

Maximizing Throughput in Heterogeneous Networks by WiFi Offloading

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Abstract - Due to penetration of smart phones in daily life, mobile data traffic has suddenly grown in last decade. Thus, cellular networks are facing a problem of overloading. This is undesirable from operator's perspective and alternative network technology is required to meet future data demand. WiFi offloading is a solution proposed recently which can benefit operators for transferring data originally targeted to cellular base stations. Recent theoretical and experimental results shown that delayed offloading scheme can give better performance than on-the-spot offloading scheme. In this paper, throughput analysis has been carried out for both the schemes and results shows that delayed offloading is better than on-the-spot scheme.

Keywords— Delayed offloading, per-user throughput, HETNETS

I. INTRODUCTION

The popularity of social networking sites as well as penetration of smart devices caused large numbers of users to communicate with each other and sharing content. Smartphones became so popular because of some of the factors like ease of use, cost, reliability, security. Due to these advantages, it is used in various applications like location based services (GPS), healthcare services, social networking etc.

Mobile networks are dominated mostly by data as compared to voice services. Due to penetration of smartphones in daily life, mobile data traffic has suddenly grown in last decade. User data demand is reaching to the order of exabytes per month. According to statistics given by CISCO VNI white paper [1], 497 million mobile devices joined to mobile network in 2014 out of which nearly 88 percent devices were smart phones. Amount of average data traffic generated per month by one smart phone grew from 563 MB to 819 MB. Thus, cellular networks are facing a problem of overloading. Due to this, users in urban areas face problems like call drops, unreliable coverage especially in peak hours. Congestion and overloading of cellular networks during peak hours leads to poor user experience. This is undesirable from operator's perspective and alternative network technology is required to meet future data demand. There is a need of increasing network capacity by approximately 80 % to meet such a tremendous data growth. To handle this much huge amount of data traffic and to fulfill customer demands, network infrastructure is required of such capacity. There are various options available for service providers to meet with this problem. Such as :

1. Installing new base stations (BSs)
2. Low power wireless access points such as picocells and femtocells
3. Updating networks to modern, advanced next-generation networks such as 3GPP Long-Term Evolution (LTE), High Speed Packet Access (HSPA) or WiMAX
4. Installing new base station architectures with multiple remote radio heads (RRHs)
5. Offloading traffic through WiFi networks in a heterogeneous network (HETNETS)

A. CAPEX/OPEX with respect to network capacity

When we throw some light on overall mobile market and its usage, it indicates that network expansion methods such as acquiring more and more spectrum licenses, deploying new small cells, and upgrading technologies are expensive and time-consuming i.e. high CAPEX/OPEX required. As per recent market analysis, macrocells cost \$30,000 on average depending on the configuration, whereas small cells average \$5,000 to \$10,000. Further if we ignore the cost factor, capacity expansion methods may provide three or four times the current capacity but we cannot neglect the fact that data traffic load is not uniformly distributed.

Next generation technologies like LTE and LTE Advanced aims for more network capacity and more accommodation to users but demand in data traffic varies and is a major concern in designing these technologies. These facts cannot be ignored which is not uniformly distributed in time or space. Throughout the day, there is a major transformation and variation in mobile data traffic demand. In metro areas during work hours, high usage is observed whereas in residential areas very low usage is seen.

Due to such variation, providing a additional capacity in particular area as per demand during few hours of a day is more challenging and requires careful planning. Getting government approval for building a new base station tower can take couple of years. Also, it is extremely expensive to increase the number of cellular base stations just for high traffic demands. The health issues due to cellular tower radiation also comes with a public concern. The gap between Long Term Evolution (LTE) performance and Shannon capacity is very small which limits the potential to increase spectrum efficiency [2]. Because of these technical, economical and regulatory problems, the last option of WiFi offloading seems most promising solution. WiFi is and only

viable solution at the moment for operators that will continue its major role for answer to growth in network capacity.

B. Overall Aim

- 1) Encouraging users to offload traffic through WiFi networks so that throughput can be increased.
- 2) To study various challenges in the deployment of small cells.
- 3) Offloading schemes to improve throughput and increasing delay.
- 4) Numerical and graphical modelling of proposed Wi-Fi offloading model in NS2 simulator to improve throughput and less delay requirement.

II. RELATED WORK

There has been lot of studies and activities on WiFi offloading. Kyunghan Lee and Injong Rhee in [3] have done experimental setup to find out measurement statistics like offloading efficiency. For that first, mobile application is used which will track the WiFi connectivity. The application will track various parameters as user moves. It will record the connection details occurring every time. From these every day movements, users will be categorized as users with high mobility and low mobility. From this data, particular pattern will be generated for every user as cumulative distribution function (CDF). So predictions can be made from patterns and delayed offloading approach can be used. Nearly 65% of total mobile data traffic can be offloaded with this trace-driven simulation. 50% of 3G network usage reduction gain is seen.

In [4], authors proposed that network information is essential for performance enhancement in WiFi network i.e. “network-assisted” and “user-centric”. Mathematical model is introduced for different cases depending on user’s location. It is observed that due to variation in number of contending users, throughput is not linear as offloading ratio also changes. To deal with this, average processing time or we can say computation time is measured using MATLAB. This time is chosen carefully so that it will not reflect the changes for throughput.

[5] Proposes and evaluates an integrated architecture to migrate data traffic from cellular networks to metropolitan WiFi access points (APs). Architecture has different modules for connection, data, location, protocol, forwarding and naming for offloading purposes. User wants to download data. So it request to a nearby base station. Along with this, it provides its direction, position and speed. Base station uses this information and finds out access points which can handle this user and serve. This list is sent back to user as well as to that AP. User then contacts directly to that AP nearby to it and download the required content. Results show that this method contributes half the offloading of total traffic.

Earlier papers mostly proposed to offload the traffic whenever users move to WiFi range. In [6], one unique and different type of model is proposed. Number of access points required to cover whole single base station is found out. Number of access points installed is a important criteria CAPEX/OPEX point of view. As well as how the access

points are placed so that region of one base station is covered is found out. This paper calls it as “planned deployment”. Maximum throughput is possible if more and more APs are installed. Throughput depends on mainly three factors: proportion of users served, system capacity and number of access points. Graphical results prove above points.

Another solution in [7] is proposed by LU Xiaofeng, HUI Pan, Pietro Lio through “opportunistic routing”. Paper proposes Subscribe-and-Send architecture and opportunistic routing protocol for it. In this, required data is delivered to a user through different stages and not from service provider directly. When a user wants to download data, it contacts to service provider and subscribes it. Base station of service provider checks whether anyone have same content. If yes, then content is downloaded from that node through opportunistic routing. If deadline is crossed means contents are directly obtained from base station. HPRO protocol proposed has advantage that as numbers of nodes are increased, there is more probability of delivery to destination.

In [8], automatic system is proposed which itself decides upto what extent one application session should wait for WiFi network. It fully concentrates on three important parameters: delay, cost and throughput. “AMUSE” system has two main components: “bandwidth optimizer” and “TCP rate controller”. First, applications are categorized according to their nature i.e. browsing, streaming and downloading. Then from user input, priorities are given to every application and arranged likewise. With this data, decision is made when user enters into WiFi region. Results show that utility of others is less than above one.

In [9], system is designed called “Wiffler” for utilizing the two parameters “switching” and “delay tolerance”. Authors experimented there research in three different cities before coming to a conclusion. It makes use of predictions obtained from the designed system and accordingly makes a decision for offloading. If prediction says that delaying the offloading will result into cellular saving, then it delays transfer. Result says that combining both the technologies reduces load by almost 50 %.

III. ANALYSIS OF OFFLOADING

Offloading methods are divided mainly into two categories: *on-the-spot* and *delayed*.

On-the-spot offloading is the continuous downloading of data wherever user is. Whenever user is in cellular coverage, download continues and if user moves to WiFi region, data session will be continued. It uses spontaneous connection and data is obtained on-the-spot until transfer is finished.

Whereas in delayed offloading, each data transfer is given particular cutoff period. Data is downloaded only in WiFi region and not in cellular region. Previously paused data session is continued or resumed whenever user comes in the vicinity of WiFi coverage area. This process is continued until transfer is fully completed. And if cutoff period is reached, it means that no WiFi region is available upto the deadline and hence remaining downloading is completed from cellular networks.

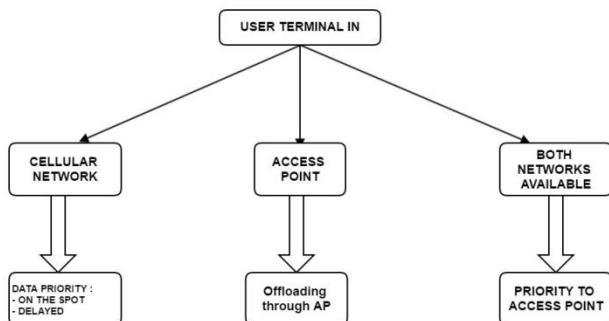


Fig 1 . Offloading cases

It means if cutoff period is larger, there are chances that user may offload more traffic through WiFi region and substantial gain can be obtained. Delayed offloading gives more adjustability and guaranteed performance enhancement to both users and operators. Importantly, traffic burden on cellular infrastructure can be reduced and decongestion that users are facing can be lowered. So point here to note is its a kind of delay-tolerant. Transmitted traffic is less delay-sensitive and can lead to energy saving. Movies download, software update, and e-mail which can tolerate some delays without sacrificing too much user satisfactions. We have to motivate or encourage the users to use delayed offloading. For that, some reward can be given as a part of encouragement. Rewards can be given from operator side and it may include some discount or refunds. So two stages are possible:

- In Stage I, the operator declares a reward to users if it delays current data cellular services for some time.
- In Stage II, user plans and decides to join the delayed offloading or not by observing the reward , their waiting costs for WiFi connection, need and the congestion in the cellular network.

Firstly there are 3 cases for user's location as shown in fig.1 :

- 1) User Terminal in cellular network
- 2) User Terminal in WiFi network
- 3) User Terminal in both cellular and WiFi networks.

When the user comes in cellular network coverage, and let he want to start one movie to download. Then firstly network will ask him whether he wants to start downloading now or can wait for getting access point (AP) coverage while moving. For waiting, he may get incentives/rewards from service provider. According to rewards and time required, user may choose any option. If he does not want to wait, downloading will start instantly from cellular network. If he prefers to wait, then one deadline is given upto which user can wait for getting AP access. If deadline expires means downloading will start from available network i.e. cellular network. If deadline doesn't expire means whenever user goes to access point coverage, downloading will automatically resume. This is called as Delayed offloading.

To provide a satisfactory user experience while using as little cellular bandwidth as possible, we aim to decrease the total cellular use, while considering the given deadline of the application. With information related to the mobile pattern, we formulate the delayed Wi-Fi offloading problem is nothing but a continuous decision making problem, where each cellular time slot used leads to a unit cost, and they will charged a penalty if the file transfer cannot be completed by the deadline.

IV. SYSTEM MODEL

We consider a scenario as two-tier network, or two-stage network where one tier consists of service provider BSs (base stations) of the same type. Let these BSs constitute tier 1 and the small cells WiFi access point be tier 2 . First tier of the HetNet consists of a macrocell type of BS with an omnidirectional antenna is located at the center of the each BS of radius r_m . The small cells are designed to be in open access policy for the purpose of offloading traffic from the macro cells which operate at 2.4 GHz frequency. Let macrocell is having M mobile users which are uniformly distributed between r_0 and r_m , so that r_0 is the minimum distance between a macrocell mobile user and its associated macrocell BS. The second tier of the HetNet consists of N low-power small-cells WiFi APs installed to provide the coverage to the cell-edge mobile users such that each small cell BS has a coverage radius of r_s .

Let

$$A = \{a_1, \dots, a_N\} \text{ and } C = \{c_1, \dots, c_M\}$$

be the sets of APs installed at random areas and BSs covering the cellular coverage area, respectively. The K BS's collectively share a unit bandwidth to serve their respective user devices. Note that, usually, $M = 1$, except is in the case of a highly dense urban deployment. Even when $M > 1$, M is

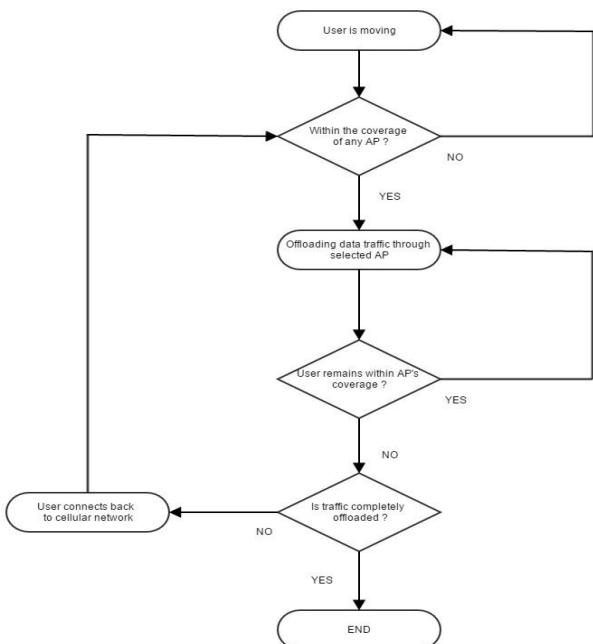


Fig 2. WiFi offloading algorithm for user in AP

much smaller than N , because, typically many APs are deployed within a cellular coverage area and are less than total base stations. The number of mobile users in each small-cell access point is given as

$$U = (M - L) / N \quad (1)$$

$$\text{where } L = M[r_l^2 - r_0^2] / r_m^2 \quad \text{and} \quad (2)$$

$$r_1 = r_m - r_s$$

In these configurations, L mobile users are uniformly distributed in between r_0 and r_l and are processed by the base station. The remaining $M - L$ mobile users are served by the N wireless access points. A user distribution of 0.005 per m^2 is assumed throughout the network for all deployment scenarios. The number of small-cells per macrocell can be expressed as $N = 4 r_m / r_s$.

We assume that the users always prefer to offload data traffic through WiFi due to attractive rewards based on delayed offloading. This means that the users which are under the coverage of WiFi APs are always assisted by nearby WiFi AP and the users outside the coverage of WiFi APs are necessarily served by the cellular network. Therefore, the WiFi network should provide minimum the same average per user throughput as the cellular network does.

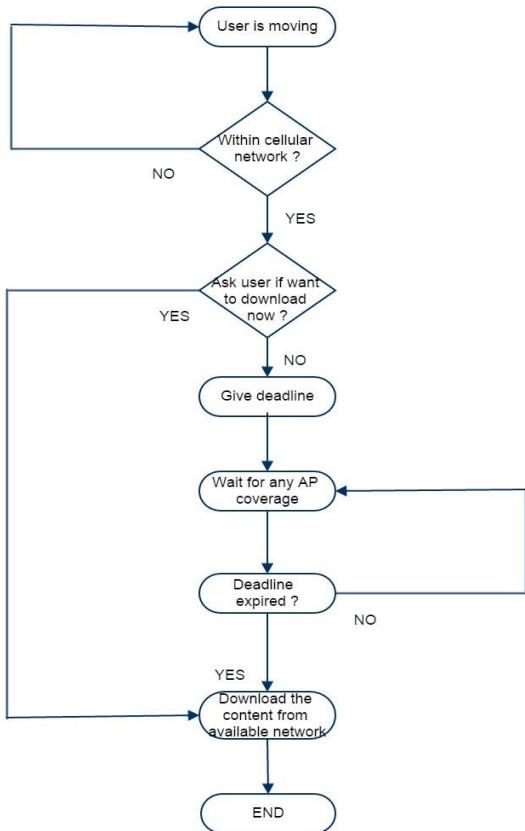


Fig 3. WiFi offloading algorithm for user in cellular network

Based upon this assumption, the average per-user WiFi throughput is as follows:

$$S_W^{user} \geq S_C^{user} = S_W^{user*} \quad (3)$$

Where S_W^{user} , S_C^{user} , S_W^{user*} is the average per-user WiFi throughput, the average per-user cellular throughput, and the target average per-user WiFi throughput, respectively.

$$S_C^{user} = \frac{S_C}{N_C} \quad (4)$$

As user moves through different locations, file will be continuously downloaded until it finishes off. While moving, user may come across different coverage areas like WiFi or cellular. At some point, it is possible that user can access both cellular network and WiFi access point.

Actual traffic offloaded through WiFi is the ratio of throughput obtained by successfully offloading WiFi traffic and traffic generated in whole network.

It is given as :

$$= \frac{S_W K}{\mu L \lambda A_{tot}} \quad (5)$$

where S_W , μ , L , λ represents WiFi throughput of single access point, total traffic generation ratio, packet size in bits, active users density in small cell respectively.

Let a user requests data packet with probability \emptyset through WiFi network. Let P_t is the probability of atleast one transfer is going on in network, P_s be the probability of successful transmission, N_w users exist in one WiFi cell, T_s is the time required for successful transmission, T_δ is time for idle slot, then throughput of a user of WiFi network is given as

$$S_w = \frac{P_t P_s E[L]}{N_w} \quad (6)$$

V. EXPERIMENTAL ANALYSIS

We have used hierarchical routing in NS2 for mixed topology consisting of a wireless and a wired domain, and data is exchanged between the mobile nodes, access points and base station.

For the mixed scenario, we are going to have 2 wired nodes, node0 and node1, connected to our wireless domain consisting of 3 nodes (nodes 3, 4& 5) via a base-station node, BS as shown in Fig.4. Base station nodes acts as a gateways between wireless and wired domains and allows packets to be transferred between the two different types of nodes. Routing protocol is DSDV.

TABLE 1 SIMULATION PARAMETERS

Parameter name	Value
NS version	NS2
Channel	Wireless channel
Propagation	Two Ray Ground
Network interface	WirelessPhy
Antenna	OmniAntenna
Interface queue	Droptail
Routing protocol	DSDV
Radio frequency	2.4 GHz
Packet size	1023 bytes
Transmission rate	1 Mbps
Node 1 start move away from AP1	10 sec
Node 1 start move towards AP2	20 sec

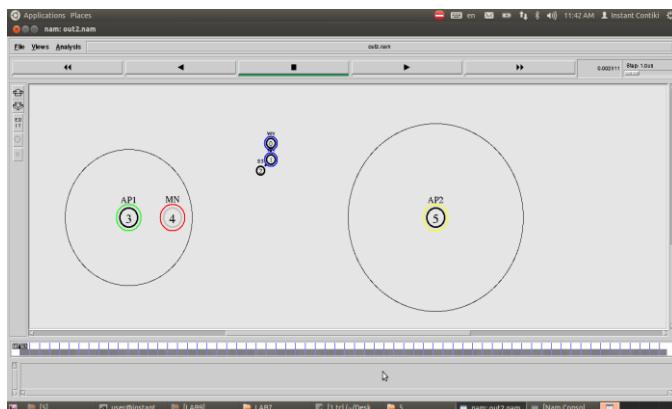


Fig 4. Mobile node in the coverage of AP1

For mixed type of simulations, we need to use hierarchical routing in order to route packets between wireless and wired domains. So in order to exchange packets among these wired and wireless nodes, we use base-stations which act as gateways between the two domains. We segregate wired and wireless nodes by placing them in different domains. Domains and sub-domains are defined by means of hierarchical topology. Throughput is calculated using awk scripts.

Out of 3 wireless nodes, 2 nodes are our WiFi access points i.e. node 3 and node 5. These AP1 and AP2 transmit there SSID with a predefined interval. At some situation user i.e. node 4 may move to coverage area of any of APs. This is shown in Fig.4 At that time if it is having any data session active, it will resume. If user tries to start any downloading it will start at that instant and will try to finish as long as user remains in the vicinity of that AP.

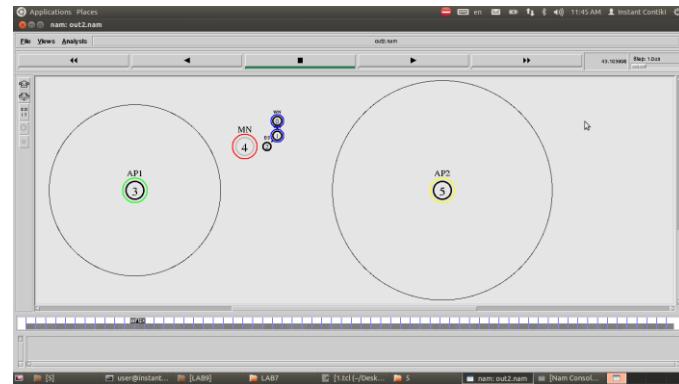


Fig 5 . Mobile node in the vicinity of base station

Now before completion of data session, user moves to other region where cellular network is available, like that shown in Fig. 5. So here user has option for delay. If he chooses for preference as AP, deadline is given for that task for completion of downloading. User again if moves to a area having AP coverage, as shown in Fig.6 , previous incomplete paused data session will start here and will continue.

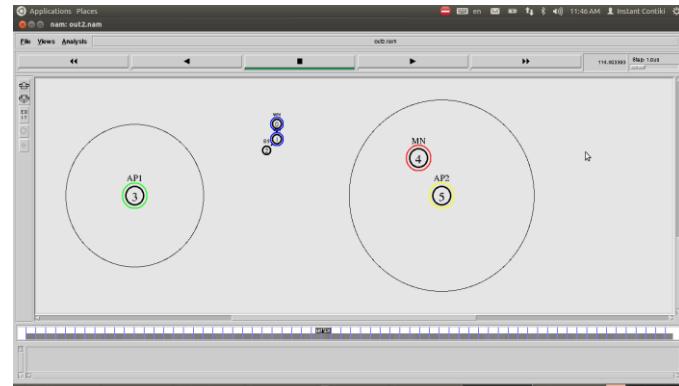


Fig 6. Mobile node in the coverage of AP2

VI. RESULTS

We validate our points with results here as in above mentioned three mobility scenarios. The data rate for mobile user is assumed to be 1Mbps. Packet size is 1023 bytes. Fig.4 and Table 2 shows that user moves to WiFi region from any base station. It continues data transfer before switching to base station as shown in Fig.5 at time 15 sec. If user still moves ahead, periodic switching will happen between both networks causing a reduction in throughput.

TABLE 2 MOBILE USER THROUGHPUT BY
ON THE SPOT OFFLOADING

Session	Time	Access	On the spot
1	5	BS1	Throughput =2.331MB/s
2	10	WiFi1	
3	15	BS2	
4	20	WiFi2	

Above case is for on-the-spot offloading. Data transfer is continuous until downloading is finished in this case. Whereas in Delayed offloading, WiFi access is given priority. Table 3 shows the case of this type.

TABLE 3 : MOBILE USER THROUGHPUT BY
 DELAYED OFFLOADING

Session	Time	Access	Delayed
1	25	WiFi1	Throughput =3.455MB/s
2	50	WiFi2	
3	75	WiFi3	
4	100	WiFi4	

Time taken by a file to download in delayed offloading will obviously more than on-the-spot. User is ready to wait until WiFi coverage is available. For experimental purpose delay for offloading or deadline is taken less. In realistic scenarios, deadline can be increased upto several hours.

VII. CONCLUSION

This paper analyzes the impact of WiFi with the use of cellular technology on the network performance. Simulation results indicate that offloading the traffic with some delay can improve the network capacity as well as network performance.

Both the network capacity and throughput can be continuously enhanced by introducing more WiFi Access Points to the network. From coverage point of view, with the same capacity target, per-user throughput increases drastically especially for the indoor users which represents an exponential growth manner.

In this analysis we have considered number of scenarios for checking the throughput in various networks such as cellular and WiFi. Finally we have shown encouraging or motivating users to offload there traffic with some delay gives better results.

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