Velocity based Dynamic Flow Mobility in Converged LTE/Wi-Fi Networks

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Abstract—**In recent years, the boost of mobile-phones, tablets and smart devices with data-hungry applications has caused massive growth in demand of "Mobile data services" and fulfilling this demand is a very challenging task with all the available resources of cellular networks. This has brought us to the option of offloading traffic from the cellular networks to Wi-Fi networks. Offloading on Wi-Fi network for static users is comparatively easy when compared to mobile users because switching mobile users to Wi-Fi network may cause unnecessary ping-pong effect, packet loss and delay during vertical handovers. But the flow mobility solutions like PMIPv6 and DSMIPv6 provide the mechanism to offload traffic from one network to another network seamlessly and offloading is done at the granularity of flows instead of moving the entire traffic generated by the mobile user. The idea is to intelligently move certain flows onto either network so as to achieve better throughput and thereby improve the capacity of the heterogeneous network. User mobility plays a significant role while moving a flow across different networks. Generally, offloading decisions are based on signal quality and load of the networks. In this paper, we propose an integrated offloading approach, called as Velocity based Integrated Flow Mobility (VIFM), for converged LTE/Wi-Fi networks, which considers the signal quality, network load and user velocity to maximize the network performance. We studied the performance of VIFM in different scenarios using extensive NS-3 simulations and found that it reduces unnecessary flow handovers by 50% and increases the Wi-Fi network utilization by 12% when compared to previous techniques [1].**

I. Introduction

With the advent of smart-phones, tablets, laptops, etc., there has been an increase in the use of data-based services. The proliferation of applications, demand for high-quality services and extensive use of data-intensive services such as video streaming has increased the data rate requirement to an unprecedented rate. This massive increase of mobile data traffic is a serious challenge to address for telecom operators with limited radio spectrum. This encouraged data offloading to wireless networks that operate on unlicensed spectrum. The third Generation Partnership Project (3GPP) recognized the importance of 802.11 WLANs popularly known as Wi-Fi networks for offloading cellular traffic. To make offloading easy and effective, 3GPP defined various standards for integrating 3G/4G networks (i.e., UMTS and LTE) with Wi-Fi networks. As most of the smart-phones and tablets come with two radio interfaces: Cellular (3G/LTE) and Wi-Fi, the users or Mobile Nodes (MNs) are always connected to cellular network, while connection to Wi-Fi is opportunistic based on the availability of Wi-Fi Access Points (WAP). We will be using keywords, users and MNs interchangeably in this paper. In heterogeneous networks, there is either a possibility of performing vertical handover (i.e., moving all flows of the MN from one interface (network) to the other) or flow mobility (i.e., moving one or more flows from current network to the other while preserving other flows on the current network). In IP flow mobility (IFOM), a flow (typically identified by the five tuple: <protocol, source IP address, destination IP address, source port, destination port>) can be seamlessly moved from one interface to the other using IP mobility management solutions. Internet Engineering Task Force (IETF) and 3GPP standardized various such mobility management solutions which are categorized broadly as:

1) **Host-based Mobility Management (HMM):** In HMM, MN is aware of the mobility i.e., the MN takes part in the mobility signaling. Examples are MIPv6 and Dual-stack Mobile IPv6 (DSMIPv6).
2) **Network-based Mobility Management (NMM):** In NMM, MN is not aware of the mobility. All the signaling and tunneling procedures are taken care by the network entities based on observed Layer 2 (L2) triggers from the MNs (E.g., Association Request message in case of Wi-Fi networks). Examples are Proxy Mobile IPv6 (PMIPv6) and GPRS Tunneling Protocol (GTP).

While both the categories have their pros and cons, the NMM is more popular since it does not require any changes in MN protocal stack. Hence, to alleviate the mobility signaling overhead, 3GPP has adopted PMIPv6, a NMM protocol that hides the complex mobility signaling procedure from MNs by relocating it to the network. IETF is developing IFOM support in PMIPv6 so that it provides seamless handover of flows between different networks. Since PMIPv6 supports offloading traffic at the granularity of flows instead of moving the entire traffic generated by the MN, some extra factors are needed to be considered to utilize the maximum network capacity. Our main contributions in this paper are as follows:

- Investigating the performance of different available offloading schemes in converged LTE/Wi-Fi networks supported by IP flow mobility. Also, we analyze the drawbacks of these schemes in IP flow mobility when user mobility is not considered.

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- Presenting a PMIPv6 based converged framework in NS-3, to support LTE/Wi-Fi based offloading with dynamic data flow mobility.
- Proposing an integrated flow offloading approach that considers SNR, Wi-Fi load, user location and user velocity for taking offloading decisions.

Rest of the paper is organized as follows. Section II discusses about related work done in LTE-WLAN interworking, the traditional offloading approaches and their pros and cons. Section III presents proposed work and considered assumptions in current work. Section IV presents the framework created in *NS-3* simulator and required changes in current LTE *NS-3* implementation. Section V presents the experimental scenario, evaluation procedure and numerical results. Finally, Section VI contains concluding remarks.

II. Related Work

Traffic offloading from 3G/LTE to Wi-Fi is an interesting province with more insight. Many strategies were proposed for decision making in offloading. In [1], Ranjan et. al. analyzed methodologies like SNR based, load based and using Access Network Discovery and Selection Function (ANDSF) framework for Wi-Fi offloading, and proposed an integrated approach of offloading which considers both SNR and load on Wi-Fi network. Balasubramanian et. al. in [2] leveraged delay tolerance of applications and used fast switching to the context of augmenting 3G with Wi-Fi in mobile environment for three US cities. Data offloading techniques in 3GPP Rel-10 are discussed in [3]. Oliva et. al. in [4] manifested the advantages and drawbacks of both user-based and network-based approaches for flow mobility. Hagos et. al. in [5] and Andreev et. al. in [6] studied performance centric approaches like SNR based, load based and using ANDSF framework for Wi-Fi offloading.

All above studies endeavor to capture the state of the network for better offloading. An ideal offloading algorithm should maximize network utilization and ensure Quality of Service (QoS) of flows. Naive flow offloading approaches like SNR based and load based flow offloading can not take full advantage of network capacity with IFOM. In case of fixed SNR based offloading, the network remains underutilized as very few flows or users are moved to Wi-Fi networks. In case of load-based offloading, as the load varies dynamically, the frequency of switching the flows between two interfaces (networks) also increases which causes a drop in achievable throughput due to additional switching overhead. Hence, in flow mobility protocols like PMIPv6 which provides seamless flow offloading, a smart approach must be used for better utilization of network resources.

Many of the offloading strategies present in the literature ignored a crucial parameter for offloading, which is *user mobility*. The velocity of user plays a significant role to estimate the time spent by a user in Wi-Fi region. The offloaded data volume is directly proportional to duration of Wi-Fi availability. As shown in Figure 1, for a fixed distance the data offloaded to Wi-Fi network is decreasing as the speed increases because the time spent in Wi-Fi region decreases as the speed increases. Hence, ignoring the user mobility is most likely overlooking a possible enhancement factor in maximizing network utilization.

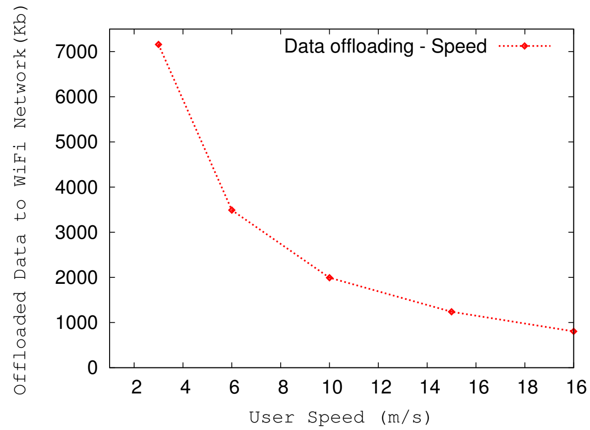

Fig. 1: Data offloaded vs User Speed

III. Proposed Work

PMIPv6 is a NMM solution which provides mobility management in a topologically localized domain, known as Localized Mobility Domain (LMD). The architecture of PMIPv6 is such that all the flows (applications) pass through the Local Mobility Anchor (LMA).

LMA is located at the Packet Gateway (P-GW) in LTE architecture and acts as the anchor to handle flow mobility for inbound flows. This centralized architecture, shown in Figure 2, allows LMA to take decisions according to the network conditions and furnishes us with application based decision-making capability. Hence, we can compare two different Radio Access Technologies (RATs) based on their characteristics and enhance the performance of the system by offloading selected to the RAT with surplus resources. Considering this aspect and multiple attributes of networks, we have designed a framework with two different RATs namely, LTE and Wi-Fi.

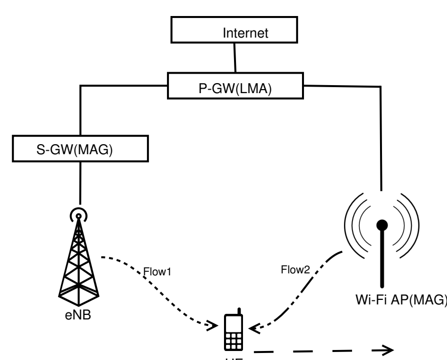

Fig. 2: PMIPv6 in Converged LTE/Wi-Fi Networks

A. WLAN Offloading Approaches

Consider a scenario where all the MNs are initially connected to the LTE network and each MN has a set of running applications. The purpose of offloading algorithm is to determine the set of MNs for which one or more flow(s) can be dissociated from the LTE network and offloaded to a suitable WAP when available. Various approaches for offloading decision are described below:

1) No Offloading to Wi-Fi: All flows of MNs are served only by the LTE network, i.e., no offloading to Wi-Fi network.

2) SNR based Flow Mobility (SFM): SNR value (a well-known measure of radio link quality) is used to determine which WAP in the Wi-Fi network can be used to offload the flows. The LMA collects SNR stats for MNs and compares them with a predefined SNR threshold (SNR_{th}). The MNs which have better SNR than the predefined threshold, switch some of the flows to the Wi-Fi network otherwise all flows continue to run on the LTE network. In case, multiple WAPs meet the SNR criteria, then the best one is chosen.

3) Load based Flow Mobility (LFM): Traffic load in a network can be used to decide whether to admit a new MN or flow into the network. The flow admission in Wi-Fi is opportunistic and therefore good SNR does not ensure good throughput all the time as the network may be overloaded. Due to this, we measure Medium Access Control (MAC)-layer throughputs of potential target WAPs over a given time interval t_{TI}. If the perceived throughput is less than the predefined load threshold ($Load_{th}$), some of the flows of MNs from the MNs are offloaded to one of the less loaded WAPs. Otherwise, all flows of MNs continue to run on the LTE network.

4) SNR-Load based Flow Mobility (SLFM): Considering both SNR and load parameters, this approach offloads flows to the Wi-Fi network when only both SNR and load conditions are met. This is more optimistic in choosing an interface which is neither heavily loaded nor suffering from poor SNR.

B. Estimating Time spent in Wi-Fi coverage

As mentioned earlier, mobility is a crucial factor which decides duration of WAP availability for users. Velocity V_t of a user is computed by taking first derivative of user position with respect to time in LTE coverage, $V_t = \frac{dp}{dt}$, where p is a position vector taken by a user. The position vector is obtained from Enhanced Serving Mobile Location Center (ESMLC), which in turn finds the MN position by a positioning technique, Observed Time Difference of Arrival (OTDOA) as specified in rel-9 [7]. Direction of user mobility is another parameter to accurately estimate the time spent by the user in Wi-Fi coverage. The direction is found by taking the difference of two latest observed user positions i.e., slope between two consecutive positions.

Linear regression technique is used to depict the path of the user. Observing past *'n'* user positions, a linear regression is formed $y = \alpha x + \beta$, where α, β depends on V_t. This line will be a chord in Wi-Fi coverage and it meets the boundary at two points. Wi-Fi coverage can be estimated using Radio Environment Map (REM). In outdoor locations, Wi-Fi coverage area can be considered in circular shape for omni-directional antennas at WAPs. We do not claim the coverage is strictly circular. In a typical outdoor environment (specifically WAP mounted on a road side pole), the coverage is expected to be circular. This work does not include beam-forming and the antenna gain is assumed to be 0 dBi.

Based on user location and direction, we estimate a line, that is supposed to be the path taken by a user in Wi-Fi. The intersection of this estimated path and the coverage area [8] can be found. Using the chord distance and user's velocity, the expected time is calculated. The velocity of user may vary over time, so the velocity ν is estimated over a fixed window of size *'s'* as in:

$$\nu = \sum_{t=1}^{s} V_t \tag{1}$$

where V_t is the instantaneous velocity of the user at time t. Expected time a user spends in Wi-Fi coverage is given by

$$ET_{Wi-Fi} = \frac{\sqrt{(Q_A - P_A)^2 + (Q_B - P_B)^2}}{\nu} \tag{2}$$

where the line meets the circle at the points (P_A, P_B) and (Q_A, Q_B).

C. Velocity based Integrated Flow Mobility (VIFM) Algorithm

To achieve maximum offloading while maintaining good user throughput, the flow offloading algorithm should consider the expected time spent by the user in WAP regions. Let us consider a scenario where a WAP is already loaded and can support only one more user with QoS guarantees but two users approach the Wi-Fi network at the same time. Which of the two users should be offloaded? Here, the user which is expected to spend more time in Wi-Fi coverage should be considered for offloading. This will increase the network utilization. Hence, the proposed VIFM algorithm, which runs at the LMA, selects user(s) with larger expected time in Wi-Fi coverage area for offloading.

The flow chart of VIFM algorithm is given in Figure 3. It includes **Expected time calculation (ETC) module** and **Flow offload decision (FOD) making module**. ETC processes MN's positions over past s observation values and finds ET_{Wi-Fi}. FOD decides number of flows from an MN to be offloaded from its LTE interface to Wi-Fi interface. FOD sorts the users based on ET_{Wi-Fi}. Number of flows for offloading is given by $NF_{of} = \lambda * N_f$, where N_f is the total number of flows at an MN. $\lambda \in$ [0 1], is an exponentially decreasing function.

For any user, if the expected time to be spent in Wi-Fi area is greater than a predefined threshold for expected time (ET_{th}), then for those users SNR is checked for making a decision. If SNR from the WAP of a chosen user is greater than SNR_{th}, then offloads NF_{of} flows on to the WAP. If SNR constraint is not met then offloads these NF_{of} flows only if the load of WAP is less than $Load_{th}$ else does not offload. This imposed condition on SNR ensures that the selected user is effectively using its Wi-Fi interface by employing higher order Modulation and Coding Scheme (MCS). If SNR condition is not checked, a user with better ET_{Wi-Fi} possibly could only employ lower MCS and end up in under utilizing the Wi-Fi network. This makes a user with better SNR (potentially high MCS) and comparatively lesser ET_{Wi-Fi} given lesser precedence.

Since VIFM processes the users in descending order of their ET_{Wi-Fi}, all the users with higher ET_{Wi-Fi} would try offloading their flows based on above conditions. For the users with ET_{Wi-Fi} less than ET_{th}, the load of WAP will be checked. If the load of WAP is lesser than $Load_{th}$, then the WAP is under utilized and could take up additional load by admitting some more flows. Therefore, it even offloads users with short stay time for increasing the network utilization.

The VIFM algorithm runs at an interval of t seconds. As the number of users in the network grows, this t can be optimally adjusted to reduce computation overhead involved. This algorithm is feasible and will work in real deployments with no modifications in MNs.

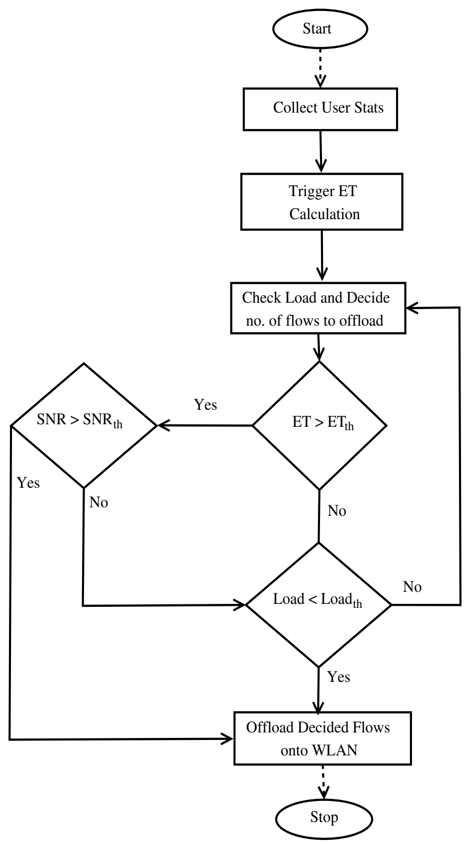

Fig. 3: Flow chart of VIFM Algorithm

D. VIFM: Time Complexity

Let there are N number of users in a converged LTE/Wi-Fi network and M users have entered Wi-Fi coverage regions, where $M \leq N$. The time complexity of VIFM algorithm is given by:

$$T(VIFM) = O(ET_{Wi-Fi}) + O(f_o) \quad (3)$$

Time complexity of expected time calculation module:

$$T(ET_{Wi-Fi}) = M \times O(s) + M \times O(1) \quad (4)$$

where s is the window size over which velocity is observed for M users. The time complexity for deciding number of flows to offload:

$$T(f_o) = M \times log(M) + O(M) \quad (5)$$

Hence, the time complexity of VIFM algorithm:

$$T(VIFM) = M \times (log(M) + O(s)) \quad (6)$$

IV. Experimental Setup in NS-3

PMIPv6 was implemented in NS-3.8 [9] and later it was ported to NS-3.12. As this implementation was not merged into the NS-3 mainline, it was not available with NS-3.19 (the latest NS-3 version available at the time of our development). NS-3 PIMPv6 only supports IPv4 type EPC. Serving Gateway (S-GW) and P-GW in NS-3 LTE system are merged in a single node. To support PMIPv6 on LTE, two basic requirements must be met:

1) Build IPv6 support for the existing LTE implementation.
2) Separate S-GW and P-GW functionalities into 2 different nodes and implement the PMIPv6 based S5 interface for connecting these nodes.

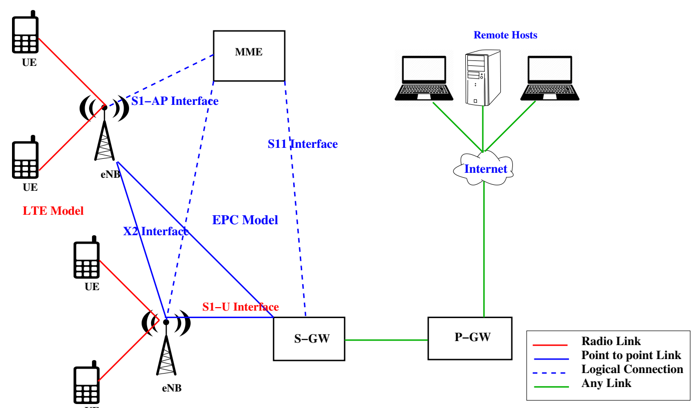

Fig. 4: Modified LTE Architecture in ns-3

We modified the LTE implementation in NS-3 [10] to satisfy these two requirements and the resulting LTE architecture is shown in Figure 4. We have built flow mobility support into PMIPv6 for LTE and Wi-Fi RATs. We assume that each MN is always connected to the LTE network and tries to form a new connection with a WAP. As shown in Figure 2, the LMA functionality is realized at the P-GW and Mobile Access Gateway (MAG) is co-located at WAPs and S-GW.

V. Simulation Setup and Results

The simulation setup consists of a Macro eNB and three operator deployed WAPs as shown in Figure 5. Simulation parameters are given in Table I. The distance between adjacent WAPs is 250 meters. We are considering operator deployed WAPs as it is NMM framework and offloading decisions are taken at the LMA. We are considering a road model where

TABLE I: Simulation Parameters

Parameter	Value
LTE Scheduler	Proportional Fair Scheduler
Number of Resource Blocks	25
Min distance travel by User	1000m
MN Speeds	3km/h, 30km/h, 60km/h
SNR Threshold, SNR_{th}	(40dB)
Load Threshold, $Load_{th}$	(80%)
Time Interval, t_{TI}	(1 second)
Wi-Fi standard	802.11g
Simulation duration	1000 seconds

WAPs are deployed on the side of the road and users are moving at different speeds on a fixed path. In this setup, we considered two scenarios: medium user density (36 users) and high user density (54 users). In each scenario, the equal number of users with three different speeds (3km/h, 30km/h and 60km/h - specified by 3GPP) are considered. Each user has two TCP flows running throughout the simulation duration. The scenario depicted here generally exists in cities where the traffic flow and user movement could be predictable. Hence, at the LMA after finding user location and its velocity, it calculates the time that user is expected to spend in Wi-Fi coverage area.

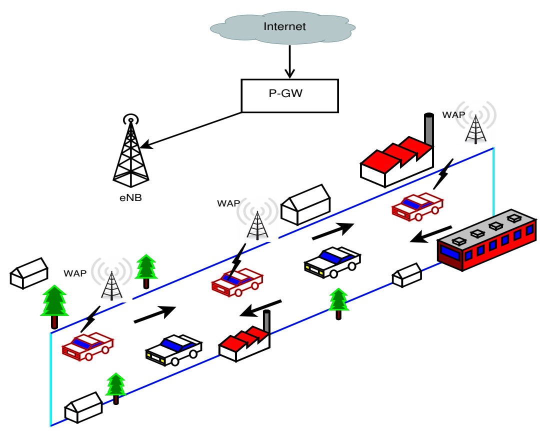

Fig. 5: Experimental Scenario

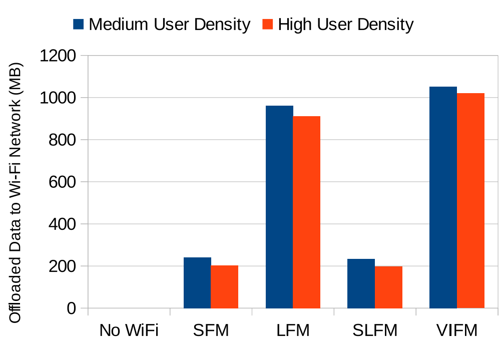

Fig. 6: Amount of Data Offloaded to Wi-Fi in different Flow Offloading Schemes

A. *Performance of SFM*

When a flow is moved from LTE to Wi-Fi network and back to LTE network, in-sequence TCP packet delivery can get affected as the delay and data rate over LTE and Wi-Fi networks are different. If Wi-Fi network is loaded then packets could even get lost due to collisions. Hence, throughput of the system gets affected. It means even in seamless handovers with flow mobility, there is a handover cost. SFM does not consider current network conditions which change frequently and there is no dynamic offloading which reacts to that. It may cause a high loss because of blind offloading, which makes Wi-Fi network heavily loaded when large number of users are moved to Wi-Fi network. Also, the SNR threshold bound may limit the number of users offloaded to Wi-Fi, which may result in very few users offloaded to Wi-Fi network. This causes under-utilization of the network as shown in Figure 6. In this case very less data is offloaded to the Wi-Fi network.

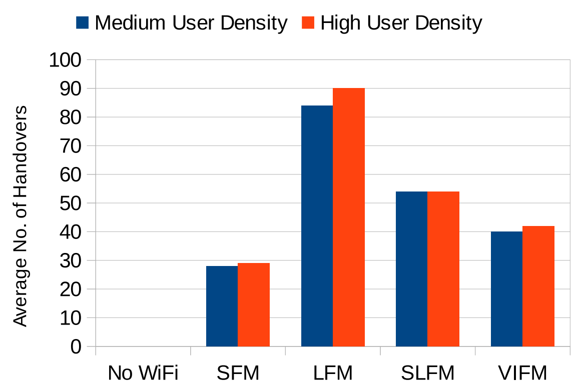

Fig. 7: Average no. of Handovers in different Flow Offloading Schemes

B. *Performance of LFM and SLFM*

LFM dynamically moves users from one network to another as the load changes. This action leads to higher number of handovers as shown in Figure 7. The average number of flow handovers between LTE and Wi-Fi network as shown in Figure 7 exhibits that in SFM very less flows are offloaded to Wi-Fi compared to LFM. In LFM, flows keep moving from one network to another as the load changes which shows high number of handovers. This handover is accompanied by a loss in throughput. Since LFM is only based on the network load, users with less SNR will also be offloaded into Wi-Fi network, which leads to inefficient use of Wi-Fi (because less SNR users get comparatively less benefit in terms of the throughput). SLFM moves users based on both SNR and load constraints which make only very few users to meet the requirement to offload their flows. This results in under utilization of the network (refer Figure 6), which in turn reflects in less throughput as shown in Figure 8. SLFM also has comparatively more handovers than SFM (refer Figure 7). This is because a user which has met SNR_{th} in Wi-Fi coverage will be subjected to move its flow back to LTE when the Wi-Fi load increases.

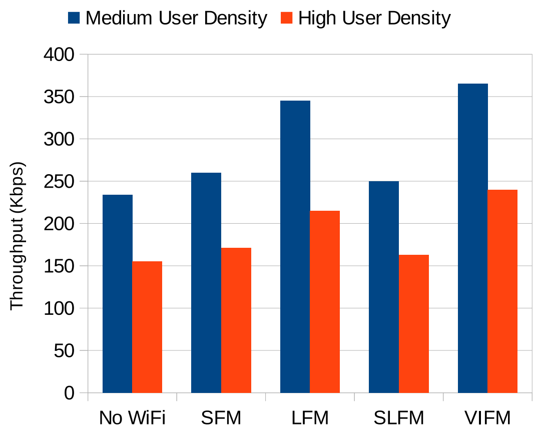

Fig. 8: Per Flow Throughput in different Flow Offloading Schemes

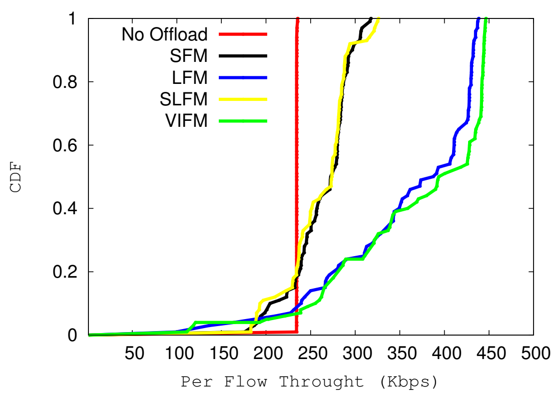

Fig. 9: CDF of Flow Throughput for Medium User Density

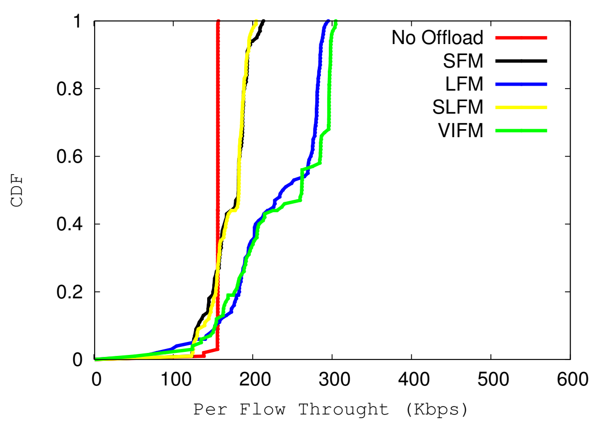

Fig. 10: CDF of Flow Throughput for High User Density

C. *Performance evaluation of VIFM*

VIFM performs flow offloading considering estimated stay time in Wi-Fi coverage as the reflection of user mobility, SNR and network load. Hence, in the VIFM, the users who are expected to spend more time in Wi-Fi network are handled according to load based scheme until they reach the SNR limit. Once the SNR crosses SNR_{th}, they are treated like in SFM. This removes the under-utilization experienced in SNR based scheme. Also it decreases the number of handovers caused in LFM, because not all the users will be switching their network according to the network load, as shown in Figure 7. As the number of flows to offload is decided according to the network load, throughput of other flows will not get affected. Because of this integrated approach to flow mobility, the amount of data offloaded to Wi-Fi network increases as shown in Figure 6 by 12% compared to LFM. VIFM achieves better utilization of network capacity and therefore gives better per flow throughput as shown in Figure 8.

Figures 9 and 10 show Cumulative Distribution Function (CDF) of user throughput for medium and higher user density scenarios, respectively. A common feature in both plots is that more than 60% of flows enjoy better throughput in VIFM compared to other offloading schemes.

VI. Conclusions

Proposed VIFM scheme prevents unnecessary offloading of flows to Wi-Fi network in converged LTE/Wi-Fi networks by considering velocity of the users which is used to estimate stay time of users in Wi-Fi coverage area. It reduced the number of offloaded flows by 50% compared to LFM scheme. It increased the utilization of Wi-Fi network by 12% compared to that in LFM by performing efficient flow offloading.

VII. Acknowledgment

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References

[1] S. Ranjan, N. Akhtar, M. Mehta, and A. Karandikar, “User-based integrated offloading approach for 3gpp lte-wlan network,” in *20th National Conference on Communications(NCC)*. IEEE, 2014, pp. 1–6.

[2] A. Balasubramanian, R. Mahajan, and A. Venkataramani, “Augmenting mobile 3g using wifi,” in *Proceedings of the 8th international conference on mobile systems,applications and services*. ACM, 2010, pp. 209–222.

[3] C. Sankaran, “Data offloading techniques in 3gpp r-10 networks:a tutorial,” *Communications Magazine, IEEE*, vol. 50, no. 6, pp. 46–53, 2012.

[4] A. De la Oliva, C. J. Bernardos, M. Calderon, T. Melia, and J. C. Zuniga, “Ip flow mobility: smart traffic offload for future wireless networks,” *Communications Magazine, IEEE*, vol. 49, no. 10, pp. 124–132, 2011.

[5] D. H. Hagos and R. Kapitza, “Study on performance-centric offload strategies for lte networks,” in *6th Joint IFIP Wireless and Mobile Networking Conference (WMNC)*. IEEE, 2013, pp. 1–10.

[6] S. Andreev, M. Gerasimenko, O. Galinina, Y. Koucheryavy, N. Himayat, S.-P. Yeh, and S. Talwar, “Intelligent access network selection in converged multi-radio heterogeneous networks,” *Wireless Communications, IEEE*, vol. 21, no. 6, pp. 86–96, 2014.

[7] “3gpp ts 36.355: Evolved universal terrestrial radio access (e-utra), lte positioning protocol (lpp).”

[8] line-cicle intersection. [Online]. Available: http://mathworld.wolfram.com/Circle-LineIntersection.html

[9] H.-Y. Choi, S.-G. Min, Y.-H. Han, J. Park, and H. Kim, “Implementation and evaluation of pmipv6 in ns-3 network simulator,” in *Proceedings of the 5th International Conference on Ubiquitous Information Technologies and Applications (CUTE)*. IEEE, 2010, pp. 1–6.

[10] NS-3 LTE Documentation. [Online]. Available: https://www.nsnam.org/docs/models/html/lte-design.html