Variable Bit Rate Video Workload Modeling for Mobile Broadband Wireless Networks

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ABSTRACT

Achieving high throughput, low packet delay, and fair bandwidth sharing are significant issues in resource allocation schemes for mobile broadband wireless networks. With the advent of the fourth generation (4G) wireless systems such as Long Term Evolution (LTE) and WiMAX, resource allocation schemes must be tailored for orthogonal frequency division multiple accesses (OFDMA). Downlink OFDMA can be modeled as a multi-channel, multi-queue system. In order to be able to evaluate resource allocation algorithms over such systems, efficient network traffic models are necessary.

The majority of the studies on scheduling are based only on simulations preventing wireless equipment vendors from obtaining quick insights into the behavior of schedulers. Only a subset of the existing work employs analytical queuing models. This thesis aims to use both model-based and simulation-based scheduling studies for 4G wireless systems. Variable bit rate (VBR) video traffic is used for generating workload for the downlink of a 4G-like system. Four scheduling algorithms, round robin (RR), opportunistic (OP), maximum weight (MW) and server-side greedy (SSG), are then investigated and their performances are compared for video over 4G. The results of the analysis show that RR is highly unstable compared to OP, MW, and SSG. In terms of the length of the user queues, the best performance belongs to SSG having small user queue lengths.

Keywords: 4G, OFDMA, scheduling, video traffic models

ÖZ

Gezgin geniş bantlı telsiz ağlar için kaynak atama yöntemlerinde yüksek hız, az gecikme ve adil kaynak paylaşımı önemli konulardır. LTE ve WiMAX gibi dördüncü kuşak (4G) telsiz iletişim sistemlerinde kaynak atama yöntemleri dik frekans bölmeli çoklu erişime (OFDMA) uygun yapılmalıdır. Aşağı bağlantı OFDMA çok kuyruklu çok kanallı sistemler olarak modellenebilmektedir. Bu tür sistemlerde, kaynak atama algoritmalarını değerlendirmek için etkin ağ trafik modelleri gerekmektedir.

Sıralayıcılarla ilgili birçok çalışma sadece benzetimlere dayanmakta ve telsiz sistem sağlayıcılarının sıralayıcıların çalışmasına dair hızlı bir öngörü oluşturmasına olanak vermemektedir. Sadece bir kısım çalışma analitik kuyruklama modellerine dayanmaktadır. Bu tezde, benzetim ve model bazlı sıralayıcı çalışmalarının beraber kullanılması amaçlanmıştır. Değişken video hızlı (VBR) video trafik modeli kullanılıp 4G sistem modelleri için trafik üretilmiştir. Dört sıralayıcı algoritması, değişmez zaman paylaşımı (RR), fırsatçı (OP), en büyük ağırlık (MW) and sunucu-taraflı aç gözlü (SSG), değerlendirilip video trafiği ile 4G üzerinde performansları karşılaştırılmıştır. Analiz sonuçlarına göre RR, OP, MW ve SSG'ye göre oldukça kararsızdır. Kuyruk uzunluğu dikkate alındığında ise, en iyi kısa kuyruk performansını SSG göstermektedir.

Keywords: 4G, OFDMA, sıralama, video trafik modelleri

Dedicated to

my father Rostam Ebadinezhad, my mother Amireh Ghayemi and my brother Sajad Ebadinezhad who have always been supportive of me during my time at EMU.

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LIST OF SYMBOLS/ABBREVIATIONS

1G	First Generation
2G	Second Generation
3G	Third Generations
3GPP	Third Generation Partnership Project
4G	Fourth Generations
ACF	Autocorrelation Function
AR	Autoregressive
ARIMA	Autoregressive Integrated Moving Average
ARMA	Autoregressive Moving Average
CBR	Constant Bit Rate
CDMA	Code Division Multiple Access
DPCM	Differential Pulse Code Modulation
FARIMA	Fractional Autoregressive Integrated Moving Average
GSM	Global System for Mobile communication
H	Hurst parameter
IEEE	Institute of Electrical and Electronics Engineers
IID	Independent Identically Distribution
IP	Internet Protocol
ISP	Internet Service Provider
ITU	International Telecommunication Union
LRD	Long Range Dependency
LTE	Long Term Evaluation

MMAC	Mobile Multimedia Access Communication
MMBP	Markov Modulated Bernoulli Process
MMS	Multimedia Message Service
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiplexing Access
PDF	Probability Distribution Function
SMS	Short Message Service
SNR	Signal to Noise Ratio
SRD	Short Range Dependency
TDMA	Time Division Multiple Access
TES	Transform Expand Sample
UE	User Equipment
VBR	Variable Bit Rate
WIFI	Wireless Fidelity
WIMAX	Worldwide Interoperability for Microwave Access
WMAN	Wireless Metropolitan Area Networks

Chapter 1

INTRODUCTION

In recent years, demand for wireless mobile multimedia services has increased due to rapid growth of applications such as voice-over-IP, real-time video conferencing, media streaming and interactive gaming. Indeed a key challenge for wireless networks is that the video traffic is increasing from 50% in 2011 to 66% that is expected by 2015 [1].

Today's fourth generation (4G) mobile broadband wireless systems such as the 3GPP Long Term Evolution (LTE) [2] and the Mobile WiMAX based on the IEEE 802.16 standard [3] are designed to satisfy this increasing demand. 4G wireless systems are generally based on the orthogonal frequency division multiple accesses (OFDMA) technique. OFDMA can provide data transmission in the same frame for multiple users.

In addition, the important factors that have effect on streaming media and storage size are media length and streaming bandwidth. Moreover, the foremost challenging aspect in video streaming is keeping the video streams steady and smooth. The prime source or problem associated with video streaming is the low bandwidth. Therefore compression techniques (e.g. JPEG, MPEG) effectively save bandwidth. The compression techniques result in variable bit rate (VBR) transmission of data streaming. VBR transmission causes stochastic behavior of network traffic [4]. Due to the stochastic nature, accurate models are necessary for determining the overall bandwidth requirement of video source.

1.1 Contribution

This thesis focuses on modeling VBR video on wireless networks from both video conferencing and video on demand. VBR video arises from video on demand which has become very widespread, especially with the introduction of applications such as *YouTube* and *Netflix*, and the traffic generated by these applications consumes a large portion of the mobile bandwidth [5]. Video conferencing is also very popular due to applications such as *Skype*. Thus, in order to be able to test and evaluate new network architectures, it is critical to implement algorithms to generate synthetic VBR video.

In this respect, in this thesis, an MPEG-4 video traffic generator is implemented, verified, and tested on a 4G-like wireless system. In particular, the queuing performance of various well-known downlink scheduling schemes are evaluated at a base station in OFDMA-based system. The framework is developed in MATLAB environment and it can be integrated to a WiMAX/LTE system-level simulator that has been developed [6].

1.2 Thesis Organization

The rest chapters of this thesis are organized as follows: Chapter 2 defines some basic terminology and concepts for video traffic types, traffic characteristics, and discusses why traffic modeling is an important issue in evaluating performance of multimedia over wireless broadband networks. Additionally, it gives a brief description on previous related work about video traffic modeling. Chapter 3 introduces the 4G of mobile telecommunication networks and describes the problems of video transmission over OFDMA based systems. Chapter 4 explains an existing

MPEG-4 video traffic generation algorithm [7]. Moreover, this chapter compares the real video traces with the generated ones. Chapter 5 introduces different schedulers for downlink and analyzes their performance on OFDMA based system. Consequently, chapter 6 concludes the thesis and proposes several open topics for future work.

Chapter 2

VIDEO TRAFFIC TYPES AND CHARACTERISTICS

2.1 Generalities of Video Streaming

Video streaming uses features in the physical layer and link layer channel to provide error-resilience over wireless networks [8]. It has been available in the second and half-generation (2.5G) network and third generation (3G) network as a common service, although improvements in video streaming have emerged in the third Generation Partnership Project (3GPP). Generally, media streaming can be separated into two main categories:

1. Live streaming: The end user has real time accessibility; i.e., the information is directly sent to end user (computer or device) without saving any data on the hard disk.
2. On-demand streaming: Progressive downloads are supplied with saving data on hard disk [9].

In order to transmit video over wireless networks, the video should be compressed by standard techniques available in International Telecommunication Union (ITU) [10]. The Moving Picture Experts Group (MPEG) standard is one set of compression standards group which supports video and audio compression formats. MPEG-1 and MPEG-2 compression techniques are frame-based model and have been proposed for analog and digital systems respectively [10] [11]. However, the bandwidth requirement for video transmission cannot be efficiently provided by these compression standards over wireless networks. Therefore, digital bit stream format and an object-based model has been proposed as a MPEG-4 standard which is launched in 1999. MPEG-4 is also a suitable compression standard for transmitting video wireless networks [10]. Additionally some objectives of MPEG-4 standard such as interactivity (interacting with the different audio-visual objects), scalability (adopting contents to match bandwidth) and reusability (for data and tools) make this standard suitable for streaming wireless video.

However, they do not deal with encoding data MPEG-7 and MPEG-21 are the other recent MPEG standards. MPEG-7 is multimedia content description interface to allow searching for material of interest. MPEG-21 is multimedia framework and seeks to fill the gaps and create the “big picture” of multimedia standards. It aims to guarantee interoperability by focusing on how the elements of a multimedia application infrastructure should relate, integrate and interact. Finally, where open standards for elements are missing, MPEG is creating new MPEG-21 parts to fill the gaps [12].

Video consists of a scene[1] sequence or shots and each scene is organized into several groups of pictures (GOP) which contains constant number of frames. Moreover, each GOP has three types of frames: one I (reference frame which is coded independently with respect to temporal redundancy[2]), a few B (bi-directional prediction) and a few P (forward prediction) frames. Intra-frames (I frames) are encoded without reference to any other frame and are the reference frames in each GOP. Also, they have the

---

[1] “Scene change” arises when image change suddenly between two sequence I frame.

[2] This method is used for reducing volume of video files by using “Motion Estimation” and “Motion Compensation”.

largest size compared to other frame types. P frames interpolate from previous frames and B frames interpolate from the forward and previous frames. The P and B frames (with B frames having the smallest size) hold only part of the picture information such as movements and differences.

A significant feature of MPEG-4 standard is the pattern of GOP that defines the order of B and P frames between I frames. N and M parameters characterize the GOP pattern that interval between two I frames is characterized by N parameter and interval between I and P frames or two consecutive P-frames is characterized by M parameter.

Hence, the information capacity of each frame is quite different from each other. Therefore, it is evident that the output of the encoder has variable bit rate. Although, the resource allocation for constant bit rate (CBR) video is simpler than VBR, VBR videos are much more prevalent on the networks. Since resources for video streams can be allocated more efficiently.

Figure 2.1 illustrates the sequence of frames. In this example, the GOP from one reference frame to another reference frame consists of 15 frames and GOP pattern sequence was set with N=15 and M=3.

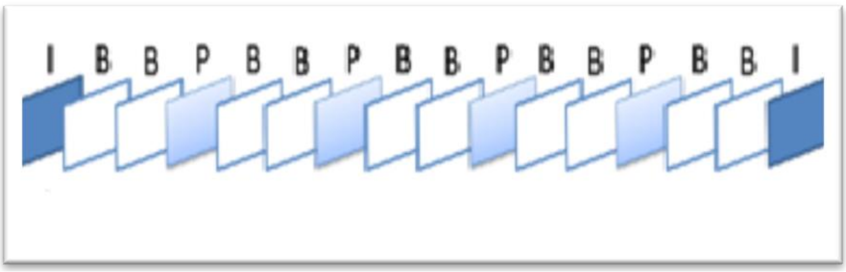

Figure 2.1: GOP structure [13]

In MPEG, the frame sequences for encoded sequence and transmitted sequence are different as shown in Figure 2.2. To take into account the video transmission is done based on the decoding order.

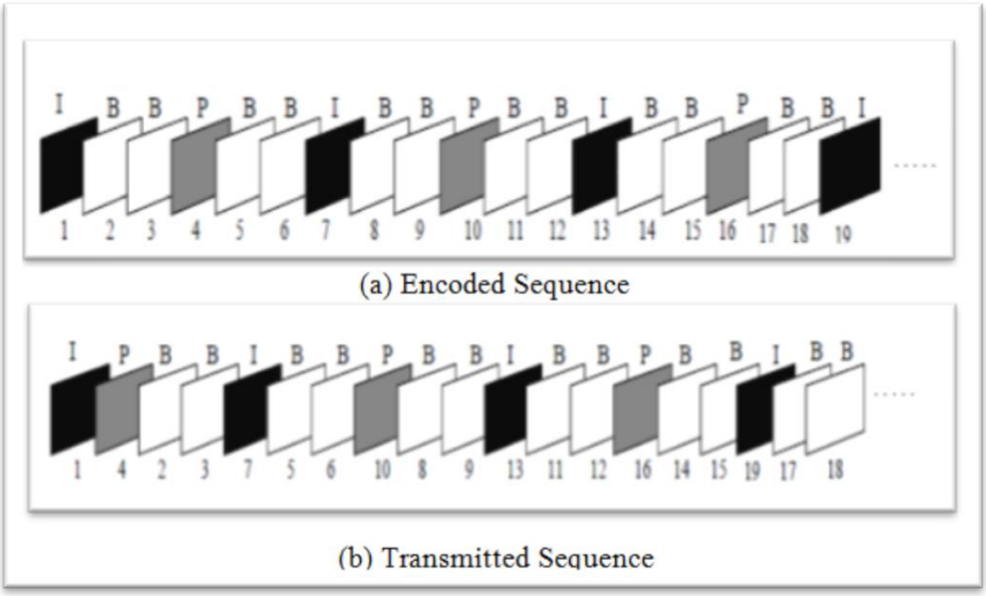

Figure 2.2: Frame sequences [7]

2.1.1 Video Traffic Modeling

Evaluation of network performance is critical and requires accurate and reliable traffic modeling for the network success in any variety. Generating reasonable results from real networks are hard and expensive. Thus, designing accurate traffic modeling for performance evaluation is significant. Networks, whether video, voice or data are designed based on many different factors. Cost and service qualities are two of the most important factors that should be considered in designing a network. Therefore, modeling can be used in predicting the costs and quality before actual deployment.

2.2 Related Work

Traffic modeling in broadband wireless networks can be categorized as traditional and non-traditional. Each of these types has their own models. Surveys of most commonly used traffic models are given in [14] [15] [16]. Traffic models are divided into two main categories, such as short-range (traditional) dependent processes and long range (non-traditional) dependent processes.

The auto-covariance function and variance of partial sum of successive values are two major ways for characterizing short-range and long-range dependent processes. According to the definition above for these two processes, auto-covariance of SRD is exponentially decaying and for LRD, decays are slower than exponential. Variance of the partial sum in SRD grows characteristically proportionally to the number of values in the sum and the variance of the partial sum for LRD increases more rapidly. These two processes are captured by the autocorrelation function (ACF) structure of variable bit rate (VBR) video traffic. Figure 2.3 illustrates the difference between ACF of long-range (LRD) and short-range dependent (SRD) models.

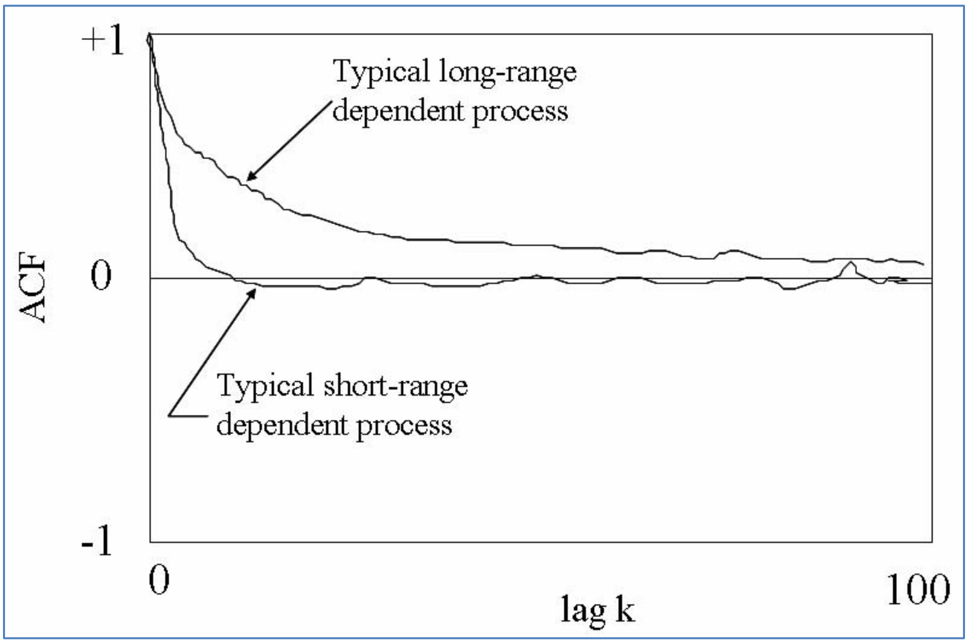

Figure 2.3: Example of autocorrelation functions for LRD and SRD processes [17]

In addition, ACF relate to the most significant factor, the Hurst parameter (H). The Hurst parameter was defined as the indicator of the traffic burstiness which is used to measure the LRD intensity in network traffic. The value of H should be between 0 and 1. Note the following:

a) LRD in a time series exists if Hurst parameter is $0.5<H<1$.
b) SRD in a time series exists if Hurst parameter is equal to $H=0.5$.
c) Actual traffic measurements generally give $0.7<H<0.9$.
d) Violent fluctuations in processes occur if $H<0.5$.

2.2.1 Short-Range Dependence

The definition for short-range dependent is with respect to Ji. Ma and Tia [18] article: the traffic trace with an exponential decay of correlation structure is produced by Short-Range Dependence (SRD). Exponential decay of ACF is a characteristic of regression models and Markov processes. Roughly, in SRD, samples separated in time are not correlated.

The simplicity of computation of this model makes it more useful than long-range dependence in traffic modeling. Three models that results in SRD are Markov chain, transform-expand-sample (TES) models and Auto-Regressive (AR) processes like Auto-Regressive-Moving-Average (ARMA) [19].

2.2.1.1 The Autoregressive Models

There are different traffic model for video, voice, game, etc. based on the encoding scheme and different video traffic models for video streaming which are based on AR models with Gaussian distribution. The aim of AR model is capture the autocorrelation of compressed video behavior.

Autoregressive model's types are: simple AR models, AR(2) model, discrete autoregressive model (DAR (1)), frame based AR models, nested AR model, gamma AR model (GAR), general AR model, Gaussian autoregressive and chi square (GACS) model, gamma-beta autoregressive model (GBAR), continuous DAR model (C-DAR) [20] [21] [22] [23] [24] [25]. In this thesis, AR (2) models are used for generating MPEG-4 traffic.

a) Simple AR Model

An autoregressive (AR) process is a function that is linearly dependent on past values produced. This process is used in many VBR video traffic models. AR process is represented as [26]:

$$x\,(n) = \boldsymbol{c} + \sum_{i=1}^{p} \mathbf{a}_i * \mathbf{x}\,(\mathbf{n}-\mathbf{i}) + \mathbf{e}\,(\mathbf{n}) \qquad (2.1)$$

where n is the time, c is a constant value, a_i are the autoregressive coefficients. Hence, all types of traffic have specific correlation coefficients. $e\ (n)$ is the white Gaussian noise. And finally p is the order of the AR process.

In video conferencing, people have less movement and the background remains approximately unchanged. For more details on teleconferencing video regression models, one can refer to [27]. Nomura in [21] evaluated video conferencing with the distribution, autocorrelation, coefficient of variation scales and quality improvements by using signal to noise ratio (SNR) and subjective rating. Moreover, simple AR (1) model is used for video conferencing traffic. He obtained the result that one AR process is not enough to model video conferencing; hence Heyman in [20] proposed a multiple AR process (AR(2)) over the ATM network because video conferencing consists of several scenes, and AR(1) process doesn't have scene change which is mentioned in [21]. Consequently, Heyman proposed a model for a simple video source by using AR(2) model and presented a model for multiple source video by using DAR(1) model which follows the Markov chain process to generate stationary discrete random variables. In addition, Heyman [28] represents a frame-layer model with multiplexed differential pulse code modulation (DPCM) video source for scene change video sequence, because the single model is not suitable for use for all video sequences.

In [7] [29] for capturing the bit rate variation, an MPEG video traffic model with scene change is proposed where all types of frames (I, P, B) have lognormal distribution. To model the size of P and B frames, independent identically distribution (i.i.d) random processes are used; and to model size of I frames, an AR (2) component and a scene related component are used. Consequently, based on GOP pattern, the whole model was generated by combination of three sub-models. The result of analyzing ACF of this model showed that the scene length distribution can be estimated by a geometric distribution; and the size distribution of all frames types (I, B, P) should be lognormal.

Lazaris et al. in [30] showed that the lognormal and Gamma distributions are appropriate distributions to model several types of video traffic except MPEG-4 video conferencing. Hence, they proposed Pearson- V distribution to be the best distribution for all the video traces specially for single MPEG-4 video conferencing sources. Also, they pay more attention to “capture” the VBR coders of multiplexed MPEG-4 videoconference’s behavior, relying on Discrete Autoregressive (DAR (1)) model’s structure.

b) Nested AR Model

Liu et al. in [31] presented an algorithm for MPEG video traffic model which uses the Gamma distribution for the three different types of frames based on the nested AR model. This algorithm is enforceable for both single and multiple video sources with consideration given to scene changes. The better autocorrelation structure is obtained from the nested AR model in comparison with the scene based AR model, at both large and small lags. This model used two AR(2) processes nested; first one was used to model the LRD for generating the main frame size of the scene, and the other one was used to model the SRD for generating the fluctuations within the scene.

2.2.2 Long-Range Dependence

Long-range dependence is the phenomenon that has long memory in non-stationary stochastic processes. Correlation structures of long-range dependent models are represented by hyperbolical decay for large lags and include fractional ARIMA (FARIMA) and wavelet-based models. The other description for the LRD is that the decay rate of autocorrelation function is hyperbolical in large lags [14].

Beran in [32] concluded that VBR video traffic exhibits inherent long range dependence (LRD) after analyzing 20 large genuine VBR video data sets; a vast different scene ranges were represented. LRD behavior may potentially affect the behavior of queuing systems, because iteration of group of picture (GOP) structure induces periodic cross correlations among all frames types.

2.2.3 Summary of Related Work

Having appropriate knowledge about characteristics of VBR video traffic is required to have an accurate video traffic model to assess bandwidth allocation and to assess network performance.

This chapter examined some types of VBR video traffic models. All these models are classified into two categories based on their characteristic as short-range or long-range dependent. Suitable models for video sequences are self-similar models, which just capture the LRD video traffic characteristics with high correlation, but with complex computation. According to this study, models based on AR processes are capable of capturing the autocorrelation behavior of video with any compression type at both large and small lags.

Chapter 3

MULTI-CHANNEL WIRELESS SYSTEMS

3.1Overview of Mobile Broadband Wireless Networks

Advances in mobile phone technology have been marked by generation (G). The pre-cell mobile phone belongs to zero-generation (0G) technology that is used for basic voice communication such as Autoradiopuhelin (ARP) and B-Netz which are respectively, first and second public commercial mobile phone networks [33] [34].

First-generation (1G) is the first complete wireless standard, in which there is one user per channel. The first generation wireless system was primarily developed in 1980s for voice call in analog systems that used frequency division multiplexing. With second-generation (2G) wireless standard having multiple users in one channel became possible by improving of 1G after 1990. Additionally, in the second generation, by introducing time division multiplexing, data could also be processed and text messaging (SMS) was introduced to everyone in 1990. Then, by providing wireless connectivity, increased frequency band and high data transfer rate created a new concept of mobile phones as a digital device. This generation was based on global system for mobile communication (GSM), and data transfer was based on circuit switching. Therefore, it became possible to provide picture messages, text messages and MMS (multimedia messages) services to the users. Moreover, it provided a sufficient security in the sender and receiver sides.

All the smart phones now belong to the third generation (3G) systems. Evolution of 3G systems and services allow for more coverage and growth with minimum investment which started in 2001 in Japan. This generation of mobile wireless provides: high quality, high bearer rate capability, small terminal for worldwide use, worldwide roaming capability, routing flexibility, multimedia traffic (voice, data, video, and remote control) and integrated voice transmission and Wi-Fi hotspots connectivity.

Consequently, video conferencing and mobile television are possible application in 3G system by making use of CDMA (code division multiple access) and TDMA (time division multiple access). In addition, 3G systems were compatible to work with 2G technology because it is a modified form of 2G technology. Between the years 2003-2005, this type of technology has matured. The data transfer in this generation is based on packet switching. Additionally, the connectivity speed that is provided by 3G is at least 200 kbps.

The third generation has more reliability, security and bandwidth than the other generation technologies. Another advantage of this technology is accessibility of variable and fixed rates, and availability of rich multimedia service. However, upgrading base stations and cellular infrastructure is not cost effective. This generation requires different handsets, closer base station and high power consumption. Also, there is not any implementation for integrating data/voice and roaming service together. It means that the full advantages of 3G networks belong to people inside of a covered zone of 3G networks.

Therefore to solve these problems, fourth generation of mobile communication (4G) technology standards replaced the 3G network. The 4G technology provides high spectral efficiency and is cost effective. It is referred to the next wave of high-speed mobile technologies. LTE and WiMAX are two contenders which are IP based networks and support more than one Gbit/s peak data rate [35]. The peak speed requirement on 4G service for high mobility communication (e.g. cars, trains) is at 100 megabits per second (Mbit/s) and for low mobility communication (e.g. stationary users) is 1 gigabit per second (Gbit/s) [36]. This generation of technology provides a better call admission control, scheduling and high capacity than 3G network. However, the implementation of 4G network is hard, expensive and requires complex hardware; moreover it has more battery usage.

Currently 5G is not a term officially used for any particular specification or in any official document yet made public by telecommunication companies or standardization bodies such as 3GPP, WiMAX Forum or ITU-R. 5G is to be a new technology that will provide all the possible applications, by using only one universal device, and interconnecting most of the already existing communication infrastructures. It will have software defined radio modulation schemes [37]. It is predicted that it will include some advantages such as lower energy consumption, better coverage and high data rates available at cell edge, more secure (better cognitive radio security), cheaper traffic fees due to low infrastructure deployment cause [38]. Table 3.1 illustrates brief description about mobile generations.

Table 3.1: Summary of mobile broadband wireless networks [35] [36] [39] [40] [38]

Properties / Generation	**0G &1G**	**2G**	**3G**	**4G**	**5G**
Launch	1970	1990	2000	2010	2015
Last	1980	Still used	Still used	Still used	Beyond 2020
Technology	FDMA	TDMA	CDMA	OFDM, SC-FDMA, OFDMA, MIMO	None yet
Standard	AMPS, NMT	GSM (GPRS)	EDGE (UMTS, HSPA)	LTE, WiMAX	None yet
Switching technique	Circuit	Circuit-Packet	Circuit-Packet	Packet	All packet
Speed	14.4kbps (peak)	9.6-14.4 kbps	3.1Mbps (peak)	100-300Mbps (peak)	Probably gigabits
Data capacity	2KBps	10KBps-473KBps	384kbps-30Mbps	200Mbps-1Gbps	Higher then 1Gbps

3.1.1 OFDMA-based Broadband Wireless Access Systems

Firstly, Orthogonal Frequency Division Multiplexing (OFDM) should be described for better understanding of OFDMA technique. OFDM has been accepted as a technique for IEEE 802.11a for 5-GHz frequency band in Mobile Multimedia Access Communication (MMAC) Systems. This modulation technique is used for increasing robustness. Efficient usage of the spectrum is provided by allowing overlap. It divides wideband channel into narrowband sub-channels, which can be controlled individually. In this technique, all channels are allocated to one single user at each time-slot and only one user can be served at a time. Hence, while 1^{st} – 3^{rd} generation systems can be called single-channel wireless system, OFDM-based 4G systems are called multi-channel wireless systems.

Multiple access technology OFDMA provides data transmission in the same frame for multiple users. High flexibility of OFDMA increases complexity of system. Figure 3.1 illustrates difference between OFDM and OFDMA.

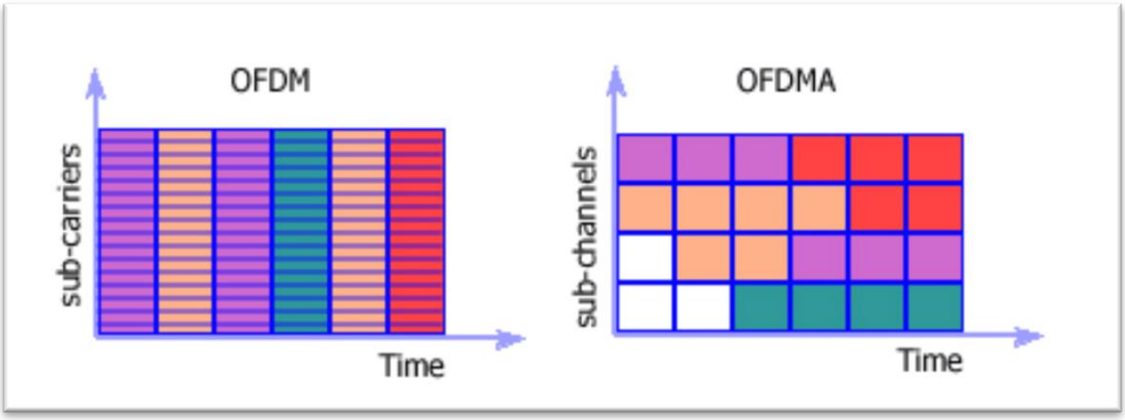

Figure 3.1: OFDM and OFDMA [41]

Some OFDMA characterizations are:

1) Each sub frame corresponds to transmission time interval.
2) The scheduling decision can change in every transmission time interval by the base station.

3.1.2 Fourth Generation Technologies

With the development of technology, the current generation of mobile telecommunication, which is the fourth-generation (4G), has emerged examples of 4G systems are the Long Term Evolution (LTE) and WiMAX technologies. These standards are based on OFDMA.

3.1.2.1 WiMAX Systems

IEEE 802.16 standards or WiMAX has a strategic value. This standard is based on Wireless Metropolitan Area Networks (WMAN) and supplies wireless data service. It also covers large geographic areas to provide wireless internet service for users with data rate up to 70 Mbps by using the 10-66 GHz frequency bands [42]. The WiMAX technology is capable of connecting Wi-Fi networks together and providing wireless broadband services from ISP (Internet Service Provider). In addition, WiMAX uses a base station for establishing the wireless connection between subscribers and works like other cellular technologies.

The IEEE 802.16d and IEEE 802.16e are two major standards which define: air interface of fixed broadband wireless access system and the air interface of both fixed and mobile broadband wireless access systems, respectively.

3.1.2.2 LTE Systems

Long Term Evolution referred to as 3GPP standard is a new radio interface technology, based on OFDM multiplexing. It uses OFDMA and SC-FDMA (Single Carrier FDMA) [43] which increase the user equipment's (UEs) power efficiency. These techniques are used in downlink and uplink transmission, respectively [43].

LTE standard was developed to be cost effective, to provide lower latencies, higher peak data rates, wider spectrum and packet optimized radio technology that applies multi-antenna methods and sophisticated scheduling. In addition, flexible spectrum is used in the LTE to deploy it in any bandwidth combinations. All UEs should support the maximum bandwidth (20 MHZ) in LTE. Figure 3.2 shows development of wireless generations with associated standards.

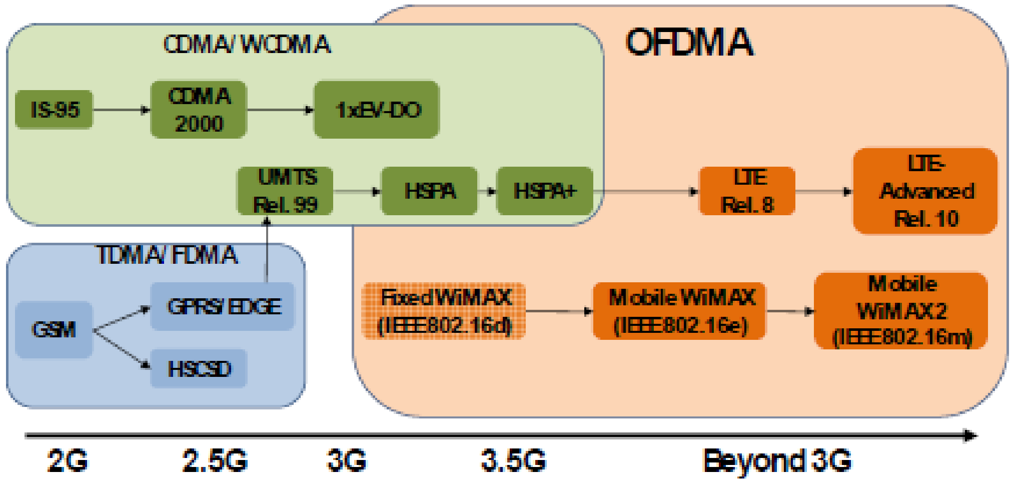

Figure 3.2: Evolution of mobile cellular systems [44]

3.2 Video Transmission over OFDMA

The bit rates of video are higher than other types of traffic. Therefore, key challenges in transmission of video stream over OFDMA-based system are video transmission with high quality or lowest loss rate and low latency in downlink. Other issues that should be considered for video transmission over multi-channel wireless networks are packet scheduling, sub-channel allocation and power allocation. To reduce the distortion and increase video quality, packet scheduling is used. This process is performed by scheduling the packets which have the highest priority [45] deciding among packets which one should be serviced.

3.3 Summary

Evaluation and creation of the technology for mobile wireless communication has started since 1970s. Wireless communication has experienced different phases from 0^{th} generation to 4^{th} generation technology revolution.

Zero-generation (0G) is used for basic voice communication. First-generation (1G) of mobile wireless communication belongs to analog technology. Then quality of wireless communication has improved in second-generation (2G) by converting the analog systems to digital. Data and voice communication have been made possible with third-generation (3G). After a while, fourth-generation (4G) of wireless networks has appeared as the next wave of high-speed mobile technologies. Moreover 4G mobile broadband wireless systems such as WiMAX and LTE standards are designed to satisfy this increasing demand. 4G wireless systems are generally based on the orthogonal frequency division multiple access (OFDMA) technique in which, time is divided into slots and bandwidth is partitioned into many parallel sub-channels. The 5G mobile networks will focus on the development of the user terminal where the terminals have to access to the different wireless technologies at the same time.

Chapter 4

MODELING MPEG-4 VIDEO TRAFFIC

Generation of accurate video traffic becomes important within evaluating performance over high-speed networks such 4G networks. Using statistical properties of video traffic source together with knowledge of the coding technique such MPEG-4 can help to develop the video traffic model used to analyze performance of network.

4.1 Distributions Used in Modeling

4.1.1 Geometric Distribution

Geometric distribution introduces a discrete random variable with p parameter which represents probability of success and it should lie in the interval (0 1]. This distribution is denoted as Geo (p) [46]. Also it is used for generating the scene length by equation (4.1).

$$R = \text{Geometric}\ (p) \qquad (4.1)$$

where R represents scene size.

4.1.2 Lognormal Distribution

Lognormal distribution introduces a continuous random variables and it is assumed for distribution of video frame sizes. Generation of the video frame size is based on lognormal distribution, which has two basic parameters μ and σ. These parameters should be obtained by measuring the mean and variance, because they cannot be obtained directly. Therefore, the probability density function (pdf) of lognormal distribution should be converted to the measureable variables. Equation (4.2) represents the lognormal pdf; the expected value and variance of this pdf are stated in equations (4.3) and (4.4).

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma x} e^{-(\ln(x)-\mu)^2/(2\sigma^2)} \quad (4.2)$$

$$E(X) = e^{\mu+\sigma^2/2} \quad (4.3)$$

$$Var(X) = (e^{\sigma^2} - 1)\, e^{2\mu+\sigma^2} \quad (4.4)$$

Additionally, the parameters of μ and σ can be calculated by the expected value and variance from the lognormal pdf formula and they are given here as.

$$\mu = -\frac{1}{2}\ln\left(\frac{Var(X)+E(X)^2}{E(X)}\right) + \ln(E(X)) \quad (4.5)$$

$$\sigma = \sqrt{-2\mu + 2\ln(E(X))} \quad (4.6)$$

4.2 Generation of Synthetic Video Traffic

Synthetic traffic generation is crucial for extensive system testing. There exist many studies that involve generating different types of network workload. An algorithm that generates variable bit rate MPEG video traffic is described by Krunz and Tripathi [7]. This algorithm was used in this study and it is implemented to provide MPEG-4 input streams to a multi-channel wireless downlink scheduler.

Figure 4.1 depicts the sudo-code for the aforementioned algorithm. In this study the fix GOP pattern with M=3 and N=12 i.e. IBBPBBPBBPBB has been adapted. In Krunz's model the length of each scene will be generated by using a geometric random variable and I, B and P frames all will be generated by using lognormal random variables. However, while the model uses i.i.d random variables for generating B and P frames, frames I will be modeled by the sum of two random components, a lognormal random variable for generating the size of I frames and then an AR (2) process for modeling the fluctuations for the size of I frames within each scene. The statistical parameters such as mean and standard deviation used in the model have been illustrated in the Table 4.1. Also, expected value of I, P and B frames size are represented as E (I), E (P), E (B), and standard deviation of I, P and B frames size are represented as STD (I), STD (P), STD (B).

These parameters came from the "Silence of the Lambs" movie and have been extracted from real video traffic traces. These statistical parameters used for generating the synthetic video traffic have been acquired from the performance evaluation methodology in 4G WiMAX systems [47].

```
Set Scene-max:= desired number of scenes
X ≜ frame size (in cell)
For j=1 to Scene-max do
    generate scene length: Nj ~ Geometric (p)
    generate XI (j) ~ Lognormal (μI, σI)
    for i= 1 to Nj do
        for k= 1 to N do
            if k=1 then                          /* I frame * /
                X= XI (j) + ΔI (i) where
                ΔI (i) = a1 ΔI (i-1) + a2 ΔI (i-2) + ε (i)
        else
            if remainder (k/M)= 1 then /* P frame */
                X ~ Lognormal (μp, σp)
            else
                X ~ Lognormal (μB, σB)
            end if
        end if
      end for
    end for
end for
```

Figure 4.1: Algorithm for generating an MPEG-4 video traffic flow [7]

Table 4.1: Lognormal values of "Silence of the Lambs" movie in bytes [47].

Video File	Quality	E(I)	STD(I)	E(B)	STD(B)	E(P)	STD(P)
Silence of the Lambs	Large (320*240 display size)	17068	7965	6839	5323	9190	7005
	Small (176*144 display size)	5640	2632	2260	1759	3037	2315

The MPEG frame size is determined by two components such as frame type and scene activity. To this aim, generation of scene length has been done based on geometric distribution computed by equation (4.1).

As it was mentioned, three random processes are used to model the MPEG-4 video traffic that each of those random processes produces one type of frames (I, P, B). Thus, the summation of an AR (2) component and scene-related component is used to model the size of I frame. To model the P and B frames size, two i.i.d. random processes are used.

Consequently, for generating the sequence of frame size, all these processes merged to form the GOP structure. Several GOPs form one "scene" which is the fluctuation of mean levels at large time scales. Additionally, combination of these three random processes, show that MPEG-4 video streaming is long-range dependent, but the important thing is that (I) frame production is short-range dependent. The size of (I) frame is obtained from equation (4.7) [7].

$$X_I(n) = X^*_I(j) + \Delta_I(n) \qquad (4.7)$$

where $X_I(n)$, $X^*_I(j)$ represent size of the n[th] I frame within j[th] scene, and mean activity of the scene, respectively. Also, $\Delta_I(n)$ shows the small fluctuation of I frames. In this regards, mean activity is a large variation of I frame which is computed by lognormal distribution. Moreover, mean and variance of I frame are defined in Equations 4.8 and 4.9, respectively, which are employed in lognormal distribution.

$$m_{X_I^*} = e^{\mu_I + \sigma_I^2/2} \quad (4.8)$$

$$V_{X_I^*} = e^{2\mu_I + \sigma_I^2} \times e^{\sigma_I^2} - 1 \quad (4.9)$$

where μ_I and σ_I represent as an expected value and standard deviation of I frame, respectively. These parameters are variable's natural logarithm with normally distributed. Furthermore, the real values are extracted from "Silence of the Lambs" movie which is shown in Table 4.1.

Finally, small variation of I frame is employed that is defined as equation 4.10.

$$\Delta_I(n) = a_1 \Delta_I(n-1) + a_2 \Delta_I(n-2) + \varepsilon(n) \quad (4.10)$$

where $\Delta_I(n)$ represents n^{th} iteration of AR (2) processes, a_1 and a_2 represent the AR coefficients which are constant for video stream and $\varepsilon(n)$ represents white noise (Gaussian distribution) with zero mean and 4.36 variance. Thus, the $\Delta_I(n)$ is independent of $X^*_I(j)$ and has different values for each scene.

$X_P(n)$ and $X_B(n)$ are processes that representing the size of P and B frame types. These processes are modeled by lognormal distribution with parameters (μ_p, σ_p) for P frames and (μ_B, σ_B) for B frames.

The MPEG traffic generator settings taken from the WiMAX System Evaluation Methodology [47] are used for generating movie streaming traffic (Silence of the Lambs), also are tabulated in Table 4.2.

This table shows that for each second there are 3 GOPs. Thus, the MPEG video traffic generator generates three I frames, nine P frames and twenty four B frames per second.

In streaming applications, the destination client has a buffer for playing out video at a rate of 30 frames per seconds. The simulation time is assumed to be 3600 seconds.

As it is mentioned in the table, The synthetic video traffic generator is designed based on two resolution types such as Common Intermediate Format (CIF) with 352 × 288 picture elements (pel) and Quarter Common Intermediate Format (QCIF) with 176 × 144 pels digital frame formats. Furthermore, it is implemented on single layer coding with 12 intra period (GOP size=12) with 30 frame per second.

Table 4.2: Intial values of MPEG-4 generator [7] [47]

Movie streaming traffic model			
Parameters	**Numerical values**		
Video duration (sec)	3600		
Scene length	Geometric (p= 0.098)		
Video codec	MPEG-4		
Direction	Downlink (uni-direction)		
Intra period	12 (IBBPBBPBBPBB)		
Frame rate of the video	30 frames/sec		
Frame format (Digital)	QCIF	CIF	QCIF
Mean bandwidth for compressed stream	0.58Mbps	1.74Mbps	0.58Mbps
I frame size (byte)	μ= 4.58, σ =0.38	μ= 9.65, σ =0.44	μ= 8.53, σ =0.44
P frame size (byte)	μ= 2.58, σ =0.87	μ= 8.90, σ =0.68	μ= 7.78, σ =0.67
B frame size (byte)	μ=1.98, σ =0.69	μ=8.59, σ =0.69	μ= 7.48, σ =0.68
AR (2) coefficients	a1=0.39, a2=0.15, σ_{ε}=4.36		

4.3 Model Verification

In this section, statistical properties of frame size (in byte) of real video traffic trace of "Silence of the Lambs" movie [48] [49] are compared with synthetic video traffic trace. This section explains the comparison of the two systems by testing the differences of real traffic frame size and generated traffic frame size. We obtained confidence interval, mean, variance and standard deviation of differences the whole stream.

The following steps in order to verify the generated MPEG-4 traffic obtained through a method in section 4.2 are performed and explained in detail. The generated video traffic has no significant difference with the real system if and only if 'zero' value lies in the interval of confidence level defined in [50].

Confidence interval for mean value is calculated to check verification of generated synthetic video traffic with real video traffic trace. To this aim using the equation 4.11 comes from [50] is necessary.

Confidence interval for mean = sample mean ± t $\sqrt{(\text{sample variance}/\text{n})}$ (4.11)

where *n* represents the number of samples. *t* parameter represents student's t-test which is obtained from the T-distribution table or Z- distribution table (both of them have bell-shaped pdf and a mean of 0). Also, (t) is used as standardized distribution. Additionally, sample mean is the mean which is obtained from differences of real traffic stream and generated traffic stream and sample variance is variance of differences these two systems.

1. Difference of real traffic frame size and generated traffic frame size is calculated as X_i. In order to, each frame of real traffic is compare with each frame of generated traffic. Difference of these streams created the other stream which is used for the next computations.

2. Sample mean and sample variance of X_i are respectively obtained from equations 4.12 and 4.13.

   $\bar{X} = \sum_{i=1}^{n} X_i$ (4.12)

   $S^2 = (\frac{1}{n-1}) \sum_{i=1}^{n} (X_i - \bar{X})^2$ (4.13)

3. Finally, all these parameters are used in equation 4.11 for computing confidence interval. This computation is used to estimate the goodness of match two systems.

In the synthetic video traffic introduced in this study, the number of generated samples is approximately near to the real samples. To ensure that the MPEG traffic generator works well, the verification process is executed several times by different generated streams.

Table 4.3 shows the statistics parameters of synthetic video traffic and real video traffic; for this trial, parameters of WiMAX [47] were used for CIF display size. Thus, from this Table, it can be concluded that the introduced synthetic video traffic trace completely matches the real video traffic trace.

Table 4.3: Statistical parameters of MPEG-4 traffic generator

Parameters	Real traffic frame statistics	Generated traffic frame statistics
Video run time	166 seconds	166 seconds
# of frames	5000	5000
GOP pattern	N=12, M=3	N=12, M=3
Mean frame size	7.5687e+03 (byte)	7.7246e+03 (byte)
Var frame size	1.5914e+07 (byte)	4.4362e+07 (byte)
Plot of I frames	Figure 4.2	Figures 4.3 and 4.4
Histogram of frames	Figures 4.5	Figures 4.6

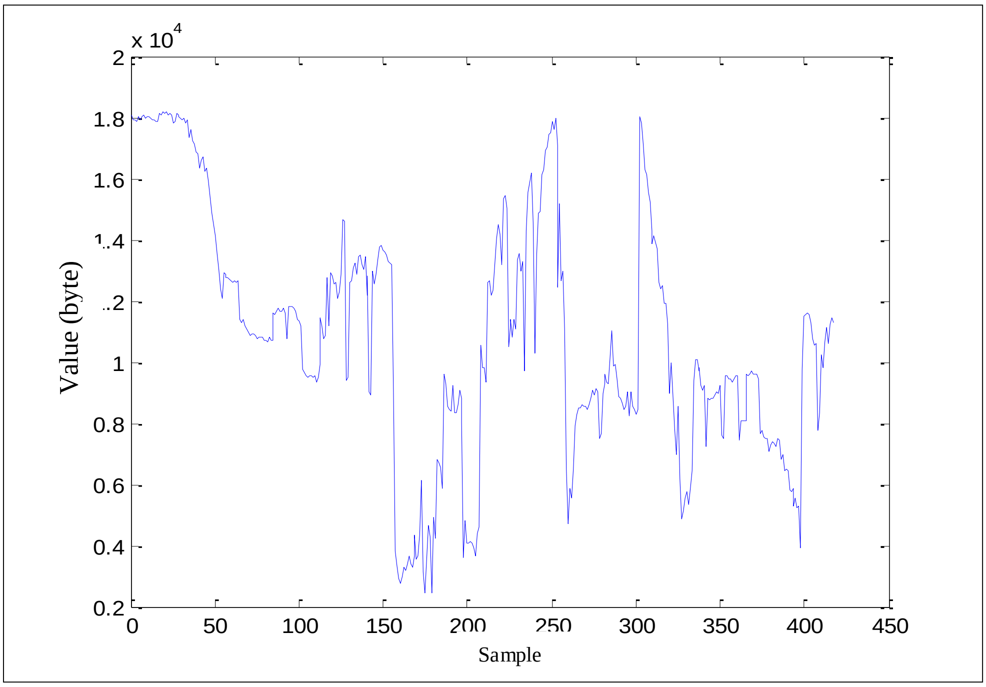

Figure 4.2: I frame size of real video traffic

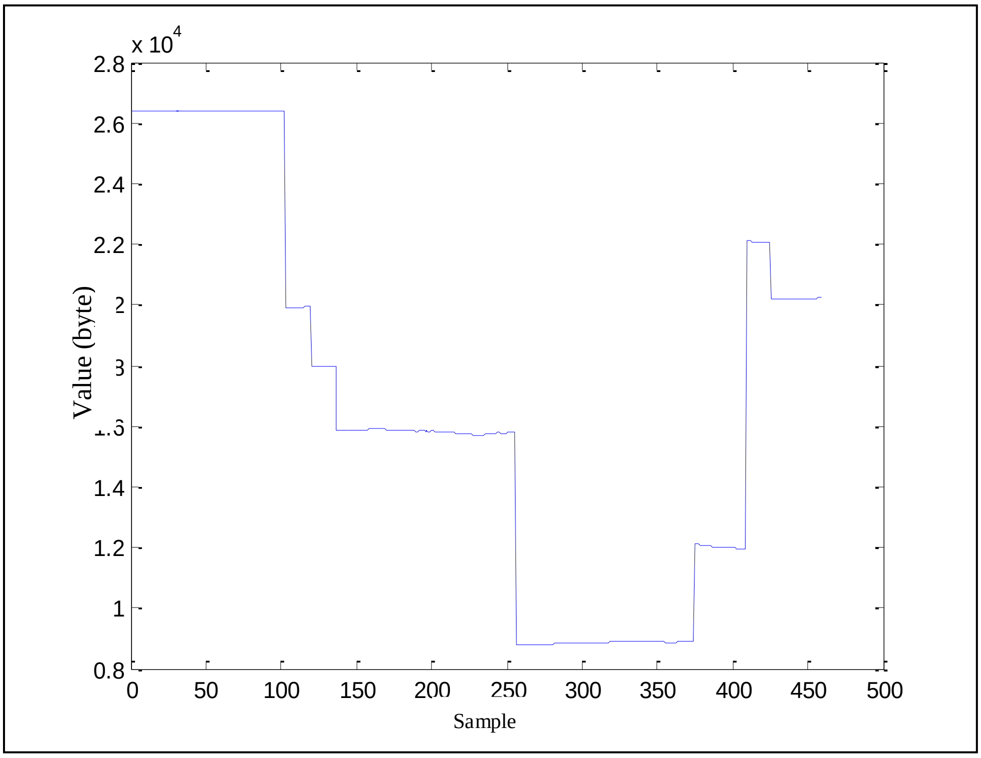

Figure 4.3: Fluctuation of I frames for 5 scene changes

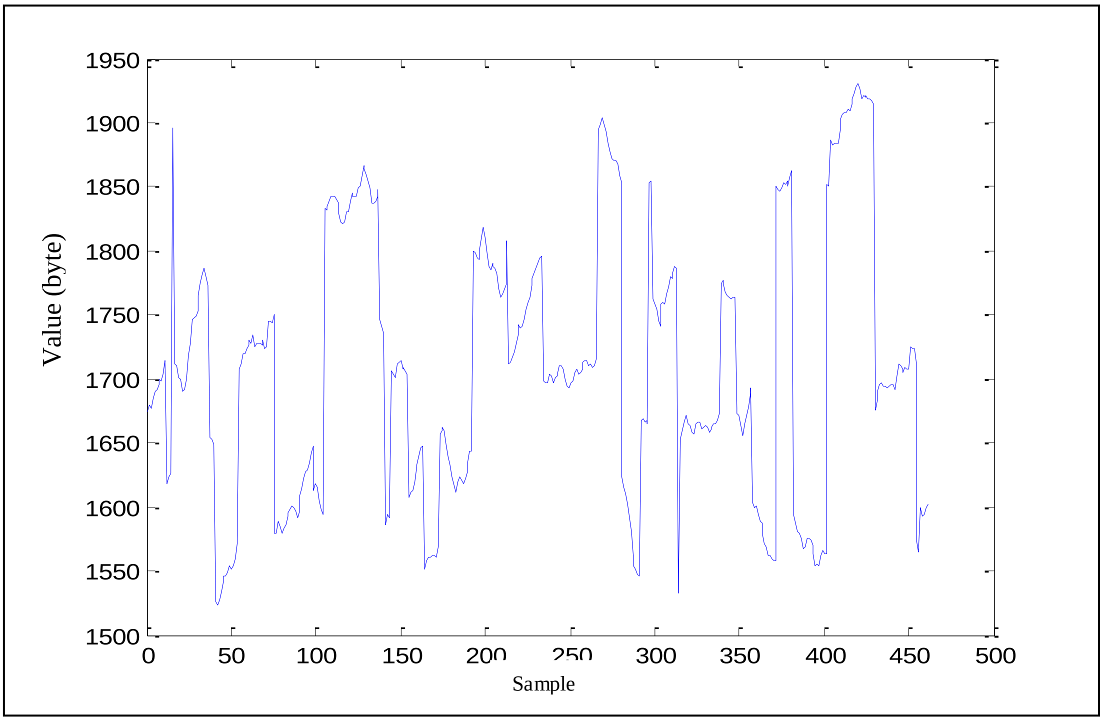

Figure 4.4: Fluctuation of I frames for 50 scene changes

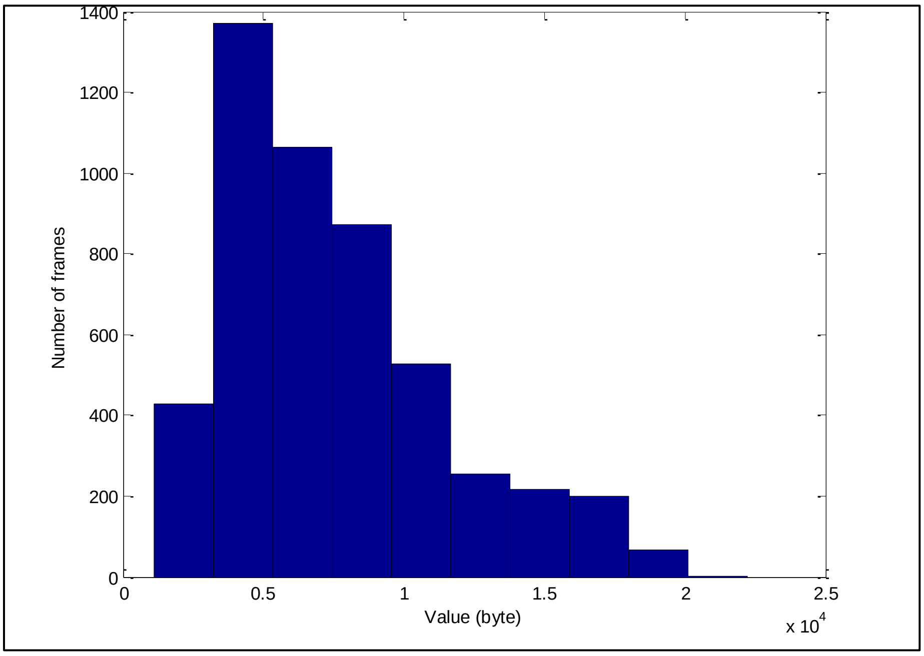

Figure 4.5: Histogram of real traffic frame size

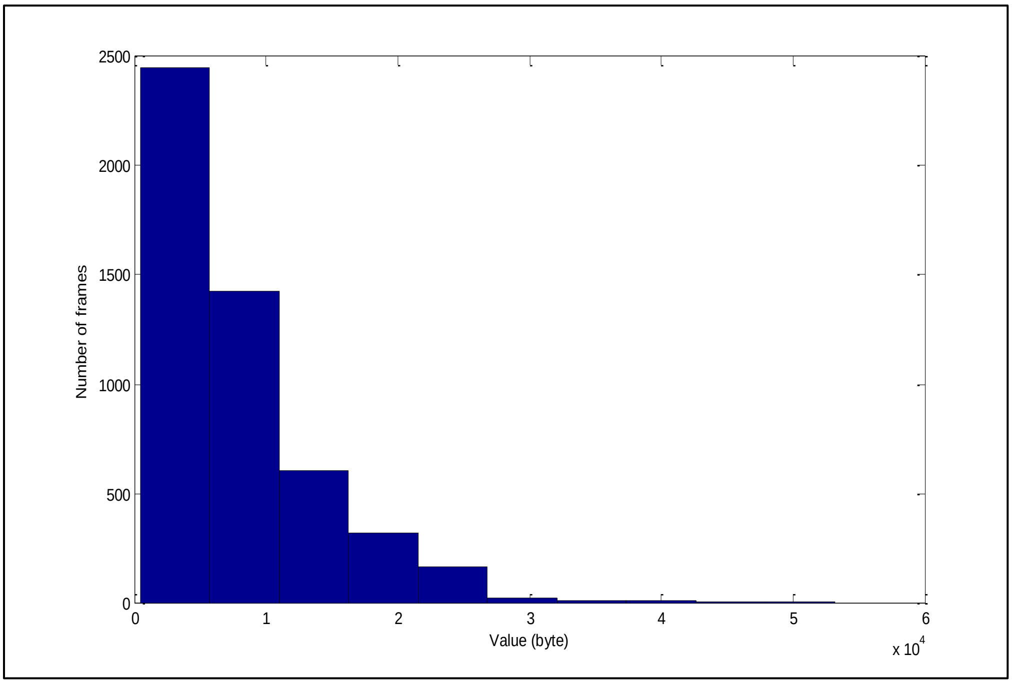

Figure 4.6: Histogram of generated traffic frame size

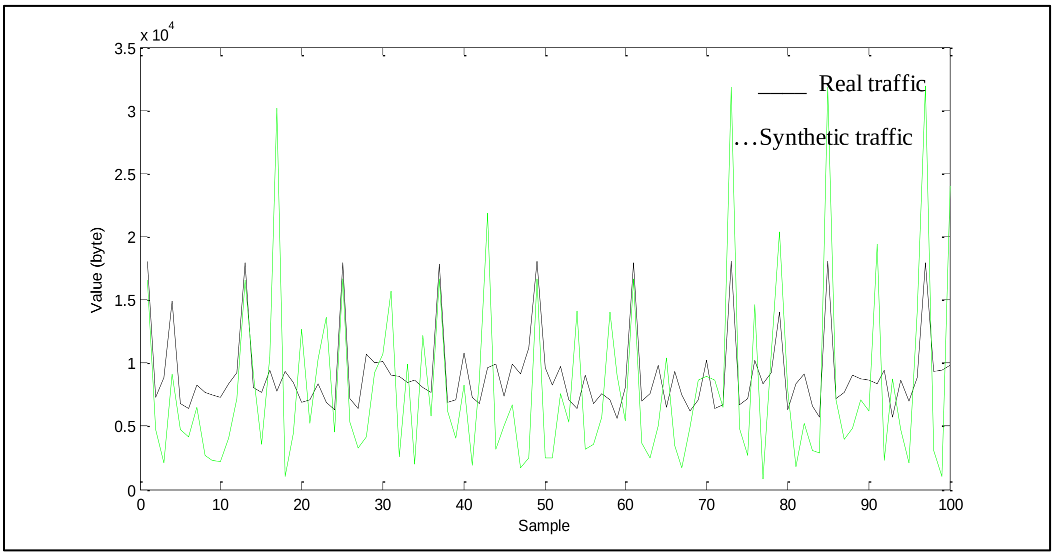

Figure 4.7: Difference of real traffic and synthetic traffic frame size

Table 4.4 illustrates the statistical parameters of verifying the MPEG-4 traffic generator which is obtained from Table 4.3. From the confidence interval which is computed in this Table, it can be concluded that the systems are not significantly different.

Table 4.4: Parameters of verify test

Sample mean	-155.8216
Sample variance	5.5130e+07
Sample std	7.4250e+03
Significance level	0.05
Confidence level	[-328.554, 16.911]
Confidence interval	95%

Table 4.5 characterizes another result in another trial with parameters of WiMAX [47] were used for QCIF display size; confidence interval of this trial is 98% which is shown in Table 4.6 and it shows the synthetic traffic trace is match the real traffic trace.

Table 4.5: Statistical parameters of MPEG-4 traffic generator

Parameters	Real traffic frame statistics	Generated traffic frame statistics
Video run time	3600 seconds	3600seconds
# of frames	89998	108000
GOP pattern	N=12, M=3	N=12, M=3
# of scene change	327	383
# of GOPs in stream	7499	9000
Mean frame size	2.8763e+03 (byte)	2.7201e+03 (byte)
Var frame size	5.2488e+06 (byte)	4.6717e+06 (byte)

Table 4.6: Parameters of verification test

Sample mean	-7.3876
Sample variance	4.2563e+07
Sample std	6.5241e+03
Significant level	0.02
Confidence level	[-196.898, 182.123]
Confidence interval	98%

In Table 4.7 the parameters of real traffic frame statistics belong to Krunz's algorithm [7]. Additionally, Table 4.8 represents verification result; and the process of verifying synthetic video traffic was done with the appropriate result.

Table 4.7: Statistical parameters of MPEG-4 traffic generator

Parameters	Real traffic frame statistics	Generated traffic frame statistics
Video run time	3600 seconds	3600seconds
# of frames	89998	71808
GOP pattern	N=12, M=3	N=12, M=3
# of scene change	327	380
# of GOPs in stream	7499	7212
Mean frame size	2.9943e+03 (byte)	2.3531e+03 (byte)
Var frame size	5.8041e+06 (byte)	5.1731e+05 (byte)
Plot of I frames	Figure 4.2	Figures 4.8
Plot of frames	Figures 4.9	Figures 4.10

Table 4.8: Verification parameters

Sample mean	29.437
Sample variance	3.2458e+06
Sample std	1.8016e+03
Significance level	0.02
Confidence level	[-22.895, 81.770]
Confidence interval	98%

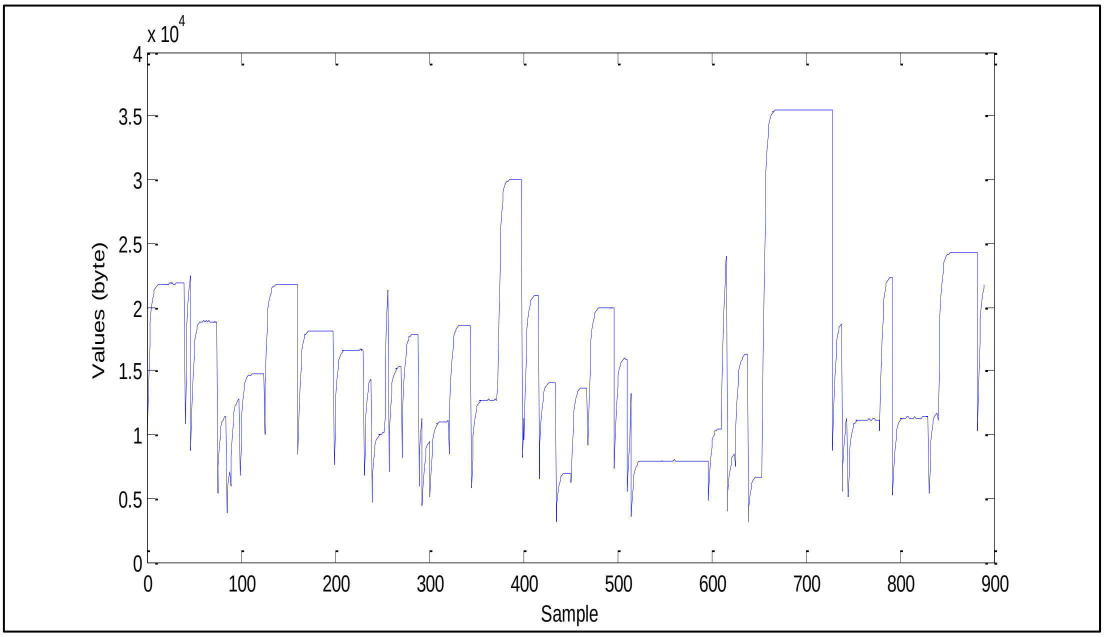

Figure 4.8: I frame size of synthetic video traffic

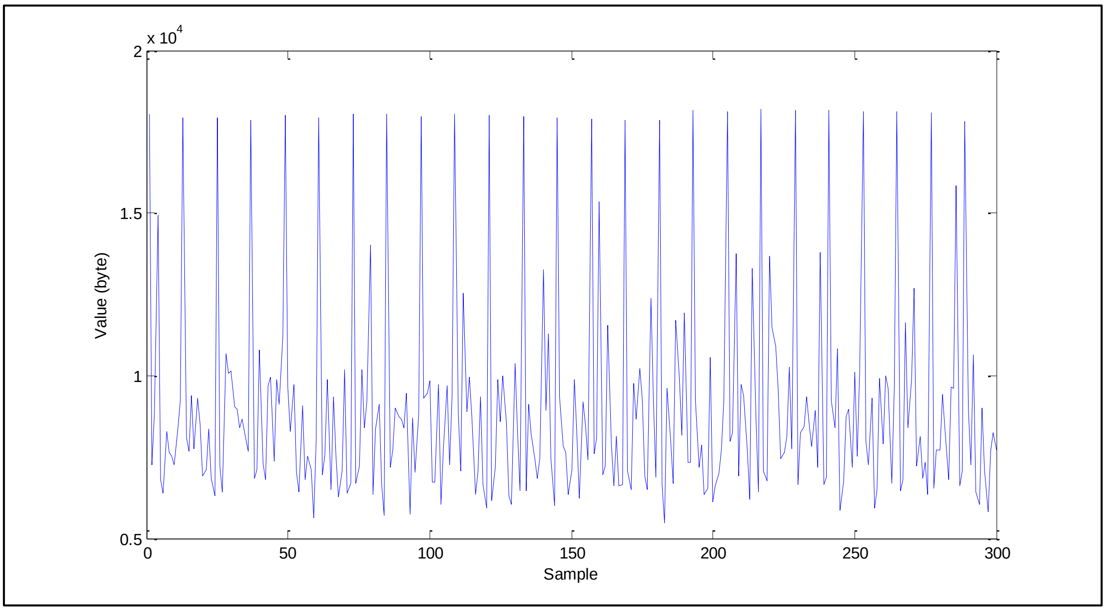

Figure 4.9: Frame size sequence for real traffic trace in 300 samples

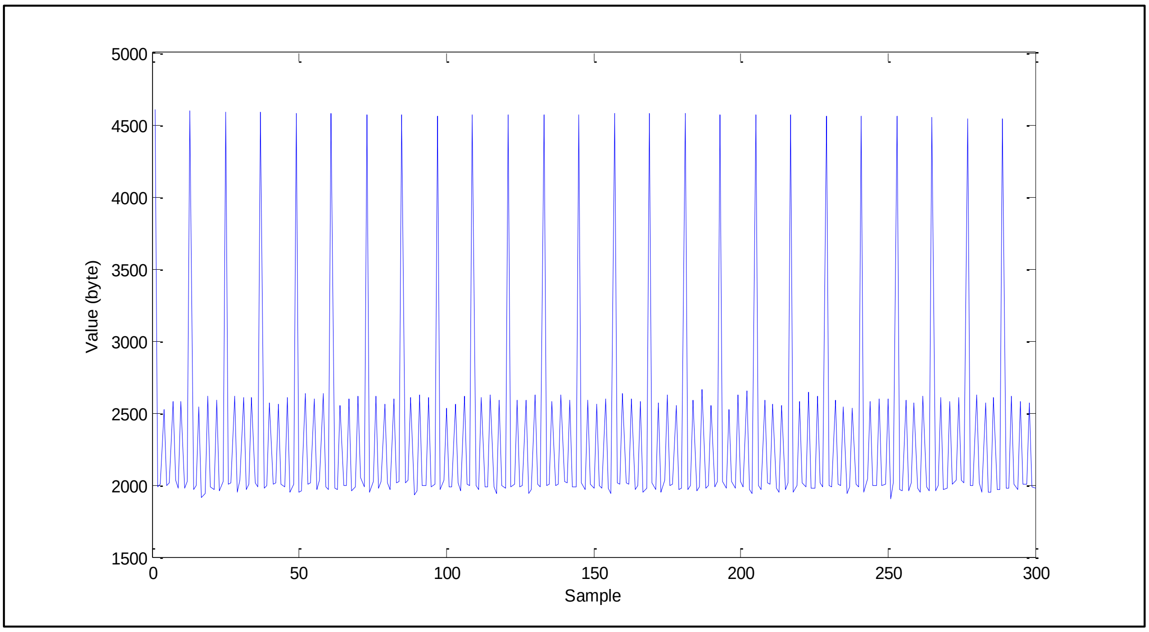

Figure 4.10: Frame size sequence for synthetic video traffic in 300 samples

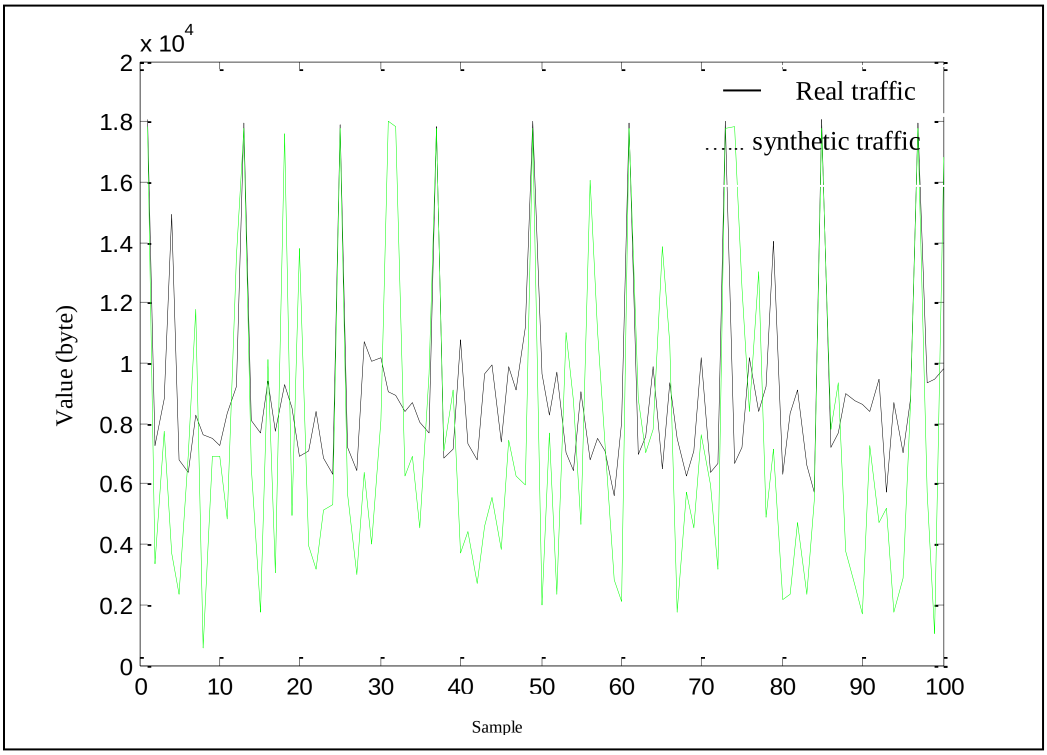

Figure 4.11: Difference of frames size in real traffic and synthetic traffic

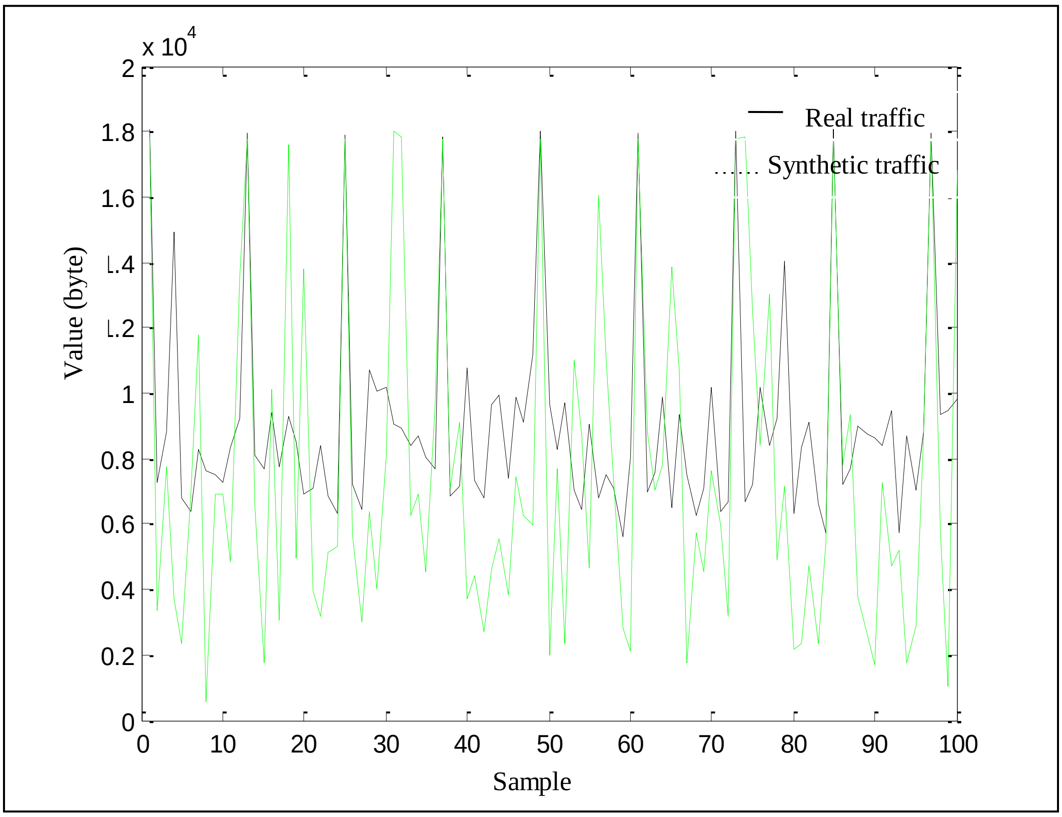

Figure 4.12: Difference of I frames in real traffic and synthetic traffic

Chapter 5

DOWNLINK IN MULTI-CHANNEL WIRELESS SYSTEMS

Optimal throughput and fairness are the most important factors in mobile broadband wireless networks. Scheduling is used to achieve high throughput with fairness to all users. Then, providing high throughput is possible at the expense of fairness and vice versa.

The scheduling problem in downlink of a 4G-like system which is based on OFDMA is considered in this chapter. The scheduling problem becomes significantly more complex in multichannel wireless networks. For a detailed review problem of designing scheduling algorithms for the downlink of a wireless network, one can see [51] and the references therein.

This study uses four types of schedulers to evaluate the queue-length performance in base station. These schedulers are: Round robin (RR), opportunistic (OP), maximum weight (MW), and Server-Side Greedy (SSG) scheduler. Preliminary results of performance of some scheduling algorithms for multi-channel wireless systems with video streaming traffic were also reported in [52]. In every time slot of OFDMA systems, the scheduler allocates each sub-channel to a possibly different user in order to use resources efficiently and to satisfy the QoS requirements of users. Scheduling decisions may be based on the quality of sub-channels, status of user buffers, allocation history and quality of service requirements. Currently, 4G technologies do not specify how to schedule users leaving it up to equipment vendors to implement effective algorithms. Additionally, fairness guarantee must be taken into consideration in order to have a desirable scheduling policy in any specific time window.

5.1ON-OFF Channel Model

The downlink OFDMA wireless channel at a base station is modeled as a multi-queue, multi-channel discrete-time queuing system where connectivity's of queues to sub-channels are time-varying (Figure 5.1). Each of the N served users has a separate, designated queue at the base station for its incoming traffic. The time-varying user-dependent sub-channel fading processes are modeled as i.i.d. ON-OFF random variables in each time slot; that is, the use of such simple and symmetric channels for users is only an approximation that will enable us to capture the important aspects of the system [52]. Figure 5.1 represents queuing system model with N user queues and K sub-channels and the probability that a sub-channel is ON for a user is given by q.

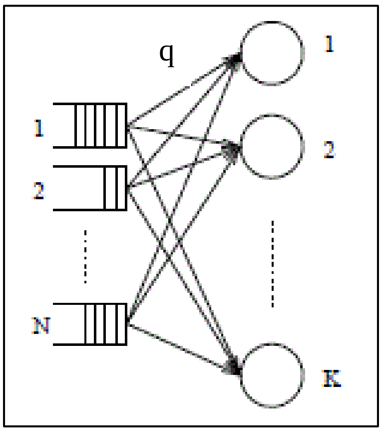

Figure 5.1: Queuing system model [52]

5.2 Scheduling Algorithms

5.2.1 Round-Robin Scheduling

Round robin (RR) scheduler is the simplest transmitter algorithm that is used to allocate fair timesharing for each user every one time-slice (quantum). This process is done by allocating the resource to each user which exists in the ready queue that can be implemented as a circular queue. Size of the time quantum has extreme effect on round-robin performance. Resource overload dramatically increases if quantum size is chosen too small [53].

5.2.2 Opportunistic Scheduling

Opportunistic (OP) scheduler or maximum throughput scheduler maximizes throughput by allocating channel to user that can transmit at the given time and has the best channel condition. This means that the base station should make a decision based on channel condition to serve queue. Note that there is one queue per user in the base station. This mechanism not guarantees the fair sharing over every time window [54].

5.2.3 Maximum Weight Scheduling

Max-weight (MW) scheduler not only considers the channel situation but also looks at users who have the largest backlog in the queues. The scheduler allocates all ON channels to that single user at the time slot. Throughput of this algorithm is optimal in the heavily loaded (large queue) case but large delays are possible. The key challenge of this mechanism is providing a proper performance when queue sizes are small [55].

5.2.4 Server-Side Greedy Scheduling

An iterative version of the MW scheduling is server-side greedy (SSG) algorithm by updating the queue length during the allocation process based on the packet numbers which are drained after each service by the servers. Channel resources are distributed between all users sequentially within each timeslot [56].

5.3 Performance Evaluation

The queue length performance is first analyzed using the common assumption of very large or infinite user buffer sizes and symmetric channels, but synthetically generated MPEG- 4 video traffic is used as arrival processes. The performance under symmetric channels of varying reliability is also analyzed. The performance of schedulers is then evaluated in terms of loss rate when users have finite buffer sizes.

In this analysis, queue size, data loss and buffer size are concentrated. The scheduler considered time slots of length 10ms. Video streams of users were initiated at different times and the measurements were collected over a period of approximately 10 minutes when all the streams were active. The performance measures reported in this section are means of time-averaged results over 10 simulation runs with different channel realizations. The standard errors associated with the reported means were also computed. Since the streams and channels of users were symmetric, the performance measures are reported for only user 1. Moreover, the air interface is based on OFDMA with 20 sub-channels. Each of sub-channels can support up to 500 bytes per slot.

5.3.1 Infinite-Buffer Behavior

In this scenario users have infinite buffer size, the sub-channel ON probability is assumed 0.5, and buffer threshold is 4KB. It can be seen that RR scheduling results in very large queue sizes and is unstable when the number of users exceeds 2. These results confirm the unsuitability of RR scheduling for multi-channel wireless systems. For other schedulers, the user queues become unstable when the number of users exceeds 4. The SSG scheduling has the smallest mean buffer occupancy. These results are shown in Figure 5.2.

Tables 5.1 and 5.3 illustrate the parameters that were used in scheduling with respect to [51]. Therefore, these trials give some different performance about average of queue size and throughput for each user. The result of these empirical trials is shown in Table 5.2 and Table 5.4 for comparing the performance of 3G systems with performance of 4G systems. Note that the values of average of queue size show the average of 5 user's results in 10 simulations run. In 3G networks, there is just one channel and it is based on code-division multiple access (CDMA); in this standard time is divided into slots [57] so capacity of CDMA channel should be equal to the capacity of 4G networks (OFDMA-based system in 4G networks consist multi-channels, each of which involves some sub-channels). According to definition of CDMA and OFDMA transmission techniques, the dissimilarities of their channels ON rate can be explained.

Table 5.1: Parameters of the 4G-like systems

Total number of slots	80000
Burst interval	40 (ms)
Buffer size	1000000000 (byte)
Channel ON rate	500 (byte/slot)
Time slots of length	10 (ms)
# of channels	20
# of users	1 to 5
Channel probability ON	0.5

Table 5.2: Scheduler results over 4G networks

Parameters	Schedulers	RR	OP	MW	SSG
Average queue size (byte)		1133832	18636.77	14587.9	14514.26
Average throughput (byte)		103101.3	5553.444	55566.018	5556.022

Table 5.3: Parameters of the 3G-like systems

Total number of slots	80000
Burst interval(slot interval)	40
Buffer size	1000000000
Channel ON rate	10000 (byte/slot)
# of channels	1
# of users	1 to 5
Channel probability ON	0.5

Table 5.4: Scheduler results over 3G networks

Parameters	Schedulers	RR	OP	MW	SSG
Average queue size (byte)		13237191	38588.95	18217.28	18378.12
Average throughput (byte)		4094.568	5491.312	55566.006	5555.904

As a result, SSG and MW schedulers (that very close together) have better performance than other schedulers in 4G system which can be seen from Figure 5.2. Moreover, MW scheduler has better queue length performance compared to other schedulers over 3G networks which was shown in Figure 5.3. Optimal throughput and average queue size in SSG and MW scheduler are very close together in both 3G and 4G networks. Totally, behavior of SSG transmitter on 4G systems gives a smaller average queue size with increasing number of users than MW scheduler on 3G systems; comparison of these behaviors is presented in Figure 5.4.

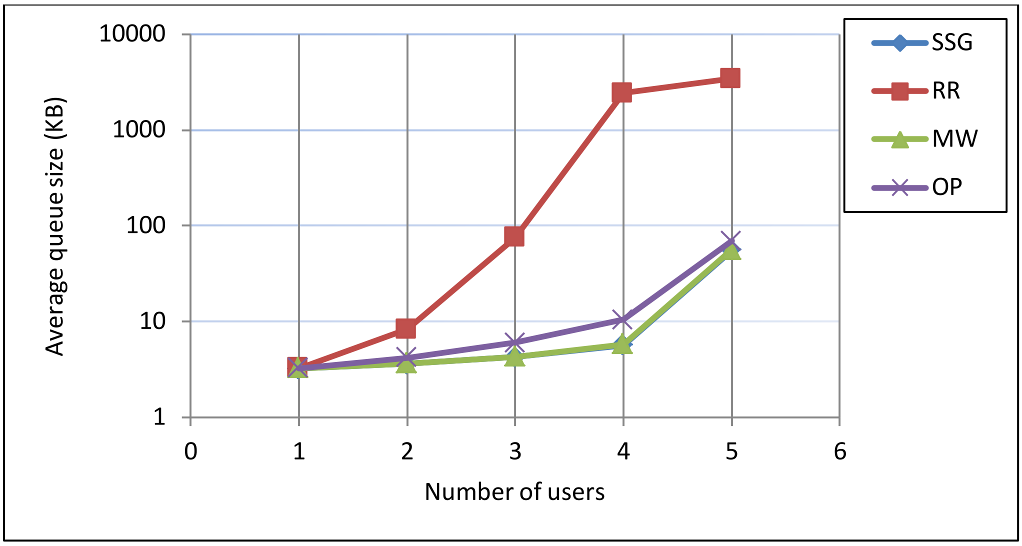

Figure 5.2: Average queue size of users on 4G network

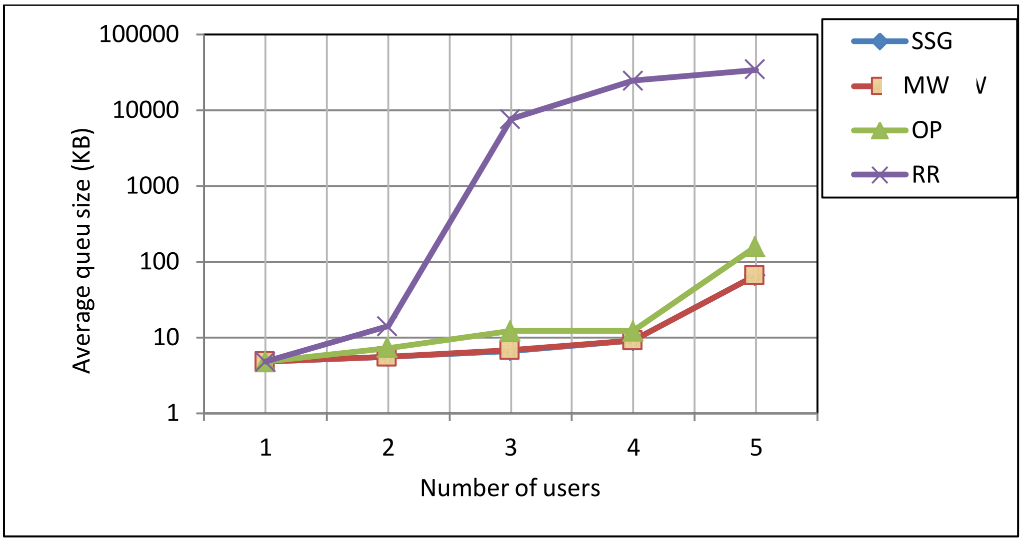

Figure 5.3: Average queue size of users on 3G network

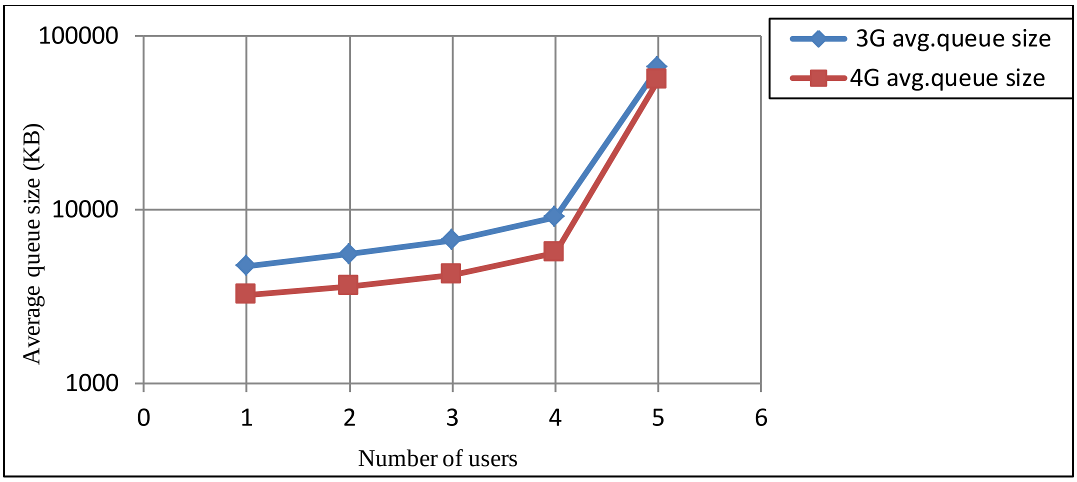

Figure 5.4: Comparison of average queue size on 3G and 4G networks

Moreover, In order to examine the dependence of queue-length performance on channel quality, the queue length is analyzed for different sub-channel ON probabilities when there were 4 users. In Figure 5.5, the mean fraction of time buffer size exceed 4KB is plotted for user 1 of the RR, SSG and MW scheduling schemes with different channel ON probabilities q from 0.3 to 0.9. Clear advantage of SSG scheduling can be seen over the whole range of channel qualities. We also observe that this advantage is more pronounced under stable wireless scenarios ($q \geq 0.5$). The system is highly unstable for very poor channel conditions ($q \leq 0.3$). For very reliable channels ($q \geq 0.9$), the queue-length performance of RR scheduling is comparable to that of SSG and MW scheduling.

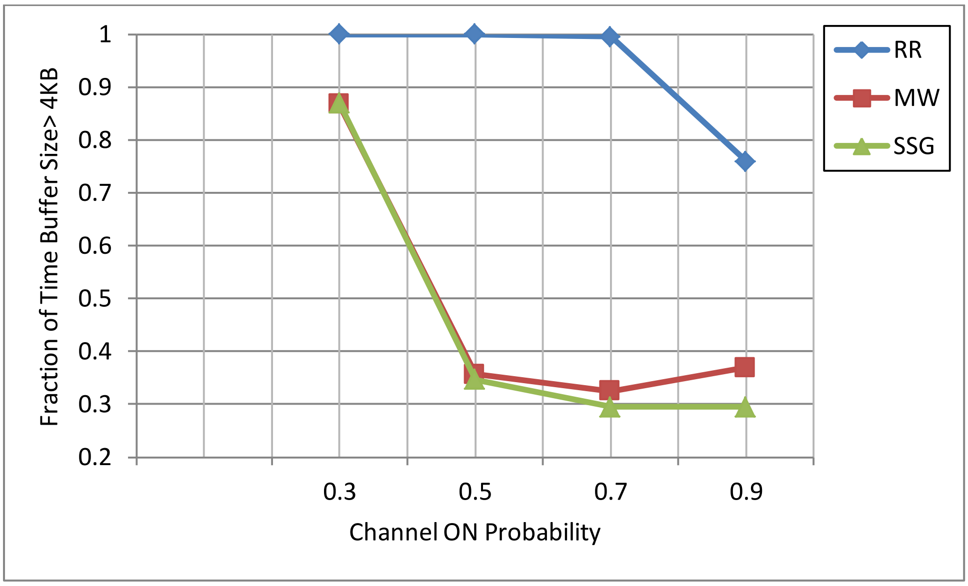

Figure 5.5: Mean Fraction of time buffer size exceed 4KB for users

5.3.2 Finite-Buffer Behavior

In this scenario, channel ON probability is 0.5 for 4 users with 20 channels and user buffer sizes ranging is from 8 to 64 KB. Also, the mean fraction of bytes and the mean fraction of I-frames are plotted that are lost for user 1. When users have finite buffers, any arrival that finds the buffer full is lost. Figures 5.6 illustrates the loss rate of I frame and data loss rate for different finite buffer size. Note that the loss rate of I-frames is more crucial for evaluating the performance of video streaming applications. In Figures 5.6, SSG and MW scheduling's curve are completely coincide on each other.

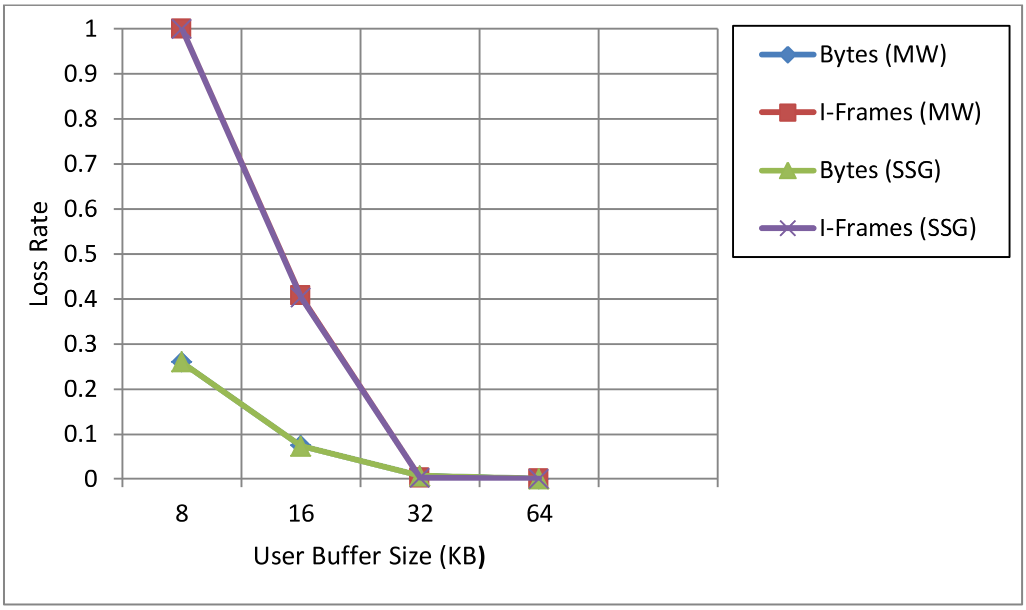

Figure 5.6: Mean fraction of bytes and mean fraction of I-frames that are lost for a user as a function of buffer size.

Consequently, when the user buffer size is small, the loss rate of I-frames is more than 90% since they cannot usually be accommodated in the buffer. Note that the loss of part of an I-frame is considered as the loss of the whole frame. As the buffer size is increased, the loss rate of I-frames decreases dramatically. It is also observed that the loss rate of bytes is much less.

Chapter 6

CONCLUSION AND FUTURE WORK

A VBR MPEG-4 video traffic generator was used to predict the queuing and throughput performance of several well-known schedulers. In particular, Queue length performance for multi-queue and multi-channel wireless system with LRD video traffic is evaluated.

Results of queuing performance analysis of schedulers' with ON-OFF channel model show that round-robin scheduler is not suitable for MPEG video streaming. On the other hand, MW and SSG are suitable downlink schedulers in 4G mobile broadband wireless networks. Additionally, performance of schedulers in terms of loss rate is investigated when users have finite buffers sizes at the base station. For the described system with symmetric arrival and channel processes, queue-length performance can directly be translated into delay performance as well.

Investigating and designing more complex schedulers for OFDMA based wireless networks can be part of future work. Particularly, this study can be extended to consider a heterogeneous user set with multi-rate, non-symmetric channels with heterogeneous traffic types in downlink of multi-channel wireless systems.

More realistic scenarios with complex channel models can also be analyzed with off-the-shelf simulation software. However, such analyses will lack insights about the dependency of parameters of the system. The sensitivity of the results to approximate models can be studied further.

In addition, the performance of the system with traffic shaping and several packet discarding policies can be evaluated as an extension to this work.

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APPENDICES

Appendix A: Z-test Tables

Table A.1: The t-test values [58]

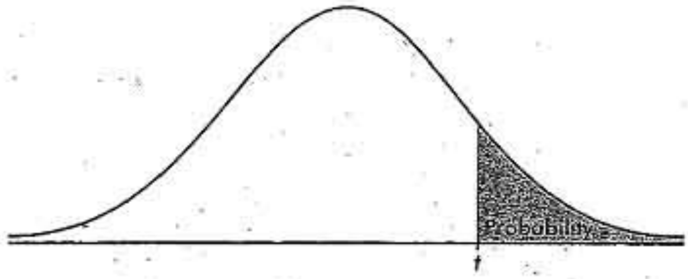

TABLE B: t-DISTRIBUTION CRITICAL VALUES

	Tail probability p											
df	.25	.20	.15	.10	.05	.025	.02	.01	.005	.0025	.001	.0005
1	1.000	1.376	1.963	3.078	6.314	12.71	15.89	31.82	63.66	127.3	318.3	636.6
2	.816	1.061	1.386	1.886	2.920	4.303	4.849	6.965	9.925	14.09	22.33	31.60
3	.765	.978	1.250	1.638	2.353	3.182	3.482	4.541	5.841	7.453	10.21	12.92
4	.741	.941	1.190	1.533	2.132	2.776	2.999	3.747	4.604	5.598	7.173	8.610
5	.727	.920	1.156	1.476	2.015	2.571	2.757	3.365	4.032	4.773	5.893	6.869
6	.718	.906	1.134	1.440	1.943	2.447	2.612	3.143	3.707	4.317	5.208	5.959
7	.711	.896	1.119	1.415	1.895	2.365	2.517	2.998	3.499	4.029	4.785	5.408
8	.706	.889	1.108	1.397	1.860	2.306	2.449	2.896	3.355	3.833	4.501	5.041
9	.703	.883	1.100	1.383	1.833	2.262	2.398	2.821	3.250	3.690	4.297	4.781
10	.700	.879	1.093	1.372	1.812	2.228	2.359	2.764	3.169	3.581	4.144	4.587
11	.697	.876	1.088	1.363	1.796	2.201	2.328	2.718	3.106	3.497	4.025	4.437
12	.695	.873	1.083	1.356	1.782	2.179	2.303	2.681	3.055	3.428	3.930	4.318
13	.694	.870	1.079	1.350	1.771	2.160	2.282	2.650	3.012	3.372	3.852	4.221
14	.692	.868	1.076	1.345	1.761	2.145	2.264	2.624	2.977	3.326	3.787	4.140
15	.691	.866	1.074	1.341	1.753	2.131	2.249	2.602	2.947	3.286	3.733	4.073
16	.690	.865	1.071	1.337	1.746	2.120	2.235	2.583	2.921	3.252	3.686	4.015
17	.689	.863	1.069	1.333	1.740	2.110	2.224	2.567	2.898	3.222	3.646	3.965
18	.688	.862	1.067	1.330	1.734	2.101	2.214	2.552	2.878	3.197	3.611	3.922
19	.688	.861	1.066	1.328	1.729	2.093	2.205	2.539	2.861	3.174	3.579	3.883
20	.687	.860	1.064	1.325	1.725	2.086	2.197	2.528	2.845	3.153	3.552	3.850
21	.686	.859	1.063	1.323	1.721	2.080	2.189	2.518	2.831	3.135	3.527	3.819
22	.686	.858	1.061	1.321	1.717	2.074	2.183	2.508	2.819	3.119	3.505	3.792
23	.685	.858	1.060	1.319	1.714	2.069	2.177	2.500	2.807	3.104	3.485	3.768
24	.685	.857	1.059	1.318	1.711	2.064	2.172	2.492	2.797	3.091	3.467	3.745
25	.684	.856	1.058	1.316	1.708	2.060	2.167	2.485	2.787	3.078	3.450	3.725
26	.684	.856	1.058	1.315	1.706	2.056	2.162	2.479	2.779	3.067	3.435	3.707
27	.684	.855	1.057	1.314	1.703	2.052	2.158	2.473	2.771	3.057	3.421	3.690
28	.683	.855	1.056	1.313	1.701	2.048	2.154	2.467	2.763	3.047	3.408	3.674
29	.683	.854	1.055	1.311	1.699	2.045	2.150	2.462	2.756	3.038	3.396	3.659
30	.683	.854	1.055	1.310	1.697	2.042	2.147	2.457	2.750	3.030	3.385	3.646
40	.681	.851	1.050	1.303	1.684	2.021	2.123	2.423	2.704	2.971	3.307	3.551
50	.679	.849	1.047	1.299	1.676	2.009	2.109	2.403	2.678	2.937	3.261	3.496
60	.679	.848	1.045	1.296	1.671	2.000	2.099	2.390	2.660	2.915	3.232	3.460
80	.678	.846	1.043	1.292	1.664	1.990	2.088	2.374	2.639	2.887	3.195	3.416
100	.677	.845	1.042	1.290	1.660	1.984	2.081	2.364	2.626	2.871	3.174	3.390
1000	.675	.842	1.037	1.282	1.646	1.962	2.056	2.330	2.581	2.813	3.098	3.300
∞	.674	.841	1.036	1.282	1.645	1.960	2.054	2.326	2.576	2.807	3.091	3.291
	50%	60%	70%	80%	90%	95%	96%	98%	99%	99.5%	99.8%	99.9%
	Confidence level C											

The structure of the Table A.1 is, based on probabilities (confidence level[3]) and degree of freedom. Because of that, the confidence interval[4] should define by significance level α using this property: $\varphi(Z) = 1 - \alpha/2$ (assuming it is $\alpha=0.05$). Additionally Table A.2 gives the *t* or *z* value for different t confidence interval (i.e., with having 95% confidence interval, z value is 1.96).

Table A.2: Z values for confidence intervals [59]

Confidence interval	Z
70%	1.04
75%	1.15
80%	1.28
85%	1.44
90%	1.645
92%	1.75
95%	1.96
96%	2.05
98%	2.33
99%	2.58

Appendix B: Empirical Experiments of scheduling behavior

Tables A.3 and A.4 represent loss important bursts and data loss rate for finite buffer consist of all information about 10 simulation run trials to obtain average of obtained data's for SSG . Moreover, the other tables' results are gain from this way with different parameters but just the average of their data's is shown.

[3] The probability of parameter's estimate belongs to the range of confidence interval and is characterized with (1-α).

[4] It gives an estimated range of population parameters and computed by 100(1- α) %.

Table A.3:Data loss rate for finite buffer size with SSG scheduling (a)

Buffer Size	8*1024			16*1024			
Trial	Loss important frame		Data loss rate	Loss important frame		Data loss rate	
1	1667/1667	1	0.25908	670/1667	0.4019	11082522/152906685	0.0725
2	1667/1667	1	0.25908	673/1667	0.4037	11097605/152906685	0.0726
3	1667/1667	1	0.25909	672/1667	0.40312	11088858/152906685	0.07252
4	1667/1667	1	0.25909	676/1667	0.40552	11083493/152906685	0.072485
5	1667/1667	1	0.25909	673/1667	0.40372	11079784/152906685	0.072461
6	1667/1667	1	0.25909	667/1667	0.40012	11082792/152906685	0.072481
7	1667/1667	1	0.25909	673/1667	0.40372	11093361/152906685	0.07255
8	1667/1667	1	0.25909	673/1667	0.40372	11091017/152906685	0.072535
9	1667/1667	1	0.25909	668/1667	0.40072	11097125/152906685	0.072574
10	1667/1667	1	0.25909	673/1667	0.40372	11067810/152906685	0.072383
Average	1		0.259088	0.402996		0.072509	

Table A.4: Data loss rate for finite buffer size with SSG scheduling (b)

Buffer Size	32*1024			64*1024		
Trial	Loss important frame	Data loss rate		Loss important frame	Data loss rate	
1	4/1667	1078885/152906685	0.007056	0/1667	70390/152906685	0.00046
2	4/1667	1075549/152906685	0.007034	0/1667	73390/152906685	0.00048
3	4/1667	1080955/152906685	0.007069	0/1667	66890/152906685	0.000437
4	4/1667	1100519/152906685	0.007197	0/1667	67390/152906685	0.000441
5	4/1667	1090429/152906685	0.007131	0/1667	65138/152906685	0.000426
6	4/1667	1077484/152906685	0.007047	0/1667	70390/152906685	0.00046
7	5/1667	1075676/152906685	0.007035	0/1667	67390/152906685	0.000441
8	5/1667	1096100/152906685	0.007168	0/1667	67390/152906685	0.000441
9	5/1667	1077979/152906685	0.00705	0/1667	68490/152906685	0.000448
10	6/1667	1086902/152906685	0.007108	0/1667	66890/152906685	0.000437
Average	0.002699	0.00709		0	0.000447	

Table A.5: Fraction of time buffer size> 4KB for infinite buffer size

Fractional of buffer size			
Probability of ON channel	SSG	MW	RR
0.3	0.8704	0.868	0.99999
0.5	0.3468	0.3568	0.99999
0.7	0.29526	0.3246	0.995503
0.9	0.29528	0.3693	0.759444

4-User Scenario (SSG)	channel probability 0.3	channel probability 0.5	channel probability 0.7	channel probability 0.9
Trial	Fraction of time buffer size > 4096			
1	0.8649	0.34773	0.2959	0.2962
2	0.86443	0.34741	0.2929	0.2954
3	0.89953	0.34763	0.2921	0.2949
4	0.86943	0.34766	0.2958	0.295
5	0.87204	0.3468	0.2963	0.2955
6	0.86648	0.34525	0.2958	0.2948
7	0.86715	0.34634	0.2961	0.2953
8	0.86504	0.34663	0.296	0.2953
9	0.86889	0.3469	0.2958	0.2951
10	0.86701	0.34614	0.2961	0.2954
avg	0.87049	0.346849	0.2953	0.2953

Figure A.1: Fraction of time buffer size> 4KB for infinite buffer size (SSG)

infinite buffer size				
4-User Scenario (MAXW)				
Trial	channel probability 0.3	channel probability 0.5	channel probability 0.7	channel probability 0.9
1	0.87281	0.35552	0.32361	0.36971
2	0.86971	0.35845	0.32543	0.36979
3	0.87023	0.35619	0.32406	0.37012
4	0.87101	0.3575	0.32532	0.3689
5	0.86476	0.35679	0.32485	0.36884
6	0.86669	0.35594	0.32399	0.36912
7	0.86304	0.35601	0.32538	0.36938
8	0.86746	0.35774	0.32488	0.37001
9	0.8678	0.35669	0.32226	0.36646
10	0.8669	0.35779	0.32634	0.37098
avg	0.86804	0.35686	0.32461	0.36933

Figure A.2: Fraction of time buffer size> 4KB for infinite buffer size (MW)

Round robin	channel probability 0.3	channel probability 0.5	channel probability 0.7	channel probability 0.9
Trial				
1	0.99999	0.99999	0.99534	0.75894
2	0.99999	0.99999	0.99321	0.75954
3	0.99999	0.99999	0.99635	0.75825
4	0.99999	0.99999	0.99477	0.75948
5	0.99999	0.99999	0.99651	0.76018
6	0.99999	0.99999	0.99674	0.76063
7	0.99999	0.99999	0.99556	0.75969
8	0.99999	0.99999	0.99525	0.75889
9	0.99999	0.99999	0.99546	0.75929
10	0.99999	0.99999	0.99584	0.75955
avg	0.99999	0.99999	0.9955	0.75944

Figure A.3: Fraction of time buffer size> 4KB for infinite buffer size (RR)

Figures A.1, A.2 and A.3 show Fractional of buffer size with infinite buffer size for SSG, MW and RR schedulers in details. These experiment are done 10 times for each channel ON probability from q=0.3 to q=0.9. Also, Table A.5 shows summary of these Figures.

Table A.6: Loss rare of I frame

Loss rate of I frame		
Buffer size	MW	SSG
8kb	1	1
16kb	0.4063	0.4029
32kb	0.0031	0.0026
64kb	0	0

Table A.7: Data loss rate

Data loss rate		
Buffer size	MW	SSG
8	0.2595	0.25908
16	0.0736	0.072509
32	0.0071	0.00709
64	0.00044	0.000447

Table A.8: Average queue length

Queue length				
Users	SSG	RR	MW	OP
1	3232.779	3236.145	3235.581	3237.447
2	3623.945	8287.992	3640.558	4213.282
3	4224.072	74765.98	4271.675	5991.186
4	5648.791	2416969	5759.536	10438.63
5	55841.7	3415902	56032.17	69303.32
Average	14514.26	1183832	14587.9	18636.77

Figure A.4 shows average queue size of SSG scheduler in details for 5 users in 10 run that summary of it is brought in TableA.8.

	A	B	C	D	E	F
1	1-User Scenario (SSG)					
2	Trial	Avg Q1	Max Q1	P(Q1>0)	T1	System throughput
3	1	3231.4608	79856	0.2496	1833.7	1833.6597
4	2	3235.1197	79856	0.2499	1833.7	1833.6597
5	3	3235.0284	79856	0.2496	1833.7	1833.6597
6	4	3239.7464	79856	0.2494	1833.7	1833.6597
7	5	3235.9733	79856	0.2494	1833.7	1833.6597
8	6	3230.5095	79856	0.2491	1833.7	1833.6597
9	7	3223.1297	79856	0.2487	1833.7	1833.6597
10	8	3227.9906	79856	0.2494	1833.7	1833.6597
11	9	3231.3934	79856	0.25	1833.7	1833.6597
12	10	3237.4366	79856	0.2512	1833.7	1833.6597
13	avgQ1	3232.7788				1833.6597
14						

	A	B	C	D	E	F	G	H	I	J
15	2-User Scenario (SSG)									
16	Trial	Avg Q1	Max Q1	P(Q1>0)	T1	Avg Q2	Max Q2	P(Q2>0)	T2	System throughpu
17	1	3619.3198	79856	0.356	1833.7	3608.468	71162	0.3553	1814.5	3648.1926
18	2	3629.311	79856	0.356	1833.7	3613.8683	71162	0.3553	1814.5	3648.1926
19	3	3627.7463	79856	0.3573	1833.7	3618.7266	71162	0.3564	1814.5	3648.1926
20	4	3626.7841	79856	0.3569	1833.7	3617.6381	71162	0.3558	1814.5	3648.1926
21	5	3621.4698	79856	0.3574	1833.7	3604.7723	71162	0.3559	1814.5	3648.1926
22	6	3627.5077	79856	0.3566	1833.7	3611.4357	71162	0.3564	1814.5	3648.1926
23	7	3623.3868	79856	0.3578	1833.7	3602.4263	71162	0.3548	1814.5	3648.1926
24	8	3621.0684	79856	0.3569	1833.7	3609.4202	71162	0.3552	1814.5	3648.1926
25	9	3616.998	79856	0.3563	1833.7	3612.8294	71162	0.356	1814.5	3648.1926
26	10	3625.8551	79856	0.3568	1833.7	3614.1081	71162	0.3563	1814.5	3648.1926
27	avgQ1	3623.9447								3648.1926

29	3-User Scenario (SSG)													
30	Trial	Avg Q1	Max Q1	P(Q1>0)	T1	Avg Q2	Max Q2	P(Q2>0)	T2	Avg Q3	Max Q3	P(Q3>0)	T3	System throughput
31	1	4214.8229	79856	0.5029	1833.7	4177.0416	71162	0.5036	1814.5	1814.5328	61292	0.5057	1864.9	5513.0729
32	2	4221.631	79856	0.503	1833.7	4167.1568	71162	0.5037	1814.5	4308.3017	61292	0.5038	1864.9	5513.0729
33	3	4230.6907	79856	0.5035	1833.7	4172.4906	71162	0.5018	1814.5	4325.9079	61292	0.5056	1864.9	5513.0729
34	4	4224.4969	79856	0.503	1833.7	4174.0625	71162	0.5023	1814.5	4325.7786	61292	0.5052	1864.9	5513.0729
35	5	4223.6378	79856	0.5033	1833.7	4180.1548	71162	0.5014	1814.5	4318.6694	61292	0.5042	1864.9	5513.0729
36	6	4225.5945	79856	0.5026	1833.7	4170.47	71162	0.5031	1814.5	4321.7926	61292	0.5059	1864.9	5513.0729
37	7	4222.5423	79856	0.5035	1833.7	4178.7863	71162	0.5024	1814.5	4322.3459	61292	0.5054	1864.9	5513.0729
38	8	4226.5601	79856	0.5033	1833.7	4175.9999	71162	0.5029	1814.5	4309.7733	61292	0.5039	1864.9	5513.0729
39	9	4221.3914	79856	0.5028	1833.7	4174.7612	71162	0.5027	1814.5	4320.7283	61292	0.505	1864.9	5513.0729
40	10	4229.3569	79856	0.5038	1833.7	4163.5342	71162	0.5027	1814.5	4309.5593	61292	0.5031	1864.9	5513.0729
41	avgQ1	4224.0725												5513.0729
42														

43	4-User Scenario (SSG)																	
44	Trial	Avg Q1	Max Q1	P(Q1>0)	T1	Avg Q2	Max Q2	P(Q2>0)	T2	Avg Q3	Max Q3	P(Q3>0)	T3	Avg Q4	Max Q4	P(Q4>0)	T4	System throughput
45	1	5663.992	84242	0.6976	1833.7	5626.773	71162	0.6977	1814.5	5703.6879	62213	0.6986	1864.9	5874.0198	87482	0.6986	1911.3	7424.4064
46	2	5641.3121	82242	0.6981	1814.5	5629.5251	71162	0.6981	1814.5	5693.5606	61292	0.6972	1864.9	5863.6313	87482	0.6991	1911.3	7424.4064
47	3	5657.9217	82742	0.6984	1833.7	5616.8827	71162	0.6979	1814.5	5700.247	61292	0.6963	1864.9	5864.5972	85982	0.6985	1911.3	7424.4064
48	4	5655.1831	82742	0.6972	1833.7	5630.2463	71162	0.6979	1814.5	5712.4145	61713	0.6966	1864.9	5875.053	86482	0.6984	1911.3	7424.4064
49	5	5636.8314	82242	0.6962	1833.7	5635.3196	71162	0.697	1814.5	5695.8999	61292	0.6962	1864.9	5868.6153	86982	0.699	1911.3	7424.4064
50	6	5641.7937	82742	0.6973	1833.7	5620.4311	71162	0.6973	1814.5	5693.906	62749	0.6968	1864.9	5868.8535	86982	0.6999	1911.3	7424.4064
51	7	5638.2588	80242	0.6979	1833.7	5623.2565	71162	0.697	1814.5	5681.9252	61292	0.6965	1864.9	5860.1881	88482	0.6968	1911.3	7424.4064
52	8	5650.405	80742	0.6981	1833.7	5618.6016	71162	0.6973	1814.5	5699.9027	61292	0.6973	1864.9	5867.493	86482	0.6981	1911.3	7424.4064
53	9	5651.6645	81242	0.6976	1833.7	5629.0639	71162	0.6987	1814.5	5716.2326	61713	0.6974	1864.9	5870.4892	85982	0.6977	1911.3	7424.4064
54	10	5650.5461	82742	0.6974	1833.7	5630.3074	71162	0.6978	1814.5	5692.3107	61749	0.697	1864.9	5873.7053	87982	0.6989	1911.3	7424.4064
55	avgQ1	5648.7908																7424.4064
56																		

57	5-User Scenario (SSG)																				
58	Trial	Avg Q1	Max Q1	P(Q1>0)	T1	Avg Q2	Max Q2	P(Q2>0)	T2	Avg Q3	Max Q3	P(Q3>0)	T3	Avg Q4	Max Q4	P(Q4>0)	T4	Avg Q5	Max Q5	P(Q5>0)	T5	System throughput
59	1	55969.972	362852	0.9452	1833.5	55924.7801	360307	0.9447	1814.4	55999.836	375425	0.9442	1864.7	56187.468	356794	0.9444	1911.2	56205.451	377627	0.945	1937	9360.8
60	2	57221.977	371064	0.9445	1833.5	57175.7577	369307	0.9448	1814.4	57250.039	383425	0.9442	1864.7	57449.009	0.9447	0.9447	1911.2	57450.414	385627	0.9444	1937	9360.8
61	3	54459.963	361626	0.945	1833.5	54404.8903	357276	0.9444	1814.4	54477.5	372317	0.9446	1864.7	54672.299	354415	0.9449	1911.2	54688.102	374683	0.9446	1937	9360.7
62	4	55735.514	361564	0.9448	1833.5	55676.6778	358807	0.945	1814.4	55760.47	373925	0.9448	1864.7	55950.123	355294	0.9452	1911.2	55962.448	376127	0.945	1937	9360.7
63	5	52994.757	347126	0.9448	1833.5	52944.7276	343276	0.9445	1814.4	5233008.2	358317	0.9446	1864.7	53204.05	339415	0.9449	1911.2	53218.247	361183	0.9449	1937	9360.7
64	6	57054.693	375352	0.9449	1833.5	57012.5945	371307	0.9448	1814.4	57079.418	385425	0.9448	1864.7	57283.669	369294	0.9448	1911.2	57289.198	389627	0.9449	1937	9360.9
65	7	54533.052	358852	0.9447	1833.5	54481.5584	354807	0.9449	1814.4	54544.744	369425	0.9443	1864.7	54751.514	351294	0.9447	1911.2	54757.125	372127	0.9448	1937	9360.8
66	8	58841.233	376564	0.9458	1833.5	58798.3847	373307	0.9456	1814.4	58876.014	387925	0.9458	1864.7	59070.863	369453	0.9458	1911.2	59074.605	390627	0.9455	1937	9360.8
67	9	56102.83	367064	0.945	1833.5	56057.0809	364807	0.9452	1814.4	56135.501	379425	0.9446	1864.7	56322.887	360794	0.9451	1911.2	56337.019	381127	0.9451	1937	9360.8
68	10	55502.971	367126	0.9447	1833.5	55455.6034	363276	0.9446	1814.4	55526.938	378317	0.9446	1864.7	55722.355	359915	0.9442	1911.2	55721.785	380683	0.9443	1937	9360.8
69	avgQ1	55841.696																				9360.8

Figure A.4: Average queue size of SSG

Appendix C: Code Descriptions

The codes of below illustrate generation of synthetic video traffic.

```
rand('state',sum(100*clock))
function [GOPMATRIX]=MPEG4TRAFFIC1(Nframes,Nseconds)
Nframes=2000;
Nframespersec=30;
Nseconds=Nframes/Nframespersec;
gopsize=12;
numgop=Nframes/gopsize;
second=1;
eachgopnum=round((Nframespersec*second)/gopsize);
a1=0.39;
a2=0.15;
SM=10.2;
SV=18.1;
Nseconds2=Nseconds/2;
sum=0;
sumgop=0;
gopnumber=0;
count=1;
q=1-1/SM;
while (sum<=Nseconds)
SN(count)=geornd(1-q);
GN(count)=(eachgopnum*SN(count));   )
sum=sum+SN(count);
```

```
sumgop(count+1)=sumgop(count)+GN(count);
gopnumber=gopnumber+GN(count);      count=count+1;
end
scenenumber=(count-1);
Im=17068;
Iv= 7965^2;
Isigma = sqrt(log(Iv/(Im^2)+1));
Imu = log((Im^2)/sqrt(Iv+Im^2));
Pm=9190;
Pv=7005^2;
Psigma = sqrt(log(Pv/(Pm^2)+1));
Pmu = log((Pm^2)/sqrt(Pv+Pm^2));
Bm= 6836;
Bv= 5323^2;
Bsigma = sqrt(log(Bv/(Bm^2)+1));
Bmu = log((Bm^2)/sqrt(Bv+Bm^2));
varnoise=4.36^2;
m=3;
scenemax=scenenumber;
ngg=0;

if_kk1=1;
icoef_kk1=1;
ii=1;
iii=1;
rownumber=0;
```

```
for j=1:scenemax
Icoef=ceil(lognrnd(Imu,Isigma));
IF1(1)=0;
IF2(1)=0;
NumI=GN(j);
NumP=3*GN(j);
NumB=8*GN(j);
Bframes=(lognrnd(Bmu,Bsigma,NumB,1))';
Pframes=(lognrnd(Pmu,Psigma,NumP,1))';
kk=1;
kkk=1;
for i=1:GN(j)  z= normrnd(0,varnoise);
rownumber=rownumber+1;
c=1;
iii=ii;
for k=1:gopsize
if (k==1)
if(i==1)
IF=((a1*IF1(i))+(a2*IF2(i))+z);
Iframes(i)=Icoef+IF;
GOPMATRIX(rownumber,1)= ceil(Iframes(i));
IF2(i+1)=IF1(i);
IF1(i+1)=IF;
frame(1)=[1];

else
```

```
IF=((a1*IF1(i))+(a2*IF2(i))+z);
Iframes(i)=Iframes(i-1)+IF;
GOPMATRIX(rownumber,1)= ceil(Iframes(i));
IF2(i+1)=IF1(i);
IF1(i+1)=IF;
frame(ii+12)=[1];
ii=ii+12;
end
elseif (k==((cc*m)+1)
GOPMATRIX(rownumber,k)=ceil(Pframes(kk));
kk=kk+1;
cc=cc+1;
frame(iii+3)=[2];
iii=iii+3;
else
GOPMATRIX(rownumber,k)= ceil(Bframes(kkk));
kkk=kkk+1;
end
end
end
icoef_kk1=icoef_kk1+1;
end
```

The code in below introduces the Verification test by using the obtained stream from the MPEG-4 traffic generator and compare with the real stream which belongs to the “Silence of the lambs” movie.

```
meanreal=mean(real)
meanmodel=mean(model)
varmodel=var(model);
varreal=var(real);
stream=cat(2,model,frame);
ggg=find(stream(:,2)==0);
stream(ggg,2)=3;
a=length(real);
df=1-a;
al=[0.25 0.20 0.15 0.10 0.05 0.025 0.02];
v=[0.674 0.841 1.036 1.282 1.645 1.960 2.054];
b=length(al);
performancedifference=(model-real);
samplemean=mean(performancedifference)
samplevariance=var(performancedifference)
samplestd=std(performancedifference)
CI1=zeros(b,1);
CI2=zeros(b,1);
SL=ones(b,1);
confidenceinterval=ones(b,1);
tresult=ones(b,4);
```

```
for w=1:b
CI1(w)=samplemean+(v(w)*(sqrt(samplevariance/a)));
CI2(w)=samplemean-(v(w)*(sqrt(samplevariance/a)));
SL(w)=al(w);
confidenceinterval(w)=100*(1-al(w));
end
tresult=cat(2,CI2,CI1,SL,confidenceinterval);
t=samplemean/((sqrt(a*samplevariance)/a-1));
CI1=samplemean+(t*(sqrt(samplevariance/a)));
CI2=samplemean-(t*(sqrt(samplevariance/a)));
MP1=(meanrealmeanmodel)+1.96*(sqrt(varmodel/a)+(varreal/a));
MP2=(meanrealmeanmodel)1.96*(sqrt(varmodel/a)+(varreal/a));

z0=((1)-samplemean)/samplestd;
```

Code below shows scheduling performance for RR, OP, MAXW and SSG schedulers. In this simulation four streams of traffic generator are called which all of that verified in previous process before using in simulation.

```
% Simulates a time-slotted multi-user multi-channel system
clear all;
clc;
```

```
% Initialization
rand('state',sum(100*clock))

noOfUsers=4;
noOfChannels=20;
burstInterval=40;
slotInterval=10;
bufferSize=1e9;
bufferThreshold=0;
rate=[500 500 500 500];
channelOnProb=0.7;

inA(1,:,:)=dlmread('E:\thises3\codes12-23\sr231.txt');
inA(2,:,:)=dlmread('E:\thises3\codes12-23\sr232.txt');
inA(3,:,:)=dlmread('E:\thises3\codes12-23\sr233.txt');
inA(4,:,:)=dlmread('E:\thises3\codes12-23\sr234.txt');
%inA(5,:,:)=dlmread('E:\thises\codes12-23\sr235.txt');
L=length(inA);
for tt=2:T
Q0=Q(:,tt-1)+A(:,tt-1);
```

```
A=createSlotArrivals(inA,burstInterval,slotInterval);
T=ceil(L*burstInterval/slotInterval); % Number of
Q=zeros(noOfUsers,T);
QBS=zeros(noOfUsers,T);
throughput=zeros(noOfUsers,1);
lost=zeros(noOfUsers,1);
importantLost=zeros(noOfUsers,1);
importantCnt=zeros(noOfUsers,1);
thresholdExceed=zeros(noOfUsers,1);
end
X=channel(noOfUsers,noOfChannels,channelOnProb,rate);
%Y=schedule_ssg(noOfUsers,noOfChannels,X,Q0);
%Y=schedule_maxw(noOfUsers,noOfChannels,X,Q0);
%Y=schedule_op(noOfUsers,noOfChannels,X);
Y=schedule_rr(noOfUsers,noOfChannels);
for ii=1:noOfUsers
if (A(ii,tt-1,2)==1)
importantCnt(ii)=importantCnt(ii)+1;
end
if (Q0(ii)>bufferSize)
lost(ii)=lost(ii)+Q0(ii)-bufferSize;
Q0(ii)=bufferSize;
if (A(ii,tt-1,2)==1)
importantLost(ii)=importantLost(ii)+1;
```

```
end
end
for ii=1:noOfUsers
S=0;
for jj=1:noOfChannels
S=S+X(ii,jj)*Y(ii,jj);
end
QBS(ii,tt)=Q0(ii);
Q(ii,tt)=max(Q0(ii)-S,0);
throughput(ii)=throughput(ii)+min(Q0(ii),S);
if (Q(ii,tt)>bufferThreshold)
thresholdExceed(ii)=thresholdExceed(ii)+1;
end
end
end
MQBS=mean(QBS,2);
maxQ=max(QBS,[],2);
MQ=mean(Q,2);
TH=throughput/T;
EX=thresholdExceed/T;
bytesum=sum(A,2);
LOSS=lost./bytesum(:,1);
disp('----------');
disp(['A ' num2str(noOfUsers) '-user-'
num2str(noOfChannels) '-channel system']);
```

```
disp(['Buffer size=' num2str(bufferSize) '. User rates={' num2str(rate) '}. Channel ON probability=' num2str(channelOnProb)]);
disp(['Total number of slots=' num2str(T) '. BurstInterval:SlotInterval=' num2str(burstInterval) ':' num2str(slotInterval)]);
for ii=1:noOfUsers
disp(['USER ' num2str(ii)]);
disp(['Average / max queue size = ' num2str(MQBS(ii)) ' / ' num2str(maxQ(ii))]);
disp(['Fraction of time buffer size > ' num2str(bufferThreshold) ' = ' num2str(EX(ii))]);
disp(['Average throughput = ' num2str(TH(ii))]);
disp(['Data loss rate = ' num2str(LOSS(ii)) '  (' num2str(lost(ii)) '/' num2str(bytesum(ii,1)) ')']);
disp(['Loss rate of important bursts = ' num2str(importantLost(ii)/importantCnt(ii)) '  (' num2str(importantLost(ii)) '/' num2str(importantCnt(ii)) ')']);
end
disp(['System throughput = ' num2str(sum(TH))]);
disp('----------');
```