OFFLOADING STRATEGIES FOR HETEROGENEOUS WIRELESS NETWORKS

A Thesis Submitted to
the Graduate School of Engineering and Sciences of
İzmir Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

in Electronics and Communication Engineering

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May 2016
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ACKNOWLEDGMENTS

First of all, I am sincerely grateful to my supervisor Assist. Prof. Dr. Berna Özbek for her instructive comments, guidance and supports throughout my thesis study.

Moreover, I would like to thank my best friends and relatives for their supports. They really motivated me to during hard periods of my study.

Finally, I would like to thank my family; my father Bekir Tuna, my mother Işık Tuna and my brother Erdem Tuna for their financial and moral supports. I am very appreciated for their unlimited support and love throughout my MSc study in Izmir. I dedicate this MSc thesis to my family.

ABSTRACT

OFFLOADING STRATEGIES FOR HETEROGENEOUS WIRELESS NETWORKS

There has been a tremendous increase in the usage of multimedia services with the rapid penetration of mobile devices. In parallel to the technological developments in hardware and software of communication devices, users demand to have higher quality and more reliable services.

The developments in network technologies are towards forming a converged structure that mobile, fixed and internet access technologies are able to operate together. Heterogeneous wireless networks have a critical role in order to meet dramatically increasing traffic demand. As a result of better operation of the systems with the help of heterogeneous wireless networks, it is possible to serve subscribers with higher performance with the help of offloading which transfer the traffic load from a network to another one. Various strategies are used in order to offload traffic between different wireless communication technologies.

The main objective of this thesis is to examine offloading strategies which provides operation of different wireless communication technologies efficiently in heterogeneous wireless networks. The performance evaluations of different offloading strategies in various scenarios are implemented. The comparisons of strategies which are user initiated and network initiated are provided by considering their overhead load.

ÖZET

AYRIŞIK KABLOSUZ AĞLAR İÇİN AKTARMA STRATEJİLERİ

Mobil cihazların hızla artmasıyla, multimedya servislerin kullanımında muazzam bir artış olmuştur. Haberleşme cihazlarının hem yazılım hem de donanımlarındaki teknolojik gelişmelere paralel olarak kullanıcılar daha yüksek kaliteli ve daha güvenli servisler talep etmektedir.

Şebeke teknolojilerindeki gelişmeler hücresel, sabit ve internet erişim teknolojilerinin birlikte çalışabileceği yakınsayan bir yapı oluşturma yönündedir. Ayrışık kablosuz ağlar kullanıcıların artan trafik talebini karşılamada önemli rol oynamaktadır. Ayrışık kablosuz ağlar sayesinde sistemlerin daha iyi çalışması sonucu kullanıcılara daha yüksek performansla servis sağlamak, trafik yükünü bir şebekeden diğerine transfer etmek anlamına gelen aktarmayla mümkündür. Farklı kablosuz haberleşme ağları arasında trafiği aktarmak için çeşitli stratejiler kullanılmaktadır.

Bu tezin amacı ayrışık kablosuz ağlarda birbirinden farklı kablosuz haberleşme teknolojilerinin verimli bir şekilde çalışmasını sağlayan aktarma stratejilerini incelemektir. Farklı aktarma stratejilerinin çeşitli senaryolarda performans sonuçları elde edilmiştir. Kablosuz ağların aşırı yüklü olduğu durum ele alınarak, ağ veya kullanıcı ile başlatılan bu stratejilerin karşılaştırmaları yapılmıştır.

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4G	Fourth Generation
QoS	Quality of Service
RAT	Radio Access Technology
WiFi	Wireless Fidelity
AP	Access Point
RSS	Received Signal Strength
RSRP	Received Signal Received Power
1G	First Generation
2G	Second Generation
IS-95	Interim Standard 95
GSM	Global System for Mobile Communications
GPRS	General Packet Radio Service
EDGE	Enhanced Data Rates for GSM
3G	Third Generation
ITU	International Telecommunication Union
IMT	International Mobile Telecommunications
UMTS	Universal Mobile Telephone Service
HSDPA	High Speed Downlink Packet Access
HSUPA	High Speed Uplink Packet Access
LTE	Long Term Evolution
WLAN	Wireless Local Area Network
BS	Base Station
UE	User Equipment
MCS	Modulation and Coding Scheme
HetNet	Heterogeneous Network
OFA	Orthogonal Frequency Allocation
RRM	Radio Resource Management

CHAPTER 1

INTRODUCTION

Traditionally, the mobile users have been only able to establish call and send message and their service demand has been provided by only cellular technologies. After the internet access technologies like IEEE 802.11, IEEE 802.15, etc. have been launched, mobile users started to connect internet. After a few years later, the developments in wireless communication technologies enabled mobile users accessing internet by not only internet access technologies but also cellular technologies. The use of multimedia services with high speed and good Quality of Service (QoS) became available with the launch of Fourth Generation (4G). Recently, the use of mobile devices increases dramatically all over the world. As a result of this tremendous increase, the amount of data demand also increases. It is necessary to improve service quality, coverage and increase data rates. One of the solutions is to deploy heterogeneous networks (HetNets) which is jointly operation of cellular technology and internet access technology.

Besides the necessary advantages of HetNet, there exists a drawback of complexity of multi layered Radio Access Technologies (RAT). Self-management and self-optimization play a critical role in the future evolution of HetNets. Self-behavior networks are able to decide which radio access technology will be used in order to provide communication in most efficient way. The change of used RAT and transfer the traffic load to another RAT is called as offloading.

The main idea of offloading is to offload traffic load from one network node to another node which operates in same RAT or different RAT. In cellular network, the offloading is implied between macrocell and smallcell such as microcell, picocell or femtocell. Smallcell has less transmitter power levels, manufacturing costs and smaller sizes. Smallcell operates in licensed bands and provides effective network solutions.

As a result of the dramatic increase in demand for mobile broadband services, spectrums in licensed band become insufficient to meet the demand of mobile users. Wireless Fidelity (WiFi) which operates in unlicensed band plays a critical role. Various offloading strategies considering different criteria can be used in these systems.

This thesis examines offloading strategies based on Received Signal Strength (RSS), Received Signal Received Power (RSRP), Path Loss (PL), Signal to Interference plus Noise Ratio (SINR) and traffic load. The strategies operate for communication systems consist of macrocells, smallcells and WiFi Access Point (AP). The fundamental of strategies which operates for only cellular network is to offload traffic from macrocell to smallcell. The aim of strategies which operates for both cellular and WiFi network is to offload traffic from macrocell to Smalcell or WiFi APs.

All of these strategies aim to decrease the traffic load, build more effective HetNet topologies and serve subscribers with better QoS. In addition, we focus on to enable more availability of User Equipment (UE), globally available spectrum capacity and ease traffic congestions. Besides these advantages, our purpose is to design more effective heterogeneous wireless network.

The outline of this thesis consisting of six chapters is given as follows:

- Chapter 2 presents brief information about the evolution of wireless communication technologies which include cellular and internet access technologies. After that, the importance of HetNets and offloading strategies are explained in detailed.
- Chapter 3 gives the algorithms for system consisting of macrocell and WiFi APs. The results of RSS, RSRP, combined RSS and RSRP and WiFi first strategies in different scenarios are examined carefully.
- Chapter 4 examines the algorithms for HetNet consisting of macrocell and smallcells. The performance results of maximum RSRP, biased RSRP, minimum path loss (PL), proposed RSRP threshold and load based and proposed traffic load based strategies in different scenarios will be given carefully.
- Chapter 5 examines the algorithms for HetNet consisting of macrocell, smallcell and WiFi APs. The performance results of RSS, RSRP and proposed traffic load based strategies in different scenarios will be provided.
- Chapter 6 is a summary of concluding remarks.

CHAPTER 2

BACKGROUND

Since the launch of the First Generation (1G) network in late 1970s, 5th iteration of the network technology evolution is recently on the way. As the capacity demand of the subscribers started to increase exponentially, the need of new communication technologies have been come out. However, there exists significant technology scale advantages to the wireless communication network with 4G and likely with Fifth Generation (5G).

As network technologies have evolved, the application area has changed as well. 1G has been all about basic voice services. 2G has been digitized mobile and it enabled basic messaging and data services. 3G introduced the potential of data services. The dramatically increasing data demand led to the acceleration of the 4G services.

The evolution of wireless communication technologies including cellular and internet access technologies will be presented in this chapter. Moreover, the importance of HetNets and the offloading techniques will be described in detailed.

2.1. Evolution of Wireless Communication Technologies

Cellular network systems have been designed to provide only use of making calls and sending message a few decades ago. The introduction of Third Generation (3G) is allowed subscribers to access internet by mobile phones. In addition to Voice and message traffic, data traffic became the new traffic load in cellular networks. The introduction of 4G is allowed higher throughputs, lower latencies and accessing multimedia services. Recently, the service demand of mobile users is increasing exponentially and the developments in wireless communication technologies are resuming [1].

The concept of wireless communications systems has been divided into two parts. The first part contains systems based on cellular access and the second part consists of systems providing wireless internet access [2]. In order to completely understand the concept of wireless convergence, it is necessary to discuss the history of both cellular technology and wireless internet technology. The evolution of communication systems are illustrated in Figure 2.1.

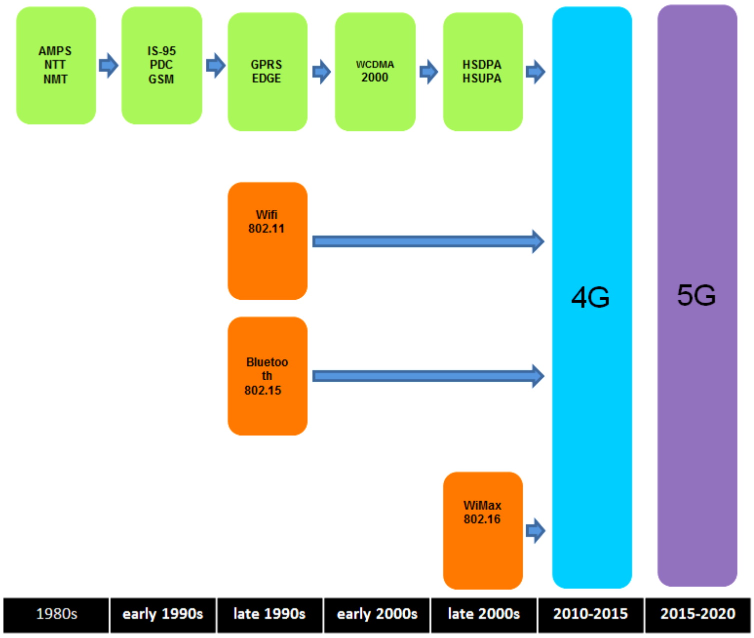

Figure 2.1. Evolution of mobile cellular and wireless internet access communications technologies

1G has been launched in the 1980s. 1G system has been provided users with basic mobile telephony services with low QoS. Examples of 1G wireless communications systems are the Nordic Mobile Telephone System (NMT) from Europe, Nippon Telegraph and Telephone (NTT) systems from Japan and the Advanced Mobile Phone Systems (AMPS) from the United States [1], [2].

During the early 1990s, Second Generation (2G) has been developed. Examples of such systems include Interim Standard 95 (IS-95) system from North America, the Global System for Mobile Communications (GSM) from Europe and the Personal Digital Cellular (PDC) System in Japan [1], [2].

In the middle of 1990s, internet based communication services have been demanded by using mobile terminal devices. As a result, the need of developed packet switched networks has been emerged. After that, 2.5G system has been developed.

Examples of such systems are the General Packet Radio Service (GPRS) and the Enhanced Data Rates for GSM (EDGE) systems [1], [2], [3].

3G has been launched during the early 2000s. The standards for the 3G systems have been developed in terms of the International Telecommunication Union's (ITU) International Mobile Telecommunications vision (IMT-2000). The objectives of 3G systems are to satisfy the need of users for advanced multimedia and data services by making use of a packet switched core network and providing high speed data rates. Two widely deployed standards for 3G systems exist, namely WCDMA which was developed according to the Universal Mobile Telephone Service (UMTS) standard and Code Division Multiple Access 2000 (CDMA2000). Over the past few years several new standards have been produced in order to improve the performance of 3G systems. These systems have been built as an upgrade of 3G systems and have been known as 3.5G systems. Examples of such systems include High Speed Downlink Packet Access (HSDPA) and High Speed Uplink Packet Access (HSUPA) [1], [2], [3].

Long Term Evolution (LTE), is the global standard for 4G supported by all major players in the industry. LTE offers the capacity and the speed to handle a rapid increase in data traffic. According to latest Ericsson Mobility Report, there will be 9.2 billion mobile subscriptions in 2020. Moreover, the number of LTE subscriptions will reach 3.7 billion by 2020 [4].

LTE which is developed mainly for performance and capacity needs, can provide downlink peak rates of at least 100 Mbps. The technology allows for speeds more than 300 Mbps. LTE supports flexible carrier bandwidths from 1.4 MHz up to 20 MHz.

IEEE 802.11 networks are currently the most popular Wireless Local Area Network (WLAN) products. One of the most common misconceptions about 802.11b is that the throughput is 11 Mbps. However, the 11 Mbps only refers to the radio data rate of the packets. The efficiency is significantly lower for smaller packet sizes. The efficiency of IEEE 802.11 is in sharp contrast to wired technologies where a 10 Mbps Ethernet (IEEE 802.3) link offers the users almost 10 Mbps. The IEEE 802.11n technology promises up to 600Mbps using a 4x4 receive antenna. In reality, most reach 300Mbps since users do not usually have more than 2 antennas. Future WiFi evolutions of 802.11ac/ad and 802.11af provide even higher data rates [5].

It is clear that from 1G to 4G, wireless communications networks are reached necessary level that every people use this technology in every time and everywhere. The number of mobile devices such as smartphones, tablets etc. increases exponentially. As a result of this, there exists a huge capacity and coverage need.

Global mobile traffic expectation is illustrated in Figure 2.2. Light orange area denotes voice created by mobile devices, red area shows data created by mobile phones and dark orange area denotes data created by any other mobile devices. According to Figure 2.2, the measured traffic is nearly 4.7 exabytes. Moreover, there will be 9 fold increase in 2020. This exponential increase creates some drawbacks. Firstly, in order to provide all UEs with good QoS, systems should be boosted and improved in terms of capacity and coverage. This issue created a need for different ways in order to come up with this increasing trend [5].

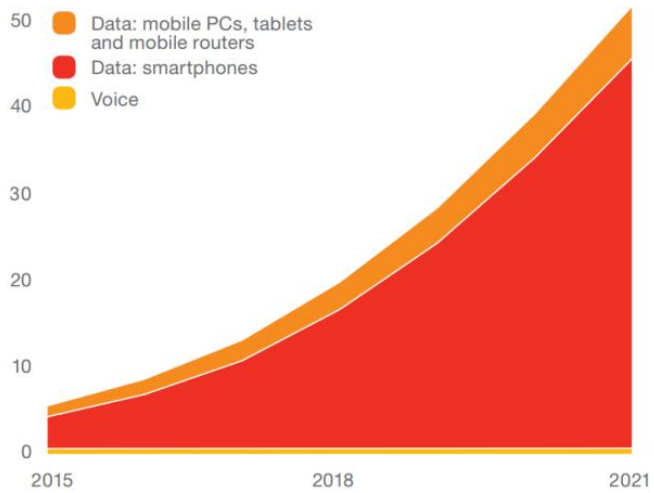

Figure 2.2. Total monthly smartphone traffic over mobile networks

Exponential growth of data traffic was resulted in limitation of available spectrum for mobile applications. In order to meet service demand, the networks must be managed efficiently. Mobile network operators have provided solutions of exponential increase in mobile traffic by using traditional ways like deploying more macro base stations. Traditional network nodes like macrocell become insufficient to meet capacity demand of mobile users. Moreover, it increases total energy consumption and operational costs [6].

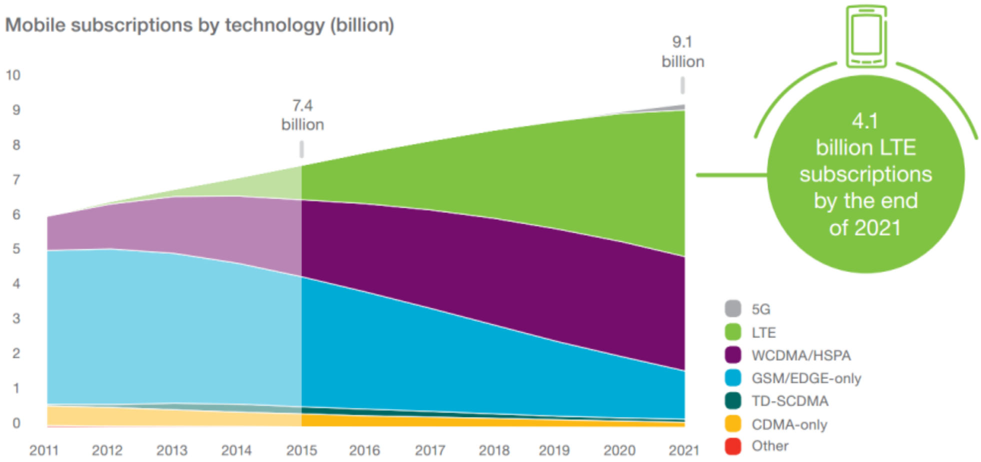

Figure 2.3. The number of subscriptions

The number of subscriptions for different wireless communication technologies is illustrated in Figure 2.3. There will be nearly 4.1 billion LTE subscriptions by the end of 2021. Thus, more different techniques in order to come up with this exponential growth should be especially compatible with 4G [4].

2.2. Heterogeneous Networks

LTE allows network operators to use new and wider spectrum. LTE provides network which has higher data rates and lower latency. These advantages are realized by not only traditional developments in wireless communication technology, but also new techniques came up with LTE. One of the techniques is HetNets.

Traditionally, cellular networks are deployed as homogeneous network which is implied by using a macrocell based planning process. Homogeneous cellular network consists of network nodes in which all of them have same transmit power levels, antenna patterns and receiver noise floors. Deployment process of macrocell in homogeneous network is complex and iterative [7].

HetNets consist of different kind of network nodes having different transmit power levels and antenna size. macrocell has the biggest antenna size and the highest transmit power level. The other cell types having less transmitting power can be named as low power nodes. HetNets can consist of different kind of wireless technologies.

Typically, a HetNet consists of macrocell, microcell, picocell, femtocell and WiFi AP. Thus, the operating band of wireless communication technologies is divided into two parts namely as licensed and unlicensed band. These low power nodes can be deployed to eliminate coverage holes in the system having only macrocell and improve capacity in hotspots.

Macrocell has the biggest cell size. It is usually deployed in rural areas or along highways. It can be mounted above rooftops. Macrocell has a wide coverage typically on the order of few kilometers. A cellular network must include macrocell. Transmitting power levels of macrocell are very high, from 37dBm to 46dBm.

Microcells are widely used for urban area. Microcell has less installation costs than macrocell. Microcell generally exists on roof of buildings. Transmitting power level is from 10dBm to 33,01dBm. The microcell has the coverage from 400 meters to 2 km.

Picocell plays an important role for high volume traffic in local areas especially for hotspots. Transmit power level is from 23dBm to 37dBm. The picocell has the coverage 200 meters or less.

Femtocell has the coverage of 10-50 meters for stationary or low-mobility users at homes or in small offices. Transmit power range is 20dBm or less.

WiFi AP plays an important role for indoor coverages especially for stationary UEs. The frequency ranges of different wireless communications technologies are illustrated in Figure 2.4.

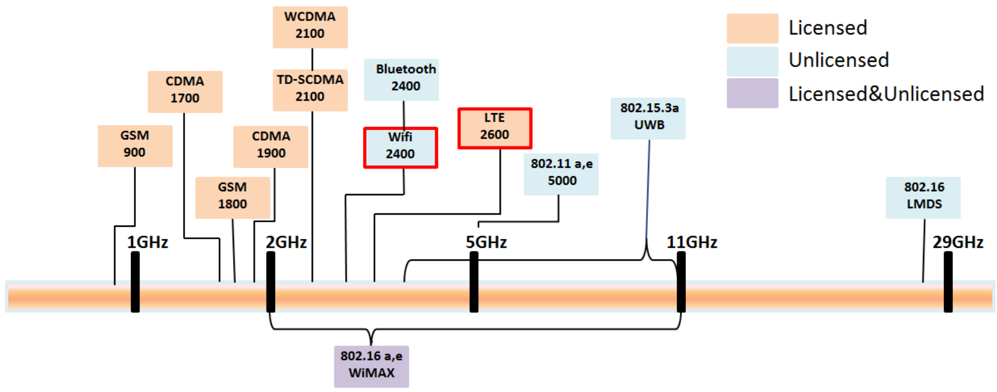

Figure 2.4. Frequency ranges of different wireless communications technologies

The channel representation of WiFi technology at 2400 MHz is illustrated in Figure 2.5.

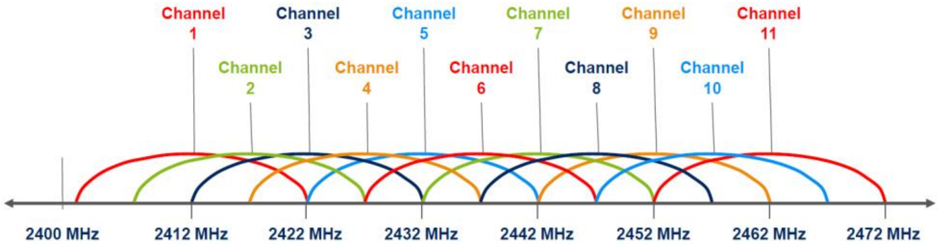

Figure 2.5. Representation of WiFi

In HetNets, different types of wireless networks are interconnected to connect from one technology to another. It is clear that each kind of wireless communication technology is designed independently for different data rates and service types. Management, security and efficient operations are challenges for development of HetNet. These can be summarized as five subheads:

Network Selection: In a HetNet, an UE can use more than one wireless communication technology. Moreover, by using different applications, terminal can connect different kind of wireless technologies at the same time. UE should be able to discover which networks are available [8].

Access Technologies: UEs should switch between access networks to maintain service continuity and provide good QoS. Dealing with the different access technologies is the main technology of designing HetNet. From the network operator perspective, selecting the network that will satisfy the good QoS in the most efficient way is a necessary issue [8].

Network Architecture: The integration of different kind of wireless communication technologies is required operation of different protocols for transport, routing and mobility management. The cooperation of these technologies is main issue of HetNets [8].

Network Conditions: Bandwidth, delay, jitter and any other terms can change in different technologies. Maintaining the stability of UEs’ QoS in different network conditions is another issue [8].

Security: The security level in different technologies may differ from one to another. Interconnection of these technologies may create vulnerability problem. Security criteria should be well designed [8].

2.3. Spectrum Allocation

The notion of spectrum allocation holds a necessary place in HetNets which consists of multi layers of the RAT. There exist three kinds of frequency allocation approaches in literature. These various approaches have advantages and disadvantages from the aspects of channel capacity and coverage [9].

Co-channel Allocation: The entire of frequency band is shared between nodes in HetNet. Different network node groups in HetNet may provide different level of average throughput to UEs. Co-channel allocation plays a necessary role in order to balance the average throughputs of network node groups. The cell edge UEs' throughputs are guaranteed with the proportional fair scheduler. [9].

Frequency Overlapped Allocation: The frequency resource is overlapped between macrocell and smallcell partially. Frequency overlapped allocation can reach a best cell group average throughput. Moreover it has poor performance in the case of cell edge [9].

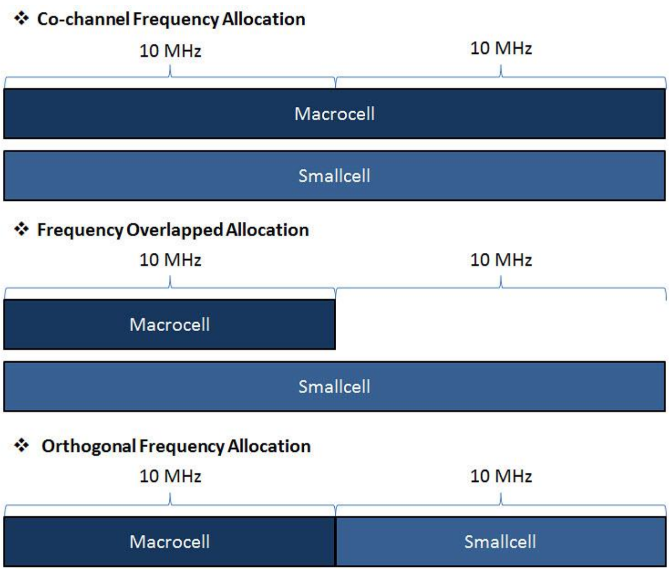

Figure 2.6. Spectrum allocation types in HetNet

Orthogonal Frequency Allocation (OFA): The entire frequency band is divided into two parts so that macrocell uses a part of frequency band and smallcell use the other. Frequency resource cannot be overlapped between macrocell and smallcell by designing system with OFA. This type of frequency allocation provides the worst average throughput value but it has better performance than overlapped frequency allocation in the case of cell edge throughput. There exists no inter cell interference between macrocell and smallcell. OFA is considered in this study [9].

There exist two types of OFA model. In Frequency Allocation Model 1, the entire bandwidth of system is shared between macrocell and each type of smallcell. As a result of that distinct sharing, different network nodes do not create interference to each other. The network elements belonging to same network node type create interference to each other.

In Frequency Allocation Model 2, half of the entire bandwidth of system is owned by macrocell and smallcell use the same other half part of bandwidth. As a result of that, smallcell nodes create interference to each other.

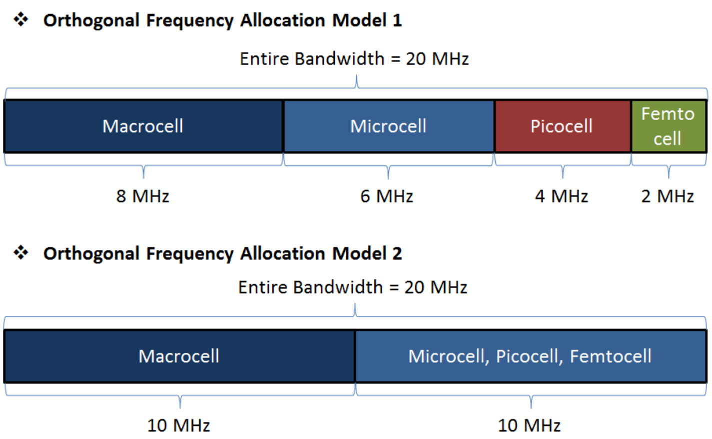

Figure 2.7. OFA Model 1 and OFA Model 2

2.5. Wireless Channels Effects

The wireless radio channel puts fundamental limitations to the performance of wireless communications systems. Radio channels are extremely random, and are not easily analyzed.

The signal coverage calculation for any environment is path loss model. Loss of strength to distance between transmitter and receiver is directly obtained by the value of path loss. Coverage area of wireless BSs and APs can be calculated by using path loss models. There are different path loss models like Okumura-Hata Model, Cost 231-Hata Model, COST 231-Walfisch-Ikegami Model and Clutter Factor Model [11].

The received signal strength can vary depending on the environment, surroundings and location of objects. Mean value of signal strength can be expected from the distance between transmitter and receiver. The actual received signal strength will vary around this mean value. This variation of signal strength due to location is referred to as shadow fading. Due to the signal being blocked from the receiver by buildings, walls and other objects in the environment, fluctuations exist around the mean value.

The achievable signal coverage can be characterized based on mean received signal strength or path loss suffered by shadowing and PL. However, the received signal is rapidly fluctuating due to the mobility of UE which causes changes in multiple signal components arriving via different paths. This type of characterization is referred to as small scale fading. The characteristic of instantaneous signal strength is necessary in order to design receivers which can mitigate these effects. As a result of multipath fading, signal amplitude fluctuates because of addition of signals with different phases. In order to model these fluctuations, the most commonly used distribution for multipath fading is the Rayleigh distribution.

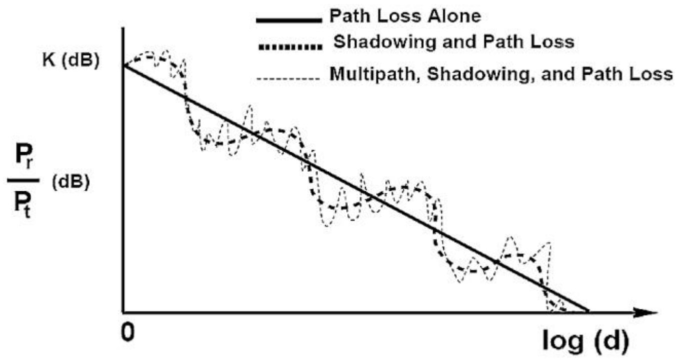

Figure 2.8. Channel modelling effects [11]

2.6. Offloading Strategies

Due to dramatic increase in mobile traffic the available spectrum is limited. Besides challenging with these technical problems, a good QoS should be provided. Offloading is a good solution in order to meet increasing traffic demand. Unfortunately, traditional network nodes like macrocell becomes insufficient to meet data demand of users. This situation created unstable highly density communication areas. Moreover, the traditional nodes have much manufacturing costs. In addition to macrocell, by employing smaller nodes with less energy, and increasing the number of nodes in order to cover these crowded places covering and providing enough capacity will be more efficient by comparing with macrocell. Mobile traffic can be offloaded to smaller nodes in same cellular technology typically named as smallcell or offloaded to different wireless communications technology like IEEE 802.11 named as WiFi offloading. Offloading enables wide spreading existing deployments, more availability of user devices, globally available spectrum capacity and easing traffic congestions. As a result of these advantages, it is cost efficient.

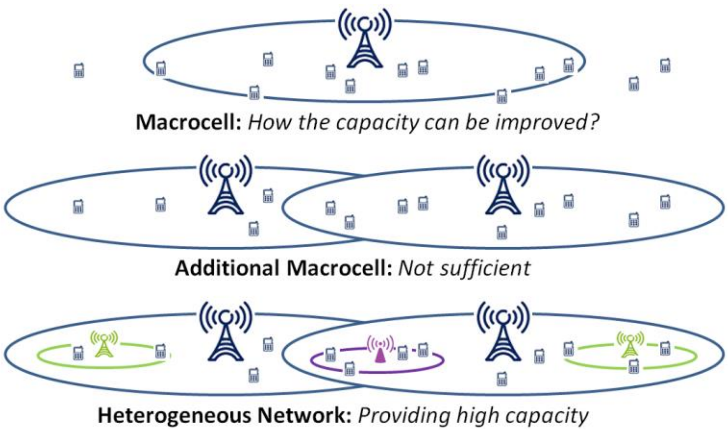

Figure 2.9. Offloading and HetNet

Mainly, two types of offloading exist. User initiated in which UE decides when and how to offload and network initiated in which network provider makes offloading decision. Offloading can be done through smallcell or WiFi network. Depending on the spectrum sharing techniques, smallcell can use same frequency band with macrocell. Thus interference effect can exist. WiFi network uses different frequency band with LTE. Thus no interference effect exists. According to offloading report of Cisco in Figure 2.10, it is expected that in 2019 more than half of the traffic will be offloaded to WiFi network [10].

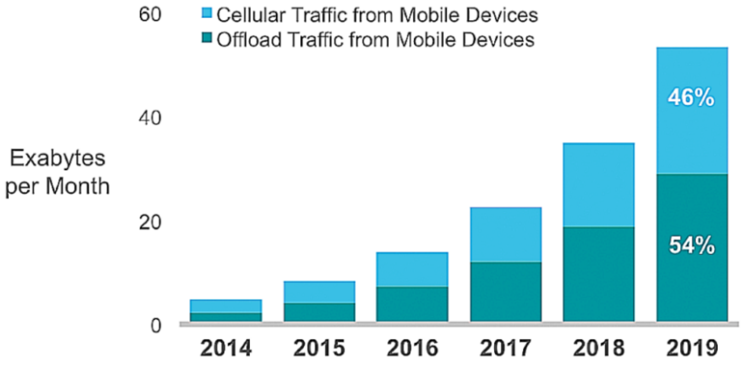

Figure 2.10. The future of offloading [10]

2.6.1. Distance Based Selection

In this approach, each user is always associated with the nearest node either in cellular or WiFi network [12].

$$u^* = arg \min_{u=1,2,\ldots,U} d_{u,k} \qquad \forall k \tag{2.1}$$

where U is the total number of nodes and $d_{u,k}$ is the distance between k^{th} user and u^{th} node.

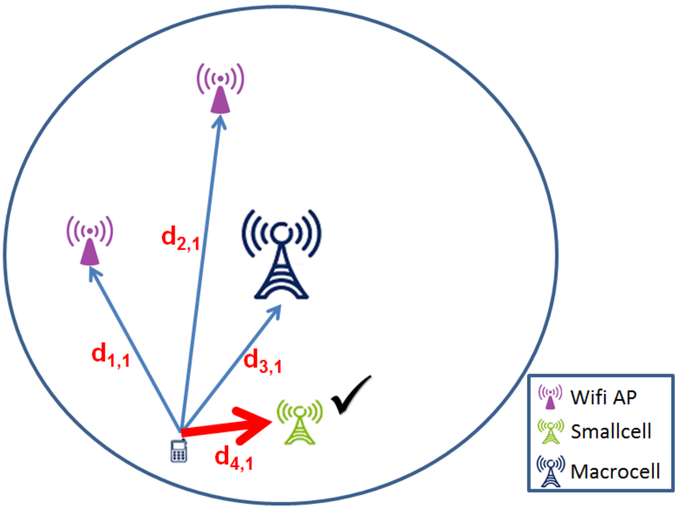

Figure 2.11. An example of association with the nearest node

2.6.2. SINR Based Selection

In this technique, each user is always connected to the network node which provides highest SINR.

$$u^*_{SINR} = arg \max_{u=1,2,\ldots,U} \gamma_{u,k} \qquad \forall k \tag{2.2}$$

where $\gamma_{u,k}$ is the SINR value of the k^{th} user belonging to u^{th} node [12].

The SINR value of the k^{th} user received from the u^{th} node is calculated as follows:

$$\gamma_{u,k} = \frac{P_t{}^u \left|\bar{h}_{u,k}\right|^2}{N_0 B + I_k} \tag{2.3}$$

where P_u is transmit power of node u , $\bar{h}_{u,k}$ is the average channel coefficient between user *k* and node *u* including PL and shadowing. N_0 is noise spectral density and I_k is the total interference power caused by other nodes for k^{th} user.

$$I_k = \sum_{j=1; j \neq u}^{U} P_j \left|\bar{h}_{j,k}\right|^2 \tag{2.4}$$

Biasing factor can also be considered in SINR formula, named as biased SINR. In this approach, users are connected to the node with the highest biased SINR.

$$\acute{u}_{SINR} = arg \max_{u=1,2,\dots,U} \acute{\gamma}_{u,k} \qquad \forall k \tag{2.5}$$

$$\acute{\gamma}_{u,k} = \beta_u \frac{P_u \left|\bar{h}_{u,k}\right|^2}{N_0 B + I_k} \tag{2.6}$$

where β_u is biasing factor for u^{th} node. Biasing factor expands the range of smallcells so that their coverage is extended. Therefore, more users can connect to those cells. Moreover, the load balancing can be achieved among all nodes in the network.

2.6.3. Utility Maximization Strategy

General framework for offloading in a cellular network has been presented in this strategy [13]. Cellular network which consist of U network nodes is considered in this approach. Each node u transmit with power $p_u > 0$. Each node u serves one distinct group of users in set K_k. Each user k in user set K_k is able to be served in node

u up to a maximum rate of $G_{u,k}$ which has a unit of nat. It can be mathematically expressed as follows:

$$g_{u,k} + \grave{g}_{u,k} \leq G_{u,k} \tag{2.7}$$

where the demand $g_{u,k}$ is served in the cellular network and the demand $\grave{g}_{u,k}$ is offloaded to be served in complementary network. The strategy considers demands $\grave{g}_{u,k}$ and $\grave{g}_{u,k}$ as variables to be optimized subject to constraint Eq. (2.7).

In this approach, the aim is to maximize the sum utility. The mathematical expression of sum utility is as shown below:

$$U^{sum} \triangleq \sum_{k \in K_k} \sum_{u \in U} w_{u,k} U(g_{u,k}) + \grave{w}_{u,k} U(\grave{g}_{u,k}) \tag{2.8}$$

where $U(g)$ is the utility function. The weights $w_{u,k}$ and $\grave{w}_{u,k}$ provides the priority of the user in cellular and complementary network, respectively.

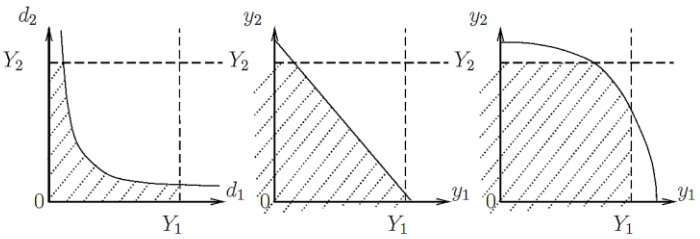

Figure 2.12. LIN, LOG and DLOG Functions

$U(g)$ is chosen to be functions, namely the linear (LIN), logarithmic (LOG), and double-logarithmic (DLOG) utility functions. Shaded areas in Figure 2.12 are the transformed feasibility sets. In linear function, the scenario serving an additional demand unit results in an additional unit of utility is modelled. In logarithmic function, to serve an additional demand unit of a user with a low demand results in more utility. This provides a fairer demand distribution among users. Double-logarithmic function further emphasizes fairness, because it favors low demand users even more [13].

2.6.4. Optimum Probability Coefficient Strategy

Network assisted user centric WiFi offloading model in a HetNet in order to maximize per user throughput has been presented in this strategy [14]. The HetNet consisting of cellular network and WiFi network is modelled as illustrated in Figure 2.13.

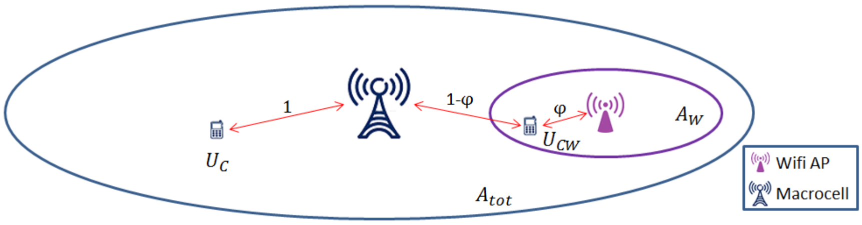

Figure 2.13. Example of a cellular and a WiFi HetNets [13]

In Figure 2.13, φ denotes the probability of a user offloaded to be served in WiFi network, A_W represents coverage of one WiFi AP, set U_{CW} represents UEs which are able to access cellular network and WiFi network, set U_C represents UEs which are able to access only cellular network and A_{tot} is coverage of one cellular network node [14].

The strategy considers that a user in U_{CW} exchanges data packets through WiFi with probability φ. The IEEE 802.11 operates on a contention based carrier-sensing multiple accesses with collision avoidance (CSMA/CA) with a binary-exponential back off (BEB) algorithm. The analysis of per-user throughput of the WiFi network is implied with a discrete-time Markov chain (DTMC) model. It is assumed that Poisson Arrivals of packets with mean μ. The probability of at least one packet awaiting transmission at the start of a counter decrement q and the expected slot time $E[T_{st}]$ are expressed as follows:

$$q = \varphi\left\{1 - e^{(-\mu . E[T_{st}])}\right\} \tag{2.9}$$

$$E[T_{st}] = Pr_{tr}Pr_sT_s + Pr_{tr}(1 - Pr_s)T_c + (1 - Pr_{tr})T_\delta \tag{2.10}$$

where T_s, T_c, and T_δ denote the average time of a successful transmission, a collision, and an idle slot, respectively. Pr_{tr} and Pr_s denote the probability that there is at least one transmission in the network and the probability that a transmission is successful, respectively. They can be expressed as follows:

$$Pr_{tr} = 1 - (1 - \tau)^{N_w} \tag{2.11}$$

$$Pr_s = \frac{N_w \tau (1 - \tau)^{N_w - 1}}{Pr_{tr}} \tag{2.12}$$

where N_W is equal to λA_W where λ represents the active user density of the uniformly distributed users. Then, the per-user throughput of a WiFi network is expressed as follows:

$$S_W^k = \frac{Pr_{tr} Pr_s E[L]/N_w}{Pr_{tr} Pr_s T_s + Pr_{tr}(1 - Pr_s)T_c + (1 - Pr_s)T_\delta} \tag{2.13}$$

where L represents per user packet size in bits. The per-user cellular throughput of user k in U_{CW} is expressed as:

$$S_C^k = \begin{Bmatrix} (1-\varphi)S_{Ch}^k, & if\ unsaturated\ (N_C^{max} \geq \overline{N_C}) \\ (1-\varphi)(N_C^{max}/N_C)S_{Ch}^k, & if\ saturated \end{Bmatrix} \tag{2.14}$$

$$S_C^k = \begin{Bmatrix} \mu L, & if\ BW_C.G.E[\log_2(1+\gamma^k)] > \mu L \\ BW_C.G.E[\log_2(1+\gamma^k)], & otherwise \end{Bmatrix} \tag{2.15}$$

where N_C^{max}/N_C represents the cellular network access probability with a fair scheduling mechanism under a saturated condition. N_C^{max} denotes the maximum number of simultaneously acceptable cellular users which are equal to BW_C^{max}/BW_C where BW_C^{max} and BW_C denote the maximum available cellular bandwidth and the allocated bandwidth for each UE, respectively. N_C denotes the average number of active cellular users equal to $\lambda A_{tot} - \varphi\, \lambda A_W^{total}$. The achievable cellular channel capacity of user k is denoted by S_{Ch}^{k}. G represents the throughput attenuation which is caused by framing and signaling overheads.

The aggregated per user throughput of user *k* in U_{CW} is modeled as follows

$$S_{user}^{k} = S_{C}^{k} + S_{W}^{k} \tag{2.16}$$

where S_{user}^{k} denotes per-user throughput of user *k*.

In the strategy, the target is to maximize the aggregated per-user throughput.

$$\varphi = argmax\ S^{k} \tag{2.17}$$

The working principle of strategy can be summarized as shown below.

Input: $K, \lambda, A_{tot},\ A_{W}$

Output: φ^{*}, S^{k}

Ensure: $0<\varphi<1$

Initialize: t=0 and $k \in K$

While 1 do

 $t = t + 9\mu s$;

 If $t =$ kT_{period} then

  Network finds $\varphi^{*} = argmaxS_{user}^{k}$;

  Network informs φ^{*} to each user;

 end

 for each user k do

  If user $k \in U_{CW}$ then

   Offload traffic through WiFi with prob. of φ^{*};

  else

   Communicates with cellular only;

  end

 end

end

2.6.5. QoS Based Strategy

This strategy has been examined an offloading control mechanism which is based on Software Defined Network (SDN) in order to increase QoS of overall system by considering a dissatisfaction parameter 'ψ'. Firstly, the strategy analyses the distances of each UEs to nodes in cellular network or WiFi network. Moreover, it classifies UEs with respect to their service demands. Finally the strategy identifies the most dissatisfied UE in the network by using 'ψ' parameter by evaluating QoS matrix and decides which UE must be offloaded to which network node. SDN based offloading algorithm provides offloading with better QoS than traditional on the spot offloading [15].

The strategy uses a QoS parameter $\emptyset_{u,k}$ which is obtained from received power $\emptyset_{u,k}$ and node density z_u. QoS parameter can be expressed as shown below [15].

$$\emptyset_{u,k} = \frac{P_{u,k}}{z_u}, \qquad \forall u \in U , \forall k \in K \tag{2.18}$$

where K is the set of users and U is the set of nodes. $P_{u,k}$ denotes received power of k^{th}user from u^{th} node.

Density of u^{th} node can be calculated as illustrated below.

$$z_u = \frac{n_u}{\alpha_u^2}, \qquad \forall k \in K , \forall u \in U \tag{2.19}$$

where n_u denotes the number of users in u^{th} node. α_u^2 indicates coverage area of u^{th} cell in meters.

QoS matrix has size KxU where K is the number of users and U is the number of nodes in HetNet. ψ depends on UE types and deviation between $\emptyset_{max}$ and $\emptyset_{u,k}$.

$$\gamma_{u,k} = \frac{\emptyset_{max} - \emptyset_{u,k}}{\emptyset_{max}} \tag{2.20}$$

where $\emptyset_{max}$ denotes value where a user satisfaction is maximum. The UEs can be classified into three groups which are gold, silver and bronze users according to their service demands. The mathematical expression of ψ can be calculated as shown below.

$$\psi_k(t) = \begin{Bmatrix} \gamma_{u,k} - \alpha, for\ gold\ users \\ \gamma_{u,k} - \beta, for\ silver\ users \\ \gamma_{u,k} - \theta, for\ bronze\ users \end{Bmatrix} \tag{2.21}$$

ψ_k varies in range between -1 and 1. If the sign of this parameter is negative, it means that user is satisfied with its type. If the sign of this parameter is positive, it means user is dissatisfied and needs to be offloaded [15].

2.6.6. Load Balancing Strategy

The aim of load balancing strategy is to achieve better performance [16]. This strategy considers cellular network and performs offloading from macrocell to smallcell. The network topology of this strategy is illustrated below in Figure 2.14.

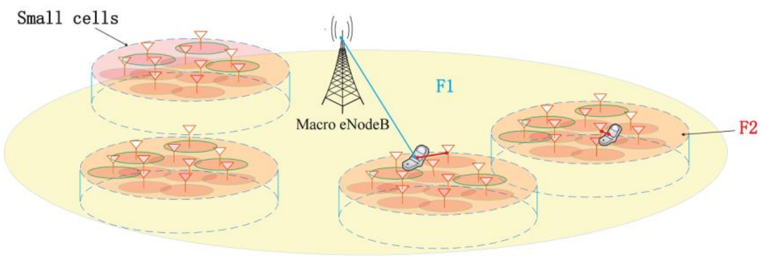

Figure 2.14. Smallcell heterogeneous scenario [15]

It is assumed that UE knows the signal strength coming from all of the network nodes in HetNet. The average received SINR of UE in u_{th} node is calculated as illustrated in Eq. (2.3).

By using the SINR term, data rate of UE can be calculated as follows.

$$\theta_{u,k} = f(\gamma_{u,k}) \tag{2.22}$$

$f(\cdot)$ is a function to map SINR to the data rate depending on the link adaption and the selected Modulation and Coding Scheme (MCS).

$$T_{u,k} = \theta_{u,k}(1 - BLER_k) = f(\gamma_{u,k})(1 - BLER_k) \tag{2.23}$$

where $BLER_k$ denotes the block error rate of UE k and $T_{u,k}$ denotes the throughput. By using the calculation of BLER, the system throughput can be obtained by sum of all UEs throughput.

$$T_{total} = \sum_{k \in K} \sum_{u \in U} X_{u,k}.T_{u,k} \tag{2.24}$$

where assignment indicator variable $X_{u,k}$ is defined, which is equal to 1 when UE u is served by node u. Algorithm works with the principle of SINR threshold while offloading from macrocell to smallcell. The operating principle of Algorithm 1 which is named as Interference and Load Restricted offloading is illustrated below.

```
Create list T for potential target cells;
while γ_{u,k} ≥ γ_{Thr} + Δ do
    u ←1;
    γ_{Thr} ← γ_{Thr} + Δ;
    T← sort
    while u ≤ size(T) do
        O ← T(u)
        Estimate the throughput T_{total,u} after offloading,
        If T_{total,u} ≥ T_{total,u−1} then
        Update load in each cell and average load p_{avg}(t)
        Update H,L;
        γ_{Thld,(O,k)} ← γ_{Thr};
    end if
```

$u \leftarrow u + 1$;

end while

end while

adjust γ_{Thr}

Voronoi load balancing algorithm applied to UEs after offloading to smallcell. The aim of this algorithm is to adjust cell coverage after load balancing handover and decrease the effect of interference. The algorithm considers a term $diff(u_u, u_{u+1}, p)$ which is difference of RSRP between smallcells u_u and u_{u+1} at sample point p. The formula is illustrated below [16].

$$diff(u_u, u_{u+1}, p) = RSRP(u_u, p) - RSRP(u_{u+1}, p) \tag{2.25}$$

The algorithm detects the smallest $diff(\cdot)$ at point p. After that it associates along the neighbor s_t with the second strongest RSRP whether the data load increase for u_u which is less than p_{avg}. After these two algorithms are applied to HetNet, the interference effect can be decreased and throughput can be improved. By assuming that there exists S smallcells, the average load of all the smallcells be expressed as follows [16]:

$$p_{avg} = \frac{1}{X}\sum_{i=1}^{X} p_i \tag{2.26}$$

where p_i is the load of smallcell x. The load of cell x is expressed as the sum of required number of PRBs of all UEs in cell x.

CHAPTER 3

OFFLOADING TECHNIQUES FOR HETNET WITH MACROCELL AND WIFI

Basic Radio Resource Management (RRM) measurements in cellular and WiFi system are RSRP and RSS, respectively. RSRP and RSS are needed for offloading decision. The strategies which operate in system consist of macrocell and WiFi APs will be examined in this chapter. The performance evaluations of RSS, RSRP and RSS&RSRP based and WiFi first strategies in various scenarios will be examined in detailed. Moreover, the advantages and disadvantages of all strategies will be discussed.

3.1. RSS Based Strategy

Various techniques have been proposed in the literature for mapping RSS measurements to distance estimates. The basic model used in this study for IEEE 802.11 technology is as shown below [3];

$$RSS_{u,k}(dBm) = P_t^u(dBm) - PL_{u,k}(dB) - L_{u,k}^f(dB) \quad (3.1)$$

where $RSS_{u,k}$ denotes the received signal strength of user k from WiFi AP u. P_t^u is the transmitting power of WiFi AP u. $PL_{u,k}$ is the Path Loss between user k and WiFi AP u. $L_{u,k}^f$ is the shadow fading which is modelled by log normal distribution.

For channel modelling case, the path loss and shadow fading effects are considered in all strategies defined in this chapter by using Modified COST231 Hata urban propagation model. The general formula for modified COST231 Hata urban propagation model is illustrated below [11], [17].

$$PL_{u,k} = A + Blog(d_{u,k}) + C - \alpha(h_r) \quad (3.2)$$

In the formula above, $d_{u,k}$ is distance between user k and node u and $\alpha(h_r)$ is correction factor [11]. $\alpha(h_r)$ can be expressed as follows:

$$\alpha(h_r) = (\,1.1\, log(f\ (MHz)) - 0.7)h_r - \ (1.56\, log(f\ (MHz)) - 0.8) \qquad (3.3)$$

where f is frequency of transmission in MHz and h_r is the node antenna effective height. The expressions of other coefficients in the path loss formula in Eq. (3.2) are as shown below.

$$A = 46.3 + 33.9\log(f) + C - \ 13.82\, log(h_b) \qquad (3.4)$$

$$B = [-\,44.9 - 6.55\, log(h_b)] \qquad (3.5)$$

$$C = \begin{Bmatrix} 0\ dB\ for\ medium\ cities\ and\ suburban\ areas \\ 3\ dB\ for\ metropolitan\ areas \end{Bmatrix} \qquad (3.6)$$

where h_b is the effective height of node antenna in meters.

In all strategies, resource block sharing model is considered. In this case, each user k receives rate proportional to its link's spectral efficiency [18]. Thus, the capacity of a user k associated with node *u* is given by;

$$C_{u,k} = \frac{B_u}{N_u} log_2(1 + \ \gamma_{u,k}) \qquad (3.7)$$

where N_u denotes the total number of users served by the node and B_u denotes the bandwidth of node u. For RSS based strategy RSS_{Thr} is applied to determine which UEs will be associated with WiFi network with respect to the following rule [19]:

IF RSS >RSS_{Thr}*, THEN*

UE served on WiFi

ELSE

UE served on macrocell

END

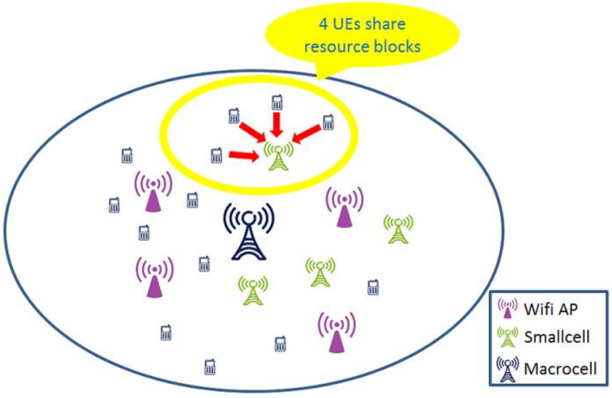

Figure 3.1. Resource Block Sharing

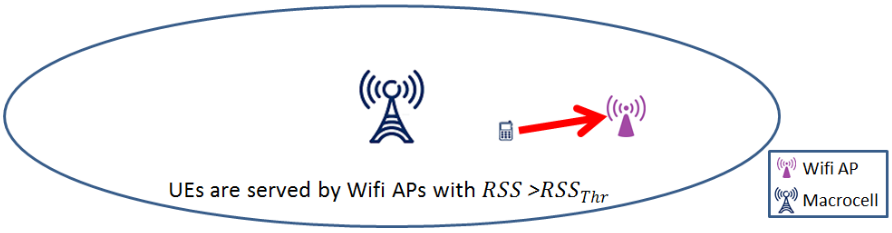

Figure 3.2. RSS based offloading mechanism in macro and WiFi deployment

When there exists more than one WiFi AP having RSS value more than RSS_{Thr}, the k_{th} user is always associated with WiFi AP with maximum RSS.

$$u^* = arg \max_{u=1,2,\dots,U} RSS_{u,k} \qquad \forall k \tag{3.8}$$

3.2. RSRP Based Strategy

For RSRP measurements, the basic model used in this study for cellular node is as shown below [3];

$$RSRP_{u,k}(dBm) = P_t^u(dBm) - \acute{PL}_{u,k}(dB) - L_{u,k}^{\acute{f}}(dB) \tag{3.9}$$

$RSRP_{u,k}$ denotes the referenced signal received power of user k from node u. $P\acute{L}_{u,k}$ is the Path Loss in dB and $L^{\acute{f}}_{u,k}$ is the shadow fading in which is modelled by log normal distribution.

$$P\acute{L}_{u,k} = \acute{A} + Blog(d_{u,k}) + C - \alpha(h_r) \quad (3.10)$$

In the formula above, $d_{u,k}$ is distance between user k and node u and $\alpha(\acute{h}_r)$ correction factor [11]. $\alpha(\acute{h}_r)$ can be expressed as follows:

$$\acute{\alpha}(h_r) = \left(1.1\, log\left(\acute{f}(MHz)\right) - 0.7\right)h_r - \left(1.56\, log\left(\acute{f}(MHz)\right) - 0.8\right) \quad (3.11)$$

where $\acute{f}$ is frequency of transmission in MHz and $\acute{h_r}$ is the mobile station antenna effective height. The expression of $\acute{A}$ coefficient in the path loss formula in Eq. (3.10) is as shown below.

$$\acute{A} = 46.3 + 33.9 \log\left(\acute{f}\right) + C - 13.82\, log(h_b) \quad (3.12)$$

where h_b is the effective height of node antenna in meters. B and C coefficients are obtained as in Eq. (3.5) and Eq. (3.6), respectively.

For RSRP based strategy $RSRP_{Thr}$ is applied to determine which UEs will be associated with macrocell with respect to the following rule [20]:

IF RSRP >$RSRP_{Thr}$, THEN

UE served on macrocell

ELSE

UE served on WiFi

END

3.3. RSS and RSRP Based Strategy

In this algorithm $RSRP_{Thr}$ and RSS_{Thr} are applied to determine which UEs will be associated with WiFi network [21].

IF $(RSRP < RSRP_{Thr})$ *and* $(RSS > RSS_{Thr})$, *THEN*

UE served on WiFi

ELSE

UE served on macrocell

END

$RSRP$ and RSS can be expressed as defined by Eq. (3.1) and Eq. (3.9) in Section 3.1 and 3.2. Moreover, path loss and shadowing calculations are implied as defined in Section 3.1 and Section 3.2. When there exists more than one WiFi AP having RSS value more than RSS_{Thr}, the k^{th} user is always associated with WiFi AP with maximum RSS as defined in Eq. (3.9).

3.4. WiFi First Strategy

In this approach, UEs always will be offloaded to WiFi network whether they exist in the coverage of a WiFi AP. When a UE exists in the coverage of more than one WiFi AP, the k_{th} user is always associated with WiFi AP with maximum RSS as defined in Eq. (3.8). The WiFi first strategy associates UEs with WiFi AP or macrocell with respect to the following rule:

IF $d_{u,k} < Cov_u$, *THEN*

UE served on WiFi

ELSE

UE served on macrocell

END

where Cov_u denotes the coverage of a WiFi AP.

3.5. Performance Evaluations

In macro and WiFi network scenario, the simulation area consists of macrocell and the WiFi APs. Macro and WiFi networks operate in 2.6 and 2.4 GHz frequency bands and have 20 MHz and 10 MHz bandwidth, respectively. WiFi network operates in different frequency band with respect to cellular network. Thus, they do not create interference to each other. Downlink communication scenario is considered in this thesis. The simulation area consists of macrocell, WiFi APs and UEs is as illustrated in Figure 3.3. The macrocell is placed at (0, 0) coordinate, and the WiFi APs and UEs are randomly placed in 1km x 1km area.

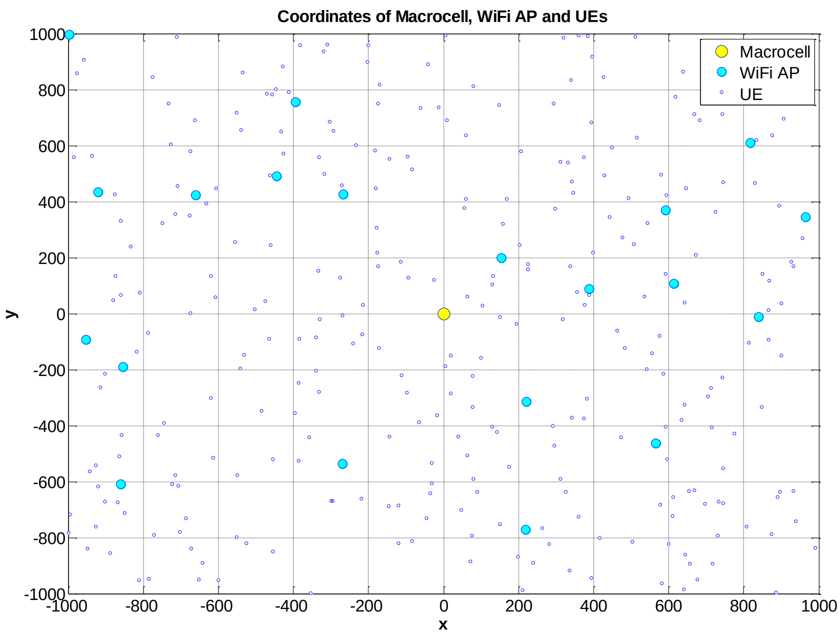

Figure 3.3. Simulation area of macrocell and WiFi APs (1kmx1km)

For RSS, RSRP and RSRP&RSS based strategies, different threshold values are implied to the system consist of various number of WiFi APs as illustrated in Table 3.1, Table 3.2 and Table 3.3. For WiFi first strategy, various numbers of WiFi APs are deployed in the network as illustrated in Table 3.4. We denote macrocell as ‘Ma’ and WiFi AP as ‘W’ in the following sections.

Table 3.1. The number of WiFi in different cases with RSS strategy

Cases (1Ma and 300 UEs)	Number of WiFi APs	RSS_{Thr}
Case1.1	0	-
Case1.2	10	-20 dBm
Case1.3	10	-25 dBm
Case1.4	10	-30 dBm
Case1.5	10	-35 dBm
Case1.6	15	-20 dBm
Case1.7	15	-25 dBm
Case1.8	15	-30 dBm
Case1.9	15	-35 dBm
Case1.10	20	-20 dBm
Case1.11	20	-25 dBm
Case1.12	20	-30 dBm
Case1.13	20	-35 dBm

Table 3.2. The number of WiFi in different cases with RSRP strategy

Cases (1Ma and 300 UEs)	Number of WiFi APs	$RSRP_{Thr}$
Case2.1	0	-
Case2.2	10	10 dBm
Case2.3	10	5 dBm
Case2.4	10	0 dBm
Case2.5	10	-5 dBm
Case2.6	15	10 dBm
Case2.7	15	5 dBm
Case2.8	15	0 dBm
Case2.9	15	-5 dBm
Case2.10	20	10 dBm
Case2.11	20	5 dBm
Case2.12	20	0 dBm
Case2.13	20	-5 dBm

Table 3.3. The number of WiFi in different cases with RSRP&RSS strategy

Cases (1Ma and 300 UEs)	Number of WiFi APs	RSS_{Thr}	$RSRP_{Thr}$
Case3.1	0	-	-
Case3.2	10	-20 dBm	10 dBm
Case3.3	10	-25 dBm	5 dBm
Case3.4	10	-30 dBm	0 dBm
Case3.5	10	-35 dBm	-5 dBm
Case3.6	15	-20 dBm	10 dBm
Case3.7	15	-25 dBm	5 dBm
Case3.8	15	-30 dBm	0 dBm
Case3.9	15	-35 dBm	-5 dBm
Case3.10	20	-20 dBm	10 dBm
Case3.11	20	-25 dBm	5 dBm
Case3.12	20	-30 dBm	0 dBm
Case3.13	20	-35 dBm	-5 dBm

Table 3.4. The number of WiFi in different cases with WiFi First strategy

Cases (1Ma and 300 UEs)	Number of WiFi APs
Case4.1	0
Case4.2	20
Case4.3	30
Case4.4	40
Case4.5	50
Case4.6	60
Case4.7	70
Case4.8	80

Simulation Parameters

The parameters which are used in all scenarios are as illustrated in Table 3.5 and Table 3.6.

Table 3.5. Simulation parameters for macrocell & WiFi AP with all strategies

Parameters	Value
Tx power of macrocell	43 dBm
Tx power of WiFi AP	23 dBm
Bandwidth of macrocell	20 MHz
Bandwidth of WiFi AP	10 MHz
Shadowing Factor for macrocell	10 dB
Shadowing Factor for WiFi AP	4 dB
Height of Tx macrocell	32 m
Height of Rx macrocell	1,5 m
Height of Tx WiFi AP	0,7 m
Height of Rx WiFi AP	1,5 m
Coverage Radius of macrocell	1000 m
Coverage Radius of WiFi AP	55 m
C coefficient	3 dB
Operating Frequency for cellular	2600 MHz
Operating Frequency for WiFi	2400 MHz

Table 3.6. Capacities of service types used for satisfaction percentages

Services	Capacity (Mbps/User)
Calling	0,1
Video Calling/HD	1,5
Group Video/3 people	2
Group Video/5 people	4
Group Video/7 people	8

Simulation Results

The simulation results of all cases with respect to all of the strategies defined in this chapter are illustrated.

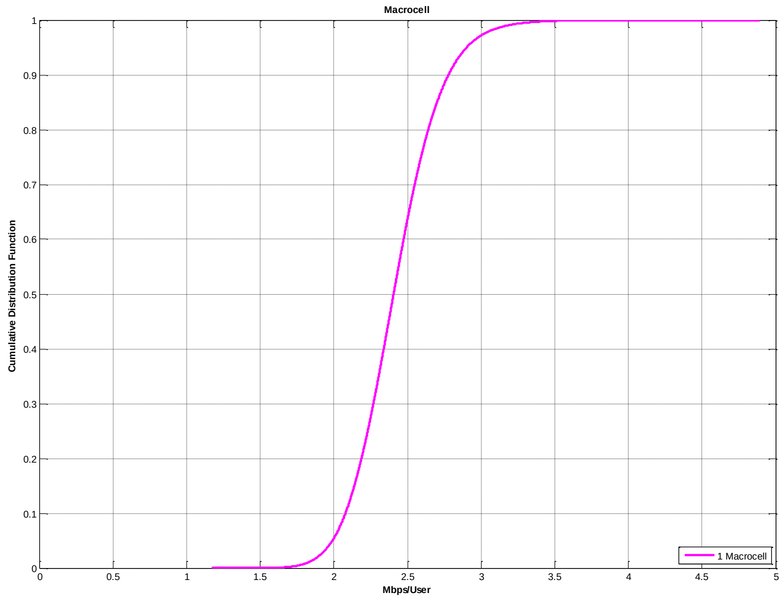

Figure 3.4. CDF for 1 macro (Case 1.1, 2.1, 3.1, 4.1)

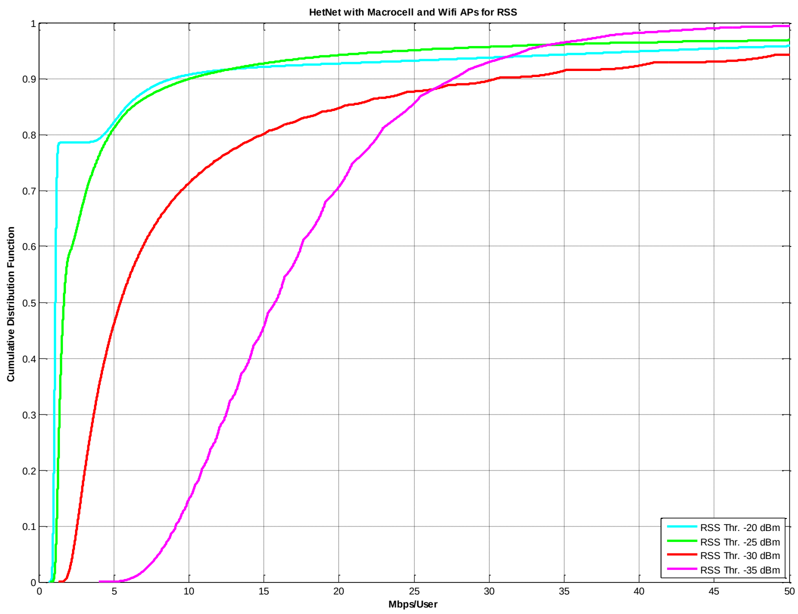

Figure 3.5. CDF for 1 macro and 20 WiFi for RSS strategy (Case 1.10, 1.11, 1.12, 1.13)

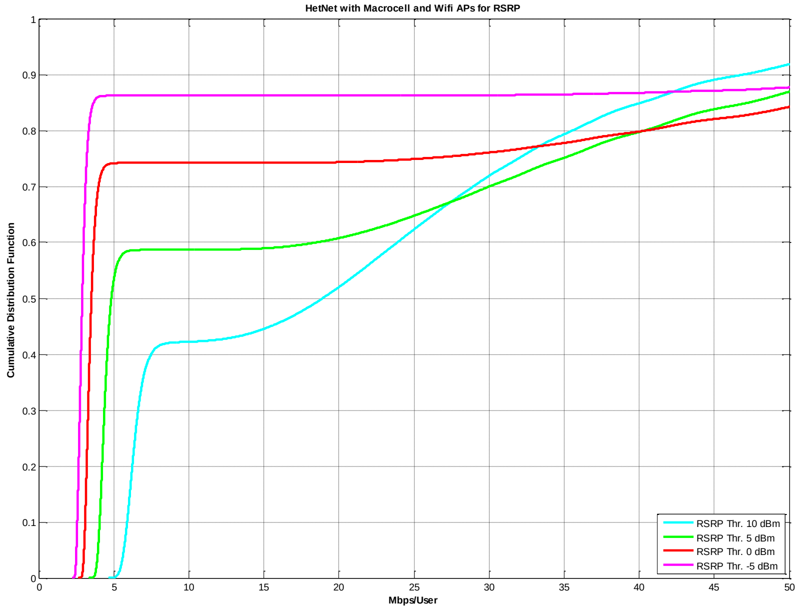

Figure 3.6. CDF for 1 macro and 20 WiFi for RSRP strategy (Case 2.10, 2.11, 2.12, 2.13)

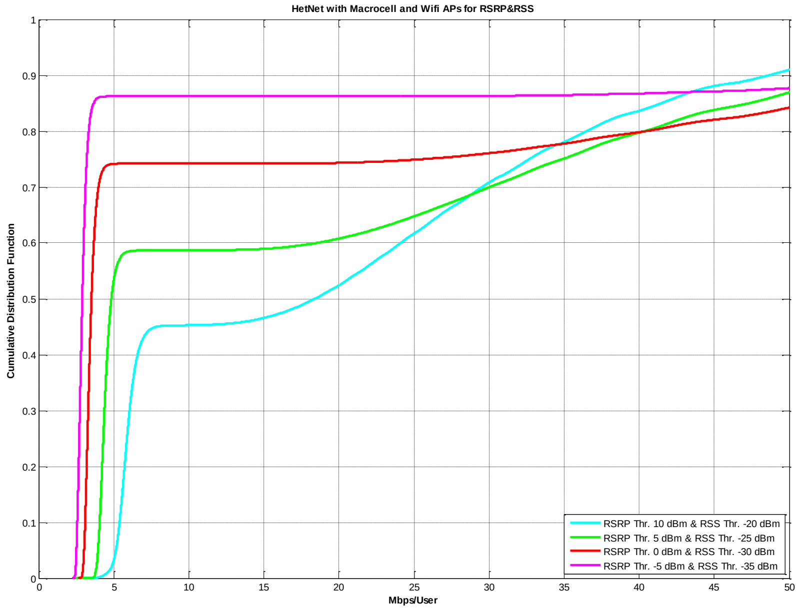

Figure 3.7. CDF for 1 macro and 20 WiFi for RSRP&RSS strategy (Case 3.10, 3.11, 3.12, 3.13)

Table 3.7. Average Capacity for RSS strategy in all cases

Cases (1Ma and 300 UEs)	Number of WiFi APs	RSS Threshold (dBm)	Average Capacity (Mbps/User)
Case1.1	0	-	2,406
Case1.2	10	-20	1,421
Case1.3	10	-25	1,704
Case1.4	10	-30	5,025
Case1.5	10	-35	8,595
Case1.6	15	-20	1,183
Case1.7	15	-25	1,657
Case1.8	15	-30	5,355
Case1.9	15	-35	12,39
Case1.10	20	-20	1,109
Case1.11	20	-25	1,679
Case1.12	20	-30	5,448
Case1.13	20	-35	**15,76**

Table 3.8. Average Capacity for RSRP strategy in all cases

Cases (1Ma and 300 UEs)	Number of WiFi APs	RSRP Threshold (dBm)	Average Capacity (Mbps/User)
Case2.1	0	-	2,406
Case2.2	10	10	10,53
Case2.3	10	5	4,83
Case2.4	10	0	3,509
Case2.5	10	-5	2,93
Case2.6	15	10	14,89
Case2.7	15	5	4,835
Case2.8	15	0	3,509
Case2.9	15	-5	2,902
Case2.10	20	10	**18,39**
Case2.11	20	5	4,843
Case2.12	20	0	3,51
Case2.13	20	-5	2,901

Table 3.9. Average Capacity for RSRP&RSS strategy in all cases

Cases (1Ma and 300 UEs)	Number of WiFi APs	RSRP Threshold (dBm)	Average Capacity (Mbps/User)
Case3.1	0	-	2,406
Case3.2	10	[10, -20]	5,441
Case3.3	10	[5, -25]	4,755
Case3.4	10	[0, -30]	3,510
Case3.5	10	[-5, -35]	2,9
Case3.6	15	[10, -20]	13,29
Case3.7	15	[5, -25]	4,823
Case3.8	15	[0, -30]	3,512
Case3.9	15	[-5, -35]	2,903
Case3.10	20	[10, -20]	**18,92**
Case3.11	20	[5, -25]	4,841
Case3.12	20	[0, -30]	3,514
Case3.13	20	[-5, -35]	2,9

Table 3.10. Average Capacity for WiFi First strategy in all cases

Cases (1Ma and 300 UEs)	Number of WiFi APs	Average Capacity (Mbps/User)
Case4.1	0	2,406
Case4.2	10	2,539
Case4.3	20	2,61
Case4.4	30	2,685
Case4.5	40	2,762
Case4.6	50	2,84
Case4.7	60	2,919
Case4.8	70	**3,003**

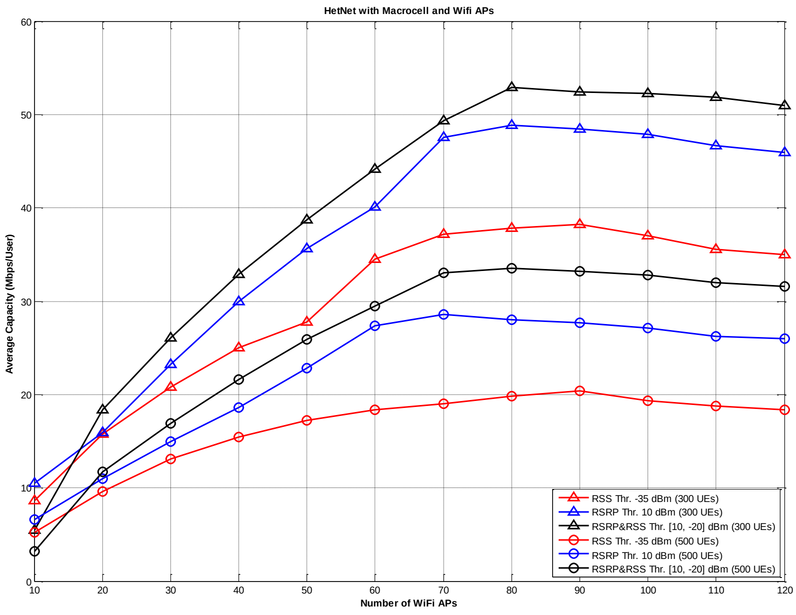

Figure 3.8. Average Capacity vs. number of deployed Wifi APs with different number of UEs

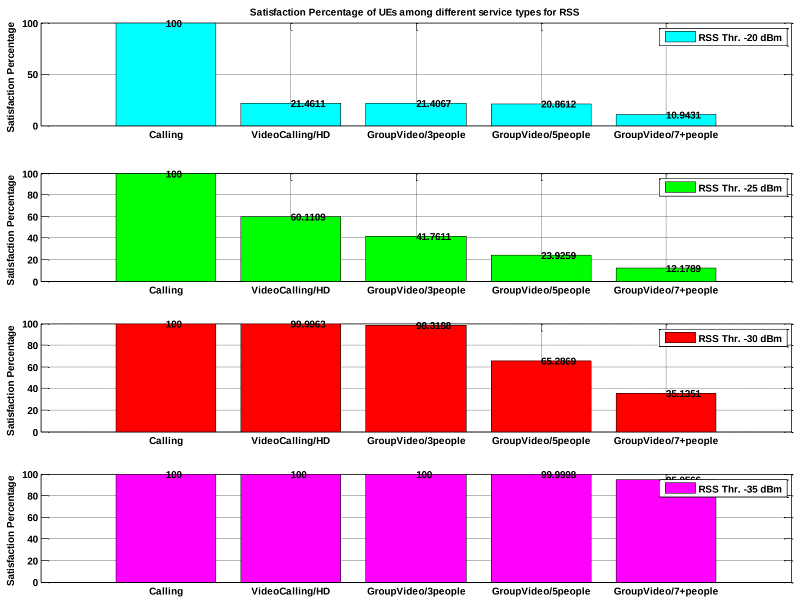

Figure 3.9. Satisfaction percentage for 1 macro and 20 WiFi for RSS strategy (Case 1.10, 1.11, 1.12, 1.13)

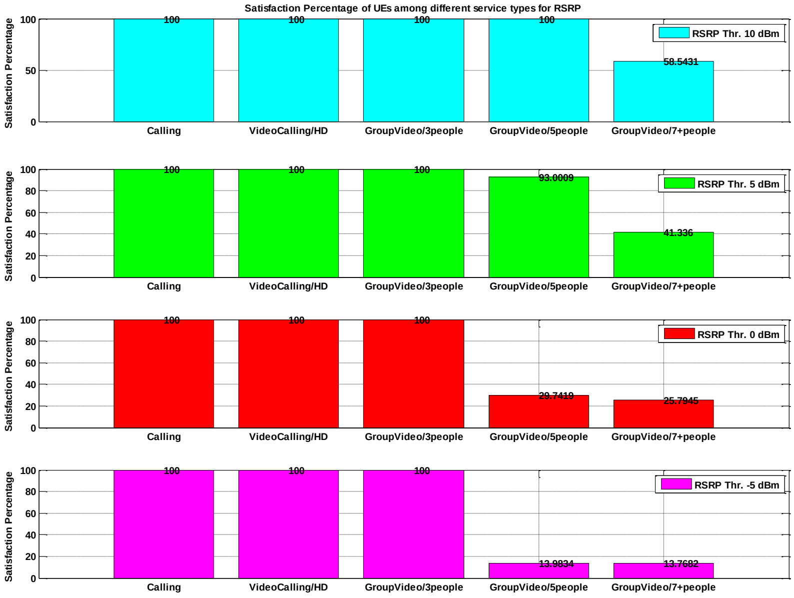

Figure 3.10. Satisfaction percentage for 1 macro and 20 WiFi for RSRP strategy (Case 2.10, 2.11, 2.12, 2.13)

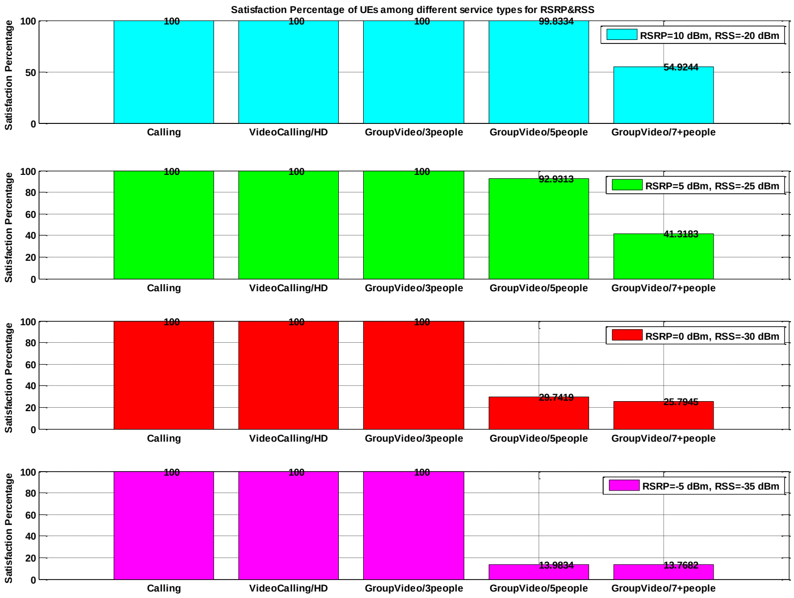

Figure 3.11. Satisfaction percentage for 1 macro and 20 WiFi for RSRP&RSS strategy (Case 3.10, 3.11, 3.12, 3.13)

Discussion

The average capacity of the system is 2,406 Mbps when there is only a macrocell in the network, as illustrated in Figure 3.4. This average capacity directly clarifies that the network became congested and additional deployment is needed.

In RSS based strategy, when the threshold value is set to -20 dBm or -25 dBm in all cases, the average capacity is lower than the network consists of only a macrocell as illustrated in Table 3.7. The strategy tends to make UEs to be served from macrocell with these threshold values. When the threshold value is set to -30 dBm or -35 dBm, the average capacity becomes higher. When 20 WiFi APs are deployed in network and threshold value is set to -35 dBm, the average capacity is 15,76 Mbps in Figure 3.5. Analysis of satisfaction percentage of users depending on different services identifies that decreasing the threshold value directly results in increasing in the number of offloaded UEs to WiFi network as illustrated in Figure 3.9.

In RSRP based strategy, the highest average capacity is obtained in Case 2.10 by setting the threshold value to 10 dBm as illustrated in Table 3.8. When 20 WiFi APs are deployed in network and threshold value is set to 10 dBm, the average capacity is 18,39 Mbps in Figure 3.6. Analysis of satisfaction percentage of UEs depending on different services identifies that decreasing the threshold value results in decreasing in the number of offloaded users to WiFi network as illustrated in Figure 3.10.

In RSRP&RSS based strategy, the highest average capacity values are obtained by setting RSRP and RSS threshold values to 10 dBm and -20 dBm, respectively as illustrated in Table 3.9. By deploying 20 WiFi APs, the average capacity per user is 18,92 Mbps in Figure 3.7. Satisfaction percentage of users can be increased by changing threshold values as illustrated in Figure 3.11.

WiFi first strategy considers UEs being in the coverage of WiFi APs in order to offload UEs from macrocell to WiFi APs. The highest average capacity is obtained by deploying 70 femtocells in Table 3.10.

The relation between average capacity of the system and the number of deployed WiFi APs is illustrated in Figure 3.8. The average capacity value increases until a certain number of WiFi APs are deployed in all strategies. Whether the number of UEs is increased to 500, the average capacity has similar trend. If more WiFi APs are deployed, the average capacity decreases. As more WiFi APs are deployed in the system, they exist in coverage area of each other and share bandwidth. As the interference effect becomes dominant, the average capacity values decrease.

The RSRP and RSS based strategy has the highest average capacity. Firstly, the strategy determines possible WiFi APs to which UEs can be offloaded by considering RSRP. After that, it determines WiFi AP which has RSS value higher than threshold. The WiFi first strategy considers coverage rather than RSRP or RSS values. Thus, it has the worst performance in all strategies.

CHAPTER 4

OFFLOADING TECHNIQUES FOR HETNET WITH MACROCELL AND SMALLCELL

The strategies which operate in system consist of macrocell and smallcell will be examined in this chapter. The performance evaluations of maximum RSRP, biased RSRP, minimum path loss, proposed RSRP threshold and load based and proposed traffic load based strategies in various scenarios will be examined in detailed. Moreover, the advantages and disadvantages of all strategies will be discussed.

4.1. Maximum RSRP Strategy

In order to map RSRP measurements, the model which is expressed by Eq. (3.9) in Section 3.2 is used in this approach for macrocell and smallcell. The k_{th} user is always associated with node u^* with maximum $RSRP$ value [21].

$$u^* = arg \max_{u=1,2,\dots,U} RSRP_{u,k} \qquad \forall k \tag{4.1}$$

For maximum RSRP strategy, the algorithm resolves cellular network node with maximum RSRP for UE. UEs will be associated with macrocell or smallcell with respect to the following rule:

IF $u^* \in$ *Node_Type(1), THEN*

UE served on macrocell

ELSE IF $u^* \in$ *Node_Type(2), THEN*

UE served on microcell

ELSE IF $u^* \in$ *Node_Type(3), THEN*

UE served on picocell

ELSE

UE served on femtocell

END

where *Node_Type(1), Node_Type(2), Node_Type(3) and Node_Type(4)* denote the set of heterogeneous wireless network nodes namely as macrocell, microcell, picocell and femtocell, respectively [22].

4.2. Biased RSRP Strategy

In a typical HetNet, there exist network nodes which have different transmit power levels depending on their types. The difference between levels of received signal power is a drawback on the performance of smallcell. Because, the macrocell can dominate smallcell while associating UEs with node having maximum RSRP. As a result of instability between macrocell and smallcell, big portion of UEs can be associated with macrocell. Thus, the maximum RSRP approach sometimes cannot provide fairness between macrocell and smallcell. Smallcells can be underutilized and resources can be wasted. Applying a cell specific offset can be a good solution for unfairness between macrocell and smallcell. Differences between power levels can be decreased and coverage area of smallcell can be extended by applying offset. Biased RSRP can be mathematically expressed as follows:

$$u^* = arg \max_u \left(RSRP_{u,k} + BIAS_u \right) \qquad \forall k \tag{4.2}$$

where $BIAS_u$ denotes the biased value of u_{th} node. In this thesis, biased value is considered as zero for macrocell and positive integer for smallcell. By applying this strategy, the k_{th} user will be associated with u_{th} node having maximum biased RSRP value [22].

4.3. Minimum PL Strategy

Attenuation of signal strength depending on the distance between node and UE is directly obtained by the value of path loss. Although same path loss model defined by Eq. (3.2) in Section 3.1 is used for macrocell and smallcell, they have different path loss values even if the distance between nodes and UE is same. In this approach, the k_{th} user will be associated with u_{th} node having minimum path loss value [9].

$$u^{*} = arg \min_{u} PL_{u,k} \qquad \forall k \tag{4.3}$$

where $PL_{u,k}$ is the path loss value between user k and node u.

4.4. Proposed RSRP Threshold & Load Based Strategy

There may be imbalance in the number of assigned UEs between the nodes when UEs are assigned to nodes with respect to maximum RSRP strategy as defined in Section 4.1. The strategy operates in order to provide service with the node having the strongest signal. However, a huge number of UEs can be assigned to a network node which serves UEs with the strongest signal individually. According to resource block sharing defined in Section 3.1, the resource blocks will be shared between UEs and they will have fewer throughputs than expected. This is a major drawback of maximum RSRP strategy.

The drawback can be eliminated by proposed RSRP threshold & load based strategy which balances the number of assigned UEs of nodes. Firstly, the UEs send their RSRP information to nodes as illustrated in Figure 4.1. After that, nodes send this information to Network Controller. Network controller then identify which UEs will be assigned to which node virtually with respect to maximum RSRP strategy. After obtaining the number of virtually assigned UEs of nodes, network controller identifies nodes which have the most and least number of assigned UEs. Then, by using the average value of these numbers, the strategy limits the number of assigned UEs of the node which may have the most UEs virtually. This strategy provides the effective usage of resource blocks in network.

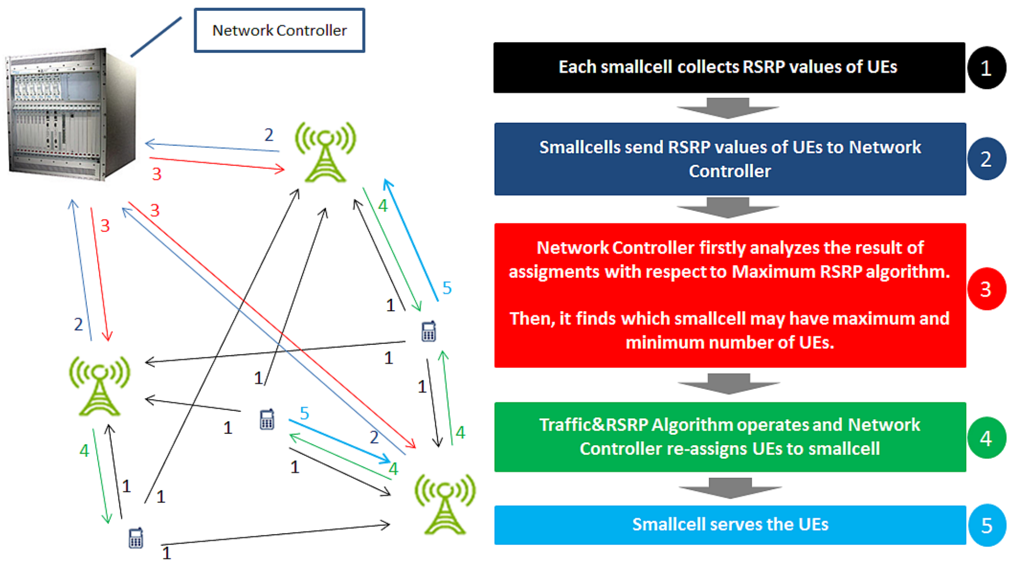

Figure 4.1. Proposed RSRP threshold & load based strategy

4.5. Proposed Traffic Load Based Strategy

In proposed traffic load based strategy, the UEs are assigned to idle network nodes until the U^{th} UE attached the system. After that at each connection time t, they are assigned to the node with minimum traffic load by checking the RSRP threshold condition. The traffic of each network nodes are denoted by w_u. The strategy works as illustrated in Figure 4.2.

$$u^* = arg \min_u w_u \tag{4.4}$$

$$w_u = \sum_{K=1}^{K^u{}_{attached}} C_{u,k} \tag{4.5}$$

where $K^u{}_{attached}$ is the total number of attached users to u^{th} node. $C_{u,k}$ denotes the capacity of a user k defined in Eq. (3.7).

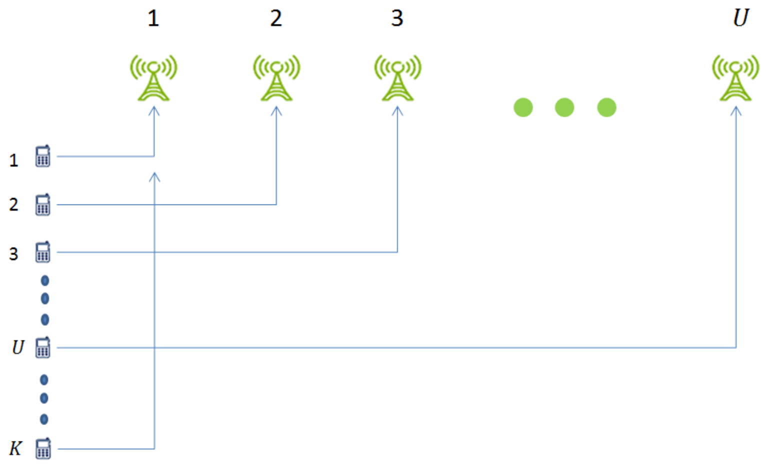

Figure 4.2. Proposed traffic load based strategy

The proposed traffic load based strategy uses the traffic load information of u^{th} node. On the other hand, the proposed RSRP threshold & load based strategy uses the number of attached UEs in u^{th} node.

4.6. Performance Evaluations

In macrocell and smallcell network scenario, the simulation area consists of macrocell and the smallcells including microcell, picocell and femtocell. Both macrocell and smallcell operate in the cellular frequency which is 2.4 GHz. Thus, these nodes interfere with each other. As it is described in Section 2.3, three types of frequency allocation techniques can be considered. For this scenario, OFA model 1 and OFA model 2 are considered for all these strategies. For maximum RSRP, minimum PL, proposed RSRP threshold & load based and proposed traffic load based strategies, various numbers of smallcells are deployed in network as illustrated in Table 4.1, 4.3 and 4.4. Moreover, for biased RSRP strategy, different biasing values are applied to the system as illustrated in Table 4.2. We denote macrocell as ‘Ma’, microcell as ‘Mi’, picocell as ‘P’ and femtocell as ‘F’ in the following sections.

Table 4.1. The number of smallcells in different cases for max. RSRP and min. PL strategies with OFA Model 1 and OFA Model 2

Cases (1Ma and 300 UEs)		Number of microcell	Number of picocell	Number of femtocell
Max. RSRP	Min. PL			
Case1.1, 2.1	Case5.1, 6.1	0	0	0
Case1.2, 2.2	Case5.2, 6.2	0	7	0
Case1.3, 2.3	Case5.3, 6.3	0	10	0
Case1.4, 2.4	Case5.4, 6.4	0	15	0
Case1.5, 2.5	Case5.5, 6.5	0	0	17
Case1.6, 2.6	Case5.6, 6.6	0	0	20
Case1.7, 2.7	Case5.7, 6.7	0	0	22
Case1.8, 2.8	Case5.8, 6.8	0	5	10
Case1.9, 2.9	Case5.9, 6.9	0	5	20
Case1.10, 2.10	Case5.10, 6.10	0	5	30
Case1.11, 2.11	Case5.11, 6.11	5	7	15
Case1.12, 2.12	Case5.12, 6.12	5	7	20
Case1.13, 2.13	Case5.13, 6.13	5	7	25

Table 4.2. The number of smallcells in different cases for biased RSRP strategy with OFA Model 1 and OFA Model 2

Cases (1Ma and 300 UEs)	Number of microcell	Number of picocell	Number of femtocell	Biasing Value (dB)
Case3.1, 4.1	0	0	0	-
Case3.2, 4.2	0	15	0	3
Case3.3, 4.3	0	15	0	6
Case3.4, 4.4	0	15	0	9
Case3.5, 4.5	0	0	22	3
Case3.6, 4.6	0	0	22	6
Case3.7, 4.7	0	0	22	9
Case3.8, 4.8	0	5	30	3
Case3.9, 4.9	0	5	30	6
Case3.10, 4.10	0	5	30	9
Case3.11, 4.11	5	7	25	3
Case3.12, 4.12	5	7	25	6
Case3.13, 4.13	5	7	25	9

Table 4.3. The number of smallcells in different cases for proposed RSRP threshold and load based strategy with OFA Model 1 and OFA Model 2

Cases (1Ma. and 300 UEs)	Number of microcell	Number of picocell	Number of femtocell	RSRP Thr. (dBm)
Case7.1, 8.1	0	0	0	-
Case7.2, 8.2	10	0	0	-10
Case7.3, 8.3	10	0	0	-5
Case7.4, 8.4	10	0	0	0
Case7.5, 8.5	0	15	0	-35
Case7.6, 8.6	0	0	22	-20

Table 4.4. The number of smallcells in different cases for proposed traffic load based strategy with OFA Model 1 and 2

Cases (1Ma. and 300 UEs)	Number of microcell	Number of picocell	Number of femtocell
Case9.1, 10.1	0	0	0
Case9.2, 10.2	0	7	0
Case9.3, 10.3	0	10	0
Case9.4, 10.4	0	15	0
Case9.5, 10.5	0	0	17
Case9.6, 10.6	0	0	20
Case9.7, 10.7	0	0	22
Case9.8, 10.8	0	5	10
Case9.9, 10.9	0	5	20
Case9.10, 10.10	0	5	30
Case9.11, 10.11	5	7	15
Case9.12, 10.12	5	7	20
Case9.13, 10.13	5	7	25

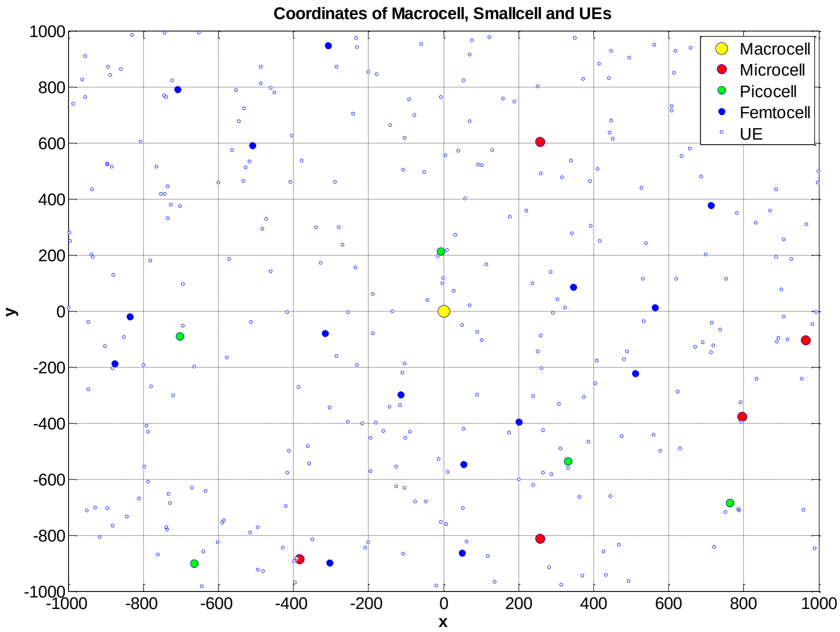

Figure 4.3. Simulation Area of macrocell and smallcell (1kmx1km)

Simulation Parameters

The value of parameters used in all scenarios is illustrated in Table 4.5. The capacities of service types used for satisfaction percentages are illustrated in Table 3.6.

Table 4.5. Simulation Parameters for macrocell and smallcell

Variable	Value
Tx power of macrocell	43 dBm
Tx power of microcell	33 dBm
Tx power of picocell	23.97 dBm
Tx power of femtocell	10 dBm
Bandwidth of macrocell (OFA1)	8 MHz
Bandwidth of microcell (OFA1)	6 MHz
Bandwidth of picocell (OFA1)	4 MHz
Bandwidth of femtocell (OFA1)	2 MHz
Bandwidth of macrocell (OFA2)	10 MHz
Bandwidth of microcell (OFA2)	10 MHz
Bandwidth of picocell (OFA2)	10 MHz
Bandwidth of femtocell (OFA2)	10 MHz
Shadowing Factor for macrocell	10 dB

(cont. on next page)

Table 4.5 (cont.).

Shadowing Factor for microcell	8 dB
Shadowing Factor for picocell	6 dB
Shadowing Factor for femtocell	4 dB
Height of Tx macrocell	32 m
Height of Rx macrocell	1.5 m
Height of Tx microcell	12.5 m
Height of Rx microcell	1.5 m
Height of Tx picocell	5.6 m
Height of Rx picocell	1.5 m
Height of Tx femtocell	0.7 m
Height of Rx femtocell	1.5 m
Coverage Radius of macrocell	1000 m
Coverage Radius of microcell	500 m
Coverage Radius of picocell	200 m
Coverage Radius of femtocell	40 m
C coefficient	3 dB
Operating Frequency for cellular	2600 MHz

Simulation Results

The simulation results of all cases with respect to all of the strategies defined in this chapter are illustrated in the figures below.

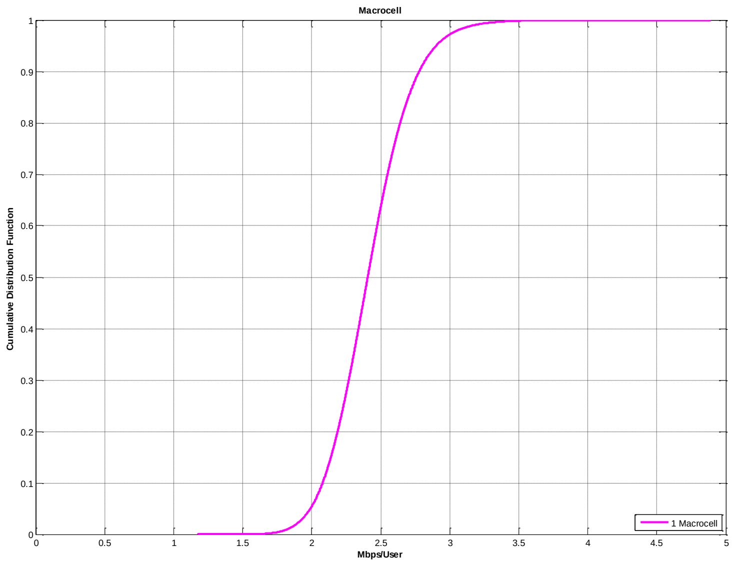

Figure 4.4. CDF for 1 macro (Case1.1, 2.1, 3.1, 4.1, 5.1, 6.1, 7.1, 8.1)

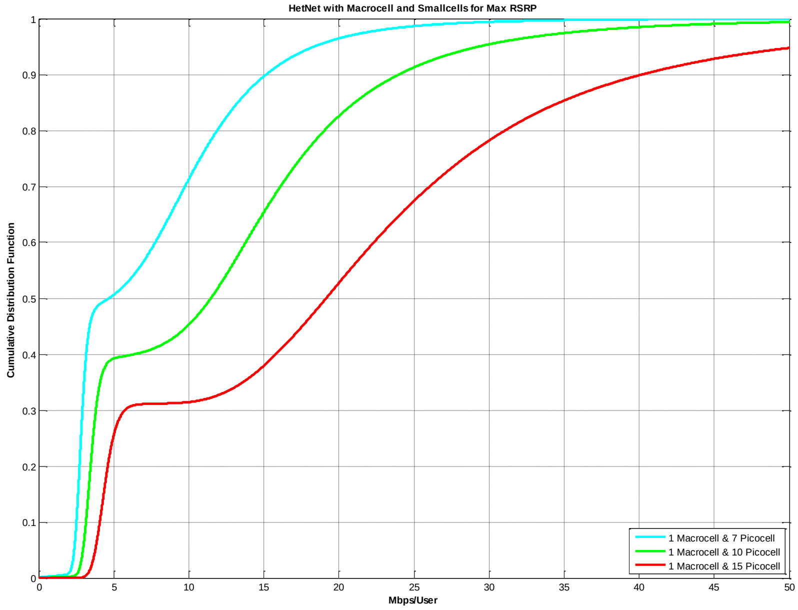

Figure 4.5. CDF for max. RSRP strategy with OFA Model 1 (Case1.2, 1.3, 1.4)

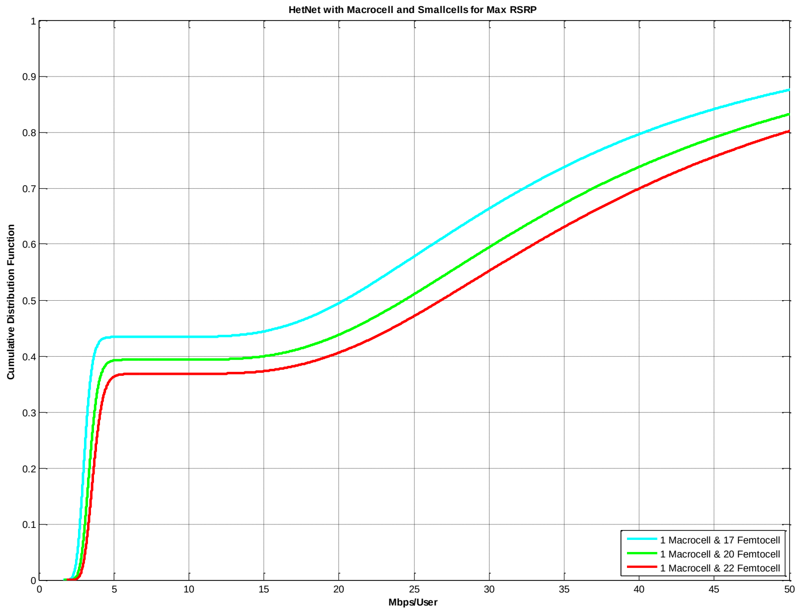

Figure 4.6. CDF for max. RSRP strategy with OFA Model 1 (Case1.5, 1.6, 1.7)

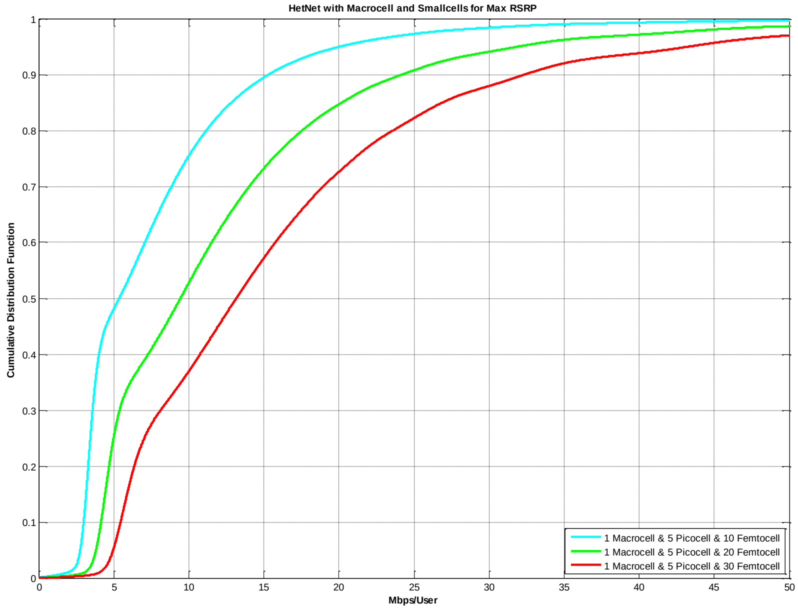

Figure 4.7. CDF for max. RSRP strategy with OFA Model 1 (Case1.8, 1.9, 1.10)

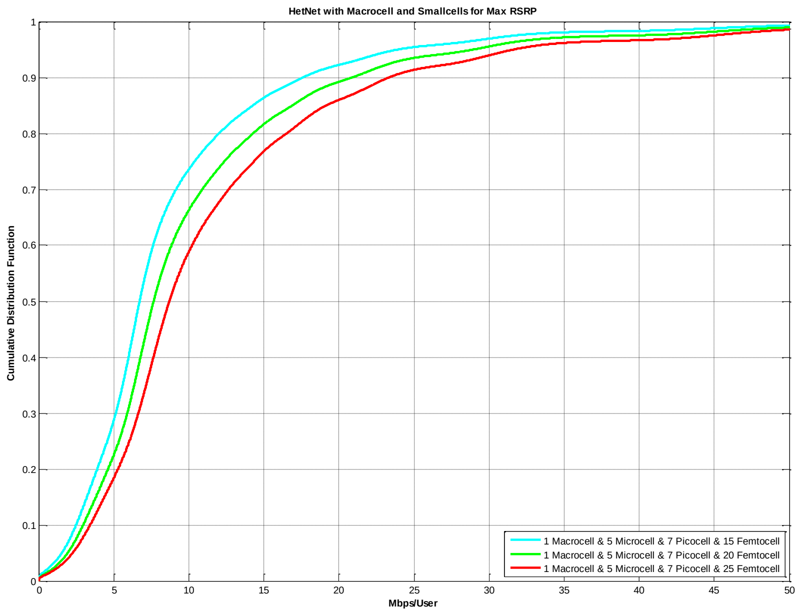

Figure 4.8. CDF for max. RSRP strategy with OFA Model 1 (Case1.11, 1.12, 1.13)

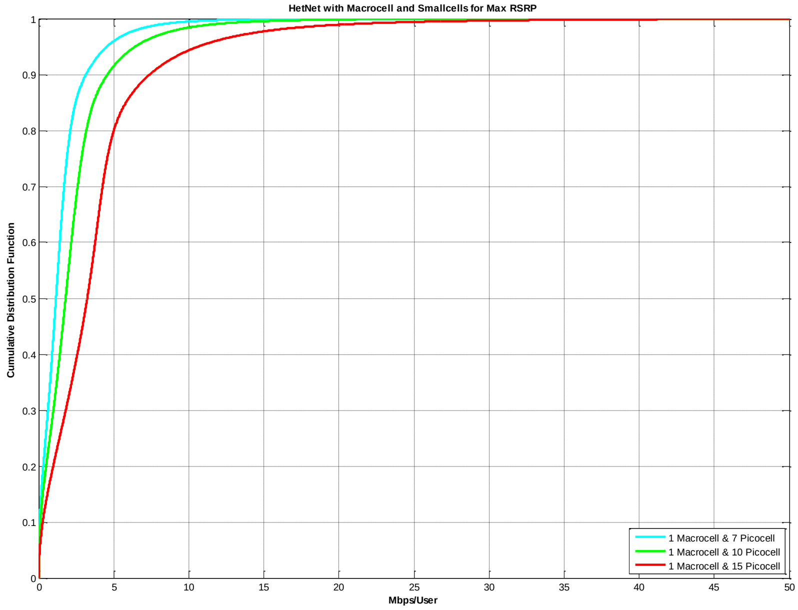

Figure 4.9. CDF for max. RSRP strategy with OFA Model 2 (Case2.2, 2.3, 2.4)

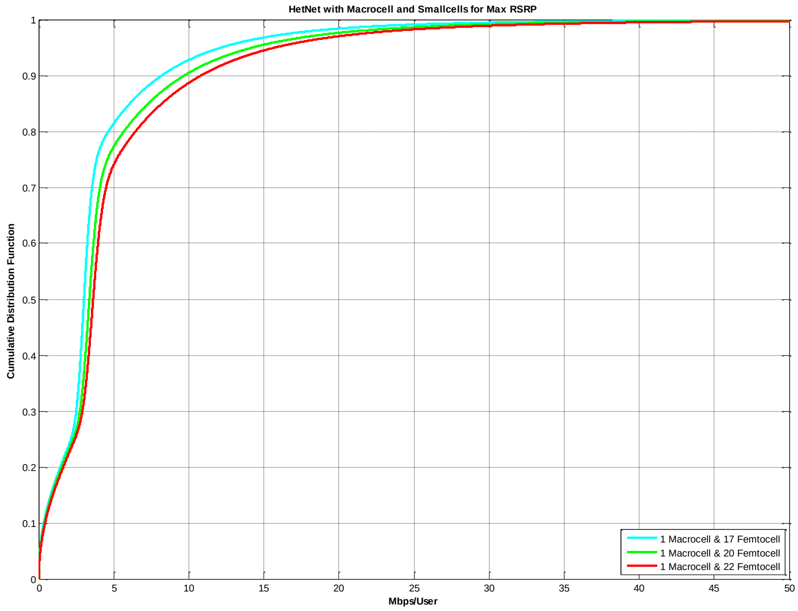

Figure 4.10. CDF for max. RSRP strategy with OFA Model 2 (Case2.5, 2.6, 2.7)

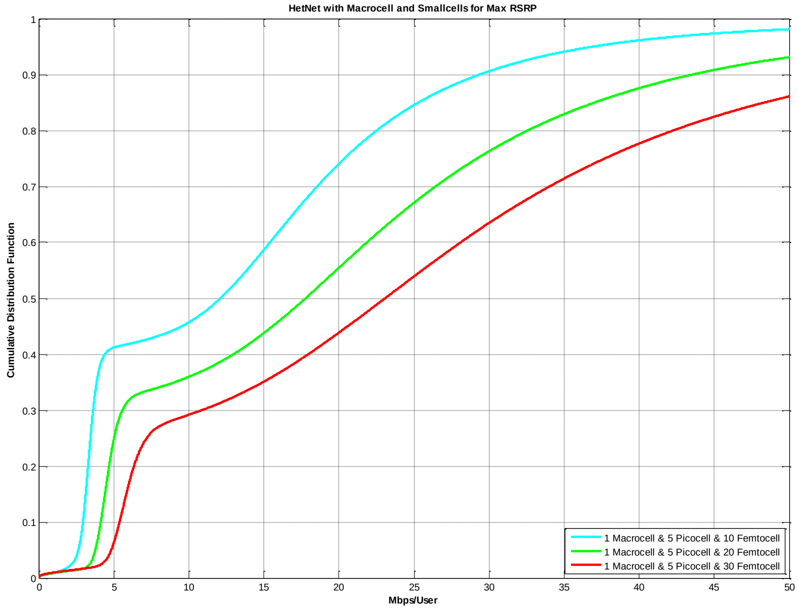

Figure 4.11. CDF for max. RSRP strategy with OFA Model 2 (Case2.8, 2.9, 2.10)

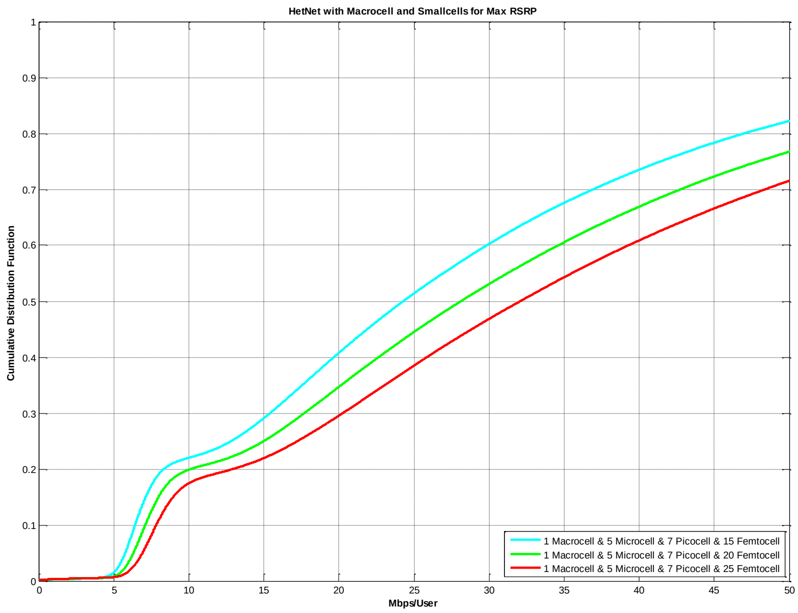

Figure 4.12. CDF for max. RSRP strategy with OFA Model 2 (Case2.11, 2.12, 2.13)

Table 4.6. Average Capacity for max. RSRP strategy with OFA Model 1 and OFA Model 2

Cases		**Average Capacity (Mbps/User)**	
		OFA Model 1	OFA Model 2
Case1.1, 2.1	1Ma	2,406	2.406
Case1.2, 2.2	1Ma, 7P	4,65	1,151
Case1.3, 2.3	1Ma, 10P	11,47	1,792
Case1.4, 2.4	1Ma, 15P	18,87	3,154
Case1.5, 2.5	1Ma, 17F	20,4	3,016
Case1.6, 2.6	1Ma, 20F	24,33	3,374
Case1.7, 2.7	1Ma, 22F	**26,85**	3,628
Case1.8, 2.8	1Ma, 5P, 10F	5,40	12,13
Case1.9, 2.9	1Ma, 5P, 20F	9,443	17,8
Case1.10, 2.10	1Ma, 5P, 30F	13,16	23,14
Case1.11, 2.11	1Ma, 5Mi, 7P, 15F	6,726	24,3
Case1.12, 2.12	1Ma, 5Mi, 7P, 20F	7,661	28,16
Case1.13, 2.13	1Ma, 5Mi, 7P, 25F	8,71	**32,1**

Table 4.7. Average Capacity for biased RSRP strategy with OFA Model 1 and OFA Model 2

Cases		**Average Capacity (Mbps/User)**	
		OFA Model 1	OFA Model 2
Case3.1, 4.1	1Ma	2,406	2,406
Case3.2, 4.2	1Ma, 15P	18,9	3,157
Case3.3, 4.3	1Ma, 15P	18,95	3,198
Case3.4, 4.4	1Ma, 15P	19,15	3,235
Case3.5, 4.5	1Ma, 22F	26,89	3,941
Case3.6, 4.6	1Ma, 22F	26,92	4,118
Case3.7, 4.7	1Ma, 22F	**26,98**	4,214
Case3.8, 4.8	1Ma, 5P, 30F	13,25	23,31
Case3.9, 4.9	1Ma, 5P, 30F	13,65	23,48
Case3.10, 4.10	1Ma, 5P, 30F	13,82	23,81
Case3.11, 4.11	1Ma, 5Mi, 7P, 25F	9,11	32,37
Case3.12, 4.12	1Ma, 5Mi, 7P, 25F	9,648	32,43
Case3.13, 4.13	1Ma, 5Mi, 7P, 25F	9,679	**32,58**

Table 4.8. Average Capacity for minimum PL strategy with OFA Model 1 and OFA Model 2

Cases		Average Capacity (Mbps/User)	
		OFA Model 1	OFA Model 2
Case5.1, 6.1	1Ma	2,406	2,406
Case5.2, 6.2	1Ma, 7P	5,174	0,2438
Case5.3, 6.3	1Ma, 10P	9,412	0,5420
Case5.4, 6.4	1Ma, 15P	15,35	1,074
Case5.5, 6.5	1Ma, 17F	17,67	0,6328
Case5.6, 6.6	1Ma, 20F	20,97	0,9374
Case5.7, 6.7	1Ma, 22F	**23,16**	1,163
Case5.8, 6.8	1Ma, 5P, 10F	4,349	6,298
Case5.9, 6.9	1Ma, 5P, 20F	7,703	10,39
Case5.10, 6.10	1Ma, 5P, 30F	11,08	15,26
Case5.11, 6.11	1Ma, 5Mi, 7P, 15F	4,879	16,52
Case5.12, 6.12	1Ma, 5Mi, 7P, 20F	5,948	19,45
Case5.13, 6.13	1Ma, 5Mi, 7P, 25F	7,048	**22,39**

Table 4.9. Average Capacity for proposed RSRP threshold & load based strategy with OFA Model 1 and OFA Model 2

Cases		Average Capacity (Mbps/User)	
		OFA Model 1	OFA Model 2
Case7.1, 8.1	1Ma	2,406	2,406
Case7.2, 8.2	1Ma, 10Mi	6,999	1,84
Case7.3, 8.3	1Ma, 10Mi	7,104	1,844
Case7.4, 8.4	1Ma, 10Mi	7,168	1,8445
Case7.5, 8.5	1Ma, 15P	20,26	3,109
Case7.6, 8.6	1Ma, 22F	**29,28**	**3,613**

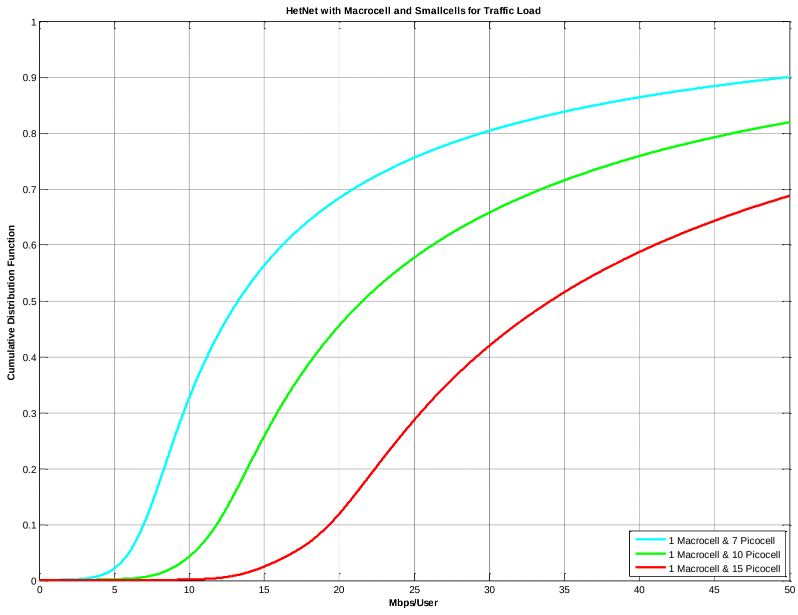

Figure 4.13. CDF for proposed traffic load based strategy with OFA Model 1 (Case9.2, 9.3, 9.4)

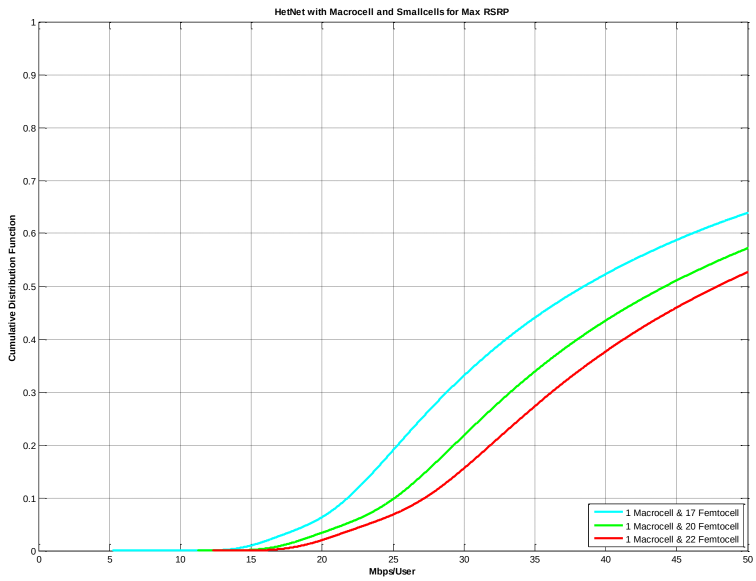

Figure 4.14. CDF for proposed traffic load based strategy with OFA Model 1 (Case9.5, 9.6, 9.7)

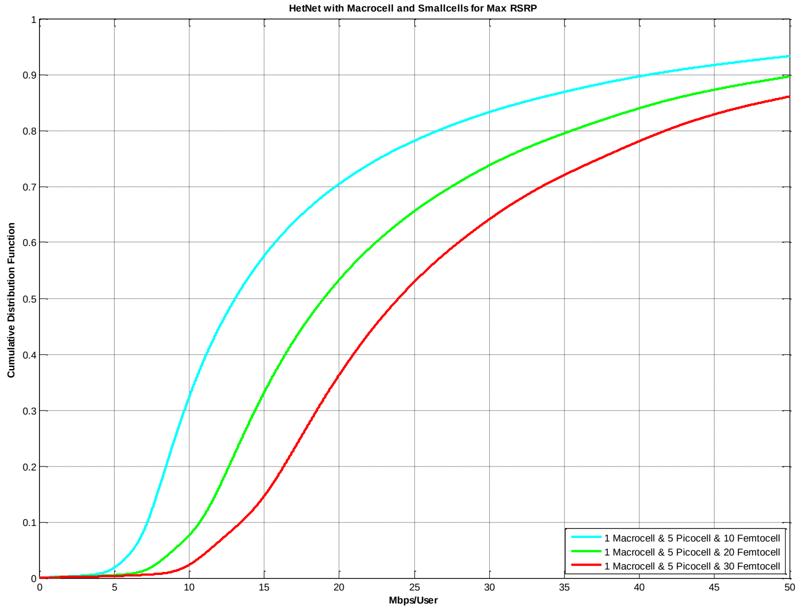

Figure 4.15. CDF for proposed traffic load based strategy with OFA Model 1 (Case9.8, 9.9, 9.10)

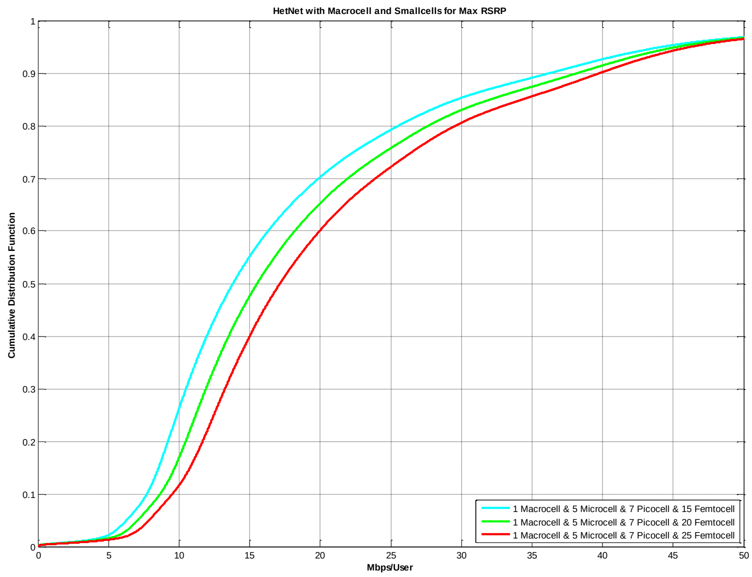

Figure 4.16. CDF for proposed traffic load based strategy with OFA Model 1 (Case9.11, 9.12, 9.13)

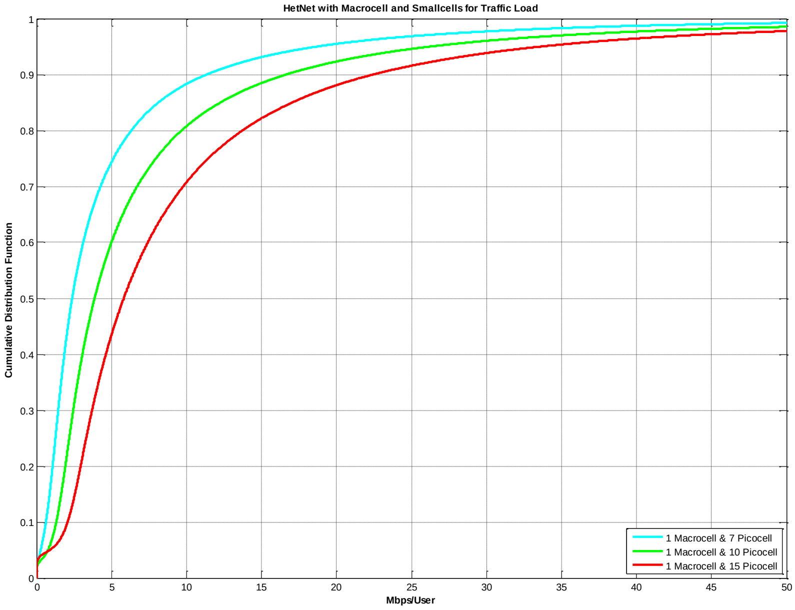

Figure 4.17. CDF for proposed traffic load based strategy with OFA Model 2 (Case10.2, 10.3, 10.4)

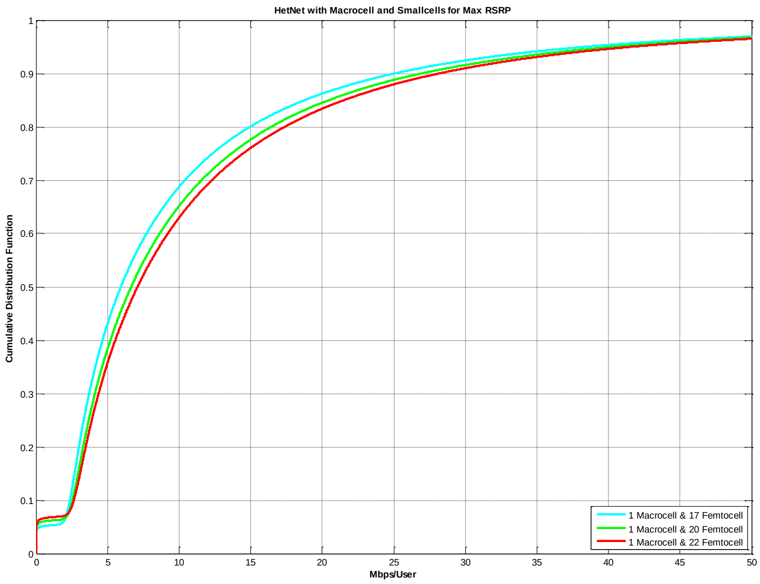

Figure 4.18. CDF for proposed traffic load based strategy with OFA Model 2 (Case10.5, 10.6, 10.7)

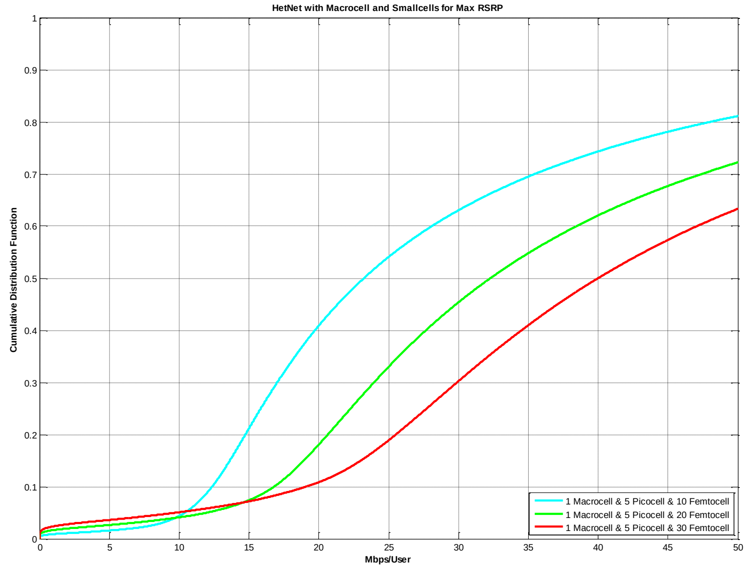

Figure 4.19. CDF for proposed traffic load based strategy with OFA Model 2 (Case10.8, 10.9, 10.10)

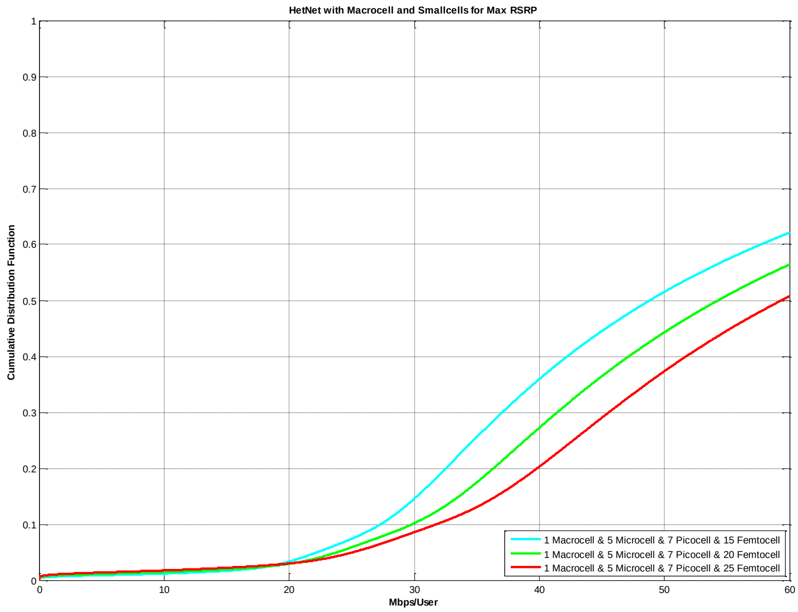

Figure 4.20. CDF for proposed traffic load based strategy with OFA Model 2 (Case10.11, 10.12, 10.13)

Table 4.10. Average Capacity for proposed traffic load based strategy with OFA Model 1 and OFA Model 2

Cases		**Average Capacity (Mbps/User)**	
		OFA Model 1	OFA Model 2
Case9.1, 10.1	1Ma	2,406	2,406
Case9.2, 10.2	1Ma, 7P	13,28	2,38
Case9.3, 10.3	1Ma, 10P	21,58	3,878
Case9.4, 10.4	1Ma, 15P	34,13	5,817
Case9.5, 10.5	1Ma, 17F	38,5	5,933
Case9.6, 10.6	1Ma, 20F	44,19	6,651
Case9.7, 10.7	1Ma, 22F	**47,85**	7,093
Case9.8, 10.8	1Ma, 5P, 10F	13,08	23,26
Case9.9, 10.9	1Ma, 5P, 20F	18,98	32,31
Case9.10, 10.10	1Ma, 5P, 30F	23,96	39,99
Case9.11, 10.11	1Ma, 5Mi, 7P, 15F	13,82	48,85
Case9.12, 10.12	1Ma, 5Mi, 7P, 20F	15,54	54,3
Case9.13, 10.13	1Ma, 5Mi, 7P, 25F	17,15	**59,41**

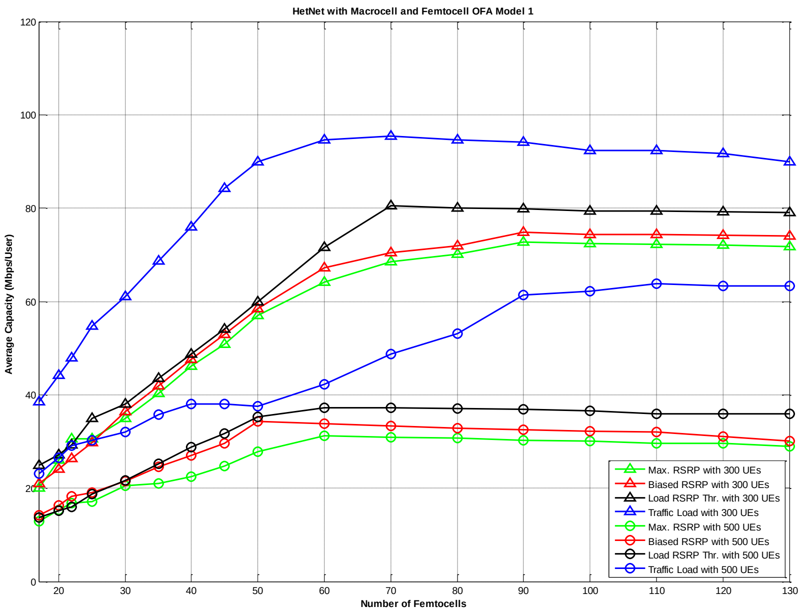

Figure 4.21. Average Capacity vs. number of deployed femtocells for OFA Model 1 with different number of UEs

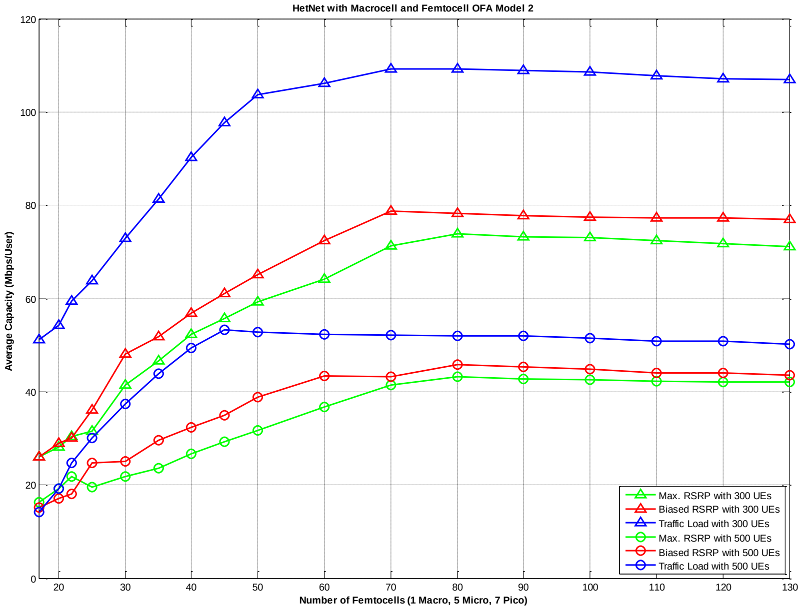

Figure 4.22. Average Capacity vs. number of deployed femtocells for OFA Model 2 with different number of UEs

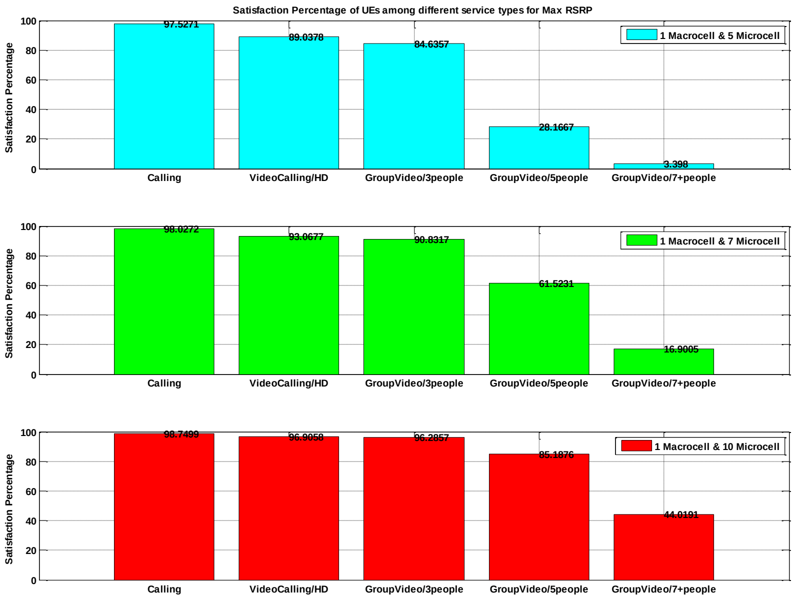

Figure 4.23. Satisfaction percentage for max. RSRP strategy with OFA Model 1 (Case 1.2, 1.3, 1.4)

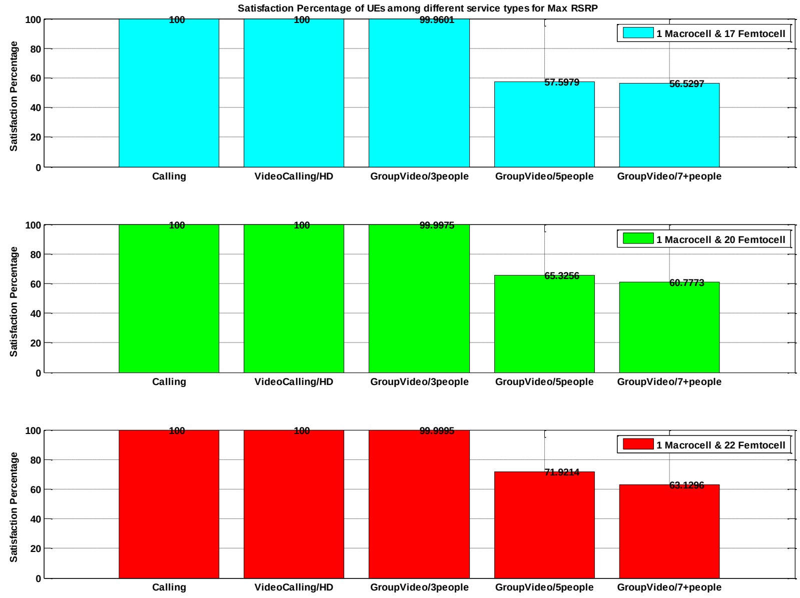

Figure 4.24. Satisfaction percentage for max. RSRP strategy with OFA Model 1 (Case 1.5, 1.6, 1.7)

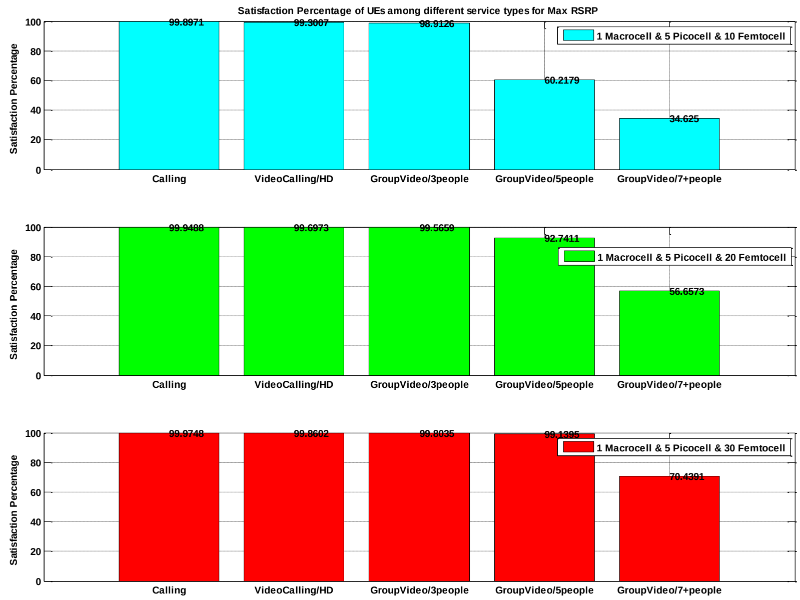

Figure 4.25. Satisfaction percentage for max. RSRP strategy with OFA Model 1 (Case 1.8, 1.9, 1.10)

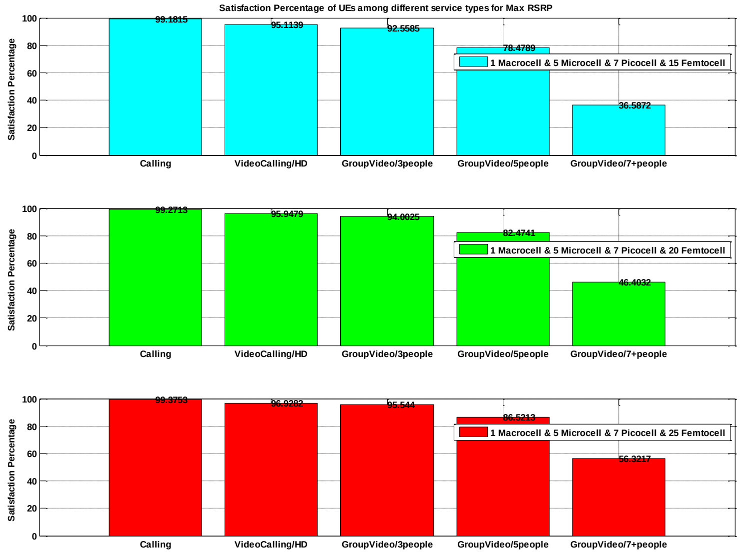

Figure 4.26. Satisfaction percentage for max. RSRP strategy with OFA Model 1 (Case 1.11, 1.12, 1.13)

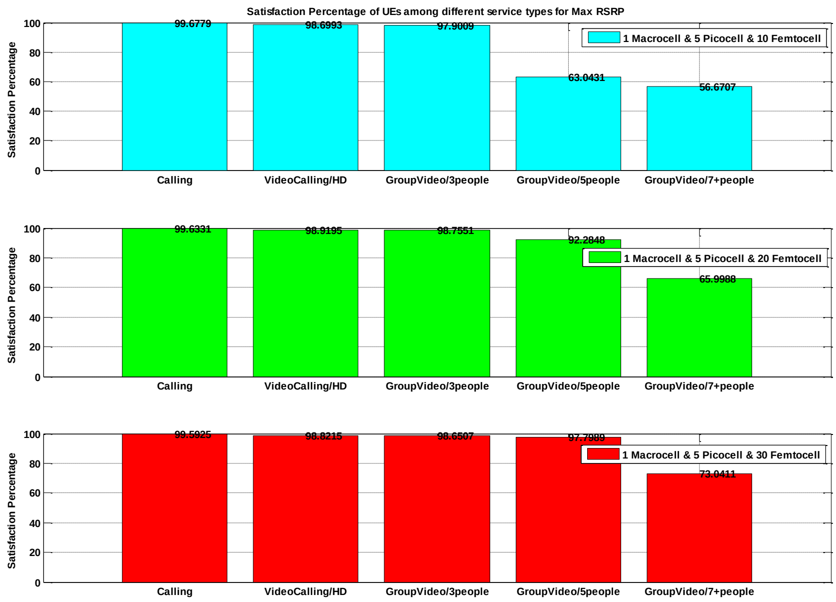

Figure 4.27. Satisfaction percentage for max. RSRP strategy with OFA Model 2 (Case 2.8, 2.9, 2.10)

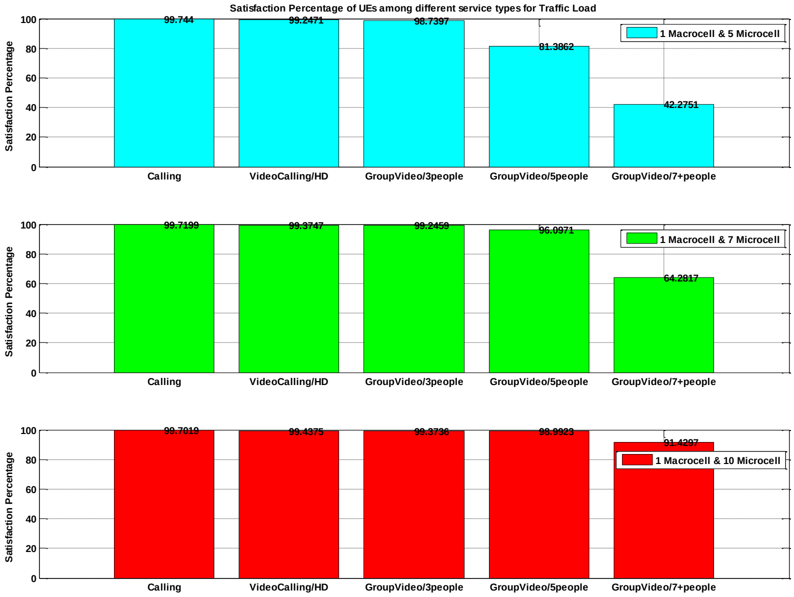

Figure 4.28. Satisfaction percentage for proposed traffic load based strategy with OFA Model 1 (Case 9.2, 9.3, 9.4)

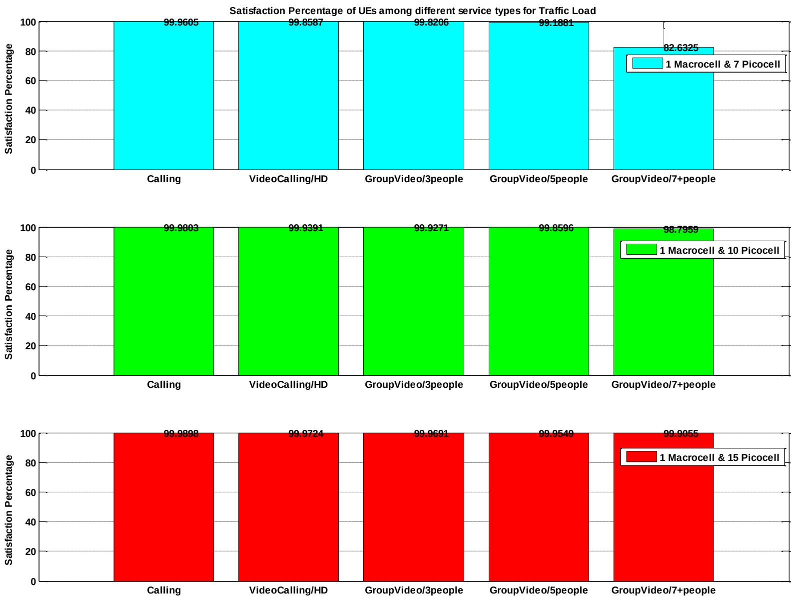

Figure 4.29. Satisfaction percentage for proposed traffic load based strategy with OFA Model 1 (Case 9.5, 9.6, 9.7)

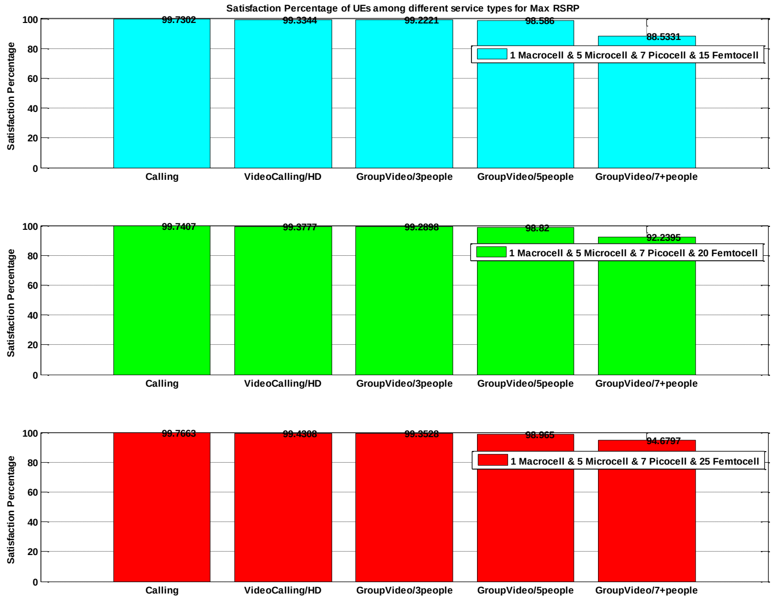

Figure 4.30. Satisfaction percentage for proposed traffic load based strategy with OFA Model 1 (Case 9.11, 9.12, 9.13)

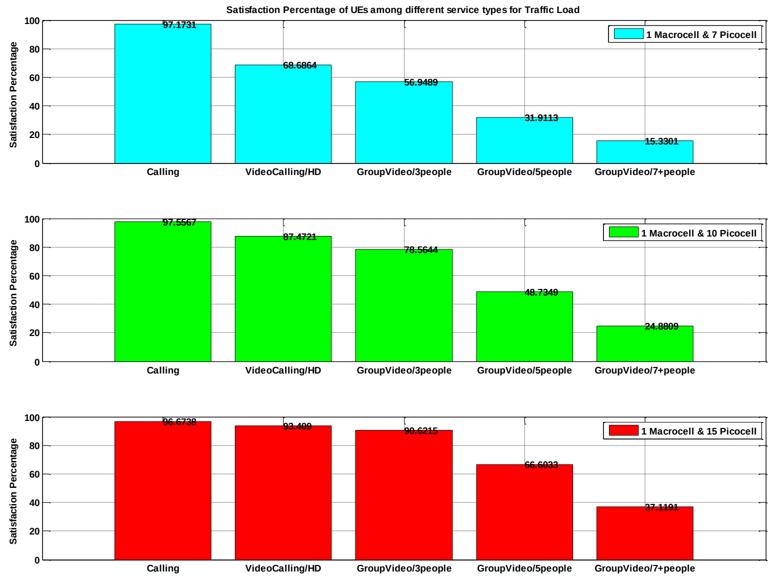

Figure 4.31. Satisfaction percentage for proposed traffic load based strategy with OFA Model 2 (Case 10.2, 10.3, 10.4)

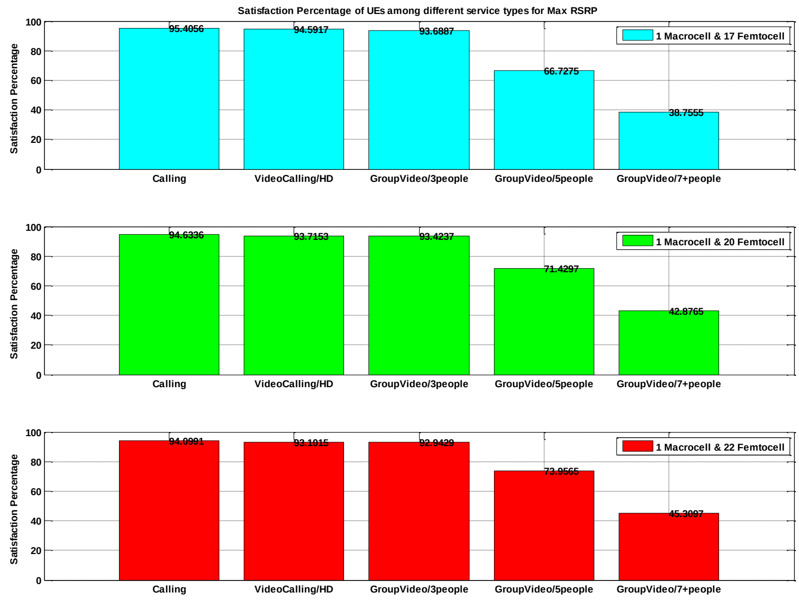

Figure 4.32. Satisfaction percentage for proposed traffic load based strategy with OFA Model 2 (Case 10.5 10.6, 10.7)

Discussion

The maximum RSRP strategy provides UEs to be offloaded nodes with maximum RSRP. The values of average capacity are higher than when there is only a macrocell in Figure 4.4 in all cases with OFA Model 1. When 15 picocells are deployed, the average capacity is 26,82 Mbps as illustrated in Figure 4.5. When 22 femtocells are added to system, the average capacity of the network reaches 30,49 Mbps in Figure 4.6. From Case 1.8 to Case 1.13, it is clear that deploying a certain number of additional femtocells in the system has positive effect on the performance of maximum RSRP strategy as illustrated in Figure 4.7 and Figure 4.8. The highest average capacity is obtained with OFA Model 1 in Case 1.7 as illustrated in Table 4.6. The average capacities with OFA Model 2 are generally lower than with OFA Model 1 in only picocell and femtocell deployments in addition to macrocell as illustrated in Figure 4.9 and Figure 4.10. Because, smallcells share same bandwidth and interference effect becomes dominant in OFA Model 2. In combination of macrocell, microcell, picocell and femtocell cases, the highest average capacities are obtained in Figure 4.11 and

Figure 4.12. Satisfaction percentages of users with OFA Model 1 and OFA Model 2 are shown between Figure 4.23 and Figure 4.27.

The values of average capacity are higher than when there is only a macrocell in the network for biased RSRP strategy in all cases with OFA Model 1 and OFA Model2. When 15 picocells are added to system, the average capacity reaches 17,22 Mbps as illustrated in Table 4.7. From Case 3.8 to Case 3.13, it is clear that deploying smaller nodes has positive effect on the performance of biased RSRP strategy. The highest average capacity value is obtained with OFA Model 1 in Case 3.7. The average capacity values are higher than when there exist a macrocell in all cases with OFA Model 2. The highest average capacity is obtained in Case 4.13.

The minimum PL strategy provides UEs to be offloaded nodes with minimum Path Loss. When 22 femtocells are deployed, the average capacity is 23,16 Mbps as illustrated in Table 4.8. The best average capacity value is obtained with OFA Model 1 in Case 5.7. For OFA Model 2, the highest average capacity values are obtained in Case 6.11, Case 6.12 and Case 6.13.

In proposed RSRP threshold & load based strategy, the highest average capacity is obtained in Case 7.6 with OFA Model 1. The highest average capacity values are obtained in Case 8.6 with OFA Model 2. Deploying only a certain number of femtocell has positive effect on the performance of this strategy as illustrated in Table 4.9.

In proposed traffic load based strategy, when 15 picocells are added to system, the average capacity reaches 34,13 Mbps with OFA Model 1 and 5,817 Mbps with OFA Model 2 as illustrated in Figure 4.13 and Figure 4.17. Deploying smaller nodes to network which consists of a macrocell has positive effect on the performance of this strategy in Table 4.10. When 22 femtocells are deployed, the average capacity reaches 47,85 Mbps with OFA Model 1 and 7,093 Mbps with OFA Model 2 in Figure 4.14 and Figure 4.18. By deploying additional picocell and microcell in addition to macrocell and femtocell, the average capacity is lower than only macrocell and femtocell deployment cases with OFA Model 1 as illustrated in Figure 4.15 and Figure 4.16. The highest average capacity values are obtained in Case 10.11, 10.12 and 10.13 in Figure 4.19 and Figure 4.20. Satisfaction percentages of users with OFA Model 1 and OFA Model 2 are shown between Figure 4.28 and Figure 4.32.

The relation between average capacity of the system and number of deployed femtocells is illustrated in Figure 4.21 and 4.22. The average capacity value increases until a certain number of femtocells are deployed in all strategies. Whether the number of UEs are increased to 500, the average capacity has similar trend. If more femtocells are deployed, the average capacity decreases. As more smallcells are deployed in the system, they exist in coverage area of each other and share bandwidth. As the interference effect becomes dominant, the average capacity values decrease.

The proposed traffic load strategy has the best performance by comparing with other strategies because this strategy considers traffic load information. The average capacities are lower than proposed traffic load strategy in proposed RSRP threshold and load based strategy. This strategy uses the number of attached UEs in nodes rather than traffic load information. Minimum path loss strategy has the worst performance.

CHAPTER 5

OFFLOADING TECHNIQUES FOR HETNET WITH CELLULAR AND WIFI

Predictions have shown that the future multimedia services will lead to an exponential traffic growth by 1000 times. According to these statistics, 80% of the traffic will be at smallcells and WiFi APs. [23]. In order to meet the large capacity demand at network, the deployment of WiFi AP and smallcell is commonly used [24]. There are many reasons to add WiFi within the smallcell enclosure. It facilitates indoor deployments of smallcells for operators who already have a WiFi network in indoor locations. Moreover, it expands outdoor WiFi coverage by deploying outdoor smallcells [25].

The strategies which operate in system consist of macrocell, smallcells and WiFi APs will be analyzed in this chapter. The performance evaluations of RSS, RSRP and proposed traffic load based strategies in various scenarios will be examined in detailed. Moreover, the advantages and disadvantages of all strategies will be discussed.

5.1. RSS Based Strategy

In order to map RSS measurements, the model which is expressed by Eq. (3.1) in Section 3.1 is used in this approach for macrocell, smallcell and WiFi AP combined HetNet. For channel modelling case, the path loss and shadow fading effects are considered in all strategies defined in this chapter by using Modified COST231 Hata urban propagation model as illustrated from Eq. (3.2) to Eq. (3.6) in Chapter 3. In all strategies, resource block sharing model is considered as illustrated in Eq. (3.7).

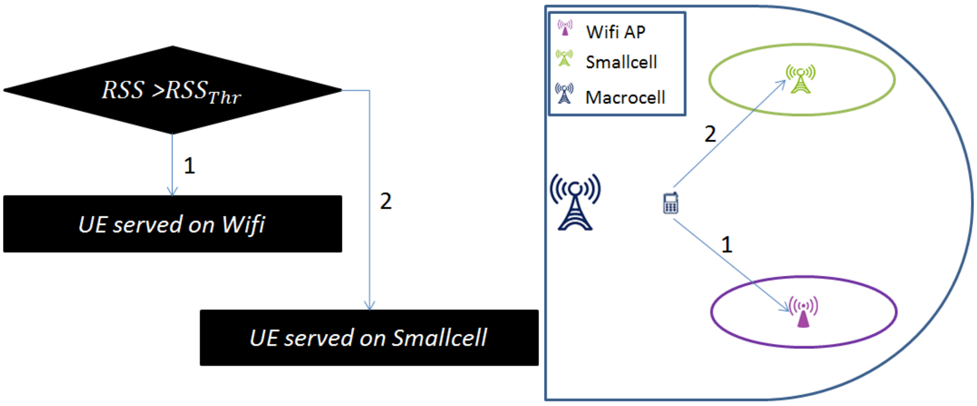

Figure 5.1. RSS based strategy

5.2. RSRP Based Strategy

In order to map RSRP measurements, the model which is expressed by Eq. (3.9) in Section 3.2 is used in this approach for macrocell, smallcell and WiFi AP combined HetNet.

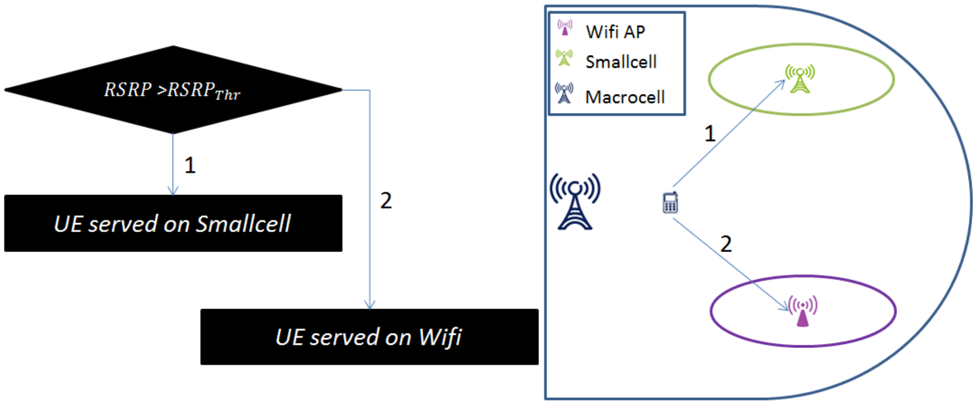

Figure 5.2. RSRP based strategy

5.3. Proposed Traffic Load Based Strategy

The algorithm offloads UEs with respect to Eq. (4.4) as defined in Chapter 4.

5.4. Performance Evaluations

In macrocell, smallcell and WiFi network scenario, the simulation area consists of macrocell, smallcells and the WiFi APs. Macrocell, smallcell and WiFi networks operate in 2.6 and 2.4 GHz frequency bands and have 20 MHz and 10 MHz bandwidth, respectively. WiFi network operates in different frequency band with respect to cellular network. Thus, they do not create interference to each other.

The simulation area consists of macrocell, smallcells, WiFi APs and UEs is as illustrated in Figure 5.3. The macrocell is placed at (0, 0) coordinate, and the smallcells, WiFi APs and UEs are randomly placed in 1km x 1km area.

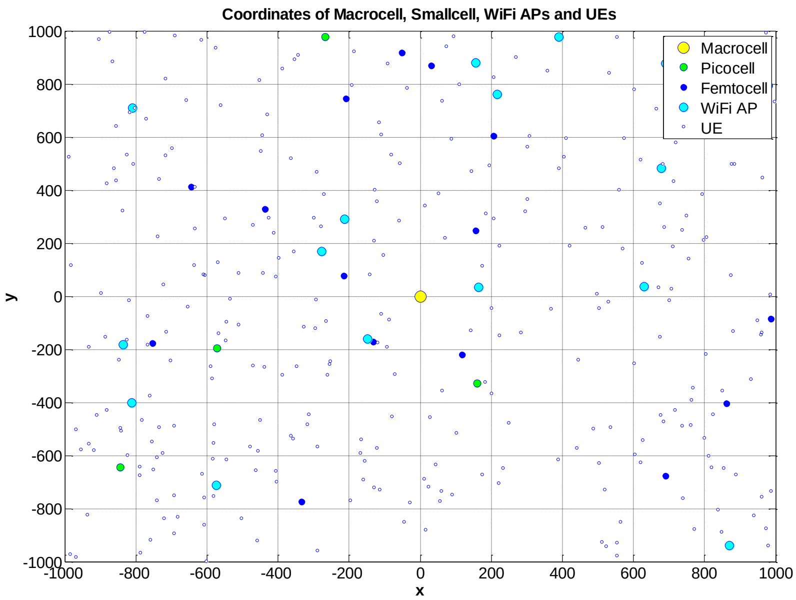

Figure 5.3. Simulation area of macrocell, smallcells and WiFi APs (1kmx1km)

For RSS and RSRP based strategies, various number of WiFi APs and femtocells are implied to the system with same RSS and RSRP threshold values as illustrated in Table 5.1, 5.2. For proposed traffic load based strategy, different number of WiFi APs and femtocells are implied to the system as illustrated in Table 5.3. We denote macrocell as ‘Ma’, microcell as ‘Mi’, picocell as ‘P’, femtocell as ‘F’ and WiFi AP as ‘W’ in the following sections.

Table 5.1. The number of smallcells and WiFi in different cases for RSS strategy with OFA Model 1 and OFA Model 2

Cases (1Ma. and 300 UEs)	Number of picocells	Number of femtocells	Number of WiFi APs	RSS_{Thr} (dBm)
Case1.1, 2,1, 3,1 4.1	0	0	0	-
Case1.2, 2.2	5	10	10	-20
Case1.3, 2.3	5	15	10	-20
Case1.4, 2.4	5	20	10	-20
Case3.2, 4.2	5	10	10	-20
Case3.3, 4.3	5	10	15	-20
Case3.4, 4.4	5	10	20	-20

Table 5.2. The number of smallcells and WiFi in different cases for RSRP strategy with OFA Model 1 and OFA Model 2

Cases (1Ma. and 300 UEs)	Number of picocells	Number of femtocells	Number of WiFi APs	$RSRP_{Thr}$ (dBm)
Case5.1, 6,1, 7,1 8.1	0	0	0	-
Case5.2, 6.2	5	10	10	15
Case5.3, 6.3	5	15	10	15
Case5.4, 6.4	5	20	10	15
Case7.2, 8.2	5	10	10	15
Case7.3, 8.3	5	10	15	15
Case7.4, 8.4	5	10	20	15

Table 5.3. The number of smallcells and WiFi in different cases for proposed traffic load based strategy with OFA Model 1 and OFA Model 2

Cases (1Ma. and 300 UEs)	Number of picocells	Number of femtocells	Number of WiFi APs
Case9.1, 10.1, 11.1, 12.1	0	0	0
Case9.2, 10.2	5	10	10
Case9.3, 10.3	5	15	10
Case9.4, 10.4	5	20	10
Case11.2, 12.2	5	10	10
Case11.3, 12.3	5	10	15
Case11.4, 12.4	5	10	20

Simulation Parameters

The parameters which are used in all scenarios are as illustrated in Table 5.4. The capacities of service types used for satisfaction percentages are as illustrated in Table 3.6.

Table 5.4. Simulation parameters for macro, smallcells and WiFi scenario with all strategies

Parameters	**Value**
Tx power of macrocell	43 dBm
Tx power of picocell	23.97 dBm
Tx power of femtocell	10 dBm
Tx power of WiFi AP	23 dBm
Bandwidth of macrocell (OFA1)	10 MHz
Bandwidth of picocell (OFA1)	7 MHz
Bandwidth of femtocell (OFA1)	3 MHz
Bandwidth of macrocell (OFA2)	10 MHz
Bandwidth of picocell (OFA2)	10 MHz
Bandwidth of femtocell (OFA2)	10 MHz
Bandwidth of WiFi AP	10 MHz
Shadowing Factor for macrocell	10 dB
Shadowing Factor for WiFi AP	4 dB
Shadowing Factor for picocell	6 dB
Shadowing Factor for femtocell	4 dB
Height of Tx macrocell	32 m
Height of Rx macrocell	1,5 m
Height of Tx picocell	5.6 m
Height of Rx picocell	1.5 m
Height of Tx femtocell	0.7 m
Height of Rx femtocell	1.5 m
Height of Tx WiFi AP	0,7 m
Height of Rx WiFi AP	1,5 m
Coverage Radius of macrocell	1000 m
Coverage Radius of picocell	200 m
Coverage Radius of femtocell	40 m
Coverage Radius of WiFi AP	55 m
C coefficient	3 dB
Operating Frequency for cellular	2600 MHz
Operating Frequency for WiFi	2400 MHz

Simulation Results

The simulation results of all cases with respect to all of the strategies defined in this chapter are illustrated.

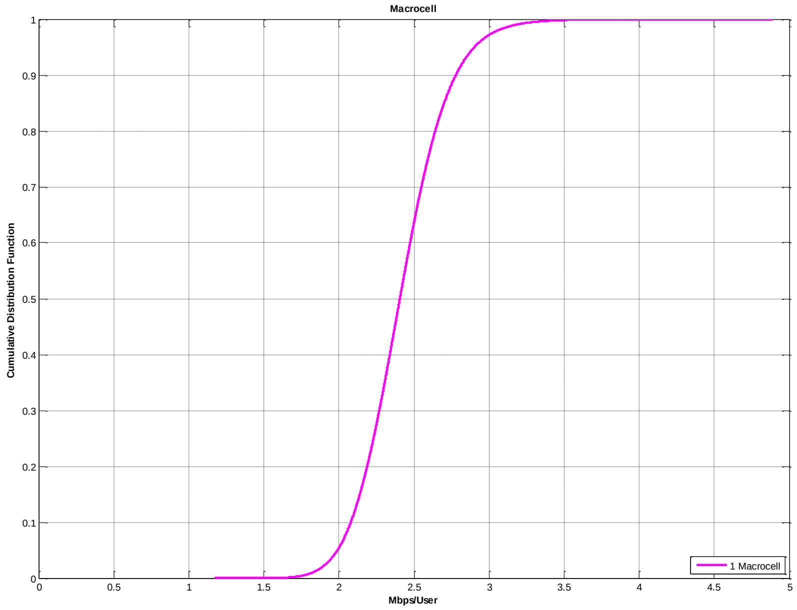

Figure 5.4. CDF for 1 macro (Case 1.1 - 12.1)

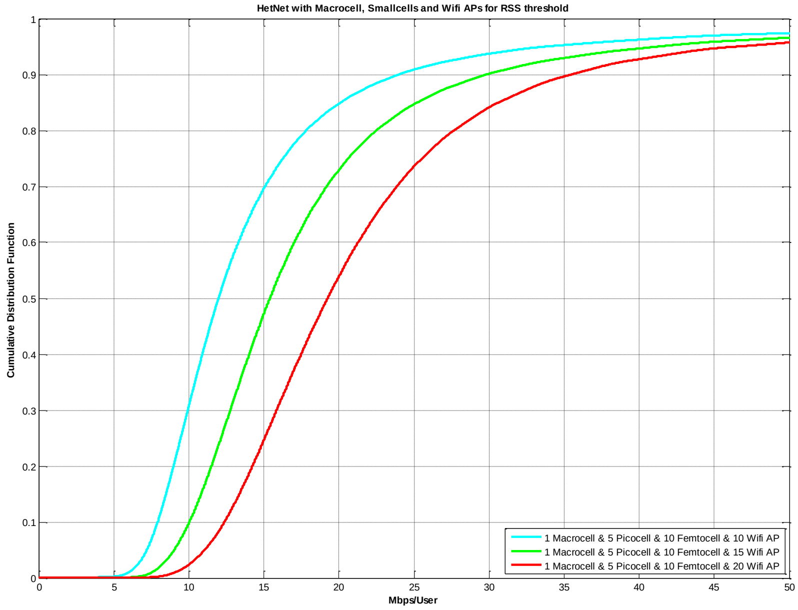

Figure 5.5. CDF for RSS strategy with OFA Model 1 (Case 3.2, 3.3, 3.4)

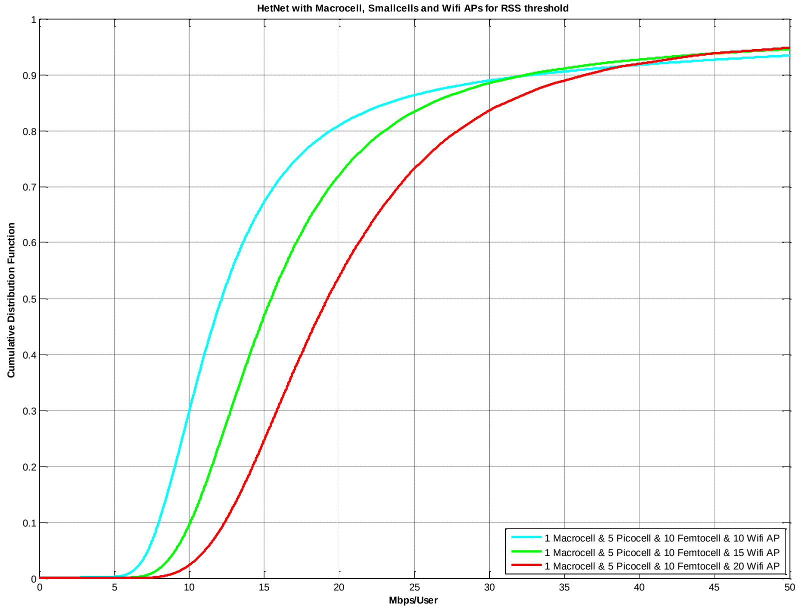

Figure 5.6. CDF for RSS strategy with OFA Model 2 (Case 4.2, 4.3, 4.4)

Table 5.5. Average Capacity for RSS strategy in all cases

Cases		**Average Capacity (Mbps/User)**	
		OFA Model 1	OFA Model 2
Case1.1 - 4.1	1Ma	2,406	2,406
Case1.2, 2.2	1Ma, 5P, 10F, 10W	11,97	12,16
Case1.3, 2.3	1Ma, 5P, 15F, 10W	12,11	12,23
Case1.4, 2.4	1Ma, 5P, 20F, 10W	12,16	12,31
Case3.2, 4.2	1Ma, 5P, 10F, 10W	11,98	12,18
Case3.3, 4.3	1Ma, 5P, 10F, 15W	15,41	15,48
Case3.4, 4.4	1Ma, 5P, 10F, 20W	**19,24**	**19,22**

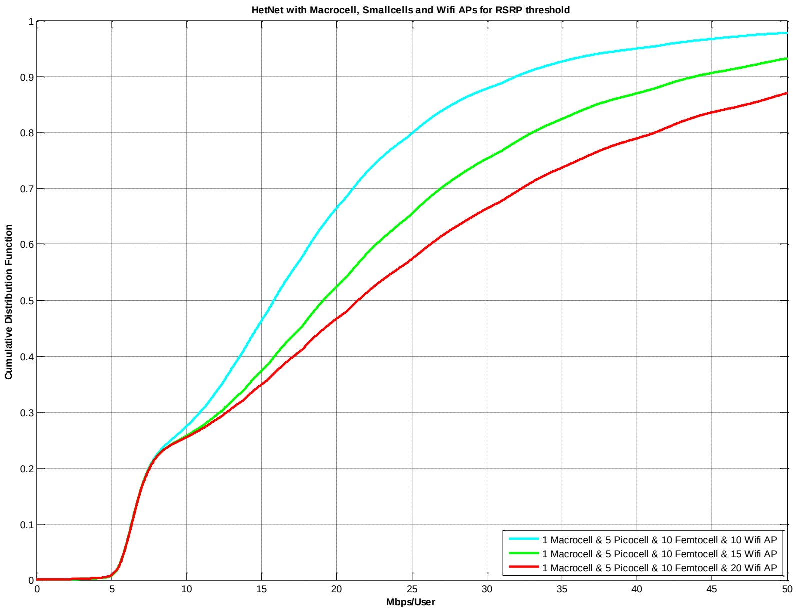

Figure 5.7. CDF for RSRP strategy with OFA Model 1 (Case 7.2, 7.3, 7.4)

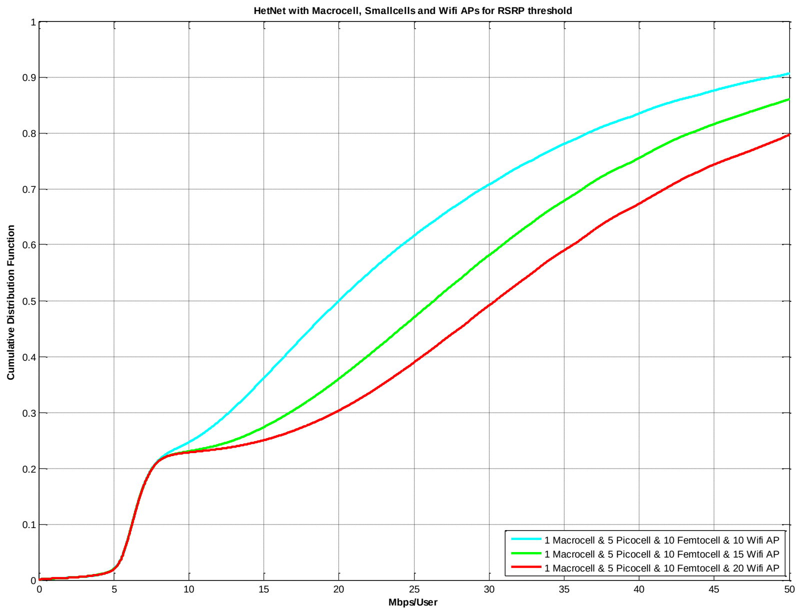

Figure 5.8. CDF for RSRP strategy with OFA Model 2 (Case 8.2, 8.3, 8.4)

Table 5.6. Average Capacity for RSRP strategy in all cases

Cases		**Average Capacity (Mbps/User)**	
		OFA Model 1	OFA Model 2
Case5.1 - 8.1	1Ma	2,406	2,406
Case5.2, 6.2	1Ma, 5P, 10F, 10W	15,88	20,07
Case5.3, 6.3	1Ma, 5P, 15F, 10W	17,74	23,16
Case5.4, 6.4	1Ma, 5P, 20F, 10W	19,17	26,24
Case7.2, 8.2	1Ma, 5P, 10F, 10W	15,83	20,03
Case7.3, 8.3	1Ma, 5P, 10F, 15W	19,18	26,38
Case7.4, 8.4	1Ma, 5P, 10F, 20W	**21,45**	**30,46**

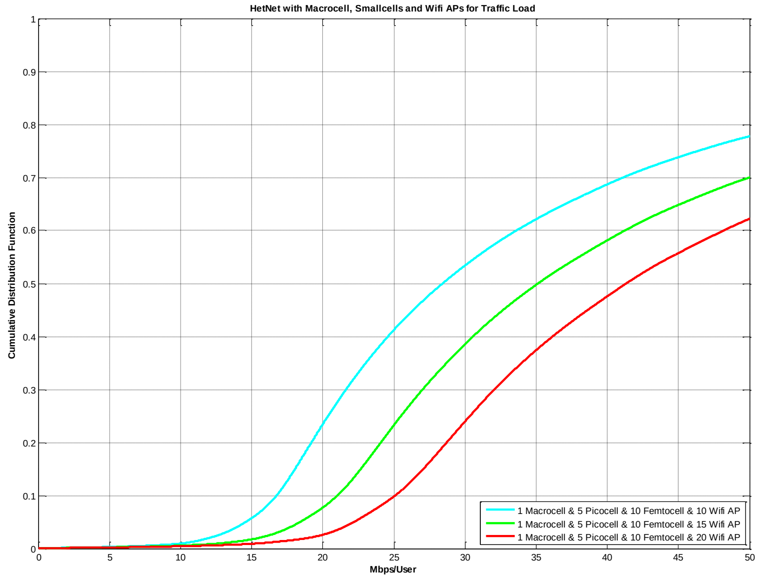

Figure 5.9. CDF for proposed traffic load based strategy with OFA Model 1 (Case 11.2, 11.3, 11.4)

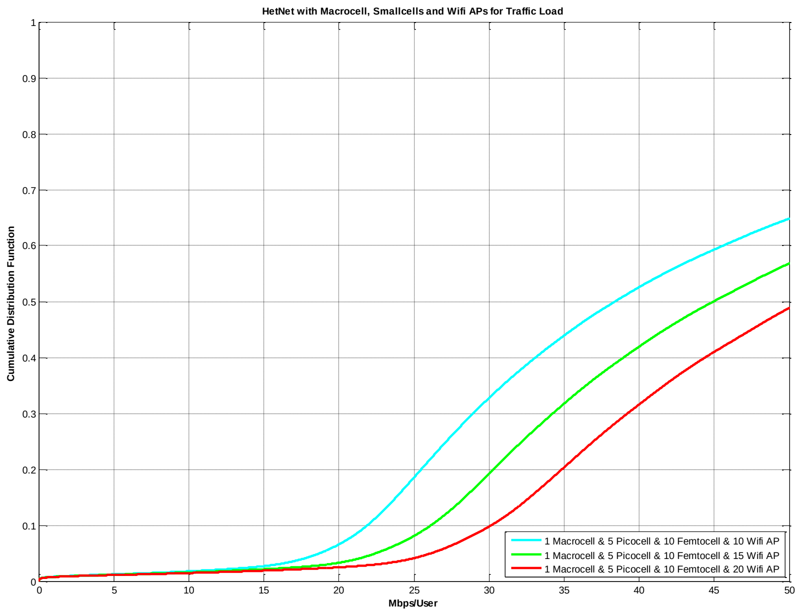

Figure 5.10. CDF for proposed traffic load based strategy with OFA Model 2 (Case 12.2, 12.3, 12.4)

Table 5.7. Average Capacity for proposed traffic load based strategy in all cases

Cases		**Average Capacity (Mbps/User)**	
		OFA Model 1	OFA Model 2
Case9.1 - 12.1	1Ma	2,406	2,406
Case9.2, 10.2	1Ma, 5P, 10F, 10W	28,38	38,33
Case9.3, 10.3	1Ma, 5P, 15F, 10W	30,50	42,33
Case9.4, 10.4	1Ma, 5P, 20F, 10W	32,55	46,1
Case11.2, 12.2	1Ma, 5P, 10F, 10W	28,35	32,48
Case11.3, 12.3	1Ma, 5P, 10F, 15W	35,14	44,95
Case11.4, 12.4	1Ma, 5P, 10F, 20W	**41,41**	**50,05**

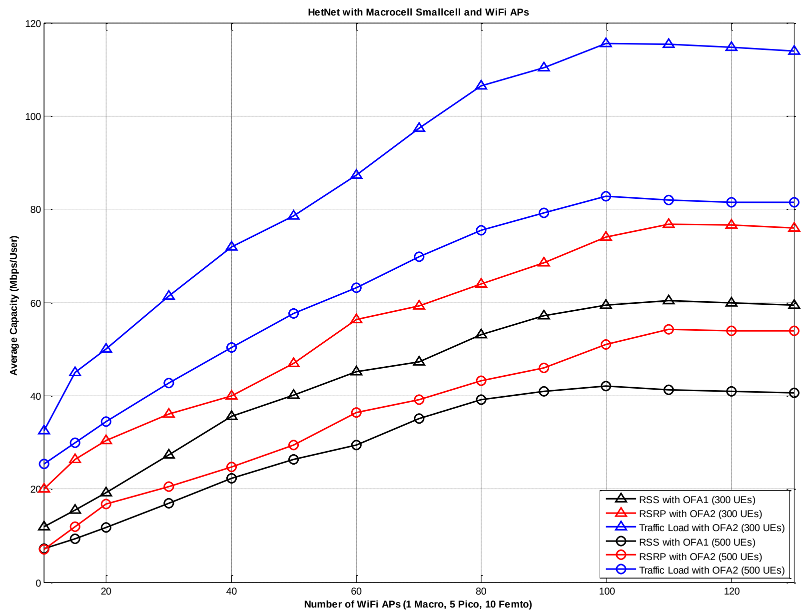

Figure 5.11. Average Capacity vs. number of deployed WiFi APs with different number of UEs

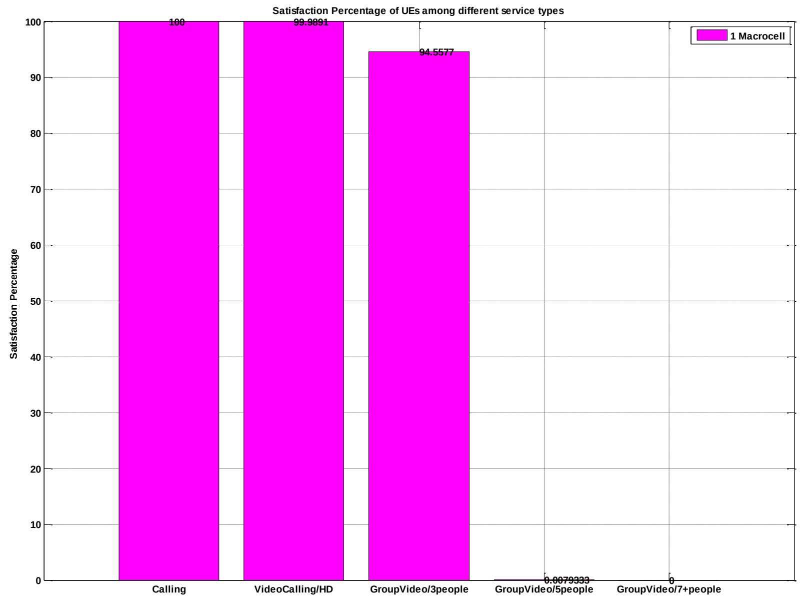

Figure 5.12. Satisfaction percentage for 1 macro (Case 1.1 - 12.1)

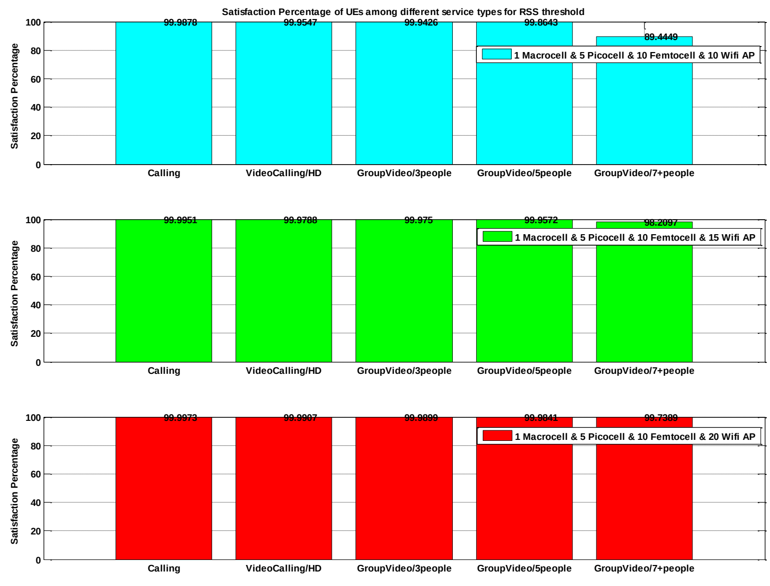

Figure 5.13. Satisfaction percentage for RSS strategy with OFA Model 1 (Case 3.2, 3.3, 3.4)

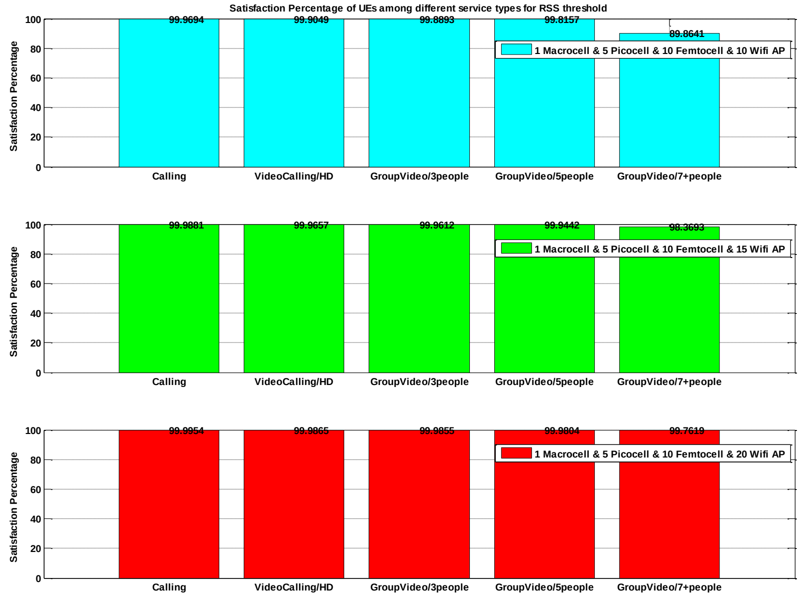

Figure 5.14. Satisfaction percentage for RSS strategy with OFA Model 2 (Case 4.2, 4.3, 4.4)

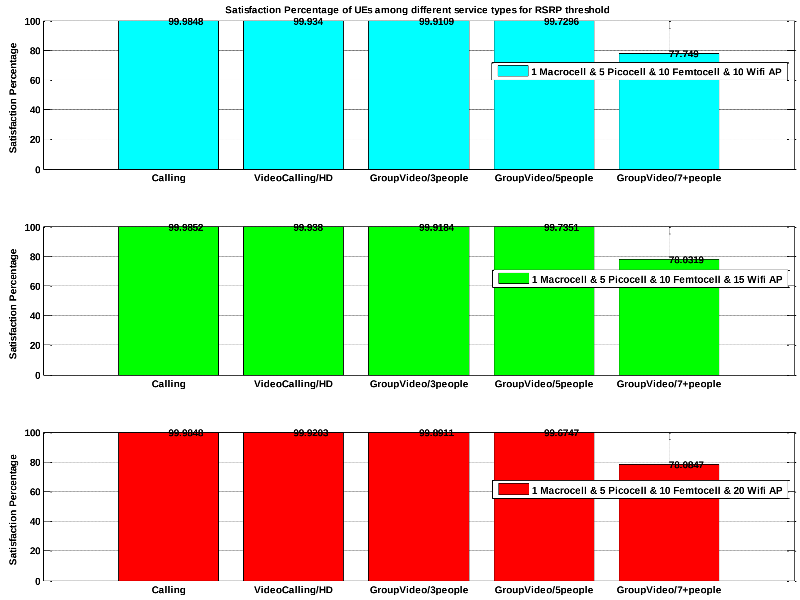

Figure 5.15. Satisfaction percentage for RSS strategy with OFA Model 2 (Case 7.2, 7.3, 7.4)

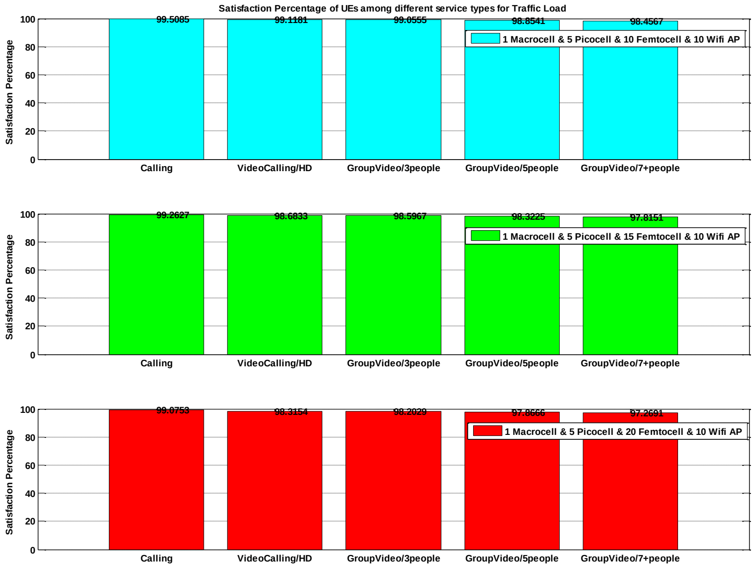

Figure 5.16. Satisfaction percentage for proposed traffic load based strategy with OFA Model 2 (Case 10.2, 10.3, 10.4)

Discussion

The RSS based strategy provides UEs to be offloaded WiFi AP if RSS value is higher than RSS threshold. If there is more than one WiFi AP satisfying this condition, the UE is assigned with WiFi AP with maximum RSS value. Otherwise, the UE is directly offloaded to smallcell. Certain number of additional femtocells provides higher average capacity in the network with OFA Model 1 and OFA Model 2 as shown in Figure 5.5 and Figure 5.6. When the number of femtocells is increased to 20, the average capacity can reach 12 Mbps in Table 5.5. When the number of WiFi APs is increased to 20, the average capacity is 19 Mbps. With the same numbers of WiFi APs and femtocells in the network, WiFi APs can provide higher average capacity than femtocells. WiFi APs operate in different frequency band and there exists no interference with smallcells. In only macrocell case, nearly none of the users can use group video/6 people and group video/7 people services in Figure 5.12. Satisfaction percentages of users increase with RSS based strategy as illustrated in Figure 5.13, Figure 5.14 and Figure 5.15.

RSRP based strategy provides UEs to be offloaded smallcell if RSRP value is higher than RSRP threshold. If there are more than one smallcell satisfying this condition, the UE is assigned with smallcell with maximum RSRP value. Otherwise, the UE is directly offloaded to WiFi AP. The effect of deploying additional femtocell and WiFi APs on the average capacity is shown in Figure 5.7 and Figure 5.8. When the number of femtocells is increased to 20, the average capacity can reach 19 Mbps with OFA Model 1 and 26 Mbps with OFA Model 2. Additional WiFi APs provides higher average capacity in the network with OFA Model 1 and OFA Model 2. When the number of WiFi APs is increased to 20, the average capacity can reach 21 Mbps with OFA Model 1 and 30 Mbps with OFA Model 2 as shown in Table 5.6.

In the proposed traffic load based strategy, the values of average capacity are higher than when there is only a macrocell in the network in all cases with OFA Model 1 and OFA Model 2 in Figure 5.9 and Figure 5.10. When the number of femtocells is increased to 20, the average capacity can reach 32 Mbps with OFA Model 1 and 46 Mbps with OFA Model 2 in Table 5.7. When the number of WiFi APs is increased to 20, the average capacity can reach 41 Mbps with OFA Model 1 and 50 Mbps with OFA Model 2. Satisfaction percentages of users with OFA Model 2 are shown in Figure 5.16.

Choosing appropriate threshold values for RSS and RSRP based strategies is to increase average capacity. If RSS threshold value is selected as a small value, a big portion of UEs are offloaded to WiFi network, and this situation causes congestion. Moreover, If RSRP threshold value is selected as a small value, many UEs continue with getting service from cellular network. The proposed traffic load based strategy provides the highest average capacity. Considering network traffic as offloading criteria is more complex when comparing with the RSS and RSRP based strategies. However, UEs can have higher average capacities.

The relation between average capacity of the system and number of deployed WiFi APs is illustrated in Figure 5.11. The average capacity increases until a certain number of WiFi APs are deployed in all strategies. Whether the number of UEs is increased to 500, the average capacity values have similar trend. If more femtocells are deployed, the average capacity decreases.

CHAPTER 6

CONCLUSION

The offloading strategies between multi layered HetNet which consist of macrocell and smallcells and WiFi network have been studied in this thesis. We have been focused on mainly three types of HetNet scenarios; the first type includes the network with macrocell and WiFi APs, the second type includes the network with macrocell and smallcells and the last type includes the network with macrocell, smallcell and WiFi APs. The offloading strategies based on RSS, RSRP, PL, SINR and traffic load information have been considered.

In HetNet which includes macrocell and WiFi AP deployment, the performances of RSS, RSRP, RSS & RSRP and PL based strategies with various numbers of WiFi APs have been examined. All of the strategies are mainly focused on offloading UEs from macrocell to WiFi network. The threshold has great effect on the average capacity of RSS, RSRP and RSS & RSRP based strategies. Whether the threshold is set to a value which is not appropriate for the system, many of the UEs can be offloaded to WiFi network and can result network congestion.

In HetNet which includes macrocell and smallcell deployment, the performances of RSRP, biased RSRP, PL, proposed RSRP threshold & load and proposed traffic load based strategies with various numbers of smallcells have been examined. We have illustrated a certain number of additional femtocell deployment increases the average capacity of the network at most. The proposed RSRP threshold & load and proposed traffic load based strategies achieve higher average capacity. We have shown that the average capacity of proposed strategies is higher than other strategies with deploying more smallcells and WiFi APs in the network. The proposed RSRP threshold & load based and the proposed traffic load based strategies can slightly increase overhead signaling in network.

In HetNet which includes macrocell, smallcell and WiFi AP, the performances of RSS, RSRP and proposed traffic load based strategies have been evaluated. Additional WiFi AP deployment results higher average capacity than additional smallcell deployment. The best performance results have been achieved by the proposed traffic load based strategy. The average capacity increases until a certain number of WiFi APs or femtocells are deployed in all strategies. When more WiFi APs or femtocells are deployed in the network, they exist in coverage area of each other or share the same bandwidth. Therefore, the interference effect becomes dominant and the average capacity per user values decrease. Deploying additional WiFi APs has better effect on the performance of strategies than smallcells because WiFi APs operate in different frequency range.

As more technological developments in wireless communication system will be implied, WiFi and smallcells offloading in HetNets can still create opportunities to meet with the exponential growth of users' service demand.

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