Optimized Wi-Fi Offloading Scheme for High User Density in LTE Networks

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Abstract —Mobile networks are facing the growing flood of Internet data, as stated by Cisco. Indeed, the traffic from smart phones is expected to grow from 92 percent to 99 percent by 2021. Therefore, new solutions must be conceived by vendors and mobile operators to reduce network congestion with a low cost to preserve customers. This issue is even more critical with mass events, which occur once a year, such as hajj, festivals and football games at stadiums. Half of smartphones and over 90% of 4G enabled laptops and notebook PCs are already Wi-Fi enabled. Hundreds of millions ubiquitous Wi-Fi access points provide large enough complementary capacity space for mobile networks. Thus, a novel mechanism for Wi-Fi offloading must be explored with the purpose of finding a suitable cell association method to assign users to the best tier. This can be done by considering suitable approaches to manage the network selection method, to gain the expected capacity enhancement. In this paper, we propose a new offloading algorithm called, Optimized Wi-Fi offloading algorithm, based on an optimization cost function. This Optimized Wi-Fi offloading algorithm, not only optimizes three important criteria in balancing the load, but also it can guarantee a Quality of Service (QoS) to the successfully connected user to any tier based on required service. Simulation results prove the expected capacity enhancement, by comparing the performance of the Optimized Wi-Fi Offloading with another tow offloading Algorithms. The first algorithm is Wi-Fi if Coverage, second, Fixed SNR threshold.

***Index Terms*—**Capacity, LTE, Network selection, QoS, Wi-Fi Offloading.

I. Introduction

Mobile communication technology evolved rapidly, with the popularity of using smart phones in the past years. This creates an exponential growth in traffic demands from users with QoS. Wireless communication will not be able to cope with the increasing demands for higher throughput and data rate. This issue is raised in congestions areas and mass events, which occur once a year. Vendors need to find new solutions for such occasions rather than building new base stations or leasing new spectrum [1], [2]. Long Term Evolution (LTE) attracts attention, as wireless operators with LTE networks can handle more mobile traffic, as LTE technology incorporates adding additional spectrum.

One promising solution to cope with the huge capacity requirements generated by the increasing number of mobiles is Wi-Fi small cell deployment. Wi-Fi is a good solution due to its characteristics, uses vast unlicensed bands 2.4 GHz and 5 GHz, high user experience, advanced security, high data rate, advanced QoS and its built in most end user devices [3], [4]. Wi-Fi small cell deployment overlay in a Macro LTE cell, introduces the offloading notion. Data offloading concept implies, the use of a complementary network technology to deliver data traffic, which originally targeting the cellular network [5]. The motivation behind using Wi-Fi offloading in high populated areas is to help users in gaining a connection with high throughput and data rate. This may relieve the congested LTE Macro cell, and improve the overall network capacity indeed.

This study aims to find a proper cell association scheme to offload users in a high-density area from LTE to Wi-Fi Access Points. This is done with the objective of enhancing the overall network capacity. Capacity enhancement is evident in terms of the number of connected users, and network throughput can validate the system improvement. This is achieved through serving users with QoS based on the required service, which is assumed to be VoIP service in this research.

The rest of the paper is organized as follows: Section 2 presents the related state of the art in Wi-Fi offloading schemes. Section 3 demonstrates the proposed Optimized Wi-Fi offloading algorithm. Network Selection Schemes (NSS) are presented in section 4. Simulation setup and performance assessment along with the result is declared in Section 5. Section 6 concludes the study, and future work is presented. Section 7 represents the author's acknowledgment statement.

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II. State of the Art

In this section authors review the related Wi-Fi offloading schemes and algorithms. The first section demonstrates levels of integration between LTE and Wi-Fi networks. The second section presents different offloading schemes or algorithms, with different network access selection mechanisms to trigger the offloading decision.

A. Levels of Integrating Wi-Fi with LTE Networks

The European Telecommunications Standards Institute has defined different levels of integration for 3GPP and non-3GPP networks. There are three levels of integration between LTE network and Wi-Fi networks. The first integration level is called: Network bypass or the un-managed data offloading. Second is: managed data offloading and the third is: integrated data offloading. The first approach is, un-managed data offloading or bypass offloading, considered the easiest type of offloading, where data are directed to Wi-Fi whenever the coverage is found with no need for equipment installation. In this immediate offloading solution operator suffers from losing revenue and control over subscribers [6], [7].

The Second approach is managed data offloading, is used by the operators who don't want to lose control of their subscribers. However, they are not allowed to send subscribed content. Managed data offloading, give operators a limited control on their subscribers without the need to fully integrate the two networks. The Third offloading approach is integrated data offloading, which empower the operators with a full control over their subscribers along with the ability to send subscribed content. Integrated offloading raises the coupling architecture notion for Wi-Fi with cellular systems, which they can be divided into two coupling architectures: loose coupling and tight coupling [6]-[8]. In loose coupling architecture, no need for a major cooperation between Wi-Fi network and the cellular network and both can be independent from each other. In tight coupling, each network is required to modify its services, protocols, and interfaces for interworking together as both owned by the same operator. This is provided through I-WLAN standard from 3GPP, which allows transferring data through Wi-Fi between user's devices and cellular systems [6], [7], [9], [10].

B. Wi-Fi Offloading Algorithms & Schemes

Offloading decisions or Network access selection triggering criteria, are performed based on different parameters. The offloading may have different objectives as well, such as boosting the capacity or user QoS [6], [9], [11]. Various offloading schemes have been tackled this in research; the first scheme is Wi-Fi if Coverage, where the offloading decision is triggered based on the SNR value [12]. At high traffic loads Wi-Fi if coverage may end with overloaded Wi-Fi APs and a poor user link quality.

Another offloading algorithm, is presented in [13], which is a Wi-Fi First algorithm (WF). This scheme connects the users first to any available Wi-Fi, whenever there is Wi-Fi coverage, otherwise the user joins LTE. The WF performance under uniform and a non-uniform Wi-Fi backhaul capacity distribution. Results proves that WF has a bad performance in terms of average throughput per user and fairness. Fixed SNR Threshold offloading algorithm is mentioned in [12], and it is a function of the WLAN load. This algorithm triggers network offloading based on choosing the best SNR min value for WLAN APs. This algorithm may have a similar behavior to Wi-Fi if Coverage only at low traffic loads. Fixed SNR algorithm is considered better than Wi-Fi if coverage in terms of balancing the load between a Wi-Fi AP tier and an LTE tier.

In [14] different traffic steering policy was investigated, which is called Best-Server algorithm. This algorithm connects users to Wi-Fi AP first rather than cellular, which is like Wi-Fi if a coverage and WF algorithm. The offloading is triggered if the Signal to Interference and Noise Ratio (SINR) perceived by end user is above a certain threshold; otherwise users are connected to LTE network. Best-Server algorithm depends on SINR, while Wi-Fi if a Coverage and WF algorithms depend on SNR with the assumption of using non-overlapping channels. All three algorithms only guarantee the connection for connected users, they do not guarantee a quality of service (QoS). Another offloading scheme presented in [13] is Physical Data Rate Based algorithm (PDR), which is technically based on the PDR measured from different available RATs. This scheme compares the perceived data rate for LTE and Wi-Fi, and chooses the highest value a user can get. A similar algorithm presented in [14], called the SMART algorithm, triggers the offloading based on the minimum PDR as long measured SINR exceeds a certain threshold.

A generic framework called Mobile Femto cells utilizing Wi-Fi (MFW) developed in [15]. The MFW exploit both Femto-cell and Wi-Fi networks at the same time. This framework permits operators to offload the traffic onto Femto base stations (mob FBS) in a public transportation system The Wi-Fi AP is utilized by mob FBS as a backhaul for routing traffic to the cellular network.

C. Network Selection Mechanisms

Offloading approach is used to overcome the congestions in a cellular network, by offloading data traffic to a complementary access network. There are various network selection mechanisms with different offloading decision. The offloading and network selection decision can be taken based on different criteria's in order to balance the load between different tiers as shown in Table I.

TABLE I. NETWORK SELECTION CRITERIA FOR LOAD BALANCING IN OFFLOADING

No	Trigger Criteria	Equation

1	RSSI Received Signal Strength Indicator	$P_{rx} = P_{tx}/ L$
2	SNR (Signal to noise ratio)	$SNR = \frac{P_{tx,i}}{L_{ij} \times N}$, i = 1,2, ……, n and j = 1,2, ……, m
3	SINR (Signal to interference plus noise ratio)	$SINR_{i,DL} = \frac{\frac{P_{tx,j}}{L_{ji}}}{\sum_{k=1, k\neq i}^{n} \frac{P_{tx,k}}{L_{ki}} + N}$
4	Distance	Euclidean Distance $= \sqrt{(x_{user(i)} - x_{cell}) + (y_{user(i)} - y_{cell})}$
5	Path-Loss	$Li = d_{ij}^{PLE} * 10^{\frac{shadowing}{10}}$
6	Throughput User-Preserved Rate	$Thr = Min\{MAX\,Thr, BWlog_2(1 + SINR)\}$

III. System Model and Components

A. Target Scenario Structure

The integrated data offloading approach empowers operators to have a full control on their subscribers either they connect to LTE or Wi-Fi network to send their subscribed content. In this work, we assume having a loose coupling architecture, as loose coupling doesn't require a major corporation as have been mentioned earlier. The authors assume a 3GPP network operator controlled scenario, and the overall assumption is having a network operator in charge of both the LTE and Wi-Fi networks.

The system is composed of a single macro cell covered with one LTE eNodeB in the center. Inside the macro LTE cell, and nine Wi-Fi APs located within the boundaries, operating on IEEE 802.11n standard. All Wi-Fi APs are assumed to work with open access mode, operating with a non-overlapping channel. The locations of the Wi-Fi APs are fixed in a specific location, predefined manually by operator. Users are randomly distributed in the macro LTE cell and overplayed by Wi-Fi APs region's as well. The proposed architecture is mainly to be tested in congested areas.

B. Link Budget Calculation

To estimate link Budget all the effects on the radio channel must be considered, which they are three main factors:

- Propagation channel effects (Path loss, Shadowing, Fast fading).
- Interference.
- Noise power.

Link budget

Link budget is a way of quantifying the link performance, with power estimation under overall losses. The link budget is used to define and calculate the SINR. For downlink traffic, SINR is used to estimate the channel quality or link budget for each user, either from eNodeB or Wi-Fi AP. SINR is calculated as follows in equation 1:

$$\mathrm{SINR}_{i,DL} = \frac{\frac{P_{tx,j}}{L_{ji}}}{I+N} \qquad (1)$$

where $P_{tx,j}$ is the transmission power either for eNodeB or WLAN AP, where L is the total path loss estimation between end user and eNodeB or WLAN AP. I represent the total interference value, at last thermal noise represented with N [16].

Path loss

Path loss measures the power reduction of a transmitted signal when it propagates through space from sender to receiver. This power attenuation or reduction could be a reflection, refraction or free-space loss outcome. There are different mathematical models for calculating the path loss in a wireless network [17].The log-distance path loss model estimates the path loss of a signal over a distance, whether a user is connected to either eNodeB or Wi-Fi AP as shown in equation 2.

$$L = r^{e} \qquad (2)$$

where r is the distance between a user to either eNodeB or Wi-Fi AP, and it is calculated by the Euclidian distance. The path loss exponent depends on the environment type. Shadowing, which is the power reduction caused by obstacles [18]. If it's added to the previous log-distance path loss model equation 2, path loss calculation interpreted as in equation 3. In LTE network the shadowing is assumed to be equal to 3 dB, while in WLAN it is neglected by assuming an indoor environment.

$$L = r^{e} * 10^{\frac{shadowing}{10}} \qquad (3)$$

Interference

Interference is a phenomenon, when two signals are interacting or affecting each other. This could happen due to using the same frequency or generating from the same source. Interference in general can be calculated according to equation 4 as follows:

$$I = \sum \frac{P_{tx}}{L} \qquad (4)$$

In the Down Link (DL) case, the interference is calculated as follows: the summation of all transmitted powers P_{tx} .Over the summation of all path losses L for all users using either the same RB LTE network, or the same channel in all APs in WLAN tier. The interference in this research for both LTE and Wi-Fi is neglected, hence I=0 equal to zero. This is valid with the assumption of simulating a single LTE cell with no boundary effect from other macro cells. Assuming a Frequency Domain Duplex (FDD) for LTE implies, allocating one Resource Block (RB) in the frequency domain for each user. This eliminates interference between different RBs allocated in one sub-frame for different users. In the Wi-Fi APs case a non-overlapping scenario is assumed, by using channels 1,6,11.

Noise

Noise power in a receiver usually is a thermal noise generated from the amplifier; it is the unwanted energy from natural and man-made sources. Noise calculated as follows:

$$N = K \times T \times B \quad (5)$$

From the latter equation: N is the noise in linear scale, K is Boltzmann's constant, which is equal to 1.381 ×10-23, T is the reference receiver temperature in Kelvin, equals to 290 and B is the noise bandwidth in hertz. The noise value in LTE differs from Wi-Fi depending on the bandwidth allocated to the user in each according to equation (5); hence each network has different noise value.

C. System target Calculations

Network throughput can be estimated based on Shannon Capacity equation as in equation (6).

$$C = B \times \log_2(1 + SNR) \quad (6)$$

From Shannon Capacity throughput estimation is done through equation 7:

$$T_i = \min(T_{max}, B \times \log_2(1 + SNR_i)) \quad (7)$$

Knowing, B is the bandwidth and T_{max} is determined by air interface capabilities. The system capabilities affect the throughput calculation in any network. The main factors affect throughput estimation in LTE network or WLAN are: the type of modulation used, antenna configuration, bandwidth, Mac overhead, cyclic prefix for LTE and guard interval or Wi-Fi.

***Maximum Throughput estimation*:** The maximum throughput of LTE under a given assumption is 300 Mbps in the downlink. Assuming to have LTE bandwidth of 20MHz with 10% reserved guard band, thus the effective bandwidth is 18MHz. One RB is 180KHz, hence the total number of available RBs is 100 in a single sub-frame. In the Wi-Fi case considering IEEE 802.11n with the assumption of using a 20 MHz band, 4×4 MIMO, 64 QAM, 84% overhead and a short guard interval, the maximum IEEE 802.11n throughput can be calculated in the DL case as follows in equation 8:

1.0385 ×65 Mbps ×4 antennas × 1.11 = 600 Mbps (8)
(Factor of 20 MHz) (Factor of short guard interval)

By reducing MAC overhead, the total throughput is approximately equal to 100 Mbps [19, 20].

SNR Requirement Calculation: to calculate the SINR requirement for VoIP service using 'Shannon Capacity equation'. The required SNR for connecting users is different in LTE and Wi-Fi, and it is estimated with equation (9) as follows:

$$SNR = 2^{T/B} - 1 \quad (9)$$

IV. Optimized Wi-Fi Offloading Scheme and Network Selection

A. Optimized Wi-Fi Offloading Scheme

The Optimized Wi-Fi Offloading Algorithm is a new offloading scheme proposed by the authors, and it's a cost-function-based scheme that guarantees QoS. The first stage of the Optimized Offloading algorithm is, by optimizing three criteria at the same time. The main three criteria are: 1) network load, 2) path loss, and 3) throughput. The cost function's main optimizing objective is to maximize the throughput and minimize the network load and path loss. Either for LTE or WLAN network, those three criteria's must be dealt with an equal weight. Two cost functions are calculated for each user request a connection, eNodeB and WLAN. The minimum cost function is selected; hence the user is connected to the minimum cost.

The second phase of the Optimized scheme is to provide connected users with QoS, either they are connected to eNodeB or WLAN. With the assumption of demanding VoIP service QoS need to achieve the required throughput for VoIP service. Different required throughput is needed to gain a good link quality based on the network type. In LTE VoIP require a minim throughput of 15kbps, while in WLAN its only 8 kbps with the assumption of using G.729 CODEC [19-21].The offloading is triggered if SNRWiFi or SNRLTE is greater than or equal to SNRmin. The SNRmin is calculated according to the required throughput to achieve acceptable VoIP service. The optimization is done through calculating a cost function as shown in equation (10):

$$C = \mathrm{Min}\left(\alpha 1 * \frac{\mathrm{load}}{\mathrm{load_{ref}}} + \alpha 2 * \frac{\mathrm{pathloss}}{\mathrm{pathloss_{ref}}} + \alpha 3 * \frac{1/\mathrm{Thr}}{1/\mathrm{Thr_{ref}}} \right) \quad (10)$$

Knowing that: $\alpha 1 + \alpha 2 + \alpha 3 = 1$

The load in equation 10 can be expressed by the total number of connected users, while path loss is calculated based on equation 3, and throughput is calculated based on equation 7. All the three factors should be divided by a reference value for each, $\mathrm{load_{ref}}$, $\mathrm{pathloss_{ref}}$ and $\mathrm{Thr_{ref}}$ Respectively to make them all unit-less. This reference value of each factor differs in LTE and Wi-Fi, by taking into account the possible range of load, path-loss and throughput either in Wi-Fi or LTE.

B. Wi-Fi if Coverage Scheme

In Wi-Fi if Coverage scheme the useri is connected to the best WLAN AP based on the best SNR value received. The best SNR value should be greater than the required SNR_{min} ,which affected with the required throughput for VoIP service. This offloading scheme implies a useri is connected to WLAN AP, whenever there is Wi-Fi coverage. If the link budget doesn't fulfill the user required SNR for all available WLAN AP, then useri is connected to LTE BS. This will happen only if there are available RBs, otherwise useri is blocked. Wi-Fi if Coverage scheme considers only SNR information to make the network selection decision; as in (11).

$$\mathrm{access} = \begin{cases} \mathrm{WLAN} & \text{if } (SNR_{\mathrm{WiFi\,AP}} \geq SNR_{min} \\ \mathrm{LTE} & \text{otherwise} \end{cases} \quad (11)$$

C. Fixed SNR Threshold Scheme

In the Fixed SNR threshold algorithm, WLAN has the priority in connection, like the Wi-Fi if coverage scheme. User connects to the best Wi-Fi AP based on the measured SNRwifi. If measured SNRwifi is greater than or equal to the threshold SNRmin. Otherwise, the user is directed to a cellular network (i.e. LTE). SNR value is the main parameter for load balancing. The Fixed SNR threshold is traffic load-dependent, which means the SNRmin is increased when the load increases at each individual AP, as shown in the following expression in (12).

$$access = \begin{cases} WLAN & if\ (SNR_{WiFi\,AP} \geq SNR_{min}+Load \\ LTE & otherwise \end{cases} \quad (12)$$

V. Simulation Setup and Performance Assessment

A. Simulation Setup and Assumptions

All simulations are done using MATLAB, Table II lists the main parameters and assumptions considered for conducting the simulation. A total of 100 RBs are used in a single sub-frame, and the scheduling requirement in the LTE case is fixed to 1 RB per user. Nine Wi-Fi APs were deployed in the hexagon area of LTE BS in fixed locations. The channel assignment for the APs is assumed to be a non-overlapping channel case, which they are 1, 6, and 11 respectively. The LTE eNodeB centered in the middle of the cell with coverage of 100 meters. The Wi-Fi APs radius is around 20m per each deployed in fixed locations. The simulation will test a single sub-frame duration which consists of a maximum approximated 1000 users accessing resources based on round-robin scheduling algorithm. All provided results are the averages for 100 iterations for each simulated algorithm scheme.

TABLE II. PARAMETERS USED IN SIMULATION

Parameter	LTE	Wi-Fi
Cell radius	100 m	20 m
Base Frequency	2 GHz	2.4GHz
Effective Bandwidth	18 MHz	20MHz
Required Throughput (R)	15 Kbps VoIP	8 Kbps VoIP
No. of Resource Blocks	100	1,6,11 Non- overlapping channels
Number of users	200,400,600, 800,1000	200,400,600, 800,1000
Path loss exponent	4	4
Position of BS & APs Position (x, y)	(0,0)	x_wifi= [-50,50,50,50, 0,0, -50,50,0] y_wifi=[50,50,-50,-50, -50,50,0,0,0]
Noise	-121 dBm	-130.9dBm
Duplexing	FDD	CSMA/CA
Modulating scheme	64 QAM	64 QAM
BS, AP Ptx	21 dBm	23dBm
Max-Throughput	300 Mbps	100 Mbps

B. Performance Assessment Results

The authors built a simulator for tow well known offloading algorithms from the literature as well as simulating an LTE macro cell, to be compared with the proposed Optimized Wi-Fi offloading algorithm scheme. The simulators run the experiments for 100 iterations to have the averages for more accurate results. Performance evaluation is conducted for the two offloading algorithms from the literature; 1) Wi-Fi if coverage, 2) Fixed SNR threshold, compared with the proposed Optimized Wi-Fi Offloading algorithm. The LTE standard case is evaluated as well with the same performance metrics. The performance is evaluated with three performance metrics in the down link case: 1) number of connected users, 2) blocking ratio as shown in equation 13, and 3) network throughput which expresses the total effective throughput of the network.

$$\text{Blocking ratio} = (\text{Blocked UEs/total UEs})*100 \quad (13)$$

Users are requesting a Voice service, which can be achieved through Wi-Fi connection or LTE. Offloading concept might dramatically increase the number of connected users. Fig. 1 demonstrates the simulation scenario for the Optimized Wi-Fi Offloading Algorithm, with 1000 users requesting VoIP service. Connected users are represented by green nodes, either connected to the LTE BS or Wi-Fi APs based on Optimized Wi-Fi Offloading Algorithm. Nodes with red color represent blocked users.

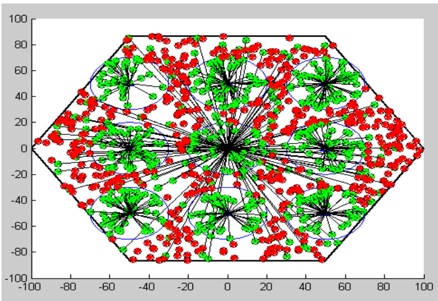

Fig. 1. Optimized offloading with 1000 UEs using VoIP.

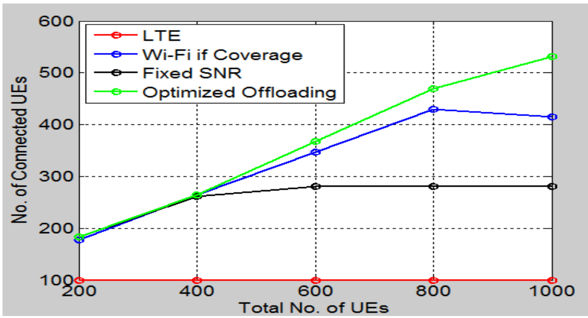

Fig. 2. (a) No. of connected UEs vs. Total No. of UE for VoIP Service.

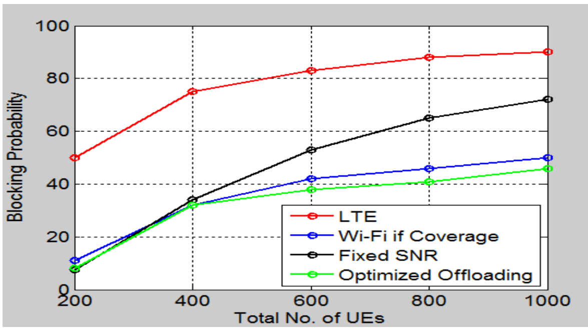

Fig. 2. (b) Blocking probability vs. Total No. of UE for VoIP Service.

Fig. 2 shows, the total number of connected users requesting a VoIP service are successfully enhanced with all three offloading algorithms compared to the LTE standard case. It's clearly shown that LTE can serve a fixed number of users no matter how much is the growth in the number of requesting users. This is due to previous a assumption which implies having only 100 RBs can serve 100 UEs in a 1ms per TTI. The optimized Wi-Fi offloading algorithm seems to outperform both offloading algorithms from literature in terms of connecting users. Optimized offloading also guarantees the QoS for all connected users with their minimum requirement. Fixed SNR Threshold tends to be the worst in term of connecting more users.

Fig. 2 shows that LTE standard case has the highest blocking ratio with high user densities, as it reaches a 90% blocking ratio with 1000 active users being in the cell. The fixed SNR threshold has the second highest blocking ratio compared to the tow other offloading algorithm with almost 75 % blocking ratio with 1000 UEs in the cell.

Fig. 3 shows the total network throughput for all Connected Users (CU) with Gbps. LTE seems to have a fixed throughput in the standard case with 0.33 Gbps for the whole network based on the successful number of CU_LTE. The throughput in LTE is bounded with its limits due to a fixed number of RBs allocated successfully to UEs requesting a voice service with a 15Kb throughput. Total network throughput is dramatically enhanced with incorporating Wi-Fi offloading along with LTE eNodeB, these appear with all three offloading algorithms compared with standard LTE case.

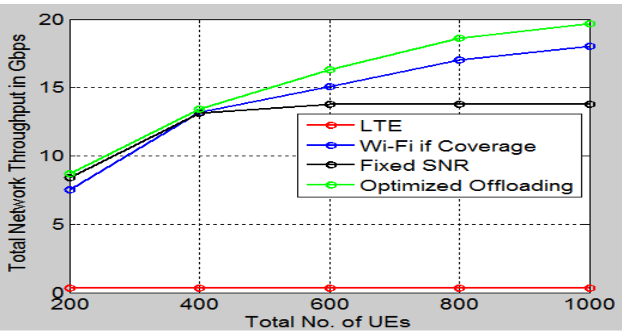

Fig. 3. Total network throughput vs. Total No. of UE for VoIP Service.

VI. CONCLUSION AND FUTURE WORK

In this research a new offloading algorithm is proposed by author called; Optimized Wi-Fi Offloading Algorithm. This algorithm performs the offloading from LTE tier to Wi-Fi tier based on a cost function that optimizes three criteria's at the same time with the guarantee of QoS. The type of service requested by a user is assumed to be VoIP service. Performance evaluation is performed to assess the capacity enhancements given by the Optimized offloading algorithm, in terms of number of connected users, blocking probability and total network throughput. This is shown by comparing the proposed algorithms with two offloading algorithms from the literature which they are; Wi-Fi if Coverage, Fixed SNR Threshold, along with the standard LTE case. Optimized Wi-Fi offloading algorithm outperform Fixed SNR threshold and Wi-Fi if Coverage in all three-performance metrics. Optimized Offloading is better as it guarantees QoS to all connected users, and it enhances the overall system capacity by 431 % with VoIP service compared to standard LTE case. Future work will consider multi LTE cell scenario, by taking LTE interference into account with different number of Wi-Fi APs for both down link and uplink case.

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