HOF: A History-based Offloading Framework for LTE Networks using Mobile Small cells and Wi-Fi

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Abstract— **Small cell deployments are seen as a promising solution for mobile operators due to their potential to improve coverage and increase capacity for indoor areas in a cost-efficient way. Meanwhile, other deployment scenarios are also being sought, such as in public transportation vehicles including buses and streetcars. In this paper, we propose a novel History-based Offloading Framework (HOF) to relieve overburdened macro networks from data traffic generated by mobile users in public transportation vehicles by utilizing small cells and Wi-Fi networks. A small base station (SBS) is installed onboard the vehicle; called a mobile SBS (mobSBS). Mobile users communicate with the mobSBS instead of the distant Macro base station (macroBS). In order to have efficient offloading in terms of bandwidth utilization, mobile data users are prioritized according to different pre-set classes. Our framework takes into account the mobile user's priority and service history to alleviate the effects of non-incessant Wi-Fi availability in order to maximize the offloaded macrocell data traffic. Extensive simulation results have shown that our proposed framework is highly effective in terms of the average offloaded macroBSs data traffic and the total count of offloaded users from the macroBSs.**

Keywords- mobile small cell; Wi-Fi; service history; mobile data traffic; offloaded traffic.

I. INTRODUCTION

Mobile operators are currently struggling to cope with the high demands on capacity and coverage. This is due to a number of reasons. First, global mobile data traffic is growing in a massive way. Cisco® indicates in its Global Visual Networking Index (VNI) that mobile data traffic grew 70% in 2012 alone. This is driven by data-hungry applications, such as online gaming, video streaming, social networks, etc. [1]. Second, the number of mobile devices is exponentially growing and already exceeds our world's population and the number of devices connected to the Internet is significantly increasing [1]. Third, many mobile operators now offer flat-rate (unlimited) data plans, which allows mobile devices to be a part of our daily life everywhere. Hence, several offloading solutions have been proposed to handle this explosive data traffic from mobile networks, such as Long Term Evolution (LTE). For example: installing more base stations, deploying heterogeneous networks with Wireless Fidelity (Wi-Fi) for dual-mode devices (two wireless access networks), etc. However, small cells and Wi-Fi networks have drawn significant attention from mobile operators due to their potential to improve indoor coverage and capacity and offloading traffic from macrocells in a cost-effective manner.

Small cells are cellular coverage areas that are served by small base stations (SBSs) and typically intended for indoor deployment. An SBS is a fully featured low-power mini base station that is typically backhauled to the operator's core network (CN) by an Internet connection (such as DSL, Cables, etc.) [2] [2]. Small cell deployments offer enhanced capacity, improved coverage and increase macrocells offloading [3]. Small cell deployments include femtocells for residential settings, metrocells for outdoor areas [4]. Due to the many advantages of small cells, mobile operators are now interested in small cell deployments. The total number of already deployed small cells has exceeded the total number of macrocells [4]. Yet, other deployment scenarios are also being sought, such as deploying in public transportation vehicles including buses and streetcars.

In this paper, we propose an efficient History-based Offloading Framework (HOF) to relieve macro networks from data traffic generated by mobile users in public transportation vehicles. We propose to deploy SBSs onboard vehicles, thereafter called mobile SBS (mobSBS). Each mobSBS has Wi-Fi antenna(s) installed on the roof of the vehicle to utilize city-wide Wi-Fi coverage (which currently exists in numerous urban centres [5]) as its backhaul. Therefore routing mobile data traffic to the operator's CN through Wi-Fi to relieve overloaded macro networks. Moreover, we take into account the mobile user's service history and Wi-Fi availability time (WAT) to efficiently offload the most suitable mobile users to the mobSBS. WAT represents the time duration in which there will be Wi-Fi coverage for mobSBSs. This parameter can be predicted based on the mobSBS location and the predefined Wi-Fi hotspot locations [5]. This is very important where Wi-Fi coverage is good but not complete.

The objective is to maximize the number of offloaded mobile users and to increase the amount of data traffic offloaded from macrocells while maintaining efficient macroBSs and mobSBSs utilizations. This is achieved through adapting a history-based approach that reduces offloading demands overhead caused by non-incessant Wi-Fi coverage. Simulation results show that our framework is able to achieve the aforementioned objectives by boosting the amount of offloaded data traffic from the macrocells while maintaining appropriate levels of macroBSs and mobSBSs utilizations. In addition, it shows a significant enhancement in terms of total offloaded traffic in comparison to typical offloading approaches where user service history is ignored.

The remainder of this paper is organized as follows. Section II provides the related work and background to the capacity and coverage issues of small cells and Wi-Fi utilization. In Section III, we represent the system model. We show our proposed framework, its components and its operational stages in Section IV. Section V presents the performance evaluation including our simulation setup and experiment design. Lastly, Section VI presents our conclusions.

II. BACKGROUND AND RELATED WORK

Most mobile operators have announced they will (many already started to) implement mobile data offloading solutions in their networks [6]. Generally, small cells and Wi-Fi have been considered as the two prominent data offloading solutions for mobile operators.

Mobile small cell deployments have recently been introduced by several researchers as coverage extension solution in vehicles [7], [8]. The difference between small cell and mobile small cell is the backhaul; mobile small cells use Wi-Fi, satellites, and mostly macroBSs, whereas, small cells use an Internet connection from a cable or a digital subscriber line (DSL). With mobSBSs the amount of data traffic that goes through macroBS is reduced because mobSBSs communicate with the operator's CN through the macroBS.

On the other hand, Wi-Fi technology is getting more and more engaged in the mobile industry. Nowadays there are a large number of Wi-Fi carriers (such as Boingo® wireless) that provide coverage and hotspots in different areas, such as downtowns, public areas. Also, numerous mobile operators have included Wi-Fi hotspots as part of their networks, such as Verizon wireless in the USA. Thus, city-wide Wi-Fi deployments cover numerous cities over the world [5]. The most recent IEEE 802.11a/c standards and next generation hotspots of Wi-Fi enable secure communication and seamless switching between different Access Points (APs).

However, there are limitations for using Wi-Fi directly with cellular networks including:

- Swapping between cellular and Wi-Fi networks is not currently seamless for mobile devices.
- The need for dual-mode devices, hence backward compatibility with legacy mobile devices is infeasible.
- Mobile users would need to subscribe to two plans, one for the mobile network and another for the Wi-Fi carrier, if not provided by the mobile operators.
- Communication through Wi-Fi typically consumes more power than cellular communication; therefore, battery life becomes a serious concern.

The authors in [9] study the feasibility of using long range Wi-Fi as a backhaul for fixed femtocells in rural areas. They show that this solution can reduce deployment and operational expenditures for mobile operators in rural areas. The survey presented in [10] stresses the utility of Wi-Fi as a backhaul for BSs in the mobile networks. The scheme proposed in [11] is the first and only work on data traffic offloading for macrocells by utilizing mobSBS, installed in public transportation vehicles, and Wi-Fi networks. Mobile small cells use Wi-Fi coverage as backhaul. The offloading process is based on the priority of the data applications. If there is enough bandwidth to accommodate, mobile data users will be offloaded. However, this approach is intended for areas with continuous Wi-Fi coverage.

Although there are a numerous Wi-Fi hotspots, these hotspots offer good, but not complete coverage. Our History-based Offloading Framework (HOF) exploits non-incessant Wi-Fi coverage in cities. Our model builds on an already established urban network of Wi-Fi hotspots, and funnels mobile-demand for cellular communication through them.

III. SYSTEM MODEL

In this section we present our network model and underlying assumptions. Without loss of generality, we assume that a prevailing abundance of Wi-Fi connectivity will facilitate utilization of HOF.

A. Network Model

We consider a Long Term Evolution (LTE) network with downlink (DL) transmission in an urban area with N Macro Base Station (macroBS) represented by the set $M = \{m_1, m_2, \dots, m_n\}$ as shown in Figure 1. Each $m_i \in M$ serves a macrocell. We also consider a set of L mobile small BSs (mobSBSs) represented by $S = \{s_1, s_2, \dots, s_L\}$. Each $s_j \in S$ is deployed in a public transportation vehicle (e.g. bus) to provide onboard cellular coverage, to offload

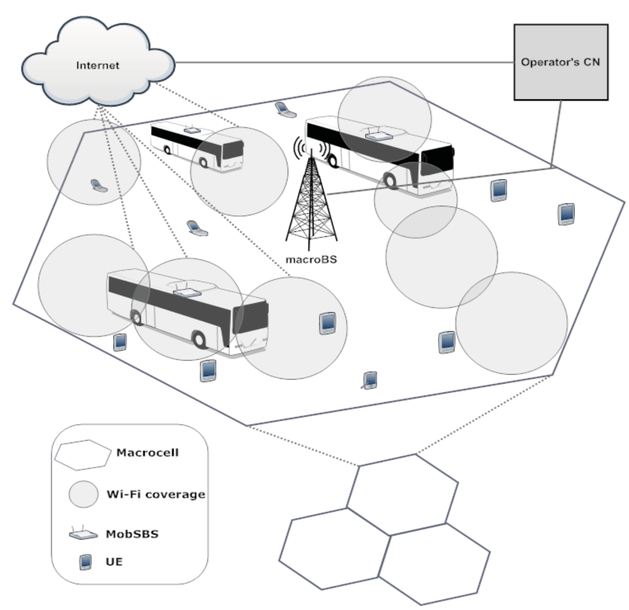

Fig. 1. Mobile small cells utilizing Wi-Fi Overview

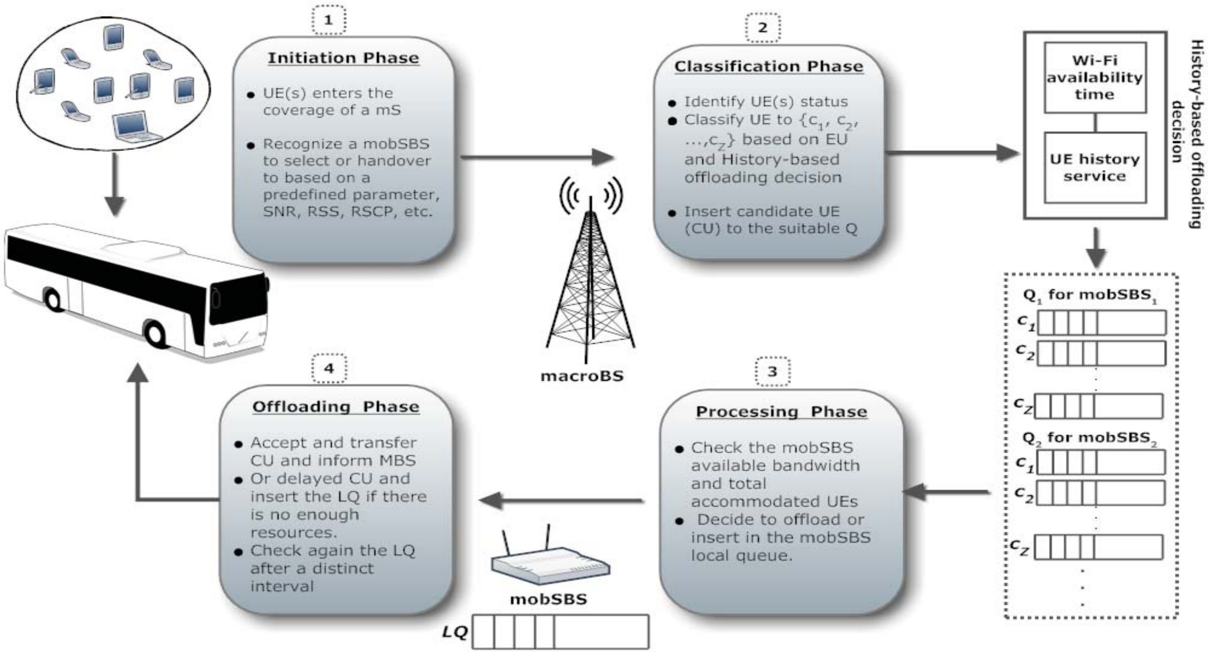

Fig. 2. The HOF Operational Stages

data traffic originated by UEs on the go. We define a set of K User Equipments (UEs), $U = \{u_0, u_1, \cdots, u_K\}$, where $u_q \in U$. In order to reflect practical ongoing traffic generated by UEs, we assume that the inter-arrival time of UE follows a Poisson distribution, with an average arrival rate of λ [11]. The onboard UEs communicate directly with the mobSBS through LTE access. The mobSBS routes the traffic to the operator's CN through a Wi-Fi transmitter mounted on the roof of the vehicle. We also classify a set of data classes $C = \{c_0, c, \cdots, c_Z\}$, where c_t is the t^{th} data class and Z is the total number of data classes. ω_t denotes the bandwidth allocated for each data class c_t, and $\omega = \{\omega_0, \omega_1, \cdots, \omega_Z\}$.

B. Assumptions

The mobSBSs are to be deployed by the mobile operator in an open access manner. MacroBSs should be aware of the mobSBSs and their associated UEs. Each mobSBS has its own physical cell-ID, so it appears to the UE as a different BS than the macroBS. Hence, the UE receives scheduling information and feedback directly from the mobSBS and sends its control channel to the mobSBS. The mobSBS transmits information and reference symbols on its own control channels to the CN through the Wi-Fi.

Mobile small cells deal with other different deployment aspects, e.g., frequency allocation, handover process of the attached group of UEs and wireless backhaul link with macroBSs. These deployment aspects are beyond the scope of this work. Currently, there are two common approaches that have been used for allocating frequency for both small cells and macrocells. The first approach adopts dedicated frequencies, where small cells are assigned separate frequency bands than macrocells [12][13]. This approach eliminates frequency interference between macrocells and small cells. The second approach adopts a shared frequency, where small cells and macrocells share the same frequency bands. The former approach, adopted in this paper, suits mobile small cells as they are constantly moving and crossing different macrocells, which eliminates frequency interference.

IV. History-based Offloading Framework (HOF): Components and Operational Phases

The History-based Offloading Framework (HOF) allows mobile operators to offload a portion of data traffic from the overburdened macrocells to the mobSBSs installed in public transportation vehicles. mobSBSs offer cellular coverage, as any regular BS, for the UEs onboard. The mobSBS is connected to a power source and Wi-Fi transmitter(s) that is installed on the roof of the vehicle. This Wi-Fi transmitter(s) provides the backhaul for the mobSBS by connecting to urban Wi-Fi APs. The mobSBSs access the Wi-Fi hotspots as opposed to each user individually. Hence, there is no need for users to have dual-mode access which makes it easier in terms of managing, billing, security, etc. We adopt a history-based approach to:

- Reduce overhead of offloading traffic demands that cannot be met with non-incessant Wi-Fi coverage.
- Use mobile user's previous usage history of such service to predict to offload or not to offload, this makes the offloading process more efficient.

In this section, we represent the components and the operational stages of the proposed offloading framework.

A. Components

Our framework is based on the following components:

- Macro BSs (macroBSs): regular BSs that already exist in any cellular network (LTE).

- Mobile SBSs (mobSBSs): regular SBSs installed onboard vehicles. They are registered in all Wi-Fi APs. The mobSBSs have preemptive priority in accessing roadside Wi-Fi APs.
- User Equipment (UE): could be any device that has cellular access interface (e.g. cell phone, smartphone, laptop, etc.).
- Wi-Fi Antenna(s)/Access Points (APs): Wi-Fi antenna(s) mounted on the roof of the vehicle to backhauled the mobSBSs to the operator's CN. The Wi-Fi antenna(s) communicate with say a city-wide APs on the roads to provide Internet to the mobSBSs.

B. *HOF Operational Phases*

The proposed HOF has four main phases, as shown in Figure 2: (1) Initiation phase, (2) Classification phase, (3) Processing phase and (4) Offloading phase.

1) *Initiation Phase*

When a u_q(s) enters a vehicle, the UE senses a mobSBS (s_j) and report the cell-id to the serving macroBS (m_i) to be switched to or to select the s_j as serving BS. These handover/selection procedures could be initiated based on different parameters, including but not limited to: a predefined condition by the operator [14], signal to noise ratio (SNR), received strength signal (RSS), and received signal code power (RSCP).

2) *Classification Phase*

After a macroBS (m_i) receives a u_q request, it checks the u_q status. The UE status is idle when the UE has no ongoing session or active when the UE has an ongoing voice call or data session. In our framework, we only aim to offload the active UE data session, as idle UE and a UE voice call do not consume enough resource and power from the macro networks to be of any concern. u_q data sessions classify into different data classes (C) based on the application requirements. Following, u_q assigned to a set of candidate UE (CU_j) to be offloaded to the s_j. After which it checks the Wi-Fi availability time (WAT_j) at this location and compares it with the average service history usage time (at_t) for the same data class c_t. The m_i then calculates the Effective Utilization (EU) ratio (as in Eq. 1) for each UE in the CU_j. Further, the m_i will insert each UE in CU_j into the target s_j's queue (Q_j) based on the EU ratio. The UE with the higher EU ratio will be given a higher priority to be offloaded to the mobSBS. There is a queue for each data class type (as shown in Figure 2). In the 3GPP standard [15], there is a queue for each UE in the macroBS; we make use of these queues for mobSBSs.

3) *Processing Phase*

The mobSBS s_j checks its queue on the macroBS (m_i) periodically to start offloading CU_j based on two conditions. First the current number of UE (sU_j) which are connected to a s_j should be less than the maximum number of UEs (sU_max_j) that s_j can accommodate simultaneously. Second, the current used bandwidth (sUB_j) of s_j in addition to the requested bandwidth (ω_t) should be less or equal to the available bandwidth of the s_j (sB_j). Once these two conditions are met, the s_j accepts CU_j, then increases the sU_j and inform m_i. Otherwise, the CU_j is inserted (delayed) in the s_j local queue (LQ_j).

4) *Offloading Phase*

The m_i will transfer the accepted CU_j to the s_j and update the queues. The LQ_j will be checked after an interval and based on the bandwidth available due to time completion of previously offloaded users. There are some cases where Wi-Fi signal strength degrades below a certain threshold. In this case, the s_j asks the m_i to transfer the set of its associated users.

C. *History-based Approach*

We consider the history-based approach in order to maximize the offloading efficiency. The history-based approach is achieved by considering each user service history and the correspondent WAT_j of a vehicle equipped with an s_j. We utilize the user profile that in the network [16], as it contains the service history. Each user will have a log file that contains all previous usages. The proposed history-based approach decides the offloading of users based on their current request and their previous history usage time (at_t) with the same type of data class (c_t) which leads to more UEs being offloaded in a certain instance of time (this history lists the previous usage time, in seconds, for each data usage type). We integrate these components together to choose UE(s) that are most useful to be offloaded via the Effective Utilization (EU) equation as follows

$$EU = \frac{c_t}{at_t} \Big/ \frac{sB_j}{WAT_j} \quad (1)$$

Algorithm 1 represents the ***Classification*** phase at macroBS (m_i). When a trigger condition is satisfied, the serving m_i checks the u_q status as indicated in lines 1-5. If u_q status is active with data, m_i assigns to the set of candidate UEs (CU_j) to be offloaded to the s_j as indicated in line 7. Then, the m_i classifies the CU_j into different data classes c_t and returns the associated data class. As a result, a c_t will be associated with each UE in CU_j as indicated in lines 8. WiFi-availability time (WAT_j) is checked and compared to the at_t of the same data class requested as in lines 9-10. m_i calculates the EU of each UE individually and then insert the CU_j into the Q_j based on the EU as indicated in lines 11-12. Finally, m_i calls the function ***Processing*** as indicated in line 13. The overall complexity of Algorithm 1 is *O(n).*

Algorithm 1: ***Classification*** **at MacroBS** $\boldsymbol{m_i}$

Input: $\boldsymbol{u_q}$, $\boldsymbol{s_j}$
Output: $\boldsymbol{Q_j}$
Check $\boldsymbol{u_q}$ status
If $\boldsymbol{u_q}$ is idle **then**
  Ignore //i.e. keep connected to $\boldsymbol{m_i}$
Else If $\boldsymbol{u_q}$ has voice call **then**
  Ignore //i.e. keep connected to $\boldsymbol{m_i}$
Else
  Assign $\boldsymbol{u_q}$ to $\boldsymbol{CU_j}$
  $\boldsymbol{c_t}$ = Classify ($\boldsymbol{CU_j}$)
  $\boldsymbol{WAT_j}$= Check WiFi-availability time
  If $\boldsymbol{WAT_j} \geq \boldsymbol{at_t}$ **then**
    Calculate $\boldsymbol{EU}$ // based on eq. (1)
    Insert $\boldsymbol{CU_j}$ in $\boldsymbol{Q_j}$
    Processing ($\boldsymbol{s_j}$, $\boldsymbol{Q_j}$)
  Else
    Keep connected to $\boldsymbol{m_i}$
  Endif
Endif
Endif
End

Algorithm 2: ***Processing at mobile*** **SBS** $\boldsymbol{s_j}$

Input: $\boldsymbol{Q_j}$
Output: Accept, Delay
Initialize:
$\boldsymbol{sU_j}$ //current total number of UEs of $\boldsymbol{s_j}$
$\boldsymbol{sU\_max_j}$ // maximum number of UEs can be served by $\boldsymbol{s_j}$
$\boldsymbol{sB_j}$ // available bandwidth to $\boldsymbol{s_j}$
$\boldsymbol{sUB_j}$ // current used bandwidth
1: Check ($\boldsymbol{Q_j}$)
2: **If** $\boldsymbol{sU_j} < \boldsymbol{sU\_max_j}$ and $\boldsymbol{sUB_j} + \boldsymbol{\omega_t} \leq \boldsymbol{sB_j}$
3:   Accept to transfer $\boldsymbol{CU_j}$
4:   $\boldsymbol{sB_j} = \boldsymbol{sUB_j} + \boldsymbol{\omega_t}$
5:   $\boldsymbol{sU_j}++$
6: **Else**
7:   Insert $\boldsymbol{CU_j}$ in $\boldsymbol{QL_j}$ //delay
8: **Endif**
9: **If** degradation **then**
10:   Trigger to transfer $\{sU_j\}$ to current m_i
11: **Endif**
12: **End**

s_j decides to accept or to delay CU_j based on the *Processing* function detailed in Algorithm 2. s_j checks its Q_j in the m_i as in line 1. s_j checks its availability bandwidth and total number of accommodated UEs as indicated in line 2. If s_j chooses to accommodate CU_j, it informs the serving m_i to transfer the data session of CU_j(as in line 3). s_j then updates sUB_j and $\boldsymbol{sU_j}$, (lines 4-5). If s_j decides not to transfer CU_j, it puts CU_j into its LQ_j as indicated in line 7. Finally, if the Wi-Fi signal strength degrades below a certain threshold, s_j asks to transfer its set of UEs $\{\boldsymbol{sU_j}\}$ to m_i as indicated in lines 9-10. The overall complexity of Algorithm 2 is *O(n)*.

V. Performance Evaluation

In this section, we evaluate the performance gains of the proposed HOF approach. We compare HOF to the offloading framework proposed in [17]. Hereafter, we refer to it as Non-History-Based Framework (NHOF). We consider the NHOF approach as a baseline to the proposed HOF scheme due to its efficiency in offloading data traffic from the macroBS while considering Wi-Fi coverage in similar settings [11]. HOF and NHOF are simulated using MATLAB R2009a. To assess the performance of the two approaches, the following metrics are used:

1) Offloaded users: this metric represents the percentage of offloaded UEs from a single macroBS.
2) Average offloaded traffic: this metric represents the total offloaded data traffic from macroBS to a mobSBS and measured in (*Mbits/sec*).
3) Macro load: this metric represents the percentage of the current traffic load on a single macroBS.

While studying these performance metrics, two parameters are varied: 1) Number of UEs, and 2) Time intervals, which represent the simulation time steps per which random UEs/requests are generated during the simulation lifetime.. In the following, we discuss our simulation setup and results.

A. Simulation Setup

We construct a packet-level simulator that allows us to observe and measure the performance of both approaches under a variety of conditions. The simulation is divided into 10 time intervals at which a number of UEs will be randomly generated with the status weights shown in Table I. Based on real outdoor scenarios, the aforementioned system model parameters are set as shown in Table I, as well. A single mobSBS is assumed to be deployed in each bus. We consider three data classes for offloading in a hierarchical manner with video highest priority, VoIP as second priority, and HTTP with the least priority. At the beginning of the simulation, a random history for every UE is generated. As simulation progresses over time intervals, each UE's service history is constantly updated with the user's previously spent amount of time on a service and the current time for which it was offloaded to the mobSBS. Non offloaded UEs will be kept in local queue at the mobSBS, where the mobSBS bandwidth will be checked at specific times to offload the delayed UEs in the queue.

B. Simulation Results

We focus our offloading problem observations on three core system components: 1) the offloaded traffic, 2) the utilized Mobile SBS, and 3) the macroBS utilization.

1) *Offloaded Traffic*

Here we examine the efficiency of the proposed HOF in terms of offloaded traffic in macro network where mobSBSs

TABLE I. SIMULATION PARAMETERS

Parameter	Value
N	3
L	10
K	500
Total simulation time intervals	10
Minimum DL bandwidth ($\boldsymbol{\omega_t}$) for: C_1 (HTTP) C_2 (VoIP) C_3 (Video)	 80 Kbits/sec 100 Kbits/sec 500 Kbits/sec
User status distribution (%): Idle Voice HTTP VoIP Video	 5% 5% 25% 25% 40%
sB_j	5 Mbits/sec (Minimum)
MacroBS bandwidth	80 Mbits/sec
sU_max_j	30

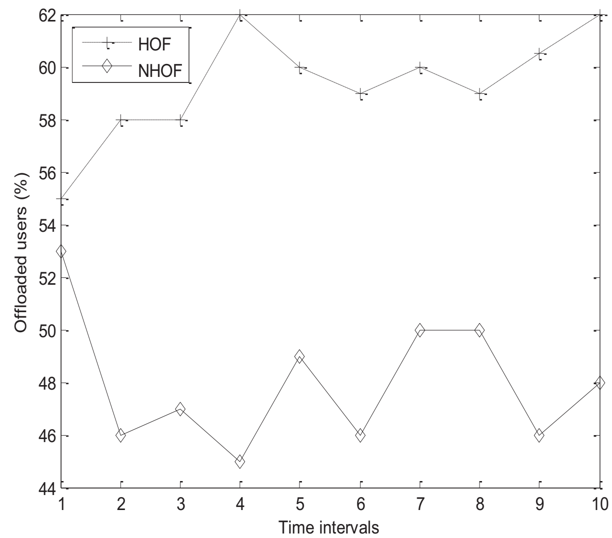

Fig. 3. Total number of offloaded UE vs. time intervals.

are used. According to Fig. 3, both approaches (HOF and NHOF) start at approximately the same level of offloaded UEs. However, due to ignoring the requested service history per UE in the NHOF approach, the majority of offloaded UEs are kept at the macroBS. HOF clearly outperforms NHOF as simulation time progresses. Also, at the middle time interval (interval 4), we notice that there is a rise in the offloaded UEs while applying HOF because most of the UEs have used up their service time. Afterwards, HOF curve stabilizes with a 14% enhancement over NHOF.

2) *Mobile SBS Utilization*

Here we take into account the effect of considering the user's service history and the non-incessant Wi-Fi availability on the overall mobSBS utilization. MobSBS utilization is calculated after every time interval in our simulation. Based on Fig. 4 both approaches tend to keep the mobSBS utilized to its maximum capacity. However, the history-based queuing in HOF represents an important feature in addressing more users as compared to the NHOF approach. At each time interval the mobSBS check the local queue to offload the delayed users. While in the NHOF approach, users are rejected and the system has to wait for the current time interval to end before considering any new user. Moreover, based on Fig. 4, we notice that the utilization in both approaches are monotonically increasing as the number of UEs increases. However, this increment continues for HOF and stops for NHOF after reaching a specific UEs count (400). This can be attributed to the utilized mobSBS queue in HOF. Consequently, NHOF reaches its saturation and cannot compensate more bandwidth for mobSBS, whereas HOF chooses the most suitable candidates for offloading, and thus, more users are offloaded during sub intervals.

3) *MacroBS Utilization*

Finally, we examine the macroBS utilization, which has a major effect on the overall cellular network performance, while considering each UE service history. In Fig. 5, mobSBS offloaded traffic is calculated every time interval; and its impact on the macroBS is analyzed while applying both approaches: HOF and NHOF. Over the simulation lifetime, mostly, NHOF maintains a higher macro load (around 18-19% of the original traffic), whereas HOF maintains a reduced macro load that can reach 20% lower than NHOF over the simulation time. Another macro load assessment is carried out through varying counts of users in Fig. 6. For small number of users (~100-200), the difference between macro loads while applying NHOF and HOF is not extraordinary. Nevertheless, as the total count of users increases, HOF shows a significant reduction in the macro load in comparison to NHOF. This is due to the history-based offloading, where the delayed users in the queue are reconsidered.

VI. CONCLUSION

Small cells and Wi-Fi networks are seen as promising solutions to enhancing coverage and capacity, and offloading traffic in currently overburdened mobile networks. In this paper, we propose a data offloading framework for mobile operators by utilizing mobile small cells and Wi-Fi. Our proposed framework utilizes a non-continuous city-wide Wi-Fi as a backhaul for mobSBSs installed in public transportation vehicles to relieve macro networks. Taking into account the mobile user's service history and Wi-Fi availability time to either offload or delay users offload, leads to a significant increase in the offloaded data. Our simulation results show that our proposed History--based offloading framework (HOF) is highly effective in terms of: 1) the amount of offloaded traffic, 2) the mobSBS utilization, and 3) the macroBS utilization. Also, it shows a significant enhancement in terms of total offloaded traffic in comparison to non-history based offloading approaches. The enhancement can reach 20% more offloaded traffic over the non-history based approach.

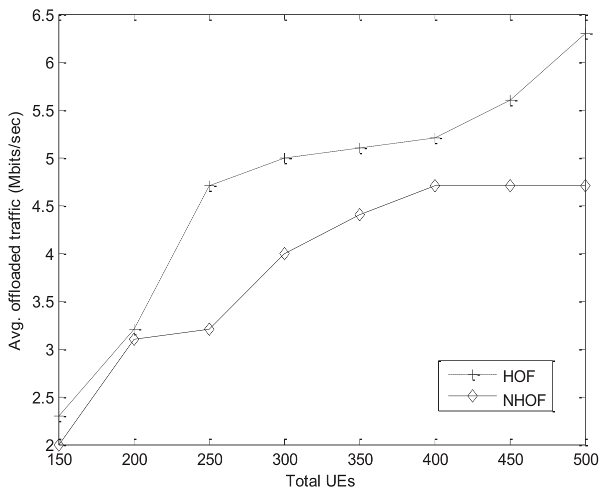

Fig. 4. Avg. offloaded traffic vs. total UEs.

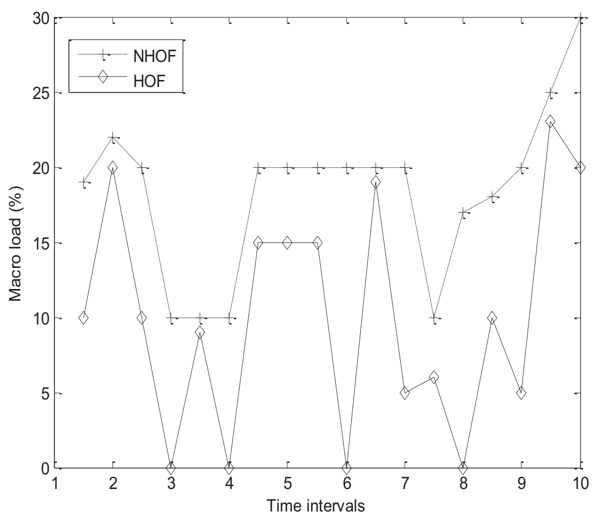

Fig. 5. Macro load vs. time intervals.

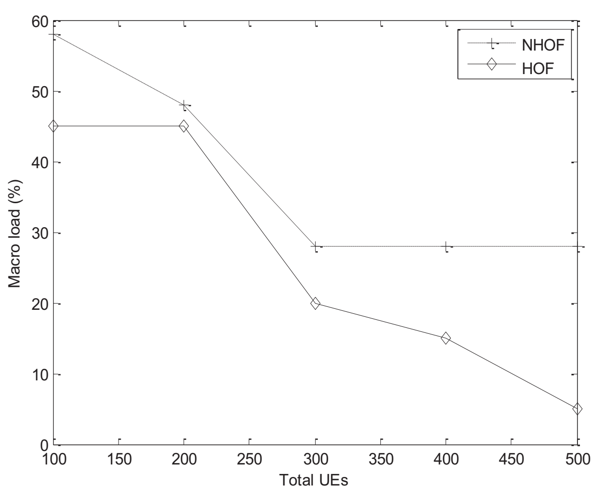

Fig.6. Macro load vs. total UEs.

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