we focus on LTE-WLAN Aggregation (LWA) that allows LTE and WLAN to co-exist and serve the UEs. Though a smart next generation network environment is expected to emerge as a result of unifying various technologies like LTE and WiFi, the chance of discovering services while entering a new environment and providing seamless operation is still questionable and stands as a challenge to implement IoT [3].

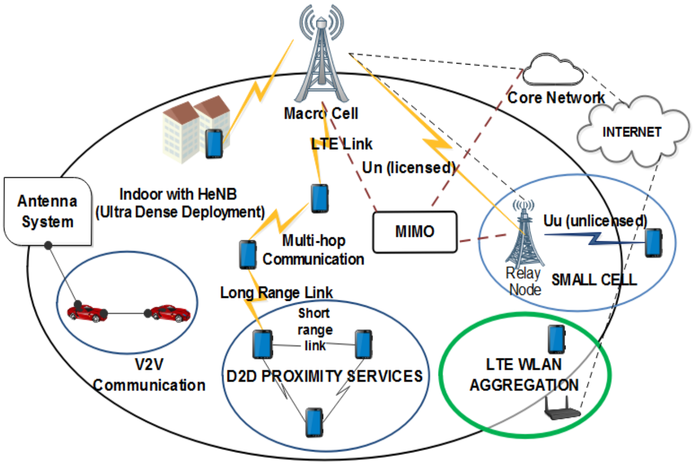

Fig.1. Heterogeneous environment in next generation networks.

Software Defined Networking (SDN) being an emerging technology is found to be suitable to address all mobility and seamless service issues as it is adaptable to dynamic behaviour of network topology and flexible to changes which are managed by Open Networking Foundation [4]. This technology decouples network control plane and forwarding policies (data plane) which is a layered approach consisting of three layers namely application layer, control layer and infrastructure layer. SDN controller logically centralizes and aggregates the intelligence of all the network components and is also dynamic to network behaviour changes. This facilitates in decision-making and this nature of SDN is beneficial for offloading and integration among multi-RAT environment in order to enhance monitoring and control. SDN intelligence avoids non optimal triggers and makes network monitoring efficient and optimal. Thus, the main objective of this proposed work LWA under SDN Assistance (LWA-SA) is to aggregate the LTE and WLAN under SDN controller's intelligence and split the traffic over the bearers based on the Quality of Channel Indicator (QCI) values.

In LWA, LTE users' aggregate traffic with WiFi using a special new interface called Xw in the non-collocated environment [5]. This Xw interface is not present in the existing versions of 802.11. LWA lacks in performance when there is frequent reconnection establishment for Dual Connectivity (DC) among LTE and WiFi for the user's service. Not a lot of research is done on the above problems which are discussed in (Third Generation Partnership Project) 3GPP Release 13. Thus, in our proposed LWA-SA scheme, SDN being an intermediary for the UE to aggregate with WiFi from LTE enables aggregation even in the absence of Xw interface. The main components of LWA-SA other than the components of LWA are open flow switches and SDN controller. Also, LWA-SA fixes the non-optimal triggers when there are fast recurrent changes in DC. In such cases, UE's QoS has a positive impact on latency and throughput.

Contributions of this work are summarized as follows:

- We split the traffic across LTE and WLAN networks according to the QoS demands of users and aggregate the service from both the networks under SDN controller's guidance.
- We proposed an efficient WiFi AP selection algorithm to select an efficient optimal AP for aggregation using GA based on multiple parameters and achieved pareto optimality.
- We formulated a mathematical model for throughput maximization of UE under aggregation using Lagrange multiplier method with subject to power and interference constraints.
- Our simulation results demonstrate that the LWA-SA outperforms the existing LWA and other approaches in the presence of frequent non-optimal triggers for initiating aggregation.

The rest of this paper is organized as follows. Section 2 provides the literature review. The problem description and system model is depicted in Section 3 and the proposed system is presented in Section 4. The results are analysed and discussed in Section 5. And finally, conclusion and future work are drawn in Section 6.

2. Literature Review

Mobile data offloading has been under research for a long period of time to handle the surging data traffic and IoT traffic. As penetration of IoT increases and Machine to Machine (M2M) communications comes into reality, the spectrum usage gets more critical [6]. Offloading being a solution requires help of some alternate networks to complement. There is a variety of offloading options available which has to be chosen according to the environment and user preferences. Some intelligent ways to offload are D2D communication via proximity services and use of available different network types. The authors in [7] proposed a D2D communication by offloading packets via WiFi to selected trusted nodes which is also shared among non-trusted nodes and generate remaining packets using erasure codes. As offloading mainly expected to save the power consumption of UE, a joint channel and power allocation scheme is developed in [8] that extends the battery life of UE. Similarly, in [9], energy harvesting is performed under stochastic geometry model. In [10], radio resources are offloaded from macro to nearby small cells and femto cells. These cells achieve high utility based on stackelberg game model. Further improvements and gains in harvesting energy is attained by switching the small cells on and off as pointed out in [11] based on the statistical data. Further an idea of deploying 5G femto cells to reduce IoT traffic and promote green communication is presented in [12]. The work in [13] shows how to use TV white space and cognitive approaches for compressed spectrum sensing to efficiently utilize it for IoT traffic.

However, all the above discussed offloading solutions rely on single radio connection (i.e., licensed spectrum) which does not minimize the backhaul overload. Offloading to other radio connections (e.g., WiFi) will ease the burden on backhaul network and the focus of this paper is also the same. Initial strategy towards WiFi offloading was, when a UE comes under WiFi coverage, offloading is triggered. In 3GPP release 8, policies were framed through Inter-System Mobility Policy (ISMP) for LTE WiFi interworking purpose. In 3GPP release 10, mobility is maintained with IP address preservation and known as IP Flow Mobility (IFOM) where routing is intended for specific traffic IP flows. Multiple Access Public Data Gateway (PDN) Connectivity (MAPCON) is another way proposed in 3GPP release 10 where PDN connections are routed to specific access point network [14]. 3GPP release 11 introduced S2a Mobility over GTP (SaMOG) where Generic Tunnelling Protocol (GTP) is used to make IP connection with trusted WLAN and also allows multiple PDN connections. 3GPP release 12 improves SaMOG and further made WiFi selection using Hotspot 2.0 specifications. These are some of the techniques introduced by 3GPP to facilitate interworking of LTE and WLAN. Furthermore, a wait for WiFi strategy is introduced where the service for non-real time applications are delayed by a bound, waiting for WiFi network. The efficiency of on the spot and delayed offloading are compared in [15] that concluded delayed offloading is beneficial, provided the delay is considerably large. In [16], authors proved that offloading 65% on the spot could potentially save 55% of the battery power of UE. To the betterment of WiFi offloading, a prediction based method is introduced in [17] where in absence of WiFi coverage, the transmission control protocol congestion window is modified in a way to accommodate the traffic.

In 3GPP release 13, new efforts were made for the coexistence of LTE and WLAN network. This initiative focused on aggregation of both networks via links or carriers. Like offloading, resource sharing and load balancing during aggregation is not an on/off procedure among multiple networks. A comparison is studied under single and multi BS scenarios for traffic offloading and resource sharing between LTE and WLAN networks in [18]. This comparison concludes as traffic offloading is beneficial until WiFi users stay below threshold. Once the WiFi users exceeds above the threshold, resource sharing outputs better results. Thus, focusing on coexistence, aggregating two networks indirectly drags attention into traffic splitting between available networks simultaneously. [19, 20] discussed the traffic portion split and the resource scheduling in heterogeneous environment in link aggregation by developing a low complexity solution for maximizing an α-optimal network utility. In [21], authors addressed the resource management issue using Lyapunov drift plus penalty optimization approach to capture queue backlog stability. This approach considers delay, power and Quality of Experience (QoE) as primary parameters to split the traffic. The work in [22] reduces the waiting time of queues by introducing a virtual WLAN scheduler and aggregating at RLC layer, however, it is not applicable for non-collocated scenarios as it demands heavy MAC layer interactions. Connecting to a BS and AP is considered as a joint optimization problem in [23] and it is solved to minimize cost and power. In [24] additionally a 5-tuple traffic flow template is used to classify the traffic classes between BS and AP. Though there are facilities to classify traffic in LTE networks, in WiFi network best effort service is provided without stringent delay or latency conditions. In [25], the downlink data in LTE network is scheduled for upcoming '*t*' interval by setting QoS parameter in Evolved Packet System (EPS) bearer. Similarly, [26] classifies traffic based on QCI considering fairness as primary parameter and guaranteeing QoS is given second priority. As an extension to QCI based traffic splitting, priority is set by the proportional fair scheduler for betterment of the service provided to poor channel conditioned users [27].

So far, the amount of data to be offloaded and shared is focused and determined, however, there is no solution provided to elect an efficient AP. This problem was addressed in [28-30] with the help of Access Network Discovery and Selection Function (ANDSF) module located in Evolved Packet Core (EPC). ANDSF server is made responsible for to suggest efficient non-3GPP access network by considering parameters like Signal to Interference Noise Ratio (SINR), channel gain, cell load etc. The work in [31] proposes two distinct self-organising networks where the access network is chosen based on Received Signal Strength (RSS) thresholds and Access Network Selection (ANS) rules, however, automatic traffic steering is not focused for ongoing connections. Even though ANDSF can communicate with non-3GPP access, it cannot cope up with dynamic nature of network. SDN is well capable of managing a dynamic environment, is used in proposing a power saving algorithm [32], in which the idea is to move the ANDSF bundle to SDN, thus, SDN becomes responsible to the accuracy of measurement reports. Other areas of focus like load balancing and queuing works are also investigated under SDN control in [33, 34]. To enhance the intelligence of SDN, GA can be used. Some solutions involving GA in offloading are: [35] 1- a GA based offloading model providing robust offloading decisions among mobile services and 2-a fast heuristic GA to solve the NP-hard problem of maximizing the user tasks [36]. Moreover, initiating the offloading procedure has always been a problem in offloading models from both UE and network perspective. A user centric offloading considering historical data about user's mobility and application usage pattern is developed in [37]; however, there is no involvement from network side. Hence, a combined approach of user focused network based offloading is proposed in [38]. It notably outperformed on the spot and SNR based offloading by 20 % per user. Similarly, in [39], a two-round solution is proposed that considered traffic load from network and channel quality from user side to decide on offloading. The results show that this approach is 26% and 8.9% better than the user and network initiated offloading, respectively. Though the combined initiation is found to be better, for a dynamic and high mobile environment, both UE and network lags behind in updating measurement reports as the interaction between UE and BS leads to latency. SDN is absolutely flexible for monitoring and updating purpose. The investigation in [40] takes an industrial perspective and focuses on the difficulties faced during link aggregation implementation and need for optimal aggregation triggers which form the central theme of this work.

Thus, for dynamicity and seamless service from LTE and WiFi to UE, we propose LWA-SA scheme that addresses all the above mentioned problems of aggregation initiation, network selection and practical deployment. It gives the advantage of deploying aggregation without the need for Xw interface with efficient monitoring. The other way for LTE and WLAN coexistence is license assisted access by selecting the carrier and performing discontinuous transmission which is out of scope of this work.

3. Problem description and System Model

3.1 Problem description

3GPP release 13 focused to aggregate LTE and WLAN to service UE simultaneously by exploiting DC facility of UE, rather than making them interwork as licensed spectrum always tops the priority list of users in providing service. This way of aggregation mentioned in [41], leads to tighter integration of both LTE and WLAN networks.

LWA is a data aggregation technique that happens at RAN level between LTE and WiFi network. It enhances control and resource utilization over links without any modifications in the core network. Macro cell of LTE network being the master controls the activation and deactivation of LWA aggregation and also responsible for scheduling packets on LTE and WLAN networks. Through LWA, data delivery would increase by 1 Gbps in near future during peak downlink speeds; however, LWA requires some changes to be made in architecture of LTE and WLAN. LWA is suitable for both collocated and non-collocated AP. In non-collocated scenario, AP is connected using standardized Xw interface [5] via non-ideal backhaul support. The special Xw interface is capable of supporting both control and data planes. LWA introduces a logical access control entity named WLAN Termination (WT) that represents the grouping of APs based on its mobility. Signalling messages are required between WT and Base Station (BS) only when a user moves from one WT mobility set to another instead of moving from one AP to another, thereby reducing the overhead of signalling messages. LWA facilitates better offloading decisions assisted by reports from UE like WiFi status report. The WiFi status report contains Basic Service Set (BSS) id, BSS load, WLAN metrics and available channel utilization, RSS Identifier (RSSI), station count, backhaul rate, admission capacity and channel utilization. Based on the report, a suitable AP is selected and traffic split is carried out between LTE and WiFi network.

The traffic flow is mapped to different service classes based on Differentiated Services Code Point (DSCP) and QCI assigned to EPS bearers. Unlike LTE network, WiFi network uses access category to classify the IP packets for traffic split. Since the IP packets that are intended to be serviced by LTE network are incompatible for WiFi service, LWA Adaptation Protocol (LWAAP) [42] is used to adapt and identify data bearer identity. Both evolved NodeB (eNB) and UE has a LWAAP entity configured in it. The main functionalities of LWAAP sub layer are identification of LWA bearer to which the LWAAP Service Data Unit (SDU) belongs to and transfer of user plane data. When transferring from eNB to UE, Radio Resource Control (RRC) configured 5 bit data bearer identity is added to 8 bit header whereas from UE to eNB data bearer identity is removed from LWAAP header. Some notable advantages of LWA over carrier aggregation are minimal signal message exchange between core network and mobile terminal, and has positive impact over the performance of cell edge users. Though License Assisted Access (LAA) overcome the drawbacks of network level traffic offloading, the inter-BS carrier aggregation is not possible unlike LWA which also facilitates AP aggregation. Also, LAA cannot be used for non-collocated deployments, however, LWA serve this purpose. Thus, LWA is found to be a better way to reduce the latency, reconnection delays, disruptions between LTE and WLAN network.

3.2 System model

Considering a heterogeneous network of various RAN's in specific LTE and WLAN network, a system model is depicted as shown in Fig. 2, containing 'm' UE's $\{ue_{1,....}ue_m\}$ whose arrival follows a Poisson point process of density 'α', 'b' macro BS $\{B_{1,....}B_b\}$and 'w' WiFi APs $\{a_{1,....}a_w\}$. Focusing on a single BS scenario, let w_i, subset of $\{a_{1,....}a_w\}$ represents the APs that fall under the coverage of a particular BS B_i and m_i the subset of $\{ue_{1,....}ue_m\}$ that are connected to the BS B_i. It is assumed that each UE remains attached to any one of the BSs at all time. Let 'a' be the number of aggregated users among the members of the set w_i. The UEs are selected for aggregation by SDN provided they reside inside a complementary network in our case it is WiFi network and experience any one of the following conditions: i) traffic congestion during LTE macro cell overload ii) low interference when being in cell edge.

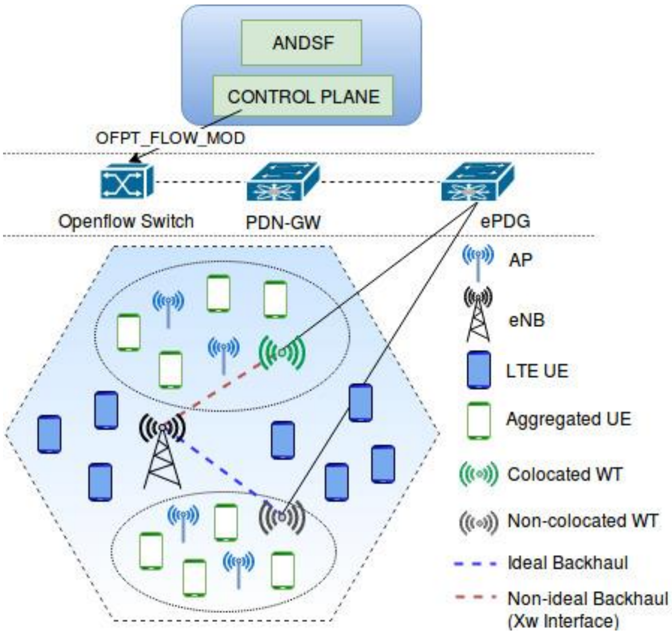

Fig. 2. System model for LWA aggregation under openflow controller.

Table I Notations used for modelling and analysing purpose.

Notations	Meaning
P_{LL}	Probability of a UE being in LTE
P_{WL}	Probability of a UE moving from WiFi to LTE network
P_{LW}	Probability of a UE moving from LTE to WiFi network
ß	Bandwidth obtained while being in LTE network
$ß_A$	Bandwidth obtained under aggregation scenarios
p^{max}	Maximum power to be consumed
p_{ul}^{max}	Maximum power consumed in LTE network
p_{uw}^{max}	Maximum power consumed in WiFi network
p_{ul}	Power consumed in LTE network
p_{uw}	Power consumed in WiFi network
g_l	Channel gain in LTE network
g_w	Channel gain in WiFi network
I_{wifi}	Interference experienced by UE from AP in LTE network
I_{lte}	Interference experienced by UE from LTE BS in WiFi network
$SINR^{th}$	Maximum threshold obtainable SINR
$SINR_{wifi}^{th}$	Maximum threshold obtainable SINR from AP

I_{max}	Maximum interference tolerable

During aggregation mechanism, a UE can be possibly in any one of the following two states namely LTE and LWA. The transition probability of UE moving between these two states is known from a transition probability matrix of a 2-state Markov chain as shown in Fig. 3.

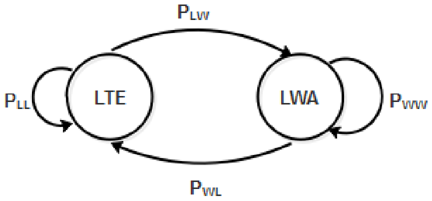

Fig. 3. 2-State markov chain depicting aggregation scenario.

The four possible transitions with their notations as mentioned in Table 1 are as follows. i) when UE is at LTE, based on the traffic density (LTE load), the UE moves to LWA state with probability P_{LW}, ii) when the complementary WiFi network is unavailable, UE remains connected in LTE state with probability P_{LL}, iii) UE being in LWA state continues to stay back in LWA with probability P_{WW}, provided the UE lies within WiFi coverage and iv) once UE lies out of WiFi coverage, the state transition happens from LWA to LTE with probability P_{WL}.

4. Proposed LTE-WLAN Aggregation under SDN Assistance Mechanisms

Despite being advantageous LWA also comes up with some drawbacks. As measurement details are reported by UE, due to its rapid mobility, macro cell aggregation triggers are not optimal enough leading to certain time variation in signalling exchanges that result in early or late handovers. This disadvantage, calls for a better control and resource management over networks at a higher level. The proposed work is to resolve the disadvantage of non-optimal macro cell triggers in LWA by introducing SDN. The proposed LWA-SA mechanism involves SDN as a decider on initiating aggregation and collector of measurement reports. SDN registers and monitors eNBs, APs and UEs. The entire sequential process of LWA-SA is shown in Fig. 4. Any user, who has established connection with LTE network is capable of getting aggregated, provided it lies within WiFi coverage. The capability enquiry is used to indicate its LWA support which is then forwarded to SDN controller via eNB and openflow switch. Now the SDN being informed about UE’s LWA capability reconfigures WLAN measurements using RRC messages. The SDN controller then fetches the LTE load and WT SINR measurements from corresponding networks and checks for updates periodically.

We propose an Efficient WiFi AP Selection (EWS) algorithm for selection of efficient AP using GA based on the cell load and SINR as critical fitness values. In addition, fitness parameters that influence the cell load are the capacity of WiFi, peak traffic hours per day, historical data about fixed WiFi users. SINR fitness value is impacted by noise figure, signal strength and interference. The capacity of serving the UEs vary with the dual or tri band of WLAN. For every AP, whose coverage the UE falls into, the ratio of cell load to SINR is calculated and stored and the AP with smallest ratio is suggested for UE to aggregate by SDN controller. If the ratio of cell load to SINR is same for any two APs, then range is considered as secondary parameter to elect an optimal AP. In addition to this, an external mutant factor cost also has impact based on the user’s preference level. By considering the multiple critical parameters, the pareto optimal solution for selecting APs is achieved using GA which is discussed in Section 3.3.1. Then, the UE gets connected dually and thus aggregation is triggered. In parallel, the load of WiFi to which the UE got aggregated, is updated by adding the data rate of aggregated user to its current load value.

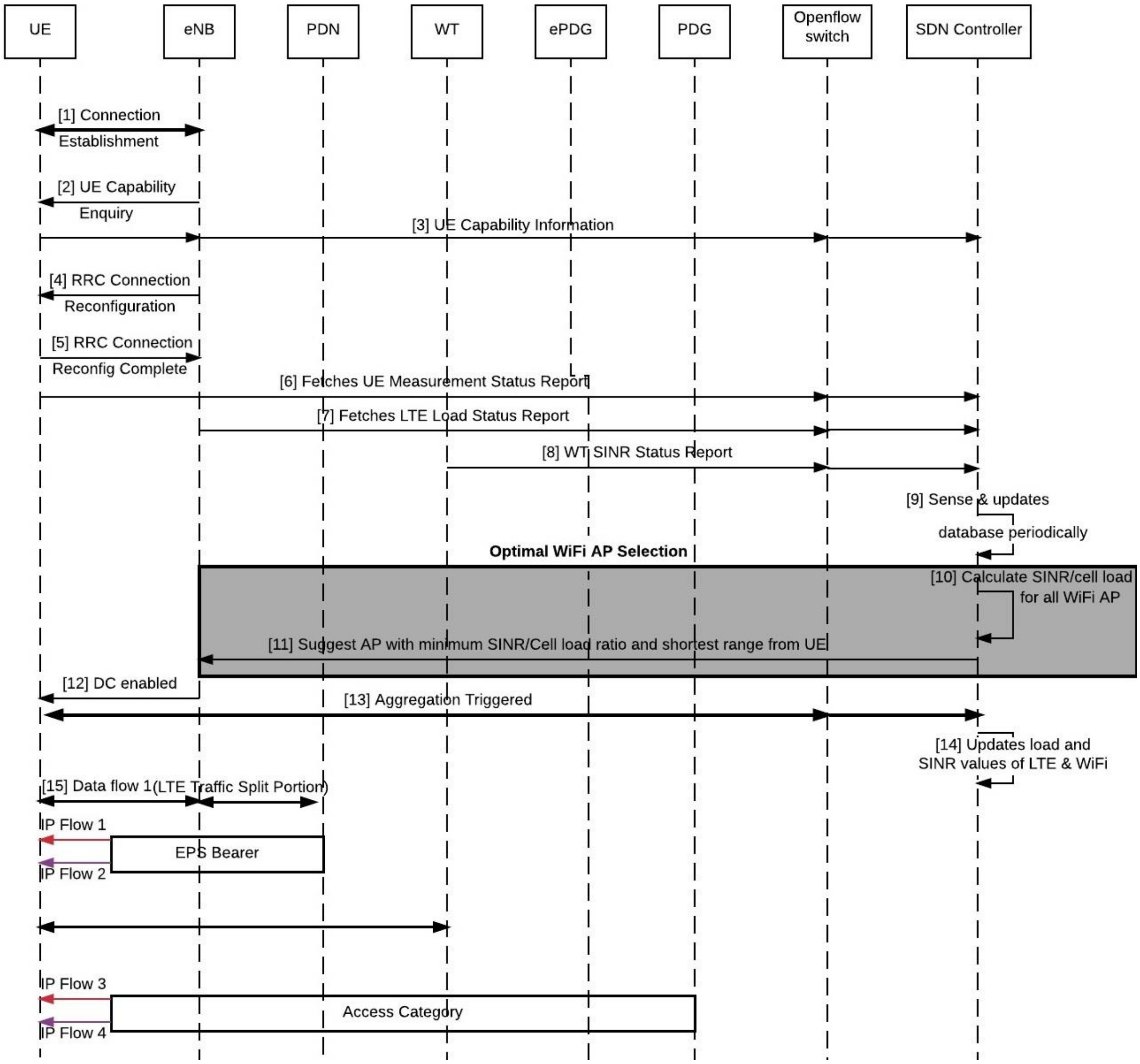

Fig.4. Sequence diagram for proposed LWA-SA mechanism.

Algorithm: Efficient WiFi AP Selection.

```
Procedure EWS ($ue_i$, $w_i$)
$l_{LTE}$: LTE load
$T_{lte\_load}$: LTE load threshold
$SINR_{LTE}$: Signal to Interference ratio of $ue_i$ in LTE network
$T_{lte\_SINR}$: Minimum SINR of LTE threshold
n: number of elements in $w_b$
r(i): coverage range of AP
if WiFi network available for $UE_i$
if (($l_{LTE}$>$T_{lte\_load}$) || ($SINR_{LTE}$ <$T_{lte\_SINR}$))
    for (i=1; i<= n; i++)
            Fetch SINR and load values from SDN
            Calculate $x_i = \frac{SINR_{w_i}}{Cellload_{w_i}}$
               if $(x_i == x_j), \forall j \neq i$
               $w_i = \max(r(w_i), r(w_j))$
            else
               Select $w_i$ which has min $x_i$
            end if
    end for
```

```
        end if
        Initiate Aggregation trigger with $w_i$ for $UE_i$ by SDN
        SDN updates $load_{WiFi}$= $load_{WiFi}$+ Datarate of $UE_i$
    end if
end procedure
```

4.1 GA based Optimal AP Selection

GA is a motivating approach and widely used in finding an optimal solution for many computer applications. Thus, the considered fitness parameters of EWS undergo phases such as initial population, selection, crossover, mutation and attain a final termination [43].

Initial population: The initial population usually contains randomly generated chromosomes of binaries 1s and 0s with many genes contained in it. Here, the initial population is the randomly selected APs that fall under the coverage of a single BS with different properties such as capacity, cost, coverage etc. These APs being under the possibility of getting aggregated are chosen as initial population. The population size is generally not variable and does not alter at later stages.

Selection: The selection process verifies and selects the parent chromosomes that can reproduce to form the next generation. The fitness function considered for selection of APs from the initial population involves the following parameters: capacity of users that the AP can accommodate, dual or tri band antenna, the noise figure (dB) of WLAN, the serving cost to the UE and power consumption of AP.

Crossover: This is the process where the parent chromosomes are united to produce children. There are many crossover techniques. For example: random crossover which is widely used, however, we select the point till a predefined probability P_d is attained; these children will have a very minimal cell load to SINR ratio. As shown in Fig. 5, we have a single point cross over after 4th position, 1 represents positive attribute of a AP and 0 represents no or negative attribute of an AP. After cross over, the child 1 gets positive characteristics of both AP1 and AP2. For example, if AP1 has good outdoor range for users and AP2 has got low serving cost, when combined we get an offspring of wider range for lower serving cost that is capable of accommodating more users.

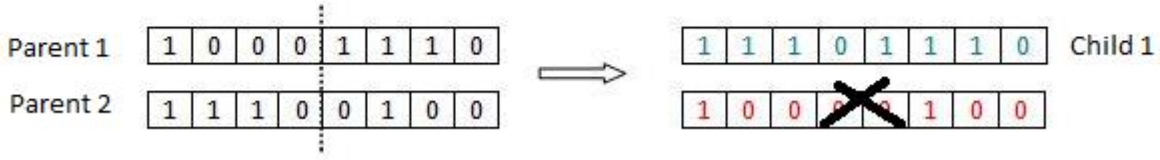

Fig. 5. Crossover technique.

Mutation: It is used to restrict the population from being dominated by the same kind of chromosomes. When the APs of higher range and low serving cost reproduce, they produce offspring’s with higher range and low cost. Later, the population may be dominated by only those kinds of APs with same characteristics which lead to local optimal solution. In order to achieve global optimum, the children chromosomes are mutated by applying some random changes such as cost. Thus, adding traits to the existing chromosome gives better result.

Termination: The termination is the final stage which is attained when it reaches the maximum number of iterations or two iterations produce the same set of new populations with same fitness value (i.e., when APs reaches maximum desirability from user’s perspective).

Hence pareto optimality is achieved in selecting APs by considering multiple parameters as fitness values for GA. Knowing the user’s desirability, it is required to combine the efficient characteristics of APs. Thus, here GA is used to select an optimal AP using crossover and mutation techniques. Each selected AP is supposed to survive through the defined fitness value that involves capacity, signal strength etc as in proposed EWS algorithm.

4.2 Traffic Splitting

This section briefly explains about how the UE is aggregated with LTE and selected optimal AP and the dataflow split across both the networks based on EPS bearer and access category of LTE and WLAN network, respectively. LWA allows a single bearer to be configured to utilize LTE and WLAN simultaneously. When the IP flow enters the evolved Packet Data Gateway (ePDG), it is encapsulated and adapted as a WiFi IP packet with Data Radio Bearer (DRB) id using LWAAP on both WiFi and UE side as shown in Fig. 6. Finally, all packets from LTE and WiFi network are scheduled packet-by-packet and the aggregated flow reaches UE's Packet Data Convergence Protocol (PDCP) layer.

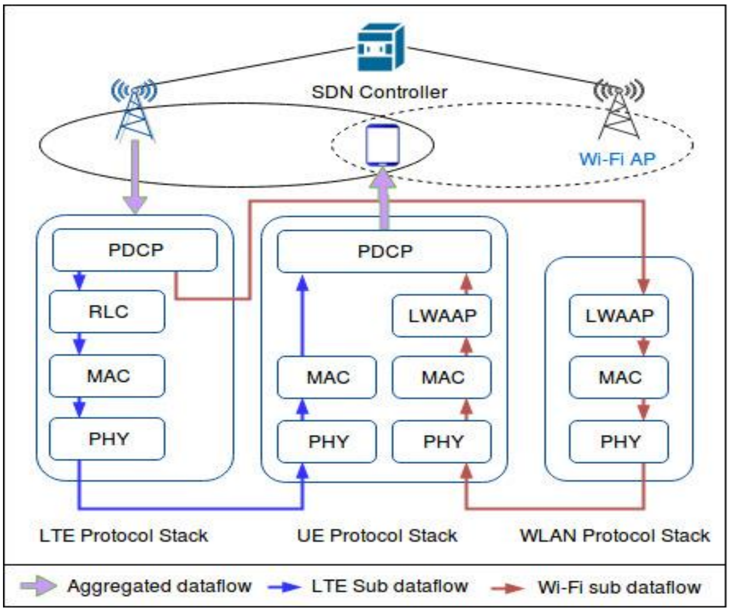

Fig. 6. LTE-WLAN traffic splitting and aggregation at PDCP level.

It also reduces the demand for having Xw interface for aggregation as SDN controller acts as an intermediate between LTE and WiFi network. This way the impact on architecture due to additional entities are reduced and hence makes aggregation backward compatible. SDN is introduced in offloading scenario for being flexible to dynamic nature of networks and to match the speed of the network entities mobility. As UEs need to assist and report the measurements about its access networks to eNB in LWA, it is difficult to provide an optimal trigger by eNB under rapid UE mobility. Instead, SDN taking responsibility in assessing and reporting the measurements about access networks would be more accurate and flexible to dynamicity. To assess the available alternate networks, LTE architecture placed ANDSF server in EPS module. It is a functional entity added by the 3GPP working group for seamless handover between 3GPP to non 3GPP access networks [14]. In order to enable the network discovery and selection feature in openflow controller, the ANDSF functionality is integrated into SDN control plane.

Since UE scans for network periodically, it leads to additional overhead on user side that results in battery consumption, limited information gathering; additionally, it need 2 receivers for scanning and for current operation. Thus, SDN's ANDSF functionality provides solution for the above mentioned problems. It provides well-gathered information about neighbour access networks, dynamic construction of database, information repository and also validates the information collected and selectively sends information to UE based on its requirements. These reports are generated from the global information collected by controller which is flexibly updated by the dynamic nature of the network. This way the network intelligence is centralized and decision making is facilitated. SDN programmability replaces management paradigm by automation and initiates aggregation taking all control of measurement reports and configuration of mobility sets, thereby relieving the load over macro cell. Thus, SDN provides expected enhanced network monitoring and management under the openflow controller assistance.

4.3 Analysis of Throughput Maximization

The aggregation capable UEs does not experience same throughput constantly. Taking a particular duration ‘t’, the variation in throughput of UE is shown in Eq. (1), where the representations ß and ß_{A} are the bandwidth obtained in the LTE network and under aggregation scenarios respectively. The channel gain in LTE network and WiFi network are represented by g_l and g_w .The interference experienced by UE from LTE BS in WiFi network is denoted by I_{lte} and I_{wifi} indicates the interference experienced by UE from AP in LTE network. p_{ul} and p_{uw} are the power consumed in LTE and WiFi network respectively. The throughput of UE is derived from Shannon-Hartley theorem as in [22] which dependent on factors like network load, interference affecting signal strength etc. It gains best throughput independent of network load when it is always aggregated, as it receives dataflow from both LTE and WiFi network which turns out to be the best case. Under worst case scenarios, UE has no possibility of getting aggregated with WiFi because of no complementary network around it and average throughput is received when it is aggregated for time ‘t_1’where $t_1<t$. As the transmission time 't_1' under aggregation increases, throughput of UE also increases and reaches the best case.

$$\text{Throughput of UE} = \begin{cases} \text{ß}\, log_2\left(1+\dfrac{p_{ul}g_l}{I_{wifi}}\right), & 0 < time < t_1 \\ \left[\text{ß}_A\, log_2\left(1+\dfrac{p_{uw}g_w}{p_{uw}g_w + I_{lte}}+\dfrac{p_{ul}g_l}{I_{wifi}}\right)\right], & t_1 < time < t \end{cases} \quad [1]$$

If $t_1=t$ then maximum throughput is achieved. From Eq. (1), it is known that UE under aggregation will experience interference from both LTE and WiFi network, thus the overall transmission rate of UE will be as given by Eq. (2).

$$\text{Overalltransmissionrate of UE} = (P_{LL}+P_{WL})\left[\beta \log_2\left(1+\frac{p_{ul}g_l}{I_{wifi}}\right)\right] + (P_{LW})\left[\beta_A \log_2\left(1+\frac{p_{uw}g_w}{p_{uw}g_w+I_{lte}}+\frac{p_{ul}g_l}{I_{wifi}}\right)\right] + \text{SDN propagation delay} \quad [2]$$

Our aim is to maximize the throughput obtained by UE during aggregation under constrained power as expressed in Eq. (3). Since a trade-off exists between {power, interference} and channel gain which varies non linearly, it is necessary to impose inequality conditions involving power, interference and channel gain so as to balance the trade-off effectively. The major constraint is power and interference which are supposed to be lesser and greater than its corresponding threshold, respectively. The maximum thresholds for power and interference mentioned in constraints from C1 to C6 are set by operator policies. Lagrange multiplier is used to maximize this non-linear function and inequality constraints C1 to C6 are imposed. The constraints with representations p^{max}, p_{ul}^{max} and p_{uw}^{max} denotes the maximum total power consumed by the overall network, LTE and WiFi. The maximum SINR threshold for overall network scenario and WiFi are $SINR^{th}$and $SINR_{wifi}^{th}$ respectively. The maximum tolerable interference by LTE and WiFi network is represented by I_{max}. Based on inequality constraints C1 to C6, KKT conditions [44] are found to be suitable for our mathematical model and notations are mentioned in Table 1.

$$\text{Max}\left[\beta \log_2\left(1+\frac{p_{uw}g_w}{p_{uw}g_w+I_{lte}}+\frac{p_{ul}g_l}{I_{wifi}}\right)\right] \quad [3]$$

Subject to the following constraints

$\text{C1}: 0 < p_{ul} + p_{uw} \leq p^{max}$

$\text{C2}: 0 < p_{ul} \leq p_{ul}^{max}$

$\text{C3}: 0 < p_{uw} \leq p_{uw}^{max}$

$\text{C4}: \dfrac{p_{uw}g_w}{p_{uw}g_w+I_{lte}}+\dfrac{p_{ul}g_l}{I_{wifi}} \geq SINR^{th}$

C5: $\frac{p_{uw}g_w}{p_{uw}g_w + I_{lte}} \geq SINR_{wifi}^{th}$

C6: $I_{lte} + I_{wifi} \leq I_{max}$

$$\begin{aligned} \mathrm{L} = \beta \log_2\left(1 + \frac{p_{uw}g_w}{p_{uw}g_w + I_{lte}} + \frac{p_{ul}g_l}{I_{wifi}}\right) - \lambda_1(p_{ul} + p_{uw} - p^{max} + s_1^2) - \lambda_2(p_{ul} - p_{ul}^{max} + s_2^2) - \lambda_3(p_{uw} - p_{uw}^{max} \\ + s_3^2) - \lambda_4\left(\frac{p_{uw}g_w}{p_{uw}g_w + I_{lte}} + \frac{p_{ul}g_l}{I_{wifi}} - SINR^{th} - s_4^2\right) - \lambda_5\left(\frac{p_{uw}g_w}{p_{uw}g_w + I_{lte}} - SINR_{wifi}^{th} - s_5^2\right) \\ - \lambda_6\left(I_{lte} + I_{wifi} - I_{max} + s_6^2\right) \end{aligned} \quad [4]$$

From the lagrangian Eq. (4), the first order derivatives are derived considering all lagrange multipliers, $\lambda_i \neq 0$ and all slack variables $s_i = 0$ where i = 1 to 6. Solving the final equation, we get the possible maximum throughput attainable in aggregated scenario of UE in LTE and WiFi network as mentioned in Eq. (5).

$$\text{Maximum Throughput} = \beta_a \log_2\left[1 + \left(SINR^{th} - SINR_{wifi}^{th}\right) + \left(\frac{(p_{uw}^{max})^2}{(p_{uw}^{max\,2}) + \left(SINR^{th} - SINR_{wifi}^{th}\right)}\right)\right] \quad [5]$$

5. Simulation Results

Our proposed LWA-SA mechanism is implemented using ns-3 simulator which is a discrete event simulator in C++. The in-built LTE and WiFi modules are used and openflow controller is integrated by enabling the openflow switch version 1.3 (ofswitch13) module using its respective patch under netbee library support. We considered 100 UEs, 10 eNBs and 30 APs, where at most 3 APs fall into the coverage of a eNB with specifications as mentioned in Table 2.

Table 2
System-Level Simulation Parameters.

Parameter	Value
LTE Adaptive Modulation and Coding (AMC) Model	GSoC
LTE Scheduler	RrFfMacScheduler
Mobility (eNB, AP)	ConstantPositionMobilityModel
Mobility (UE)	RandomWalk2dMobilityModel
WiFi Standard	WIFI_PHY_STANDARD_80211n_5GHz
WiFi Channel	YansWiFiChannel
Rate Control (WiFi)	AARF Rate Control
Path Loss Model (LTE)	FriisPropogationLossModel
Path Loss Model (WiFi)	LogDistancePropogationLossModel
Transmit Power (eNB)	45.5 dBm
Transmit Power (AP)	22.8 dBm
Noise Figure (eNB)	3dB
Noise Figure (AP)	2.3 dB

Fig. 7 shows that the proposed LWA-SA mechanism outperforms LTE-WiFi offloading and LWA. In case of cell edge users, ‘only LTE’ renders poor service to UEs as they fall far off from the eNB and experiences high interference thus reducing SINR considerably. Though the existing offloading approach is better than ‘only LTE’ approach, the results of LWA-SA is high because of the connection establishment/reconnection delays between eNB and AP. Whereas, LWA-SA having dual connection capability provides notable improvement in throughput, provided AP, are deployed around cell edge. Thereby, aggregation is highly advantageous in providing better throughput for cell-edge users.

All kinds of offloading approaches namely traditional on the spot offloading, delayed offloading, LWA and LWA-SA rely on the admission capacity of WiFi network. Assuming that 50% admission capacity of each AP is for ‘only WiFi users’ and remaining left for offloading and aggregation purpose. From the Fig. 8, it is known that with increase in WLAN admission capacity, the performance of the offloading approaches also increases gradually. The proposed LWA-SA mechanism outperforms offloading and LWA in selecting efficient AP. Thus, SDN controller's intelligence is used to avoid repeated reconnection establishment.

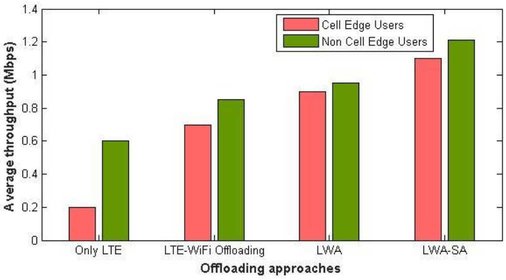

Fig 7. Throughput of UE in various offloading approaches.

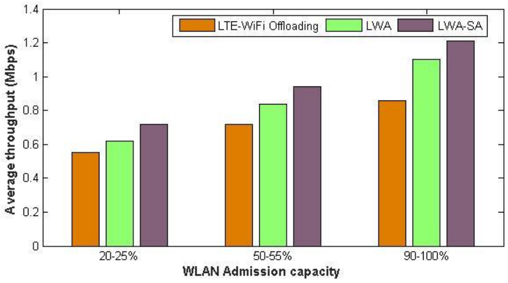

Fig. 8.UE throughput based on WLAN admissibility.

Similarly taking eNB (i.e., LTE network) load into consideration and focusing on cell edge scenarios, the relative performance of offloading approaches are shown in Fig. 9. It conveys that when the eNB is underutilized, the need to improve the QoS of UEs via offloading is less and LTE alone can provide service with tolerable QoS. As the LTE network gets over utilized, the network load goes beyond fixed load threshold and it leads to huge negative impact on cell edge users whose SINR will go below threshold. Under this condition, aggregation mechanism is very essential to boost the throughput of UE.

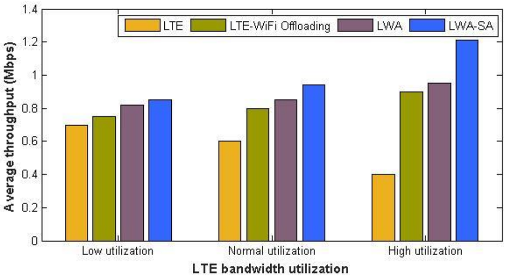

Fig. 9. Variation in UE throughput based on LTE bandwidth utilization.

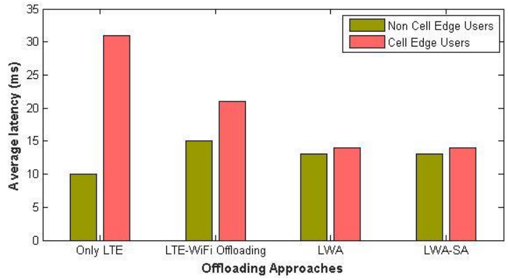

Fig. 10. Downlink latency of UE during different offloading approaches.

Downlink latency is a primary criterion that requires enough focus in case of multi-Radio Access Technology (RAT) conditions. As shown in Fig. 10, the cell edge users of LTE network experience intolerable latency unlike non cell edge users. In IoT environment, as devices to be serviced increase, the cell edge users are also expected to increase, therefore, LTE-WiFi offloading and LWA is required to reduce application service latency considerably. Our proposed LWA-SA mechanism provides equal throughput for cell edge users as achieved by non cell edge users.

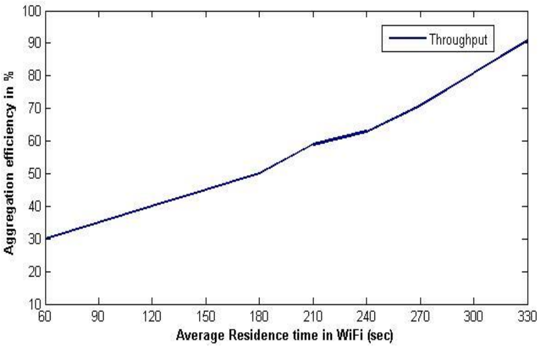

Fig. 11. Aggregation efficiency versus WiFi residence time.

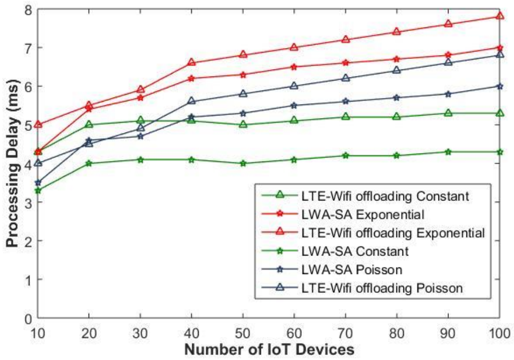

Fig. 12. Processing delay under different UE arrival rates.

Fig. 11 shows the efficiency of aggregation in relation with UE's WiFi residence time. The more the UE resides inside the WiFi coverage, higher the throughput is achieved by UE. Based on the arrival rate of users, LTE-WiFi offloading and proposed LWA-SA approach are compared in Fig. 12 where the processing delay of the IoT application is considerably minimum in LWA-SA. It also infers that under constant arrival, delay remains constant. However, with poisson and exponential arrival, delay increases.

5.1 UEs Fairness in Aggregation

We evaluate using Jain's Fairness Index (JFI) [45] with the throughput of 100 users under 'only LTE' cellular network and LWA-SA aggregation network as in [46]. In 'only LTE' network, assuming 35% of cell edge users have low radio frequency conditions, the fairness among users is not the best case. However, in case of aggregation, these 35% of users get above average throughput where all cell edge users are allocated resources fairly because of non-exhaustible bandwidth provided by unlicensed spectrum. Poor fairness is obtained in worst case where the cell edge users do not get provision to aggregate. Thus, according to JFI the worst-case fairness is $\frac{1}{n}$ where n is the number of users and the best fairness possible to be achieved is 1.

6. Conclusion and Future work

The increase in data traffic from IoT, wireless sensor and broadband mobile networks can be handled appropriately with the help of an alternate complementary network. Offloading serves a best option to handle this issue and with the help of offloading, the data traffic pressure over the LTE licensed spectrum can be significantly reduced and managed. The proposed LWA-SA mechanism removes the burden of network monitoring and management, providing seamless connection unlike UE and network centric offloading approaches. Our simulation results prove that LWA-SA aggregates data with minimal latency and avoids the occurrence of initiating aggregation frequently by selecting an optimal AP as prescribed in GA based EWS algorithm. Also, the maximum throughput attainable is formulated using Lagrange multiplier method. Hence an efficient traffic controlled and organized network is maintained by aggregating LTE and WLAN using SDN controller's intelligence and adaptability to dynamicity. Although, SDN controller's intelligence monitors the compliance nature of WiFi, it does not focus on the intelligence with respect to UE's dwell time prediction; our future work is to use intellectual and learning algorithms for UE's dwell time prediction in SDN apart from WiFi's adaptableness.

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