Bayesian Information Criterion in LTE Downlink Scheduling Algorithm

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Abstract: *Real time multimedia has been a major trend in people daily life. With the rise of demands in faster internet connection for multimedia purpose, Long Term Evolution (LTE) has been used as a medium of transmission to fulfil these demands. Still, the need of handling multiple simultaneous multimedia transmission, either voice or audio is a challenge that LTE is facing. Many proportional fairness scheduling algorithms have been implemented in LTE such as Modified Largest Weighted Delay First (M-LWDF) that can handle up to 90 users in a single cell simultaneously with good bandwidth distribution. Yet there is still room for improvement as the allocation for simultaneous transmission of video and VoIP are affected by other best effort flows. Best effort flow such as internet surfing does not require a huge amount of bandwidth allocation whereas a sufficient amount from the best effort bandwidth allocation for best effort can be reallocated to video and VoIP flows. Hence, an adaptive algorithm named Criterion-Based Algorithm (C-B), Criterion-Based Proportional Fairness (C-BPF) and Criterion-Based Modified Largest Weighted Delay First (C-BMLWDF) based on Bayesian Information Criterion (BIC) had been proposed by the author. The result simulation of the solution had shown a better performance in throughput, delay, packet loss and fairness index of both video and VoIP transmission with a respective allocation for the best effort flow.*

Keywords: *LTE, criterion-based, bayesian information criterion, downlink scheduling, quality of service.*

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1. Introduction

Bayesian network is well known for its precise mathematical approximation result. There is still no approach made in Long Term Evolution (LTE) that involves Bayesian. Bayesian is used for approximation that involved uncertainty factor where in LTE, there is several uncertainties occur within a transmission such as congestion. Hence, Bayesian Information Criterion (BIC) had been implemented to get a better approximation result for Quality of Service (QoS) provisioning mechanism in downlink scheduling area. BIC that derives from Bayes Factor [25] and also an improvement of Akaike Information Criterion (AIC) [7] is selected as the method to be implemented.

Real time traffic has been increased rapidly nowadays with the rise of various multimedia allocation. This is the new challenge face in the implementation of LTE because multiple user with multiple real time traffic will indeed exhaust the bandwidth allocation, increase the delay and will lead to unsatisfied QoS. This causes scheduling algorithm to paid attention for a better distribution on real time traffic, both video and Voice over Internet Protocol (VoIP) traffic. Throughout the years of development in networking, scheduling algorithm is one of the most important factors of improvement for bandwidth allocation in downlink channel. Scheduling algorithm deals with many issues such as congestion, delay and throughput in a certain network. In LTE, satisfying the QoS while optimizing the bandwidth is the main objective as real time application is growing rapidly and need a better carrier for its purpose to be fulfilled.

The literature study had led to the research of utilizing bandwidth more efficiently for both multimedia traffic, video and VoIP. However, the implementation of Bayesian approach in LTE scheduling is very limited. The reason of this limitation is caused by:

1. The complexity of Bayesian approach in computing.
2. The required resource to complete a Bayesian based scheduling process is too larger.

The main contribution of our paper is, a less complex Bayesian approach, called, BIC, which based on an equation is implemented in LTE downlink scheduling process. BIC does not involve complex computation and does not require high processing power. Moreover, the effectiveness and the improvements of QoS in LTE network have been proven in this paper with the implementation of BIC. It is firm to conclude that BIC (a Bayesian approach) is applicable in LTE scheduling process. Our study will focus on downlink environment because most multimedia traffic will encounter deadline for its transmission which is determined by the bandwidth that is allocated to the transmission. By applying BIC rule in the downlink scheduling environment, leads a better bandwidth allocation for both video and VoIP. With BIC, the bandwidth will be allocated more to real time flow and at the same time allocate respective amount of bandwidth usage for the non-real time flow. BIC has the capability to penalize the necessary priority for every simultaneous flow based on the information obtained from the transmission.

Criterion-Based (C-B) is built from the mention BIC had increased the performance of LTE downlink scheduling. It is proven based on the simulation done in LTE-Sim [18] that C-B had outperform the Modified Largest Weighted Delay First (MLWDF) [23] in throughput, delay, and packet loss ratio in a multiple simultaneous transmission scenario. C-B has a significant improvement in video throughput with 31% of different percentage compared to MLWDF, with a stable higher increment throughout the transmission. Other than video throughput, C-B also contributed to 87% improvement at the middle of transmission which occupied by 50 users and resulted having below 0.065 seconds delay at the end of the transmission. Whereas for VoIP, C-B have reduced the delay down to 0.023 seconds at the end of the transmission and 50% lower packet loss ratio different percentage compared to MLWDF. C-B utilizes the scheduling on multimedia flow compared to best effort flow which further prioritize the scheduling to allocate more bandwidth to video and VoIP which caused the increase in the QoS performance.

In section 2, related works to this research are briefly explained which consists of the LTE downlink architecture, E-UTRAN Node B or also known as Evolved Node B (eNodeB) and also Bayesian works in networking environment. BIC implementation in LTE downlink scheduling is described in section 3. Section 4 discusses the proposed BIC theorem implemented in the research. Section 5 contains the results and discussion of simulation by comparing BIC, Modified Largest Weighted Delay First (MLWDF) and Proportional Fairness (PF). Finally, Section 6 concludes the paper.

2. LTE Downlink Study

LTE has reached its evolution time where the current LTE need to be improvised to suits the latest development, LTE-Advanced [10]. LTE-Advanced contains futuristic requirement and one of it is backward compatibility with the current LTE implementation. As its name suggest, LTE-Advanced requirement includes more advance support to the networking environment which one of its main concern would be heterogeneous network support. LTE-Advanced able to manage and control the interference that consist of different network environment, which required a flexible deployment strategy in field such as femtos, picos, relays and macros [14]. One of the requirements stated by ITU-R is the flexibility to support a wide range of services and application both real time and multimedia service heavily on mobile. The need to handle multiple type of device across heterogeneous network is already pursued by the industry [10].

In the current LTE, the performance of its implementation especially in wireless environment had encountered several questions from various researchers. In a research conducted, the load balancing issues with smart phones in LTE network had been raised along with other issues [23]. Due to the rise of mobile era, multimedia services and also social network, real time management have been demanded in LTE. Voice and video are the main factor of the need for better bandwidth allocation. Along with other factor such as degradation in spectral efficiency at low Signal-to-noise-ratio (SNR), which proved by a research conducted for performance measurement [24]. It is shown that performance in LTE downlink hasn't fully utilizes although LTE downlink is claimed to have as high as 300 Megabyte (Mb) peak rate. Some study shown that this problem arises because of transmission power and bandwidth allocation issues in downlink. Downlink architecture is located within eNodeB which is a part of E-UTRAN architecture, refer to Figure 1. Thus the scheduling of transmission based on the type of service is the one affecting the most bandwidth allocation for downlink [6].

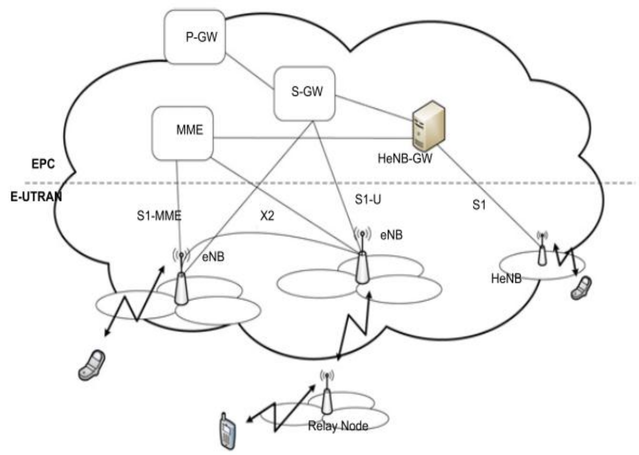

Figure 1. LTE-Advanced E-UTRAN architecture [10].

The challenge is to estimate the channel quality of an eNodeB for the User Equipment (UE) under it, called as the anchor cell which allowed the bandwidth allocation to be much better if a provisioning mechanism is added into the scheduling in the downlink area. Such an approach had been done in the past few year with the goal of designing the channel quality state scheme with more sufficient accuracy [15, 19, 29]. The next section describes the existing downlink scheduling algorithm that is used in LTE downlink.

2.1. LTE Downlink Scheduling Algorithm

There are already a few of scheduling algorithm that is widely used for downlink in LTE to serve the purpose of utilizing the bandwidth distribution for real time traffic, MLWDF, PF, EXP Proportional Fairness

(EXP/PF) is some of them. The key design on choosing the scheduling algorithm is mainly based on the trade-off between decision of optimality and computational complexity [6].

As stated, some of the consideration need to be taken will resolve based on its complexity and scalability whereas the Resource Block (RB) allocation must reach to the farthest extend within its coverage area. Along with less complex for low computing resources that suits the eNodeB architecture [22]. Spectral Efficiency and Fairness is among the optimality factor as bandwidth utilization is the key issues on handling multimedia traffic. So based on the key design, this several algorithm is chosen and used for LTE downlink implementation and had been proven to be efficient but room for improvement is still available for a scheduling algorithm that have better optimality along with less computational complexity. Followed is the brief study of the existing algorithm.

2.2. Modified Largest Weighted Delay First

MLWDF is proven to be one of the best downlink scheduling algorithms that manages the multimedia traffic [4]. In another paper, a Quality of Experience (QoE) research has been conducted to test the efficiency of MLWDF, EXP/PF and PF in real time and non-real time traffic [3]. The research had resulted that MLWDF is the best suitable downlink scheduling algorithm which has lesser delay and manage to support up to more than 50 users at a time. MLWDF has a simple complexity with optimal performance which suits the key design.

Performance wise in satisfying the QoS is also own by MLWF where it has higher system throughput, fairness and user in video streaming service [1]. MLWDF is a channel-aware algorithm which considers both the channel condition and user's QoS. In another paper, MLWDF multi-user diversity is tested and the result shown that MLWDF can suits the Orthogonal Frequency-Division Multiple Access (OFDMA) system performance with 45 video stream and 175 VoIP UE's at the same time [26]. MLWDF implementation is based on the Head-Of-Line (HOL) Delay information received from the UE's and the drop probability set by the QoS of the network. It will then be treated as a weight for PF for determining the priority of which flow that has the largest delay. This approach had been proven effective as the HOL will contain all the information pass by the UE and it is based on the Channel Quality Indicator (CQI) of the network. While for the best effort traffic, MLWDF uses PF to handle the traffic.

MLWDF have been widely used as the base research and had been improvise by many researchers. Some of the approach that has shown improvement would be Adaptive Modified Largest Weighted Delay First (AMLWDF) that uses Greedy Dynamic Resource Allocation which is assigning RBs from multiple channels at the same time [11, 30]. Other than that, another downlink scheduling algorithm that uses MLWDF as its base will be Virtual-MLWDF (VT-MLWDF) that added the concept of virtual token into MLWDF architecture [16].

2.3. Proportional Fairness

PF is one of the earliest algorithms implemented in LTE downlink scheduling strategies. It has a simple complexity and optimal fairness output. Proportional Fairness is widely known to be used as a base of numerous scheduling algorithm such as MLWDF, EXP/PF [4, 27], and etc. PF implementation is quite straight as its name suggest, it calculate the metric based on the average bandwidth of the current transmission and divide it with the available bandwidth of the network.

The algorithm has been proven to be optimal in fairness and has been brought from the 3rd Generation Partnership Project (3GPP) architecture into LTE where as it performs well in LTE especially in best effort traffic. It utilizes the bandwidth fairly and this left a room of improvement where an algorithm such as MLWDF where PF is the base of the algorithm and a weight priority is multiplied. Due to its fairness calculation, it can also be incorporated with Packet Loss Ratio (PLR) [13]. EXP/PF is one of the famous variations of PF modification where it is widely used in LTE to handle multimedia traffic [6]. EXP/PF implementation is by adding an exponential value of the total delay and user as a weighting element for PF. It has comparable result to MLWDF but lost in throughput and also UE's support whereas MLWDF can support up to more than 50 users.

The conclusion of the related work is MLWDF is the best widely known and use downlink scheduling algorithm in the LTE for multimedia traffic due to its capability to support more UE's as well as maintain the throughput of each user. Still the study shown that MLWDF is already been used by many researchers as a base for new downlink algorithm and have been outperformed by its modification such as AMLWDF and VT-MLWDF. The modification may have a slight complexity compared to MLWDF so a modification of MLWDF but with less complexity and better optimality is needed. This is the objective of the research where MLWDF will be incorporated as one of the criteria in Bayesian Information Criterion implementation for LTE downlink scheduling algorithm.

3. Bayesian Information Criterion

Bayesian Information Criterion [20, 25] is used in statistic where it is a criterion for model selection among a finite set of models. It uses likelihood function and is also closely related to Akaike

Information Criterion (AIC) [2]. As the BIC incorporate the Bayes Factor [12] into the equation, BIC is claimed to penalize free parameter more than AIC which make it to have a better selection result. Statistically, BIC also incorporates Maximum Likelihood Estimation (MLE) [2].

Due to its nature of usage in statistics, BIC is built to be an adaptive calculation where it will deal with uncertainty with the set of criteria or factors that change with the models. Or in real world, BIC can be used to determine the uncertainty of a selection based on a set of criteria that is available. BIC is derived as followed:

BIC under the normality assumption:

$$\mathrm{BIC} = x^2 + k \cdot \ln(n) \tag{1}$$

Where *x* is treated as the observed data, which focuses on the variable that would be the main influence of the output changes. Whereas n is referred as the number of data points in *x*, or equivalently the sample size of the observed data. While *k*, it representing the number of free parameter to be estimated based on the environment of the observed data. This formula is derived from the logic of normal assumption based on the information environment and other factor such as the value of the observed data and its sample size.

BIC is not a stranger to networking, in some research, BIC had been used as the estimation method for a certain process. In a cognitive network, BIC is used as the score function to determine the congestion level in the network [21]. Due to Bayes Factor, BIC can adaptively calculate the weight of a certain network parameters and make a priority selection based on it thus determine the congestion on which hop in the cognitive wireless network. The result shown that the selection made is precise and is treated as a provision mechanism in cognitive control of a multi-hop wireless network.

Another incorporation of BIC component, Bayes Factor is in wireless network fault diagnosis [28] which has shown that Bayes Factor is suitable for analyzing and dynamic adaptation of estimation in various networking issues. It is also proved to be a used in bandwidth allocation as one of the Bayesian statistical model used to alleviate greediness in a wireless mesh networks [7]. Adaptation and dynamic is the key of using Bayesian and it is proven again with Bayesian Theory implemented for ad-hoc networks to have on-the-fly ability in learning the wireless network environment [17].

For a better provisioning mechanism, the author had selected BIC as it is best suited for a probability model that deal with the realization of random variables [31], which again is claimed to suits factor analysis models where the prior distribution can be adjusted to different level with a better approximation output as the result [9]. Based on its predecessor such as AIC, DIC and WAIC, BIC is proved to be useful when it comes to comparing highly dissimilar models [8]. Due to its Bayes Factor integration, BIC is used more for an evaluation criterion for models defined in terms of their posterior probability [5] where the equation is described under a normality assumption [20] in Figures 2 and 3.

4. Proposed Algorithm

The idea is to use BIC to determine the weight of the flow in the multimedia traffic and the weight based on the criterion selection made. BIC requires a set of criteria for its implementation where downlink scheduling can provides such as QoS parameter, CQI and etc. Several approaches have been made and are classified as follows:

4.1. Approach 1: Criterion-Based Algorithm

In this approach, Criterion-Based (C-B) is used as a downlink scheduling algorithm and is designed for QoS-Aware approach. The implementation has shown that C-B penalizes the observed data as comparison between other observed data and this lead to exhaustion to the bandwidth utilization for other flows that did not have QoS such as Best Effort Flows. Other than that, the approach also has shown that VoIP flow will not perform well under C-B as the priority will go to Video flow that has a bigger queue size. Below are the C-B algorithm based on Equation (1):

Criterion-based:

$$C - B = \left(\frac{\text{Available Bandwidth}}{\text{Average Transmission Rate}} \right)^2 + HOLD.\ln(\text{QueueSize}) \tag{2}$$

Where HOLD represents the Head of Line Delay that is received in every transmission as the notification of the packet transmission current delay status. Queue size is increasing based on the transmission flow numbers, while the available bandwidth and average transmission rate differ based on the queue size, transmission flow number and also delay of the current network environment. Refer Figure 2 for the flow explanation.

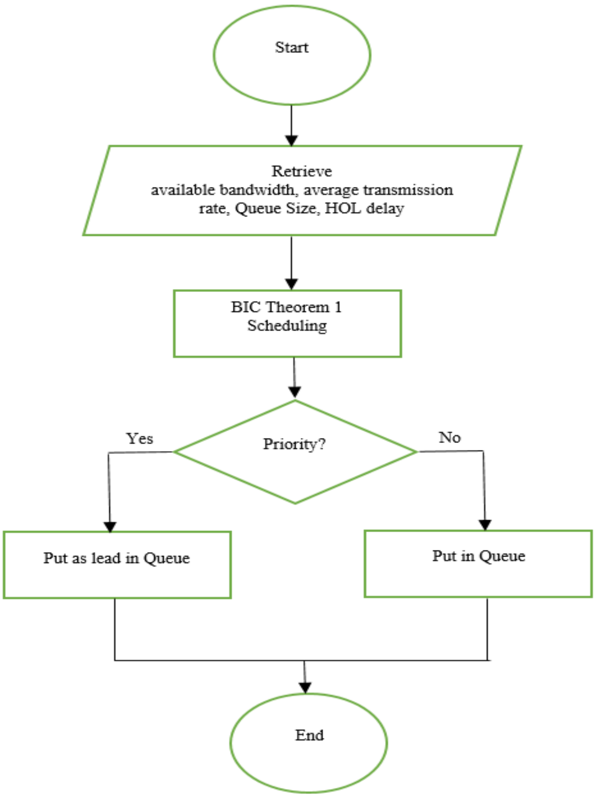

Figure 2. Criterion-based algorithm flowchart.

This research has also shown that C-B didn't take fairness into calculation as it simply selects the higher priority based on the calculation. Figure 2 shows the flow of C-B where the input does not retrieve enough information for a fairer scheduling which resulted not as good as C-BMLWDF, refer section 5.

4.2. Approach 2: Criterion-Based Proportional Fairness Algorithm

This theory is based on other downlink scheduling algorithm in LTE where the base is proportional fairness and the weigh is the one vary. So in this approach, Criterion-Based Proportional Fairness (C-BPF) will calculate and estimate the weight of the spectral efficiency based on the Queue Size. The approach has a better result in delay and throughput compare to the first theorem as PF metric is used as the metric return with BIC incorporated to PF as a weight. The only disadvantage is Best Effort (BE) flow still suffers insufficient bandwidth utilization which will cause the high packet loss. The flow start with receiving input from eNodeB, calculate the weight using C-B where the criteria evaluated is changed and added into the PF for priority metric as shown in Figure 3. Following is C-BPF algorithm based on Equation (1) and Proportional Fairness (3):
Proportional Fairness:

$$PF = \left(\frac{\text{Available Bandwidth}}{\text{Average Transmission Rate}}\right) \qquad (3)$$

Criterion Based Proportional Fairness:

$$C\text{-}BPF = \left(\text{SpecEff}^{2} + \frac{\text{SpecEff}}{\text{NbFlow}}.\ln(QueueSize)\right) \times PF \qquad (4)$$

SpecEff represents the spectral efficiency that is retrieved based on the current network bandwidth distribution and available bandwidth. It is then divided with the number of flow (NbFlow) for the current transmission of the estimated efficiency of bandwidth that is treated as the free parameter. The Queue size is used for the sample size of the SpecEff as it is affected by the current size of the transmission. To add the fairness index into the equation, it will then be added as a weight to the PF calculation for a better scheduling allocation that has the weight of spectral efficiency. Refer Figure 3 for the flow of C-BPF.

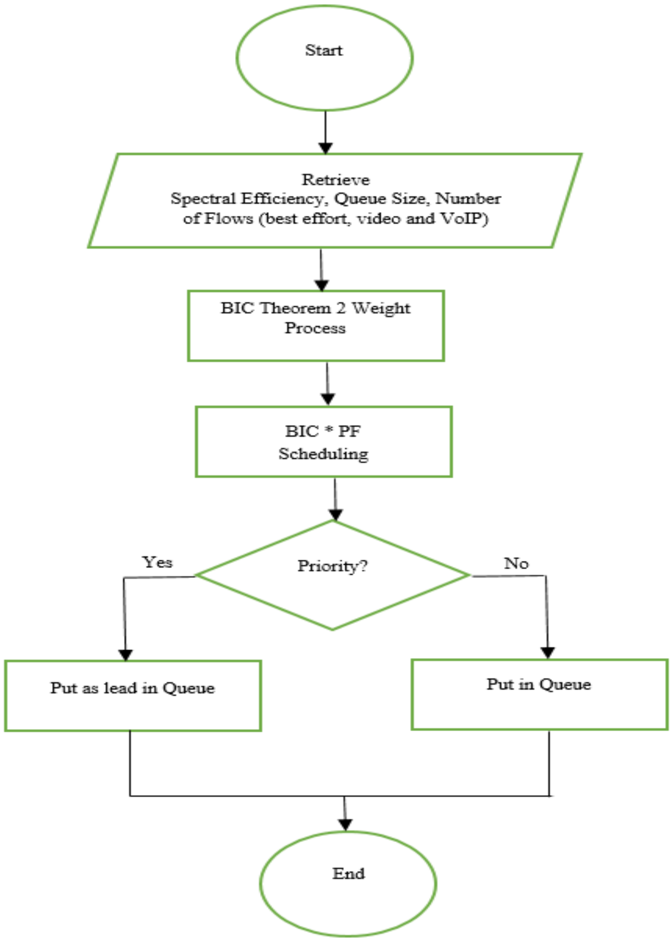

Figure 3. Criterion-based proportional fairness algorithm flowchart.

4.3. Approach 3: Criterion-Based Modified Largest Weighted Delay First Algorithm

The last approach is the most complicated but still consider as a simple implementation for the physical layer because the algorithm just need to have a temporary buffer to calculate the total delay of the current transmission that involved every single flow. This is crucial as knowing the current total delay can help the C-B to calculate the delay estimation much precisely.

Along with the incorporation of MLWDF that will involve their main calculation algorithm, Criterion-Based Modified Largest Weighted Delay First (C-BMLWDF) is the best achievement for the time being with the most satisfying result. The result are also good for both real time flow which is Video and VoIP as it will prioritize the scheduling based on the delay of the current transmission and the current flow. The implementation of C-BMLWDF is as described:

$$C\text{-}BMLWDF = \left[\text{Total Delay}^2 + \left(\frac{-\log_{10}(\text{Drop Probability})}{\text{Max Delay}} \times HOLD\right).\ln(RNbFlow)\right] \times PF \qquad (5)$$

The Total Delay and RNb Flow is acquired from filtering only the delay and flow of real-time transmission which are Video and VoIP, hence is used as the new observed data and number of data unit for C-BMLWDF. It is separated from other transmission such as Best Effort flow and only contains the total number of flow for real time transmission. This is then accompanied with the MLWDF weight algorithm [18], where will calculate the weight of the delay for every transmission which is treated as the free parameter in C-BMLWDF. To add the fairness index, it is then multiplied with PF as a weight of delay. Refer Figure 4 for more description on C-BMLWDF.

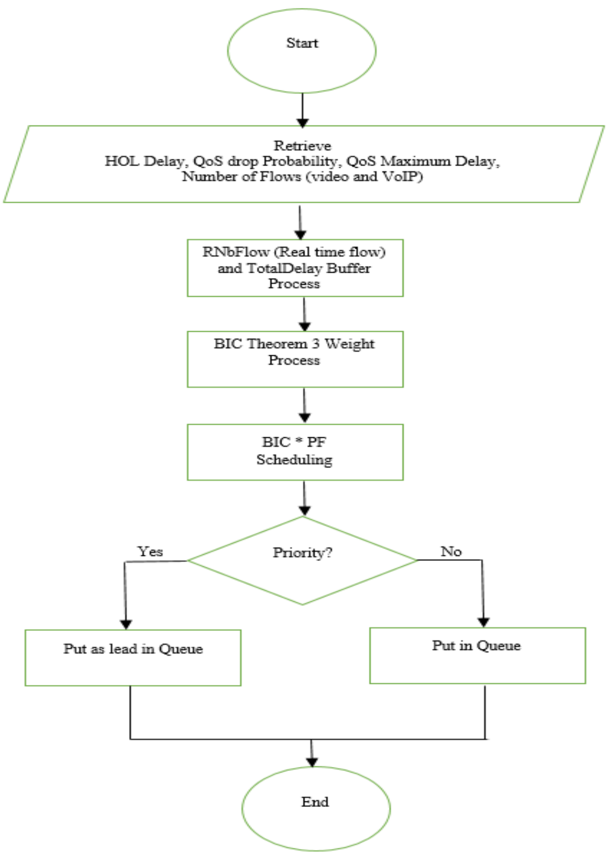

Figure 4. Criterion-based modified largest weighted delay first flowchart.

Figure 4 shows that the information needed from eNodeB are the standard QoS parameters, which indicate flexibility to integrate with other heterogonous networks as. The information such as RNBflow is acquired through the process which filters the real time transmission into a temporary buffer where RNbFlow (Real Time Number of Flow) will be counted for the purpose of allocating and scheduling more priority on real time service. Along within the temporary buffer, the total delay of the current transmission which consists of multiple flows will be counted based on the HOL delay received from every flow. It will then sum up and keep on increasing as the transmission is still ongoing. Both RnBFlow and Total Delay are then used in C-BMLWDF which also incorporates MLWDF weight calculation as a part of BIC free parameter calculation. This is to estimate the highest delay of the network can tolerate and predict the output based on the RnBFlow and TotalDelay information. The output will then be the weight that will be incorporate with PF for priority metric scheduling.

C-BMLWDF is and improvisation of the previous proposed solution that is C-B and C-BPF. It contains more criteria to be evaluate, more fairness for real time transmission and a more precise delay calculation. The incorporation of M-LWDF into the algorithm is due to the flexibility of delay calculation which is required for a better criterion evaluation. As C-BMLWDF derived from BIC calculation, it penalized more on the observed data which is delay, hence a better delay focused algorithm compared to C-B, C-BPF or MLWDF.

5. BIC Simulation Results And Discussion

The simulation is conducted in LTE-Sim [18] where the existing algorithm such as MLWDF, PF and Exp Rule are already implemented in the downlink scheduling. C-B is first compared by its approached and from the result, the best C-B will be tested with other existing algorithm. The objective of the simulation is to test C-B in a more than 50 user environment with real time traffic and non-real time traffic that consist of best effort, video and VoIP traffic. Table 1 is the simulation parameter for C-B comparison.

The simulation is conducted with several parameters as shown and others are defaulted by LTE-Sim simulator. For this simulation, a fixed video data rate of 242kb is used for video traffic. While for VoIP traffic, the data rate is 20 bytes in 20 seconds transmission. The UE position is randomized for every UE's interval and is also randomized for every simulation. The randomization is within 1km of radius of eNodeB. The number of traffic within UE's is randomized where there will be video and VoIP traffics within the UE's number, e.g., 10 UE's transmitting 3 video traffic and 7 VoIP traffic. C-B, C-BPF and C-BMLWDF performances are compared with MLWDF, refer Table 2 for results.

Table 1. Simulation parameters for BIC1, BIC2 and BIC3 in VoIP and video traffic.

Parameter	Value
PHY	OFDMA
Bandwidth / Frame Length	5 MHz / 10 ms
Frame Structure	TDD
Modulation	QAM, 4-QAM, 16-QAM
Simulation Period	60s
Number of Simulation	5
Traffic Models	Real-time: Video and VOIP; non Real-time: best-effort
Mobility	eNodeB: Constant Position; UE: Random Direction
Speed	3km/h
Number of UEs	10-90
UE's interval	10
Downlink Scheduling Algorithm	C-B, C-BPF, C-BMLWDF, MLWDF

5.1. Criterion-based Comparison

Based on the summary found in Table 2, C-B have then better value compared in the simulation that consist of Video, VoIP and BE traffic. Still, C-BMLWDF have better fairness index in both video and VoIP. While C-BPF is only good in Video delay, BE throughput and Spectral Efficiency. Regarding BE traffic affected by C-B, C-B have the highest fairness index, C-BPF have the highest throughput comparable to MLWDF BE throughput. Based on the result, C-BMLWDF is chosen as the most stable BIC algorithm. It is then compared to MLWDF in Table 3.

Table 2. Criterion-based comparison summary.

BIC Theorem	Video				VOIP				BE			SE
	D	FI	PLR	T	D	FI	PLR	T	FI	PLR	T	
C-B	x	x	√	√	√	x	√	x	√	x	x	x
C-PF	√	x	x	x	x	x	x	x	x	x	√	√
C-MLDWF	x	√	x	x	x	√	x	√	x	√	x	x

5.2. Simulation Results and Discussion

In Figure 6, C-B had shown a low delay in handling simultaneous user flow for video. Due to C-B penalization on delay, it had lower delay handling as the user increase. All C-B algorithms started with a lower delay value when it is 10 users. While all algorithm increased slightly as user increased, with a lower starting value, C-B algorithm have lower increasing value compared to MLWDF. The average different percentage of 3.8% has shown between C-BMLWDF and MLWDF on 90 users. The result shows that all C-B algorithms handle better Video delay compared to MLWDF with C-B having the lowest delay throughout the simulation. The most significant different would be the starting value of delay between C-B and other algorithm with the value of 0.01 seconds delay. VoIP Delay in Figure 7 is another QoS parameter that had been improved by C-B with the decreased value starting from 20 users. The average different is 73% at 30 users and highest different of 87% at 50 users between C-B and MLWDF. Delay is the most significant contribution in C-B implementation with a decreased value as low 0.065 seconds for 90 users in Video and 0.023 seconds for 90 users in VoIP which are good for real time transmission.

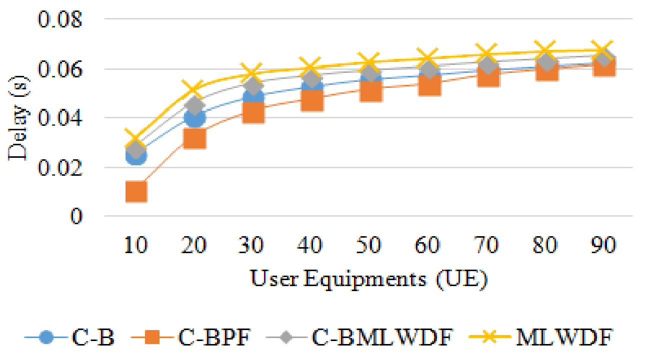

Figure 6. Video delay LTE-sim simulation result.

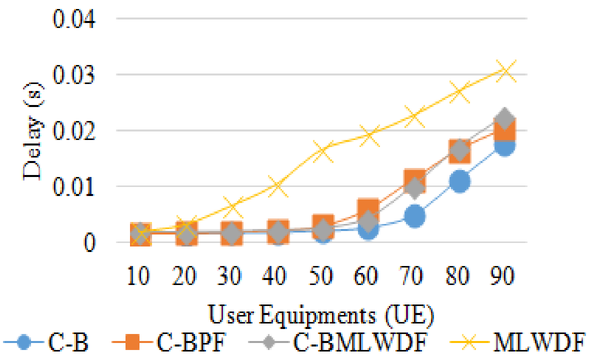

Figure 7. VoIP Delay LTE-sim simulation result.

Figures 8 and 9 show that C-B has a slight improvement in packet loss ratio for both Video and VoIP. C-BMLWDF has stable lines with minimal changes compare to MLWDF in Figure 8 with a slight increasing value for every user interval. The average different percentage start to have a significant different starting at 20 users with 33% compared to MLWDF and maintain constantly until 90 users for video. While for VoIP, both C-B and C-BMLWDF having a constant lower value compared to MLWDF starting at 60 users with the average improvement of 60% and 46% respectively. The value at 90 users shows that C-BMLWDF has 59% different compared to MLWDF. By prioritizing delay as the observed data, C-BMLWDF had shown a constant performance in handling both Video and VoIP packet loss ratio along with the delay compared to MLWDF.

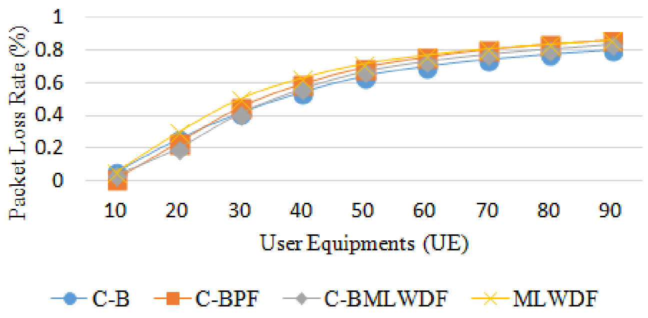

Figure 8. Video packet loss ratio LTE-Sim simulation result.

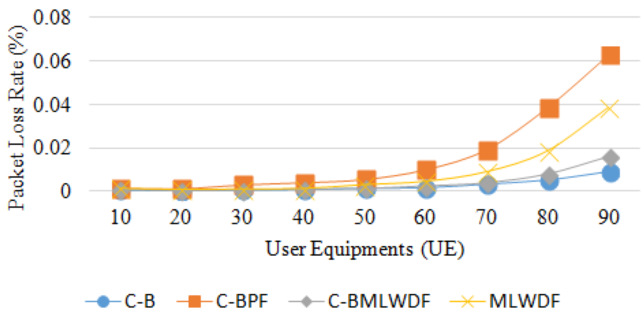

Figure 9. VoIP packet loss ratio LTE-Sim simulation result.

A slight improvement in Video Fairness index is shown by C-B and C-BMLWDF compared to MLWDF as shown in Figure 10. The average different of 13% had been gained by C-BMLWDF compared to MLWDF at 40 users. C-BMLWDF had an increase in fairness index at 20 and decreases minimally until the end. By filtering the real time flow and delay, the fairness for Video and VoIP had slightly increased compared to MLWDF. VoIP fairness index in Figure 11, C-BMLWDF had shown a slight improvement compare to MLWDF as much as 0.6% improvement at 80 users. The result is comparable to MLWDF VoIP fairness index from the early transmission until 90 users. As for VoIP, the fairness index is satisfying for all algorithms including MLWDF as the size of data transmitted through the simulation for VoIP is small compared to the size of data transmitted in Video transmission.

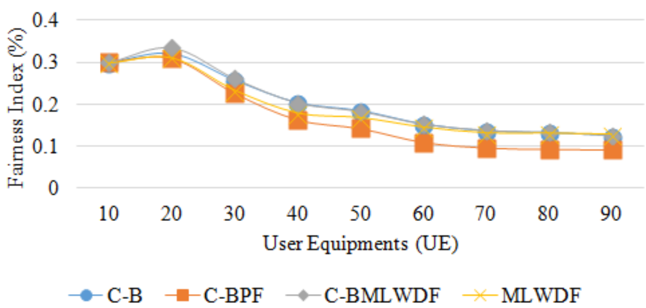

Figure 10. Video fairness index LTE-Sim simulation result.

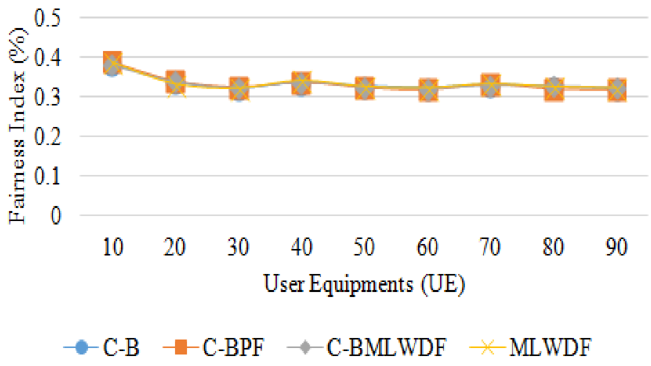

Figure 11. VoIP fairness index LTE-Sim simulation result.

In Figures 12 and 13, C-B had shown a significant improvement for Video and VoIP Throughput as it have higher throughput for almost every user interval. The bandwidth allocation is based on the priority metrics calculated by the scheduling algorithm and due to the penalization of real time flow, all C-B algorithm have a better throughput compared to MLWDF. C-BMLWDF started to have higher throughput at 20 users and continues with stable lines with the average increment compare of 28% at 30 users, 30% at 80 user and 31% at 90 users compared to MLWDF.

As for VoIP throughput, due to the minimal data transmitted, there is not much bandwidth used for the transmission but a better throughput had been shown by C-BMLWDF constantly compared to MLWDF with the average improvement of 2.9% at 90 users. Spectral Efficiency for C-B is comparable to MLWDF as shown in Figure 14, with C-BPF has a slight improvement at 90 users with an average different of 3% compare to MLWDF. Spectral efficiency includes BE traffic along in the calculation which will result less performance for C-B as it focuses more on real time transmission. Refer Table 3 for a complete summary comparison on C-BMLWDF and MLWDF.

C-BMLWDF outperforms most of MLWDF performance except for BE fairness index, BE throughput and Spectral Efficiency. The result shown that in most of the QoS parameter, C-BMLWDF outperforms MLWDF in the simulation. For fairness index, the fairness is calculated by the network environment which consists of the fairness index given to a certain transmission during a simultaneous transmission like in this research it is consist of BE, Video and VoIP transmission. Spectral Efficiency is also affected by the same rule and that is the main reason why C-BMLWDF is chosen over its predecessor as it has better value in fairness index and a comparable value for spectral efficiency with an overall better result compare to MLWDF.

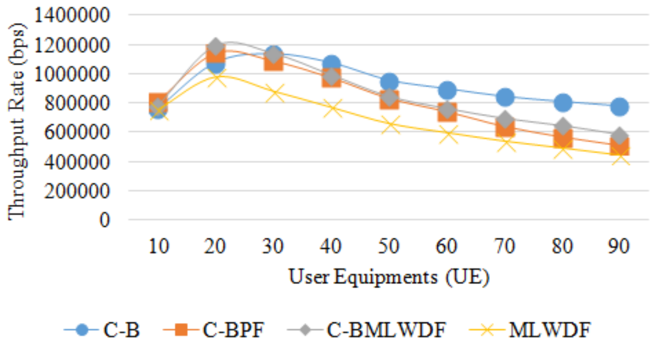

Figure 12. Video throughput LTE-Sim simulation result.

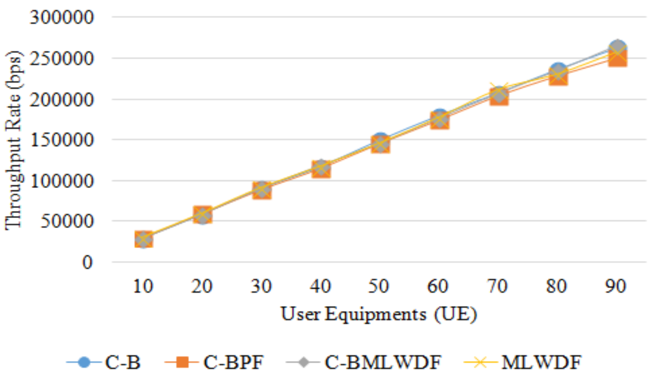

Figure 13. VoIP throughput LTE-Sim simulation result.

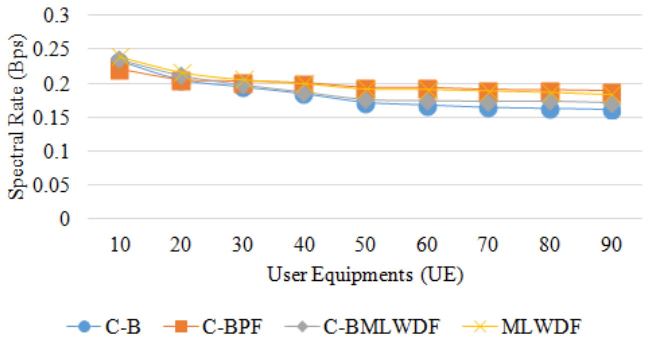

Figure 14. Spectral efficiency LTE-Sim simulation result

Table 3. BIC theorem Vs MLWDF comparison summary.

Downlink Algorithm	**Video**				**VOIP**				**BE**			**SE**
	D	FI	PLR	T	D	FI	PLR	T	FI	PLR	T	
C-BMLWF	√	√	√	√	√	√	√	√	x	√	x	x
MLWDF	x	x	x	x	x	x	x	x	√	x	√	√

6. Conclusions

Based on simulation conducted, C-B had significantly contributes to the LTE downlink scheduling environment by focusing more on real time transmission aspect and its improvement. With a better fairness index, C-BMLWDF had been chosen as the proposed solution as it outperforms most of the MLWDF performance. Having a better focus on real time flow and delay, C-BMLWDF is more suitable in handling multiple simultaneous user compared to its predecessor, C-B and C-BPF. C-BMLWDF has lower delay, packet loss ratio and higher throughput compared to MLWDF. The most significant improvement would be Video and VoIP delay as C-BMLWDF penalized the delay as its observed data based on the BIC calculation.

As for future works, implementing one of the C-B algorithm into uplink would benefit LTE network as C-B can be adjusted flexibly based on the criteria available. MLWDF have been chosen as the algorithm to be tested against due to its wide implementation and good capability in handling multiple simultaneous user. Hence, a further testing will be conducted again with different scheduling algorithm that covered a different objective.

References

[1] Adibah H., Ramli M., Basukala R., Sandrasegaran K., and Patachaianand R., "Performance of Well Known Packet Scheduling Algorithms in the Downlink 3GPP LTE System," *in Proceedings of IEEE 9th Malaysia International Conference on Communications*, Kuala Lumpur, pp. 815-820, 2009.

[2] Akaike H., "A New Look at the Statistical Model Identification," *IEEE Transactions on Automatic Control*, vol. 19, no. 6, pp. 716-723, 1974.

[3] Alfayly A., Mkwawa I., Sun L., and Ifeachor E., "QoE-based Performance Evaluation of Scheduling Algorithms Over LTE," *in Proceedings of IEEE Globecom Work*, Anaheim, pp. 1362-1366, 2012.

[4] Basukala R., Ramli H., and Sandrasegaran K., "Performance Analysis of EXP/PF and M-LWDF in Downlink 3GPP LTE System," *in Proceedings of 1st Asian Himalayas International Conference Internet*, Kathmandu, pp. 1-5, 2009.

[5] Boehm B., "A Spiral Model of Software Development and Enhancement," *IEEE Computer Society*, vol. 21, no. 5, pp. 61-72, 1988.

[6] Capozzi F., Piro G., Grieco L., Boggia G., and Camarda P., "Downlink Packet Scheduling in LTE Cellular Networks : Key Design Issues and a Survey," *IEEE Communications Surveys and Tutorials*, vol. 15, no. 2, pp. 678-700, 2013.

[7] Djahel S., Begriche Y., and Nait F., "A Bayesian Statistical Model to Alleviate Greediness in Wireless Mesh Networks," *in Proceedings of IEEE Global Telecommunications Conference*, Miami, pp. 1-6, 2010.

[8] Gelman A., Hwang J., and Vehtari A., "Understanding Predictive Information Criteria for Bayesian Models," *Statistics and Computing*, vol. 24, no. 6, pp. 997-1016, 2014.

[9] Hirose K. and Kawano S., "Bayesian Information Criterion and Selection of the Number of Factors in Factor Analysis Models," *Journal of Data Science*, vol. 9, pp. 243-259, 2011.

[10] Ian F., David M., and Elias C., "The Evolution to 4G Cellular Systems: LTE-Advanced," *Physical Communication*, vol. 3, no. 4, pp. 217-244, 2010.

[11] Jang H. and Hu C., "Fairness-Based Adaptive QoS Scheduling for LTE," *International Conference ICT Converge*, South Korea, pp. 626-631, 2013.

[12] Kass R. and Raftery A., "Bayes Factors," *Journals of the American Statistical Association*, vol. 90, no. 430, pp. 773-795, 2007.

[13] Khan N., Martini M., Bharucha Z., and Auer G., "Opportunistic Packet Loss Fair Scheduling for Delay-Sensitive Applications over LTE Systems," *in Proceedings of IEEE Wireless Communications and Networking Conference*, China, pp. 1456-1461, 2012.

[14] Khandekar A., Bhushan N., Tingfang J., and Vanghi V., "LTE-advanced: Heterogeneous Networks," *in Proceedings of European Wireless Conference*, Lucca, pp. 978-982, 2010.

[15] Mushtaq M., Shahid A., and Fowler S., "QoS-Aware LTE Downlink Scheduler for VoIP with Power Saving," *in Proceedings of IEEE 15th International Conference on Computational Science and Engineering*, Cyprus, pp. 243-250, 2012.

[16] Nasralla M. and Martini M., "A Downlink Scheduling Approach for Balancing QoS in LTE Wireless Networks," *in Proceedings of IEEE 24th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications*, London, pp. 1571-1575, 2013.

[17] Nguyen H., Pissinou N., and Iyengar S., "Enabling On-the-Fly Learning for Mobile Ad-hoc Wireless Networks using Bayesian Theory," *in Proceedings of International Conference on Computing, Management and Telecommunications*, Vietnam, pp. 223-227, 2014.

[18] Piro G., Grieco L., Boggia G., Capozzi F., and Camarda P., "Simulating LTE Cellular Systems : an Open Source Framework," *IEEE Transactions on Vehicular Technology*, vol. 60, no. 2, pp. 498-513, 2010.

[19] Pokhariyal A., Kolding T., and Mogensen P., "Performance of Downlink Frequency Domain Packet Scheduling For the UTRAN Long Term Evolution," *in Proceedings of The 17th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, Helsinki, pp. 1-5, 2006.

[20] Priestly M., *Spectral Analysis and Time Series*, Academic Press, 1981.

[21] Quer G., Meenakshisundaram H., Tamma B., Manoj B., Rao R., and Zorzi M., "Using Bayesian Networks for Cognitive Control of Multi-hop Wireless Networks," *in Proceedings of Milcom Military Communications Conference*, San Jose, pp. 201-206, 2010.

[22] Stefania S., Issam T., and Mattew B., *LTE-The UMTS Long Term Evolution*, Wiley, 2011.

[23] Striegel A., Liu S., Hu X., and Meng L., "LTE and WiFi: Experiences with Quality and Consumption," *in Proceedings of the 11th International Conference on Mobile Systems and Pervasive Computing*, Niagara Falls, pp. 418-425, 2014.

[24] Thiruvengadathan R. and Srikanth S., "Performance of MIMO Channel Estimation in LTE Downlink," *in Proceedings of 3rd IEEE International Conference on Computing Communication and Networking Technologies*, Coimbatore, pp. 1-7, 2012.

[25] Wit E., Heuvel E., and Romeijn W., "All Models are Wrong...: an Introduction to Model Uncertainty," *Statistica Neerlanica*, vol. 66, no. 3, pp. 217-236, 2012.

[26] Xiantao L., Guangyi L., Ying W., and Ping Z., "Downlink Packet Scheduling for Real-Time Traffic in Multi-User OFDMA System," *in Proceedings of IEEE 64th Vehicular Technology Conference*, Canada, pp. 1-5, 2006.

[27] Yang H., Ren F., Lin C., and Zhang J., "Frequency-Domain Packet Scheduling for 3GPP LTE Uplink," *in Proceedings of IEEE INFOCOM*, San Diego, pp. 1-9, 2010.

[28] You J., "Research of Wireless Network Fault Diagnosis Based on Bayesian Networks," *in Proceedings of 2nd International Symposium on Knowledge Acquisition and Modeling*, Wuhan, pp. 59-64, 2009.

[29] Zhao L., Qin Y., Ma M., Zhong X., and Li L., "QoS Guaranteed Resource Block Allocation Algorithm in LTE Downlink," *in Proceedings of 7th International Conference on Communications and Networking in China*, Kun Ming, pp. 425-429, 2012.

[30] Zreikat A., "QoS-Based Performance and Resource Management in 3G Wireless Networks in Realistic Environments," *The International Arab Journal of Information Technology*, vol. 10, no. 1, pp.1-9, 2013.

[31] Zucchini W., "An Introduction to Model Selection," *Journal of Mathematical Psychology*, vol. 44, no. 1, pp. 41-61, 2000.

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