Performance Evaluation of Voice Traffic of IEEE 802.16e under Femto Cellular Network

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ABSTRACT

The paper deals with the packet scheduling of voice traffic of IEEE 802.16e under femto cellular network where the length of wireless link is few meters. Instead of distribution of MCS (Modulation and Coding Scheme) levels of previous literature, only availability of traffic channel is considered in packet scheduling since the short wireless link of femto cell is not affected by multipath fading like the link of micro cellular network. The steady probability states of the proposed model is compared with the existing model of WiMAX under Rayleigh fading environment. Finally the performance of the network is measured based on throughput, mean queue length and blocking probability.

Keywords

Throughput, steady probability states, packet scheduling, transition matrix and mean queue length.

1. INTRODUCTION

Initially IEEE 802.16d was developed to support high speed wireless data service of fixed user and its later version IEEE 802.16e supports both fixed and mobile users. In such network sometimes several users are combined on complete sharing mode of traffic channels called subscriber station (SS). To enhance the throughput of broadband wireless network adaptive modulation and channel coding scheme (MCS) is used according to the fading condition of the wireless link. This scheme is widely used in OFDMA based IEEE 802.16e network to support VoIP traffic. IEEE 802.16e is destined for wideband wireless service of Metropolitan Area Network (WMAN). Both WiMAX and 3GPP LTE support VoIP service using IEEE 802.16 where MS sends bandwidth (BW) request and BS allocates it from the central pool of BW. The BS allocates the BW based on availability of BW, possible MCS levels of MSs under fading condition of links between BS and MS. A pictorial presentation of uplink and down link BW scheduling technique is shown in [1]. Three common types of BW allocation algorithms are implemented in [2-3]: Dedicated Resource Allocation (UGS Algorithm) where fixed amount of BW is allocated to each user hence possibility of waste of BW when a user needs to send data at low rate; Polling-Based Resource Allocation (rtPS Algorithm) where BS allocates the BW dynamically therefore incurs some protocol overhead and delay; Hybrid Resource Allocation Algorithm is the combination of above two. IEEE 802.16 deals with five different types of service where the performance of real-time polling service (rtPS) is evaluated in [4]. The down link packet scheduling technique of VoIP traffic is analyzed in [5] based on two states MMPP (Markov Modulated Poisson Process) and probability of using MCSs level, the similar job is enhanced by the same author for both up and down link in [6].

WiMAX (Worldwide Interoperability for Microwave Access) is the IEEE 802.16 based broadband wireless technology whereas the LTE-Advanced (Long Term Evolution-Advanced) is another 4G wireless service proposed by 3GPP (Third generation Partnership Project). In 2009 4G LTE started its commercial service in Scandinavia. Two important features of LTE are: femtocell deployment and OFDMA-based physical layer access. The architecture of LTE consists of two major parts: the E-UTRAN (Evolved Universal Terrestrial Radio Access Network) and the EPC (Evolved Packet Core) [7-9]. The first part provides air interface between MS or UE to BS and the second part is interconnected switching network called backbone or core network. The core network of LTE is fully IP based packet-switch but the circuit switched network service like voice service is handled by IP multimedia subsystem network. E-UTRAN (Evolved Universal Terrestrial Radio Access Network) deals with two types of Base Stations: Evolved node-B (eNB), which communicates with user equipment like conventional BTS and Home eNode-B (HeNB) of small coverage called femtocell. The very limited service area is covered by femtocell like access points of Wi-Fi. Femto cell is also proposed in 5G mobile cellular network to offload traffic.

The paper is organized like: section 2 provides the traffic model of VoIP of IEEE 802.16e based on Markov chain and MMPP, relation between traffic parameters and fading environment of WiMAX link and LTE; section 3 provides the results bases on analytical model of section 2 and finally section 4 concludes the entire analysis.

2. SYSTEM MODEL

Recent literature shows that the most convenient way of evaluating the steady probability states of VoIP traffic is to use combination of two dimensional DTMC (Discrete Time Markov Chain) and MMPP found in [10-12]. To model the burstiness of packet traffic MMPP is preferable compared to ordinary Poisson's model shown in fig.1.

A two state MMPP is represented by:

$$\mathbf{R} = \begin{bmatrix} -r_1 & r_1 \\ r_2 & -r_2 \end{bmatrix} \text{ and } \mathbf{\Lambda} = \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix}$$

where $\mathbf{R}$ is transition rate matrix and $\mathbf{\Lambda}$ is arrival rate matrix.

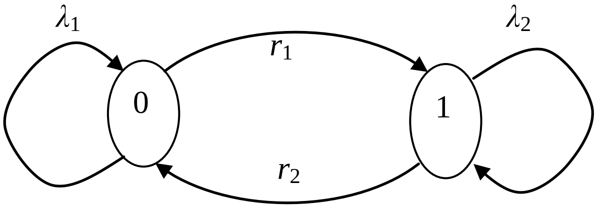

Fig.1 Two state MMPP

The transition matrix,

$$\mathbf{C} = \mathbf{\Lambda} - \mathbf{R} = \begin{bmatrix} \lambda_1 + r_1 & -r_1 \\ -r_2 & \lambda_2 + r_2 \end{bmatrix} \tag{1}$$

The state transition probability matrix,

$$\mathbf{U} = \mathbf{C}^{-1}.\mathbf{\Lambda} = \begin{bmatrix} \dfrac{-(\lambda_2 + r_2)\lambda_1}{Y} & \dfrac{-r_1\lambda_2}{Y} \\ \dfrac{-r_2\lambda_1}{Y} & \dfrac{-(\lambda_1 + r_1)\lambda_2}{Y} \end{bmatrix}; \tag{2}$$

where $Y = \lambda_1\lambda_2 + \lambda_1 r_2 + r_1\lambda_2$

Let M is the number of MCS levels of the wireless link. If b packets are scheduled in the network then it is represented as an M-tuple as discussed in [13]:

$$X_b = (x_1, x_2, x_3, \ldots\ldots, x_M); \text{ where } \sum_{i=1}^{M} x_i = X_b \ .$$

A number of X_b is possible under different combinations of x_is with the constraints,

$$\sum_{i=1}^{M} x_i l_i \le N_{slot,u} \tag{3}$$

;Where x_i is the number of packets under MCS level i and l_i is the number of slots occupied per ith MCS level.

If there are S possible X_b satisfying above constrain then let us indicate jth X_b as X_b^j. All possible X_b^j are placed under a set Ψ_b as [13-14]:

$$\Psi_b = \{X_b^1, X_b^2, X_b^3, \ \ldots \ , X_b^S\} \tag{4}$$

If a particular $X_b^j \in \Psi_b$ and after one increment of x_n satisfies the constraints (3) with $X_{b+1}^j \in \Psi_{b+1}$ then index probability[14-15],

$$I_n(X_b) = \begin{cases} 1; & \text{if } X_b^j \in \psi_b \text{ and } X_{b+1}^j \in \psi_{b+1} \\ 0; & \text{otherwise} \end{cases} \tag{5}$$

Under the constraint (3) we have several ψ_bs under the set, $\Psi = \{\Psi_{b_1+1}, \Psi_{b_1+2}, \Psi_{b_1+3}, \ \ldots \ , \Psi_{b_2}\}$;where the minimum value of b is b_1 and its maximum value is b_2.

If a BS is scheduling b VoIP packets from uplink queue then its probability is expressed as [13-15],

$$P_S^u(b) = P_r\{X_b \in \psi_b \text{ and } X_{b+1} \notin \psi_{b+1}\} = \sum_{\forall X_b \in \psi_b} \left[\left(b! \cdot \prod_{m=1}^{M} \frac{p_m^{x_m}}{x_m!} \right) \left(1 - \sum_{m=1}^{M} p_m \cdot I_m(X_b) \right) \right] \tag{6}$$

Where P_m is the probability that a packet being modulated by mth MCS level in uplink.

In [3] the probability of scheduling k packets by a BS is expressed as,

$$Pr(N(\Psi_{on}) = k) = P_s(k) \tag{7}$$

Where $P_s(k)$ is the number of cases k packets can be scheduled.

In a femto cell of LTE a user anywhere inside the cell experiences approximately exponential path loss model since the path length between transmitter and receiver is only of few meters. In microcellular network the link between transmitter and receiver experiences small and large scale fading hence packet scheduling depends on the condition of link of individual users which requires MCS level distribution. The femocellular links are immune of huge fading therefore instead of MCS level distribution we can consider only one type of modulation and coding scheme for voice traffic. In this case we can only change $P_S^u(b)$ of (6) where the number of uplink packet scheduling depends on availability of traffic channel can be expressed as:

$$P_S^u(b) = 1 - \sum_{x=1}^{b} P_{n-b+x} \tag{8}$$

;where $P_x$is the probability state of occupying xth traffic channel.
To evaluate P_x let us use the Markov chain of *M/M/n/n+K* shown in fig.2.

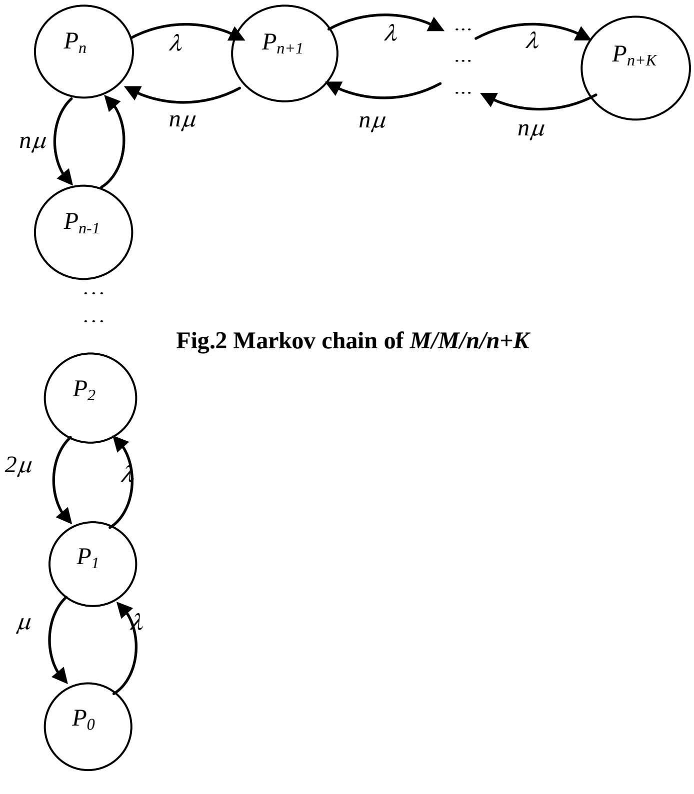

Fig.2 Markov chain of *M/M/n/n+K*

Solving above chain any probability state in generalized form is derived as,

$$P_x = \begin{cases} \dfrac{\dfrac{A^x}{x!}}{\sum_{i=0}^{n-1} \dfrac{A^i}{i1} + \dfrac{A^n}{n!} \sum_{j=0}^{K} \left(\dfrac{A}{n}\right)^j} & ; x < n \\[2ex] \dfrac{\dfrac{A^n}{n!}\left(\dfrac{A}{n}\right)^x}{\sum_{i=0}^{n-1} \dfrac{A^i}{i1} + \dfrac{A^n}{n!} \sum_{j=0}^{K} \left(\dfrac{A}{n}\right)^j} & ; x \geq n \end{cases} \quad (9)$$

Now the transition matrix of the uplink queue is,

$$\mathbf{P} = \begin{bmatrix} \mathbf{p}_{0,0} & \mathbf{p}_{0,1} & \cdots & \mathbf{p}_{0,K} \\ \mathbf{p}_{1,0} & \mathbf{p}_{1,1} & \cdots & \mathbf{p}_{1,K} \\ \cdots & \cdots & \cdots & \cdots \\ \mathbf{p}_{K,0} & \mathbf{p}_{K,1} & \cdots & \mathbf{p}_{K,K} \end{bmatrix} \quad (10)$$

Elements of the matrix **P** is expressed as [16-17],

$$\mathbf{p}_{i,j} = \sum_{b=b_1}^{b_2} \mathbf{UD}(j - \max(i-b, 0)P_S^u(b) \quad (11)$$

;where $\mathbf{U} = (\mathbf{\Lambda} - \mathbf{R})^{-1}\mathbf{\Lambda}$ and diagonal probability matrix,

$$\mathbf{D}(k) = \begin{bmatrix} \dfrac{(\lambda_1 T_f)^k}{k!} e^{-\lambda_1 T_f} & 0 \\ 0 & \dfrac{(\lambda_2 T_f)^k}{k!} e^{-\lambda_2 T_f} \end{bmatrix}.$$

Here, T_f is the duration of a frame, **R** and **Λ** are the transition rate matrix and arrival rate matrix of MMPP.

The steady probability vector $\boldsymbol{\pi}$ can be found from [18-20],

$$\mathbf{\Pi.P} = \mathbf{\Pi} \text{ and } \mathbf{\Pi.1} = 1 \quad (12)$$

If $\mathbf{\Pi} = [\pi_1 \quad \pi_2 \quad \pi_3 \quad \cdots \quad \pi_{2K_u+2}]$ then

$$\pi(i) = \pi_{2i-1} + \pi_{2i}$$

The mean queue length,

$$\overline{L} = \sum_{i=1}^{K_u} i.\pi(i) \quad (13)$$

Finally the throughput or the carried traffic is:

$$Th = 1 - \pi(K_u) \text{*(offered traffic)} \quad (14)$$

Next section provides the results based on analysis of this section.

3. RESULTS

Let us consider a system with 3 MCS levels shown in table -1. Considering N_s = 50 TS as the available resources the BS can schedule. The number of packets under *m*th MCS level is x_m, here m = 1, 2 and 3 since the case of 3 MCS levels. We have to check whether, $36x_1 + 24x_2 + 12x_3 \leq N_s$ or not.

Table-1

MCS levels	Modulation	Slot/PDU
1	BPSK	36
2	QPSK	24
3	16-QAM	12

Now, $X_1 = (x_1, x_2, x_3) = (1, 0, 0)$; slots = 1×36 = 36 $<N_s$

$X_1 = \{(0, 1, 0)\}$; slots = 1×24 = 24 $<N_s$

$X_1 = \{(0, 0, 1\}$; slots = 1×12 = 12 $<N_s$

The possible set of X_1,

$\Psi_1 = \{(1, 0, 0), (0, 1, 0), (0, 0, 1)\}$;

Similarly

$\Psi_2 = \{(1, 0, 1), (0, 2, 0), (0, 1, 1), (0, 0, 2)\}$;

$\Psi_3 = \{(0, 1, 2), (0, 0, 3)\}$;

$\Psi_4 = \{(0, 0, 4)\}$;

Now,

$\mathbf{\Psi} = \{\Psi_1, \Psi_2, \Psi_3, \Psi_4\}$;

The minimum number of PDU from Ψ_1 is 1 i.e. $b_1 = 1$ and the maximum number of PDU from Ψ_4 is 4 i.e. $b_2 = 4$.

Now the index probability $I_m(X_b)$ can be found for m = 1, 2 and 3 and b =1, 2, 3 and 4.

$(1, 0, 0) \in \Psi_1$; $I_3(X_1) = 1, I_1(X_1) = I_2(X_1) = 0$

$(0, 1, 0) \in \Psi_1$; $I_2(X_1) = I_3(X_1) = 1, I_1(X_1) = 0$

$(0, 0, 1) \in \Psi_1$; $I_1(X_1) = I_2(X_1) = I_3(X_1) = 1$

$(1, 0, 1) \in \Psi_2$; $I_3(X_2) = 1, I_1(X_2) = I_2(X_2) = 0$

$(0, 2, 0) \in \Psi_2$; $I_1(X_2) = I_2(X_2) = I_3(X_2) = 0$

$(0, 1, 1) \in \Psi_2$; $I_1(X_2) = I_2(X_2) = 0, I_3(X_2) = 1$

$(0, 0, 2) \in \Psi_2$; $I_2(X_2) = I_3(X_2) = 0, I_1(X_2) = 0$

$(0, 1, 2) \in \Psi_3$; $I_1(X_3) = I_2(X_3) = 0, I_3(X_3) = 1$

$(0, 0, 3) \in \Psi_3$; $I_1(X_3) = I_2(X_3) = 0, I_3(X_3) = 1$

$(0, 0, 4) \in \Psi_4$; $I_1(X_4) = I_2(X_4) = I_3(X_4) = 0$

Now the probability that BS schedules b packets from uplink queue:

$$P(b=1) = 1!.\frac{P_1^1}{1!}.1.1.\{1 - P_3\} + 1!.1.\frac{P_2^1}{1!}.1.$$

$$\{1 - P_2 - P_3\} + 1!.1.1.\frac{P_3^1}{1!}.\{1 - P_1 - P_2 - P_3\}$$

$$P(b=2) = 2!.\frac{P_1^1}{1!}.1.\frac{P_2^1}{1!}.\{1 - 0\} + 2!.1.\frac{P_2^2}{2!}.1.\{1 - 0\}$$

$$+ 2!.1.\frac{P_2^1}{1!}.\frac{P_3^1}{1!}.\{1 - P_3\} + 2!.1.1.\frac{P_3^2}{2!}.\{1 - P_2 - P_3\}$$

$$P(b=3) = 3!.1.\frac{P_2^1}{1!}.\frac{P_3^2}{2!}.\{1 - 0\} + 3!.1.1.\frac{P_3^3}{3!}.\{1 - P_3\}$$

$$P(b=4) = 4!.1.1.\frac{P_3^4}{4!}.\{1 - 0\}$$

P_m is the probability that a packet being modulated by mth MCS level in uplink. For Rayleigh fading environment,

$$P_1 = \int_0^{\gamma_1} \frac{1}{\gamma_{av}} e^{-\gamma/\gamma_{av}} d\gamma\,, \quad P_2 = \int_{\gamma_1}^{\gamma_2} \frac{1}{\gamma_{av}} e^{-\gamma/\gamma_{av}} d\gamma \quad \text{and}$$

$$P_3 = \int_{\gamma_2}^{\gamma_3} \frac{1}{\gamma_{av}} e^{-\gamma/\gamma_{av}} d\gamma$$

Now, $P(b) = \sum_{i=b_1}^{b_2} P(i)$; where $b_1 = 1$ and $b_2 = 4$

We consider the traffic parameters: $\lambda_1 = 0.656$, $\lambda_2 = 0.842$, $r_1 = 0.41$ and $r_2 = 0.32$, the corresponding matrix becomes,

$$\mathbf{U} = \begin{bmatrix} 0.688 & 0.312 \\ 0.19 & 0.81 \end{bmatrix},$$

$$\mathbf{D}(k=1) = \begin{bmatrix} 0.061 & 0 \\ 0 & 0.077 \end{bmatrix}$$

The steady probability states: $\pi(i)$, $i = 1,2, 3,.. , 8$ is shown in fig.3 for both the fading channel of WiMAX and awgn channel of femto cell (using eq. (12)). The distribution of probability state is like Gaussian for femto cell and found exponential for the case of fading channel of WiMAX. The probability of occupancy of whole queue or blocking probability is found higher in WiMAX because of adverse condition of channel in sending the packets.

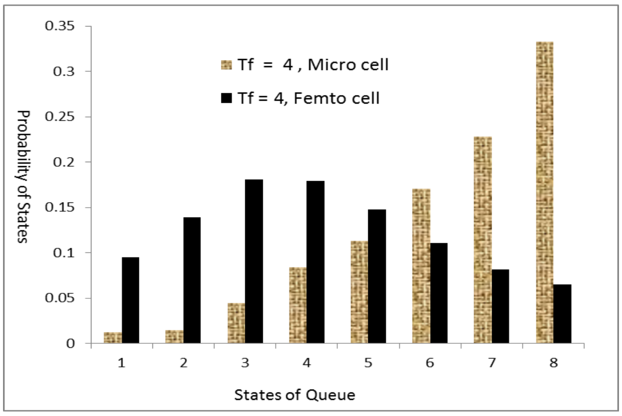

Fig.3 Comparison of states of queue of WiMAX under Rayleigh fading and that of femto cellular network under AWGN

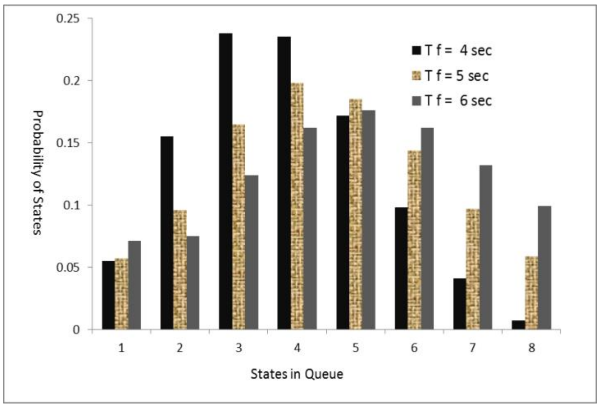

Fig.4 Impact of packet length on steady probability states

The impact of packet length on probability sate is shown in fig.4 where we consider large packets of length: 4, 5 and 6s. At lower packet length the occupancy of lower probability states are found higher i.e. availability of space of buffer but for larger packet the tendency of occupancy of higher states are found higher hence gives the indication of full occupancy of buffer or higher blocking probability.

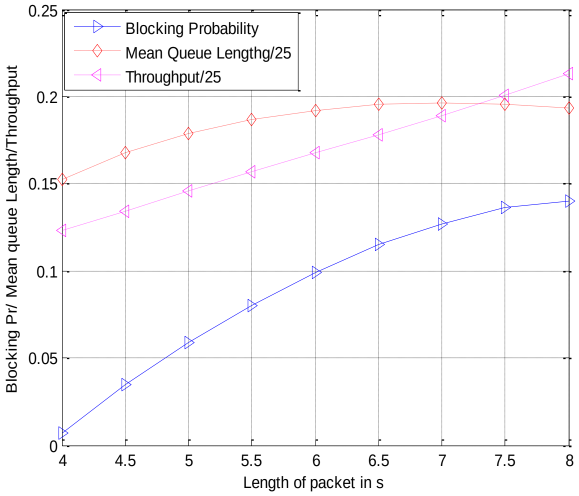

Fig.5 Impact of length of packet on performance of femto cellular network

Finally fig.5 shows the profile of blocking probability, normalized mean queue length and throughput of the network against the length of packets. All the parameters rise with increase in the length of packet since the offered is directly proportional the length of packet. The mean queue length become saturated at some threshold value of $T_f = 6.5$s which indicates the fully occupied condition of the queue.

4. CONCLUSIONS

The paper actually compares the steady probability states of voice traffic of WiMAX and that of femto cellular network of LTE. The profile of blocking probability, normalized throughput and mean queue length are shown against the length of packet. The traffic model we consider is *M/M//n/n+K* but we can extent the work for traffic of *M/D/1/K* of fixed cell or mixed traffic like *M/G/1/K*. Traffic shaping algorithm can also be incorporated to observe the improvement of throughputs. Even the concept of the paper in can be applied in cognitive radio network only adding the parameters: probability of correct detection of primary users on a traffic channel and the probability availability of free traffic channels. The concept of the paper is also applicable in ultra dense cellular network of 5G.

5. REFERENCES

[1] Claudio Cicconetti, Luciano Lenzini, and Enzo Mingozzi, 'Quality of Service Support in IEEE 802.16 Networks,' IEEE Network, pp.50-55, March/April 2006

[2] H. Lee, T. Kwon, D.-H. Cho, 'Extended-rtPS algorithm for VoIP services in IEEE 802.16 systems,' in Proc. IEEE International Conf. Commun., vol. 5, pp. 2060-2065, June 2006.

[3] Howon Lee, Hyu-Dae Kim, and Dong-Ho Cho, 'Smart Resource Allocation Algorithm Considering Voice Activity for VoIP Services in Mobile-WiMAX System,' IEEE Transactions on Wireless Communications, vol. 8, no. 9, pp.4688-4697, Sept' 2009

[4] Thiaw Seng Ng, Teong Chee Chuah, Yi Fei Tan, ‘Improved Radio Network Dimensioning for Real-Time Polling Service on IEEE 802.16 Wireless Networks with QoS Consideration,’ Int. J. Communications, Network and System Sciences, pp.192-205, vol.5, 2012

[5] Jae-Woo So, ‘A down link Performance Analysis of VoIP Services over an IEEE 802.16e OFDMA System,’ IEEE Communications Letters, vol. 11, no.2, pp. 155-157, Feb’ 2007

[6] Jae-Woo So, ‘Performance Analysis of VoIP Services in the IEEE 802.16e OFDMA System With Inband Signaling,’ IEEE Transactions on Mobile Computing, vol. 57, no. 3, pp. 1876-1886, May 2008

[7] Francesco Capozzi, Giuseppe Piro, Luigi A Grieco, Gennaro Boggia and Pietro Camarda, ‘On accurate simulations of LTE femtocells using an open source simulator,’ EURASIP Journal on Wireless Communications and Networking, pp.1-13, 2012

[8] Ian F. Akyildiz ∗, David M. Gutierrez-Estevez, Elias Chavarria Reyes, ‘The evolution to 4G cellular systems: LTE-Advanced,’ Physical Communication, Elsevier, pp. 217–244, no. 3, 2010

[9] Matthias Fricke, Andrea Heckwolf, Ralf Herber, Ralf Nitsch, Silvia Schwarzed, Stefan Vob, and Stefan Wevering, ‘Requirements of 4G-Based Mobile Broadband on Future Transport Networks,’ Journal of Telecommunications and Information Technology, vol.2, pp.21-28, 2012

[10] Chuan Heng Foh, Moshe Zukerman and Juki Wirawan Tantra, ‘A Markovian Framework for Performance Evaluation of IEEE 802.11,’ IEEE Transactions on Wireless Communications, pp.1275-1285, vol. 6, no. 4, April 2007

[11] Haruo Akimaru and Konosuke Kawashima, ‘Teletraffic Theory and Applications,’ Springer-Verlag, Berlin, 1993

[12] Sang H. Kang, Yong Han Kim, Dan K. Sung and Bong D. Choi, ‘An application of Markovian Arrival Process (MAP) to modeling superposed ATM cell stream,’ IEEE Transaction on Communications, vol.50, no.4, pp.633-642, April 2002

[13] Jae-Woo So, ‘Performance Analysis of VoIP Services in the IEEE 802.16e OFDMA System With Inband Signalling,’ IEEE Transactions on Vehicular Technology, pp.1876-1886, vol. 57, no. 3, MAY 2008

[14] Jaewoo So, ‘Scheduling and Capacity of VoIP Services in Wireless OFDMA Systems,’ VoIP Technologies, chapter-11, pp.237-252, www.intechopen.com

[15] Anupam Roy, Md. Imdadul Islam, And M. R. Amin, ‘Performance Evaluation of Voice-Data Integrated Traffic in IEEE 802.11 and IEEE 802.16e WLAN,’ WSEAS TRANSACTIONS on COMMUNICATIONS, Issue 7, Volume 12, pp.352-365, July 2013

[16] Howon Lee and Dong-Ho Cho, ‘Capacity improvement and analysis of VoIP service in a cognitive radio system,’ IEEE transactions on Vehicular Technology, vol.59, no.4, pp. 1646-1651, May 2010

[17] Howon Lee, T. Kwon and D. H. Cho, ‘An enhanced uplink scheduling algorithm based on voice activity for VoIP services in IEEE 802.16d/e system,’ IEEE Communications Letters, vol. 9, no.8, pp. 691-693, August 2005

[18] Abdelali EL Bouchti, Abdelkrim Haqiq and Said EL Kafhali, ‘Analysis of Quality of Service Performances of Connection Admission Control Mechanisms in OFDMA IEEE 802.16 Network using BMAP Queuing,’ Journal of Computer Science Issues, IJCSI, vol. 9, Issue 1, no. 2, pp 302-310, January 2012

[19] Ummy Habiba, Md. Imdadul Islam, and M. R. Amin, ‘Performance Evaluation of the VoIP Services of the Cognitive Radio System, Based on DTMC,’ J Inf Process Syst, vol.10, no.1, pp.119~131, March 2014

[20] Said EL Kafhali Abdelali EL Bouchti, Mohamed Hanini and Abdelkrim Haqiq ‘Performance Analysis for Bandwidth Allocation in IEEE 802.16 Broadband Wireless Networks Using BMAP Queueing,’ International Journal of Wireless & Mobile Networks (IJWMN), vol. 4, no. 1,pp.139-154, February 2012