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A Survey of Performance Models for LTE-WiFi Wireless Heterogeneous Networks

Un estudio de Modelos de Desempeño para Redes Heterogéneas Inalámbricas LTE-WiFi

HERNANDEZ-OCHOA, Martha†* & TORRES-LOPEZ, Alfredo

Universidad de Guadalajara, Centro Universitario del Norte, Carretera Federal No. 23, Km. 191, C.P. 46200, Colotlán, Jalisco, México. Teléfono: +52 (499) 9921333. Departamento: Fundamentos del Conocimiento

ID 1st Author: *Martha María, Hernández-Ochoa* / **ORC ID:** 0000-0002-3464-108X, **CVU CONACYT ID:** 256067

ID 1st Coauthor: *Alfredo Netzahualcoyotl, Torres-Lopez* / **ORC ID:** 0000-0002-0926-4999

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Abstract

Nowadays, the network traffic has increased exponentially due to amount of information and number of users which are connected to Heterogeneous Networks (HetNets) in this case we focus on LTE-WiFi technologies. This is an important issue that need to solve for an efficient network communication process end to end. The aim of this article is to present the-state-of-the-art about performance models for LTE-WiFi HetNets and a classification of key performance metrics which help to analyze HetNets behaviour. The article concludes with a methodology that will be applied later for this research problem, as well as opened research questions. We believe, that apply our methodology using accurate and suitable models in HetNets the transmission process will have a fairness traffic when both networks coexist.

Hetergoeneous networks, Performance models, LTE

Resumen

En la actualidad, la creciente demanda de información y la cantidad de usuarios conectados a las redes inalámbricas heterogéneas (en este caso nos enfocamos en LTE-WiFi) está creciendo de forma exponencial. Es muy importante disminuir la congestión de la red generada por esta demanda para tener un eficiente proceso de comunicación fin a fin. EL objetivo principal de este artículo es presentar el estado del arte de modelos de desempeño para redes inalámbricas heterogéneas LTE-WiFi y una clasificación de métricas de desempeño claves para el análisis del comportamiento en estas redes. El articulo concluye con una metodología que será aplicada más adelante para este problema de investigación, así como preguntas de investigación abiertas. Nosotros creemos que al aplicar esta metodología utilizando modelos de desempeño precisos y adecuados en la red heterogénea el proceso de comunicación tendrá un tráfico equitativo cuando ambas redes LTE-WiFi existan y de esta forma se tenga una eficiente comunicación entre los usuarios finales.

Redes Heterogéneas, Modelos de desempeño, LTE

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* Correspondence to Author (email: martha.ochoa@cunorte.udg.mx)
† Researcher contributing first author.

Introduction

Nowadays, the network traffic has increased exponentially due to number of connected users and amount of information. This is an important issue that need to solve for an efficient network communication process, in other words, the end user can connect anywhere, anytime and any device with a better network quality of service to support user traffic demands.

Therefore, wireless networks are constantly evolving due to different factors that change the network behaviour, such as: (1) amount of users, (2) available bandwidth, (3) employed technology, (4) network load, (5) noise, (6) interference, (7) medium access control (MAC) protocols, etc. Also, the network performance can be affected with these factors. We consider a Heterogeneous Networks (HetNets) such as a set of devices interconnecting with different network protocols. We focus in LTE and WiFi networks which are widely used technologies today.

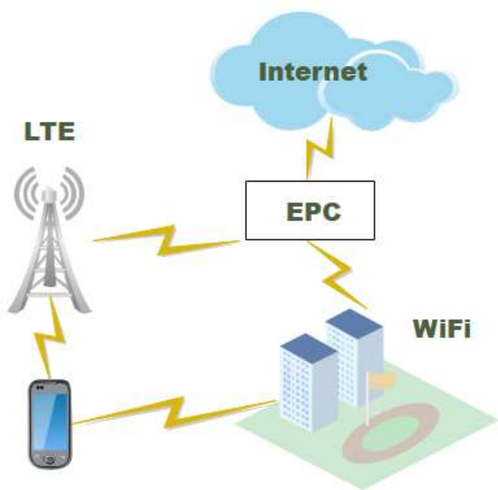

Figure 1 HetNet (LTE-WiFi) Scenario

For example, in Figure 1, we can see an HetNets scenario which components are: a Long Term Evolution (LTE) Network, an User Equipment (UE), a WiFi Network, the Evolved Packet Core (EPC) and Internet. The WiFi Network, in this case is an University Network.

Our motivation is that students can have an efficient connection, when both networks (LTE-WiFi) coexistence, at moment they want to do laboratory practices, school activities, homeworks, research, among others.

We think that performance models, which consider key factors such as: bit error rate (BER), Signal Noise to Ratio (SNR), signal-to-noise-plus-interference ratio (SNIR), packet collision probability, packet retransmission, among others, help to solve this network issue.

Some relevant related work about performance models for LTE and WiFi networks are described below.

The analytical model of Bianchi (2000) is used to estimate the throughput of an IEEE 802.11 network using the Distributed Coordination Function (DCF) under saturated conditions. This assumes: (i) any transmission queue always has packets to be sent, (ii) an ideal channel and (iii) a finite number of stations. The model considers two DCF techniques: basic and request to send/clear to send (RTS/CTS). The approach adopted is to analyze a single station modeled using a Markov Chain. The results demonstrate better performance is achieved when the RTS/CTS mechanism is used.

Duffy, Malone and Leith (2005) present an extension of Bianchi's model. They consider on-saturated network conditions, collisions in the Physical (PHY) layer and no noise present in the medium. The analysis is focused on the throughput, collision probability, delay, total offered load and (the optimal) minimum contention window. They employ three load types: Poisson, conditional and uniform.

Lin and Wong's model (2006) (IEEE 802.11n) addresses a uni-directional and bi-directional RTS/CTS access mechanism in the presence of collisions and channel errors in the system. This model, which is an extension of Bianchi's model, considers BER probability, minimum contention window length and a maximum backoff stage. Their model also includes the Medium Access Control (MAC) Protocol Data Unit Aggregation (A-MPDU) and MAC Service Data Unit Aggregation (A-MSDU) techniques to improve the MAC protocol performance. Simulation and analytical results are presented for throughput and delay. This is done for a different number of aggregations MPDUs and BER conditions.

Kumar et al. (2017) address load imbalance problem in LTE networks. They propose a novel QoS aware load balance and a centralized software defined LTE RAN framework. The results show a better QoS data rates for more 80% of cells in the networks.

Chaves et al. (2013) present some challenges of WiFi/LTE coexistence, also they consider two mechanisms to enable the WiFi coexistence. These mechanisms are: a) blank subframes and b) uplink power control; both are described by Chaves et al. (2013). The results show a better throughput to use these mechanisms when WiFi coexistence.

Baswade et al. (2018), propose a scheme for WiFi for user fairness and efficient spectrum utilization in the presence of LTE-U. The results improve the performance of WiFi Network in presence of LTE-U.

This paper is structured as follows. First, we present a theoretical background about LTE and WiFi Protocols. Second, some performance metrics in HetNets are discussed. Next, various modelling tools for Networks are reviewed. Latter, we address some future directions and research challenges. Finally, conclusions are drawn up.

LTE and WiFi Protocols theoretical background

LTE protocol

The LTE protocol is developed by 3rd Generation Partnership Project (3GPP), which promises latency reduction, high spectral, frequency and bandwidth flexibility, short round trip time, among others.

The LTE protocol stack has the next layers for eNodeB: Radio Resource Control (RRC), Packet Data Convergence Protocol (PDCP), Radio Link Control (RLC), MAC and PHY; for UE Non-access stratum (NAS), RRC, PDCP, RLC, MAC and PHY. We can see in Figure 2, the LTE protocol stack.

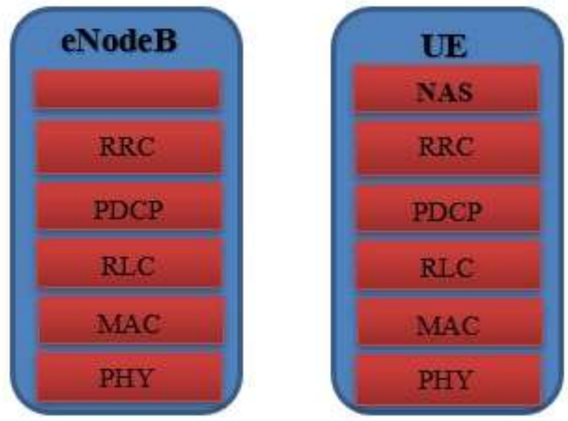

Figure 2 The LTE protocol Stack

MAC Layer

The MAC layer sends logical channels as transport channel and configures PHY layer for the next transport block. Some Mac layer functions are: Logical channel prioritazation, Error correction through hybrid Automatic Repeat Request (ARQ), mapping between transparent and logical channels and priority handling with dinamic scheduling. eNode schedules the uplink and downlink channels.

PHY Layer

This layer is typically full duplex and provides multiple channels simultaneously with different modulation (QPSK, 16QAM, 64QAM). The physical interface is a transport block which has 12 subcarries in one slot. LTE employs Orthogonal Frequency Division Multiplex (OFDM) for downlink data transmission and Single Carrier FDMA (SC-FDMA) for uplink transmission. Peak date rate: 300 Mbps for downlink and 75 Mbps for uplink whilst for LTE-A is 1 Gbps (downlink) and 500 Mbps (uplink).

WiFi protocol

MAC Layer

The DCF is the fundamental mechanism to access the medium based on carrier sense multiple accesses with collision avoidance (CSMA/CA). The DCF employs a binary exponential back-off scheme. When a station wants to transmit a new packet, it monitors the channel activity. If the channel is idle for a period equal to the distributed inter-frame space (DIFS) the station transmits the packet.

On the other hand, if the channel is busy (either during or immediately after the DIFS), the station continues to monitor the channel until it senses idle for the DIFS. The station generates a random back-off interval before it transmits the packet. After an idle DIFS, a time slot is available and a station can only transmit at the start of each time. The time slot depends on the PHY layer (see Table 1). The back-off time is chosen in the interval 0 to W-1 in each packet transmission. The value W represents the Contention Window (CW) i.e. the amount of time available for the slots (Forouzan, 2013). In the first attempt, the W is equal to CW_{min} (minimum CW); after each unsuccessful transmission the W is doubled subject to a maximum of CW_{maxim}(maximum CW). CW_{maxim}=$2^{max}CW_{min}$, max is the maximum number of attempts or stages. The values of CW_{min} and CW_{maxim} are shown in Table 1. The back-off time counter decreases when the channel is sensed as being idle, but stops when there is a transmission in the channel (Hernandez et al., 2014).

The attempt rate is defined by Duffy, Malone and Leith (2005) as the probability that a station transmits in a randomly chosen slot time.

PHY	Slot Time	CW_{min}	CW_{maxim}
Frequency Hopping Spread Spectrum (FHSS)	50 µs	16	1024
Direct Sequence Spread Spectrum (DSSS)	20 µs	32	1024
Infrared (IR)	8 µs	64	1024

Table 1 Three PHY layers specified by *IEEE 802.11 Standard (2007)*

PHY Layer

We describe the IEEE 802.11g protocol for PHY layer. This protocol was finalized until June 2003; 802.11g is a relative late-comer to the wireless marketplace. Despite the late start, 802.11g is now the de facto standard wireless networking protocol. This standard is used on most laptops and handheld devices. The 802.11g protocol uses the same Industrial, Scientific and Medical (ISM) frequency range as the 802.11b protocol. This physical layer is based on DSSS according to the IEEE 802.11 Standard (2007).

This PHY operates in the 2.4 GHz ISM band and at a maximum raw data rate of 54 Mbit/s (with usable throughput of about 22Mbps). Also, this PHY layer can consider OFDM modulation. This makes it incompatible with 802.11b, and the higher frequency means shorter range compared to 802.11b/g at the same power. The frequency range is 2.400 - 2.495 GHz, which is used by the 802.11b and 802.11g radio standards (corresponding to wavelengths of about 12.5 cm). A single 802.11g link may use 54 Mbps radios, but it will only provide up to 22 Mbps of actual throughput. The remaining bandwidth is the overhead that the radios need in order to coordinate their signals using the 802.11g protocol. Since the 802.11g wireless equipment is half duplex (that is, it only transmits or receives, never both at once) the required throughput must be doubled accordingly, for a total of 10 Mbps. The wireless links must provide that capacity every second**,** or conversations will lag.

Performance Metrics in HetNets

In this subsection, we introduce some performance metrics that affect data transmission quality in HetNets. We focus mainly on: Packet Error Rate (PER), SNR, packet collision probability, bandwidth, throughput and delay. These metrics are described as follows:

1. PER. This metric is determined by the BER. The BER is defined as the number of bit errors divided with the total number of transfer bits in a time interval which is defined by Lin and Wong (2006). The PER is denoted as pe while the BER is P_{BER}. The PER is defined as:

$$pe = 1 - (1 - P_{BER})^{L_a} \quad (1)$$

L_a is the DATA packet length in bits, which includes physical layer header (PHY_H), MAC layer header (MAC_H) and packet load. The payload information is defined as:

$$P_{aload} = \frac{L_a - H_{total}}{\tau^a} \quad (2)$$

where

$$H_{total} = PHY_H + MAC_H \quad (3)$$

Physical layer header and MAC layer header are defined by IEEE 802.11 Standard (2007).

2. SNR. The SNR is a metric which compares the desired signal level to the level noise, and it is defined as:

$$SNR = \frac{P_{signal}}{P_{noise}} \quad (4)$$

P_{signal} is the average power of signal and P_{noise} is the average power of noise.

3. Packet Collision probability. It is the probability that a packet chrashes with other packet during the transmission process and is defined as:

$$Pc = 1 - (1 - t)^{n-1} \quad (5)$$

Where t is the stationary probability (presented in Bianchi, 2000) when a station transmits a packet in a random slot time. At least one of $n - 1$ stations transmit, in a time slot.

4. Bandwidth. This metric refers to the number of bits per second that can transmit in a channel, in other words, “refers to the speed of bit transmission in a channel” (Forouzan, 2013).

5. Throughput. Fakhri et al. (2006) defined the throughput as: the number of payload bits received with no error per second and kept this quantity as high as possible. They used the equation:

$$T = \sum_{i=1}^{N} \frac{L-C}{L} * R_i * f(\gamma_i) \quad (6)$$

Where L is total packet length (bits), C is a bit Cyclic Redundancy Check (CRC), R_i is the symbol rate assigned to sub-carriers i, $f(\gamma_i)$ is the packet success rate (PSR) defined as the probability to receive a correct packet.

Baswade et al. (2018), calculate the average throughput for non-victim users which are deprived of packets in LTE-U ON period and victim users which receive packets in both LTE-U ON and OFF periods, as follows:

$$\Gamma_{nv}^{new} = (1 - \alpha)\Gamma_{nv}^{prev} + \alpha\Gamma_{nv}^{old} \quad (7)$$

$$\Gamma_{v}^{new} = (1 - \alpha)\Gamma_{v}^{prev} + \alpha\Gamma_{v}^{old}$$

Where α is a smoothing parameter,”Γ_{nv}^{prev} and Γ_{v}^{prev} are average throughputs in the previous duty cycle period, and Γ_{nv}^{old} and Γ_{v}^{old} are the Γ_{nv}^{new} and Γ_{v}^{new} of the previous duty cycle period, for non-victim and victim user, respectively”(Baswade et al., 2018).

6. Delay. According to Forouzan (2013) the delay is defined as the time that a complete message takes to arrive to its destiny from the moment that first bit is sent through its source. Delay is composed in the following times (equation 8):

- Propagation Time (T_{pg}).
- Transmission Time (T_{tx}).
- Processing Time (T_{ps}).
- Queueing Time (T_Q).

$$Delay = T_{pg} + T_{tx} + T_{ps} + T_Q \quad (8)$$

Where: T_{pg} is Propagation time which is represented such as (equation 9):

$$T_{pg} = \frac{d_x}{S_{pg}} \quad (9)$$

The propagation speed of electromagnetic signals depends of medium and frequency signal. T_{tx} is transmission time (Forouzan, 2013) which is represented such as:

$$T_{tx} = \frac{message\ length}{bandwidth} \quad (10)$$

Abu-Ali et Al. (2014) mention that LTE defines nine categorias for delay 50 ms and 300 ms for the tightest and slackest respectivately.

Modelling for Networks

Queueing Models

One important tool for communication system is queueing analysis. This tool is similar to Markov’s chains. Some examples of queues are: the number of customers in a bank line, the number of tasks needed to be processed, the number of messages in a network to be sent to their destiny, the number of patients in a hospital’s waiting room, etc. The main purpose of queueing analysis is to predict the system performance.

For instance, the average delay a customer endures before served, the number of customers that are processed per time step and the queue size or waiting room requested (Dattatreya, 2008). The queueing model has the following characteristics (according with Adan and Resing, 2015):

1. Arrival Process of customers. This characteristic assumes that inter-arrival times have a common distribution and thus are independent. In some cases, the customer arrival ratio is based on Poisson Stream such as exponential inter-arrival times. The number of customers can arrive individually or in groups.

2. Behavior of customers. We can observe two kinds of customer´s behavior. Either a customer could have the patience to wait for a short or long period and could be impatient or leave after a short time.

3. Service Times. Adan and Resing (2015) mentioned that these kinds of times are independent and identically distributed and are also considered independent of inter-arrival times.

4. Service Discipline. There are two disciplines for customers: (1) they are served individually or (2) in groups. We present some of the common disciplines: First in – first out, Last in – first out, Priorities (e.g. hierarchical token bucket filter), Random order and Stochastic Fair.

5. Service Capacity. The service capacity is handled by a single server or several servers to provide support to the clients.

6. Waiting Room. Every system has a limited size of customers. Waiting room is less when a buffer size tends to be infinity. This is an important factor to the number customers that can be stored in system.

Process Algrebra

This methodology is defined as: “a mathematical framework in which system behaviour is expressed in the form of algebraic terms, enhancing the available techniques for manipulation” by Fokkink (2007).

Hernández Ochoa, et al. (2014) proposed a HMAN end to end communication process which is represented using process algebra. They presented the next communication processes: transmission process from the source, receiving process at the destination node, for any intermediate node and aggregation process at bridge node. They described a case study between 802.11 and 802.16.

Cross Layer Design

Currently, Cross Layer Design has become a great potential in wireless communication systems according to Aune (2004). Different Cross-Layer proposals are depicted in figure 3. Srivastava and Motani (2005) mentioned that layered architecture could be modified in the following different ways: Creation new interfaces (figs. 3 a-c); Fusion of adjacent layers (fig. 3 d); Design coupling without new interfaces (fig. 3 e); Vertical calibration across layers (fig. 3f).

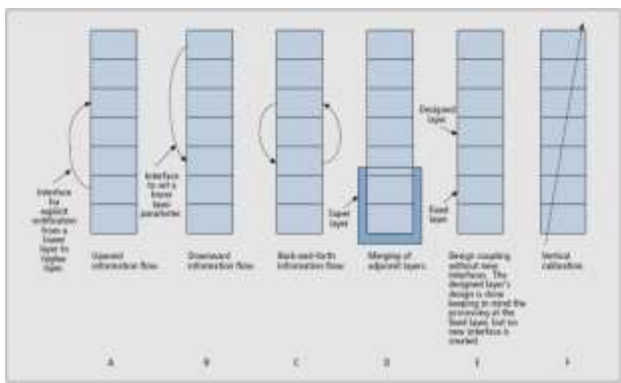

Figure 3 Different Cross-layer proposals by *Srivastava and Motani (2005)*

Performance Modelling

Performance modelling is a real system abstraction of a simplified representation to realize the performance’s prediction (Ackerley, 2003). Although there are different working domains to the basic principles of modeling they are the same. However, the people who are working under those domains have to adapt them in accordance to their needs.

The two main domains for telecommunications are: (1) Network performance and (2) IT (Information technology) System Performance.

Performance modelling has the following advantages: inexpensive predictions for future performance, designed to allow objective polls to be made, support to decide for future of existing systems, a clear understanding of characteristics for system performance, a management mechanism for risks and reduction.

Future Directions and Research Challenges

In this survey, we present a review of some LTE-WiFi performance models and key metrics which give us a general vision of our methodology that we will apply in the near future. We can see in Fig. 4, the network performance before congestion (e.g. $t_k, k\epsilon N$), latter the factors can decrease the network performance and affect some Quality of Service (QoS) metrics, such as: delay, throughput, jitter, packet loss ratio, bandwidth, BER, PER, SNR, SNIR, among others. However, it must also be considered scalability, interoperability, and security to achieve a better communication process in the HetNets. Achieving this issue in HetNets at network domains is challenging. Thus, there should be mechanisms join to performance models capable to modify some processes, characteristics or state of the system caused by changes in network.

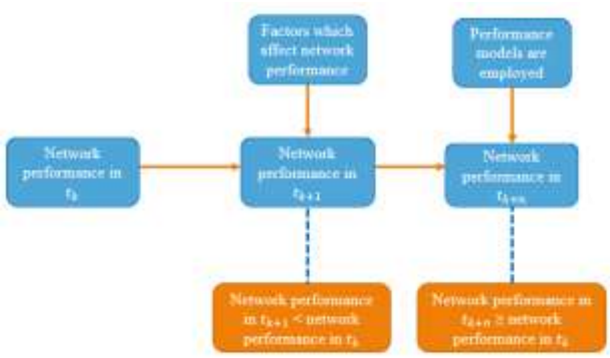

Figure 4 Methodology for HetNet (LTE-WiFi) performance

We believe, that apply a suitable methodology using accurate models that occurs in any network domain, the transmission process will have a fairness traffic when both networks coexist. Once the factors have affected the network behaviour (e.g. t_{k+1}), mechanisms and performance models are employed in a time ahead (e.g. $t_{k+n}, n = 2,3,4, \ldots.$), as a result the network performance is improved.

For example, when university students (that is our study case, see the example of Fig. 1) can use this methodology, they could have a good end to end communication process although LTE and WiFi coexistence. Also, with this methodology, we will find key performance metrics that affect network behaviour. We wonder whether exists a metric that affects more than other metrics in network performance.

Conclusions

The HetNets behaviour problem can be studied considering BER, SNR, SNIR, packet collision probability, packet retransmission, among others. When all of them are analyzed together it becomes an interesting investigation. In this article, we presented a concise review of performance models between WiFi-LTE, a classification of key performance metrics and a methodology for HetNet (WiFi-LTE) performance. We showed that some fundamental challenges are to find accurate and adequate performance models as well as key metrics which it will depend on the context and needs in each HetNet. Hovewer, we still don´t know which key performance metrics will have greatest impact in this investigation. Research results of the main idea from our methodology will be issued in near future.

Annexes

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References

Abu-Ali N., Abd-Elhamid M., Salah M., and Hassanein H. (2014) IEEE Communications Surveys & Tutorials, vol. 16, no. 3, pp. 1239-1265.

Ackerley R. (2003) Telecommunications Performance Engineering, IEEE (288 pages).

Adan I. and Resing J. (2015), Queueing Systems, Department of Mathematics and Computing Science Eindhoven University of Technology.

Aune F. (2004), Cross-Layer Design Tutorial, Norwegian University of Science and Technology, Recuperado el 26 de Noviembre de 2004. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.452.7247&rep=rep1&type=pdf

Baswade A., Anwar Atif T., Reddy Tamma B., Franklin A. (2018), A novel coexistence scheme for IEEE 802.11 for user fairness and efficient spectrum utilization in the presence of LTE-U, Computer Networks, pp. 1-18

Bianchi G., (2000). "Performance analysis of the IEEE 802.11 distributed coordination function," IEEE Journal on Selected Areas in Communications, vol. 18, no. 3, pp. 535–547.

Chaves F. S., Cavalcante A. M., Almeida E. P. L., Abinader Jr. F. M., Vieira R. D., Choudhury S. And Doppler K. (2013) lte/wi-fi coexistence: challenges and mechanisms, xxxi simposio brasileiro de telecomunicacoes sbrt2013, 1-4 de setembro de 2013, Fortaleza, CE.

Dattatreya G. R. (2008), Performance Analysis of Queuing and Computer Networks, Taylor & Francis Group, LLC Chapman & Hall/CRC.

Duffy K., Malone D., and Leith D. J., (2005). Modeling the 802.11 distributed coordination function in non-saturated conditions, IEEE Communications Letters, vol. 9, no. 8, pp. 715–717.

Fakhri Y., Nsiri B., Aboutajdine D., and Vidal J. (2006), Throughput Optimization Via the Packet Length and Transmission Rate for Wireless OFDM System in Downlink Transmission, IJCSNS International Journal of Computer Science and Network Security, vol.6, no.3.

Fokkink W. (2007), Introduction to Process Algebra, Second Edition, Springer-Verlag.

Forouzan B. A. (2013) Data communication and networking, fifth edition, McGraw-Hill.

Hernandez Ochoa, M., Siller, M., Woods, J., Duran, L. (2014). A Performance Analysis Framework for WiFi/WiMAX Heterogeneous Metropolitan Networks Based on Cross-Layer Design, International Journal of Distributed Sensor Networks, Volume 2014, Article ID 750971, 16 pages, http://dx.doi.org/10.1155/2014/750971

IEEE 802.11 Standard for Information technology (2007) —Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, IEEE Computer Society Sponsored by the LAN/MAN Standards Committee.

Kumar A., Valerrian T., Reddy B., (2017), QoS Aware load balance in software defined LTE networks, Computer Communications, pp.52-71.

Lin Y. and Wong V. W. S., (2006). Frame aggregation and optimal frame size adaptation for IEEE 802.11n WLANs, in Proceedings of the Global Telecommunications Conference (IEEE GLOBECOM '06), pp. 1–6, San Francisco, Calif, USA.

Srivastava V. and Motani M., (2005), Cross-Layer Design: A Survey and the Road Ahead, IEEE Communications Magazine, pp. 112-119.

3GPP, "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures," 3rd Generation Partnership Project (3GPP), Technical Specification TS 36.213 (Release 10), Jul. 2012.