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Simulation of Packet Scheduling in Cognitive Long Term Evolution-Advanced

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Abstract

Real Time (RT) and Non-Real Time (NRT) multimedia content demand on mobile devices are increasing at a high pace. Long Term Evolution-Advanced (LTE-A) is expected to cater these demands. However, LTE-A operates at fixed spectrum which leads to spectrum scarcity. Cognitive Radio (CR) is one the promising technologies that is used to overcome spectrum scarcity and implementation of CR into LTE-A will improve spectrum availability and efficiency of the network. Furthermore, with addition of Packet Scheduling (PS) in the cognitive LTE-A, QoS requirement of the mobile users can be guaranteed. However, the study on the stated is very limited. Thus, this paper models, simulates and evaluates performance of five well-known PS algorithms for supporting the RT and NRT multimedia contents. The simulation results show that Maximum- Largest Weighted Delay First (M-LWDF) is the best candidate for implementation in the cognitive LTE-A.

Keywords: *Cognitive LTE-A, Packet Scheduling, Quality of Service, Multimedia*

1. Introduction

Multimedia consumptions on mobile devices are increasing at a fast rate [1] and on top of that, these multimedia applications demand for satisfactory Quality of Services (QoS). Long Term Evolution-Advanced (LTE-A) is a new mobile communication standard that is expected to meet this demand. However, LTE-A operates at a fixed spectrum which leads to spectrum scarcity. Albeit, research conducted by Federal Communication Commission (FCC) suggested that there many under-utilized portions in the licensed spectrums such as in the TV spectrums [2]. This provides an opportunity for research in improving spectrum efficiency and availability which is important to provide satisfactory QoS for more mobile cellular users. A communication technology known as Cognitive Radio (CR) is one of the promising technologies that can be used in LTE-A to improve spectrum availability and efficiency [3].

Implementation of CR into LTE-A allows unused licensed spectrum such as TV white space that belongs to Primary User (PU) to be utilized by Secondary User (SU) (LTE-A user). This is possible due to the spectrum sensing management of CR where it is a process of obtaining information of the spectrum such as existence of PU in the spectrum. Using the information, idle licensed spectrum can be detected and provide an opportunity for SU to occupy the spectrum without causing interference to PU.

Multimedia contents are categorised into two types; real time (RT) and non-real time (NRT). RT is a multimedia content that is delay sensitive whereas NRT is delay tolerant but is sensitive to packet loss. Both RT and NRT multimedia contents are currently facing high demand as internet on mobile devices is becoming easier to access. However, due to this high demands, providing satisfactory QoS to more mobile cellular users becomes more challenging and difficult to achieve. In order to overcome this challenge, packet scheduling (PS) is needed in the system as it provides intelligent selection of users for packet transmission so as to efficiently utilize the scarce resources.

Computer simulation is a well-established technique that allows modelling and investigations of a mobile cellular system to be more practical [4]. There are various simulation tools available to evaluate the mobile cellular systems, however, the tools are too general and some may not be able to simulate the cognitive LTE-A environment. Furthermore, PS in this

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system is considered as a new area of research (given the limitation of scarce resources in LTE-A) and limited work has been published to date which are related to modelling and simulation of PS for the stated system. This paper provides detailed descriptions on the modelling and simulation of PS in the cognitive LTE-A system using C++ simulation tool.

The remainder of this paper is organized as follows. Section 2 contains research method that discusses the PS algorithms, simulation modelling and environment of the simulation. Results are analysed and discussed in Section 3 while Section 4 contains a summary of the paper.

2. Research Method

PS algorithm represents an approach on how to efficiently select users for packet transmission by using proper scheduling criteria such that specified performance metrics are fulfilled. This paper will model, simulate and evaluate five different PS algorithms for supporting the required QoS of RT and NRT multimedia contents in cognitive LTE-A where the system consists of licensed TV users (PU) and the cognitive LTE-A users (SU). It should be noted that the minimum transmission of the TV spectrum is referred to as Resource Block (RB). The RB consists of 12 subcarriers of 180kHz total bandwidth in the frequency domain and of 1 ms duration in the time domain. Packet scheduling in this system is performed in every 1 ms Transmission Time Interval (TTI). Additionally, the TV spectrums considered in this paper consists of two non-contiguous bandwidths (also refered to as Component Carriers (CCs)) where each CC is of 3 MHz bandwidth).This section is divided into 3 sub-sections which will discuss in detail about PS algorithms, simulation model as well as the environment for simulation.

2.1 Packet Scheduling Algorithms

The five algorithms are Maximum Rate (Max-Rate), Proportional Fair (PF), Maximum-Largest Weighted Delay First (M-LWDF), Round Robin (RR) and Exponential Rule (EXP). The description of all five algorithms are provided next.

2.1.1 Maximum Rate (Max-Rate) [5]

The Max-Rate algorithm determines the user to be receive its packets based on its channel quality. User with best channel quality is highly likely to be selected by Max-Rate for packet transmission and this algorithm less likely to select a user with poor channel quality. Max-Rate algorithm can be mathematically expressed as:

$$\mu_{i,j}(t) = r_{i,j}(t) \tag{1}$$

Where µi,j(t) is the priority of user i on RB j at interval t and ri,j(t) is the instantaneous data rate of user I on RB j at TTI t.

2.1.2 Proportional Fair (PF) [6]

PF algorithm was initially developed to support NRT services in Code Division Multiple Access (CDMA) systems. It provides a good trade-off between throughput maximization and fairness. In this paper, in each TTI and on each RB, PF selects of a user that maximizes µi,j(t) in Equation (2) to receive its packets:

$$\mu_{i,j}(t) = \frac{r_{i,j}(t)}{R_i(t)} \tag{2}$$

$$R_i(t+1) = \left(1 - \frac{1}{t_c}\right) R_i(t) + \frac{1}{t_c} {}^{*} rtot_i(t+1) \tag{3}$$

$$rtot_i(t+1) = \sum_{j=1}^{RB_{max}} I_{i.j}(t+1) \, {}^{*} r_{i,j}(t+1) \tag{4}$$

$$I_{i,j}(t+1) = \begin{cases} 1 \; if \; packets \; of \; user \; i \; are \; scheduled \; on \; RB \; j \; at \; TTI \; t+1 \\ 0 \; if \; packets \; of \; user \; i \; are \; scheduled \; on \; RB \; j \; at \; TTI \; t+1 \end{cases} \tag{5}$$

Where μi,j(t) is the priority of user i on Resource Block (RB) j at interval t and ri,j(t) is the instantaneous data rate of user i on RB j at TTI t, Ri(t) is the average throughput of user i at TTI t, tc is a time constant, rtoti(t+1) is the total data rate being used to transmit packets user i at TTI t+1, Ii,j(t+1) is the indicator function of the event that packets of user i are selected for transmission on RB j at TTI t+1 and RBmax is the maximum available number of RBs.

2.1.3 Round Robin (RR) [5]

RR algorithm was developed to overcome the fairness issue in Max-Rate algorithm. RR provides equal share to each user to receive its packets in cyclic manner. This algorithm improves fairness performance at the cost of sacrificing throughput maximization, as it does not consider user's channel quality when selecting users.

2.1.4 Maximum-Largest Weighted Delay First (M-LWDF) [7]

M-LWDF algorithm used in this paper is slightly modified from the original to be applied in cognitive LTE-A. The algorithm selects a user to receive its packet according to:

$$\mu_{i.j.k}(t) = a_i{}^{*}W_i(t)^{*}\frac{r_{i.j.k}(t)}{\sum_{j=1}^{j=CCmax} R_{i,j}(t)} \tag{6}$$

$$a_i = \frac{(log\ \delta_i)}{T_i} \tag{7}$$

$$R_{i,j}(t) = \left(1-\frac{1}{t_c}\right)R_{i,j}(t-1) + I_{i,j}(t)^{*}\frac{1}{t_c}{}^{*}rtot_{i,j}(t) \tag{8}$$

where μi,j,k(t) is the priority of user i on Carrier Component (CC) j on RB k at TTI t, ai is the QoS requirement of user i as defined in equation (7), Wi (t) is the delay of the HOL packet of user i at TTI t, ri,j,k (t) is the instantaneous data rate of user i on CC j at RB k at TTI t, Ri,j (t) is the average throughput of user i on CC j at TTI t as defined in Equation (8) and CCmac is the maximum number of CCs.

2.1.5 Exponential Rule (EXP) [8]

EXP algorithm used in this paper is also slightly modified in order to be used for cognitive LTE-A. The modified EXP algorithm can be expressed in the following equation:

$$\mu_{i.j.k}(t) = a_i{}^{*}W_i(t)^{*}\frac{r_{i.j.k}(t)}{\sum_{j=1}^{j=CCmax} R_{i,j}(t)}{}^{*}exp\left(\frac{a_i{}^{*}W_i(t)-aW\_avg}{1+\sqrt{aW\_avg}}\right) \tag{9}$$

$$aW_{avg} = \frac{1}{N}\sum_{i=1}^{i=N} a_i{}^{*}W_i(t) \tag{10}$$

where μi,j,k(t) is the priority of user i on Carrier Component (CC) j on Resource Block (RB) k at TTI t, ai is the QoS requirement of user i as defined in equation (3), Wi (t) is the delay of the Head of Line (HOL) packet of user i at TTI t, ri,j,k (t) is the instantaneous data rate of user i on CC j at RB k at TTI t, Ri,j (t) is the average throughput of user i on CC j at TTI t as defined in Equation (8), CCmac is the maximum number of CCs and aW_avg is defined in Equation (10).

2.2 Simulation Model

A C++ simulation tool was developed to model and simulate PS in cognitive LTE-A system which consists of five modules. The descriptions of the five modules are provided as follows:

2.2.1 Mobility Module (MM)

MM simulates the mobility of users within a single hexagonal cell. Users are randomly distributed within the area of simulation and move at 30 km/h in a random direction. The location of user i is determined based on the Equation (11):

$$loc_i(t+1) = loc_i(t) + (v_i(t)^{*}dir_i(t)) \tag{11}$$

Where vi(t) is the speed of user i at time t, diri(t) is the direction of user i at time t. To ensure users remain inside the simulation area, a wrap-around method is used at the cell boundary.

2.2.2 Radio Propagation Module (RPM)

RPM uses the speed and location obtained from MM to compute path loss, shadow fading and multi-path fading. For path loss gain computation of each user, Hata Model [9] is used and mathematically expressed as:

$$pl_i(t) = 46.3 + 33.9^* \log_{10}(f) - 13.82^* \log_{10}(h_b) - a(h_m) + (44.9 \\ -6.55^* \log_{10}(h_b))^* \log_{10}(|d_i(t)|) \tag{12}$$

$$a(h_m) = \left(1.1^* \log_{10}(f) - 0.7\right)^* h_m - (1.56\ ^*\ \log_{10}(f) - 0.8) \tag{13}$$

Where pli(t) is the path loss of user i at time t (in dB), di(t) is the distance of user i at time t (in km), f is the frequency of the transmission (in MHz), hb and hm are the heights of eNodeB and user terminal (in m) and a(hm) is the mobile antenna correction factor.

Shadow fading gain computation is performed by using the method proposed by Gudmundson [10] where it is modelled as a correlated log-normal distribution with 0 mean and 8 dB standard deviation. The Gudmundson model is shown using Equation (14):

$$\varepsilon_i(t+1) = \rho_i(t)\ ^*\ \varepsilon_i(t) + \sigma\ ^*\ \left(\sqrt{1-\rho_i(t)^2}\right)\ ^*\ W(t) \tag{14}$$

$$\rho_i(t) = \exp\left(\frac{-v_i(t)}{d_o}\right) \tag{15}$$

Where σ is the shadow fading standard deviation, w(t) is a Gaussian random variable of user i at time t and ρi(t) is the shadow fading autocorrelation function as shown in Equation (15).

Multi-path fading gain computation is calculated using the Rayleigh fading algorithm. This algorithm is based on statistical model and considered to be a logical model for signal propagation [11]. The Rayleigh fading can be further explained using Equation (16):

$$\mu\_ap_i(t) = \sum_{n=1}^{N_i} c_{i,n} \cos(2\pi f_{i,n}\, t + \theta_{i.n})\ \ i = 1,2,3 \tag{16}$$

$$C_{i,n} = \sigma_{\mu 0} \sqrt{\frac{2}{N_i}} \tag{17}$$

$$f_{i,n} = f_{max} \sin\left(\frac{\pi}{2}\mu_n\right) \tag{18}$$

Where μ_api(t) is the approximated uncorrelated filtered white Gaussian noise with zero mean of process i at time t, ci.n, fi,n and θi,n is the Doppler coefficient, discrete Doppler frequency and Doppler phase of process i of the nth sinusoid respectively, Ni is the number of sinusoids of process i, μn is the uncorrelated filtered white Gaussian noise with zero mean of the nth sinusoid, σμ0 is the variance and fmax is the maximum Doppler frequency.

2.2.3 Signal-to-Interference-plus-Noise-Ratio to Data Rate Module (SINR)

SINR uses path loss, shadow fading and multi-path fading gains to determine channel gain as well as SINR values of each user and on each RB and maps it to the associated achievable data rate. The channel gain is computed using Equation (19):

$$Gain_{i,j}(t) = 10^{\left(\frac{pl_i(t)}{10}\right)} * 10^{\left(\frac{\varepsilon_i(t)}{10}\right)} * 10^{\left(\frac{mpath_{i,j}(t)}{10}\right)} \tag{19}$$

Where mpathi,j(t) is the multi-path fading gain of user i on a RB j at time t. Using the computed channel gain the SINR value is computed using Equation (20):

$$\gamma_{i,j}(t) = \frac{P_{total}\ ^*\ Gain_{i,j}(t)}{N_{RB}(I+N_0)} \tag{20}$$

Where Ptotal is the total eNodeB downlink power, NRB is the number of RBs, N0 is the thermal noise and I is the inter-cell interference which is assumed to be constant.

Computation of bits per symbol of user i at time t on a sub-carrier within RB j is performed using the method proposed in [12]. The user's achievable data rate on two consecutive RBs are calculated by using:

$$dr_i(t) = \frac{nbits_{i,j}(t)}{symbol} * \frac{nsymbols}{slot} * \frac{nslots}{TTI} * \frac{nsc}{RB} \tag{21}$$

where dri(t)is the user's achievable data rate, nbitsi,j(t)/symbol is the bits per symbol of user i at time t on a sub-carrier within RB j, nsymbols/slot is the number of symbols per slot, nslot/TTI is the number of slots per TTI, and nsc/RB is the number of sub-carriers per RB. Table 1 shows the minimum SINR value and related achievable data rate used in this module.

2.2.4 Traffice Generator Module (TGM)

TGM generates the RT and NRT packets for each user and queues the packets in the buffer. Video streaming with average data rates of 256 kbps is used to model RT multimedia content while web browsing is used to model NRT multimedia content. In this paper, the TGM generates equal number of RT and NRT multimedia content.

2.2.5 Packet Scheduler Module (PSM

PSM selects user with the highest priority at each TTI on each vacant RB based on PS algorithm. The selected users' packets which are generated by TGM are taken out of the buffer and transmitted over the selected vacant RB using the data rate [13] given in Table 1. Figure 1 shows the intercommunication of each module within the simulation tool.

Table 1. SINR to Data Rate Mapping Table

Minimum SINR (dB)	Modulation and Coding	Data Rate (kbps)
<-6.936	Out of range	-
-6.936	QPSK	22.5404
-5.147	QPSK	34.6912
-3.18	QPSK	55.8108
-1.253	QPSK	89.0368
0.761	QPSK	129.796
2.699	QPSK	174.0184
4.694	16 QAM	218.5368
6.525	16 QAM	283.2868
8.573	16 QAM	356.1324
10.366	64 QAM	404.114
12.289	64 QAM	477.004
14.173	64 QAM	577.5404
15.888	64 QAM	669.4632
17.814	64 QAM	757.0496
19.829	64 QAM	822.0956

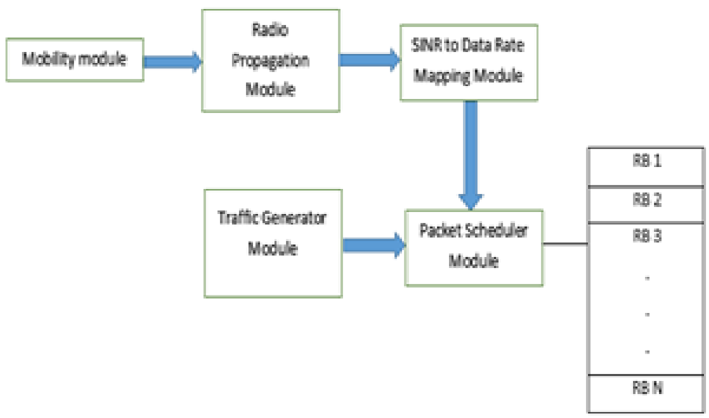

Figure 1. Simulation Tool Block Diagram

2.3 Simulation Environment

A series of C++ computer simulation is performed to evaluate the performance of the five PS algorithms for the cognitive LTE-A system. In this paper. A cell consists of two CCs of 700 MHz and 1800 MHz carrier frequencies are considred. Each CC contains 15 RBs. Each user moves at 30 km/h within 300 m radius of the cell. The threshold for the buffer delay is set at 80 ms. In this case, packets are discarded if they exceeded the 80 ms buffer delay threshold. In order to satisfy the QoS requirement of video streaming users, the PLR should be kept below 10-3 [7]. For web browsing, the PLR should be kept below 10-6 [7].

The performance of Max-Rate, PF, M-LWDF, RR and EXP are evaluated on the basis of the PLR, system throughput and fairness metrics. The mathematical expressions for each metric is given below [14]:

$$PLR = \frac{\sum_{i=1}^{K}\sum_{t=1}^{T} pdiscard_i(t)}{\sum_{i=1}^{K}\sum_{t=1}^{T} psize_i(t)} \tag{22}$$

$$system\ throughput = \frac{1}{T}\sum_{i=1}^{K}\sum_{t=1}^{T} prx_i(t) \tag{23}$$

$$fairness = 1 - \frac{ptotaltransmit_{max} - ptotaltransmit_{min}}{\sum_{i=1}^{K}\sum_{t=1}^{T} psize_i(t)} \tag{24}$$

Where pdiscardi(t) is the size of discarded packets of user i at time t, psizei(t) are the size of all packets that have arrived at the serving eNodeB buffer of user i at time t, prxi(t) is the total size of properly received packets of user i at time t, ptotaltransmitmax and ptotaltransmitmin are the total size of the transmitted packets of the highest and the lowest served users respectively K is the total number of users and T is the total simulation time.

3. Results and Analysis

Figure 2 and Figure 3 show the RT PLR and NRT PLR performances respectively of Max-Rate, PF, RR, M-LWDF and EXP algorithms with increasing cognitive LTE-A users (the cognitive LTE-A user is also refered to as system capacity in this paper). In order to meet the QoS requirements of video streaming, the RT PLR should be kept below the 10-3 as shown in Figure 2 while for web browsing, the NRT PLR should be kept below 10-6 as shown in Figure 3. The results in both figures demonstrate that both M-LWDF and EXP have significantly better RT and NRT PLR compared to the Max-Rate, PF and RR with Max-Rate has the worst performance. For NRT PLR result, due to scarce resources (i.e. the cognitive LTE-A users can only use the RBs only when the licensed TV users are not active) all five algorithms exceed the 10-6 threshold of NRT PLR as shown in Figure 3 thus fail to meet the web browsing requirement. However, as observed in Figure 3, the NRT PLR of the PF, M-LWDF and EXP are better compared to the Max-Rate and RR algorithms.

Based on Table 2, it is observed that EXP and M-LWDF has similar maximum system capacity of 50 users whereas the Max-Rate, PF and RR support 30, 40 and 40 cognitive LTE-A users, respectively. The significant achievement of the M-LWDF and the EXP (i.e. 66.7% capacity improvement over the Max-Rate) is because both algorithms account for packet delay, in addition to the channel quality and the average throughput, when selecting users for packet transmission. This allows the algorithms to prioritize packets of users that have resided the longest in the buffer at the base station and hence minimizing the packets being discarded for delay violation. However, given that these algorithms always prioritize users that have waited the longest, these algorithms are highly likely to sacrifice the NRT packets that are more tolerant to delay, which results in the degradation of the NRT PLR of both algorithms (as illustrated in Figure 3).

Figure 4 shows the system throughput performances obtained by the Max-Rate, PF, RR, M-LWDF and EXP algorithms. It can be observed that all five algorithms have comparable performance. Though, the system throughput of the Max-Rate, PF and RR are comparable to the EXP and M-LWDF at 50 users, these algorithms fail to simultaneously meet the required QoS of RT and NRT multimedia contents ar the stated number of cognitive LTE-A users.

Table 2. Maximum System Capacities to Satisfy The Qos Requirements Of Video

Algorithms	Maximum System capacity	Percentage of improvement over Max-Rate (%)
Max-Rate	30	0
PF	40	33.3
RR	40	33.3
M-LWDF	50	66.7
EXP	50	66.7

Figure 5 shows the Max-Rate, PF, RR, M-LWDF and EXP fairness performances. It can be observed that PF, M-LWDF and EXP performs the best with Max-Rate algorithm trailing behind while RR algorithm has the worst performance. Though the RR is expected to provide good fairness, but given that this paper assumes the data rate used for packet transmission depends on the channel quality of the user, this degrades the fairness achieved by the RR. Observation based on Table 3 shows PF, M-LWDF and EXP are the best algorithms to allocate equal share of resources among 60 users which has 100% more performance while Max-Rate provides 33.3% better performance compared to RR.

Table 3. Fairness Performance

Algorithms	Maximum System capacity	Percentage of improvement over RR (%)
Max-Rate	40	33.3
PF	60	100
RR	30	-
M-LWDF	60	100
EXP	60	100

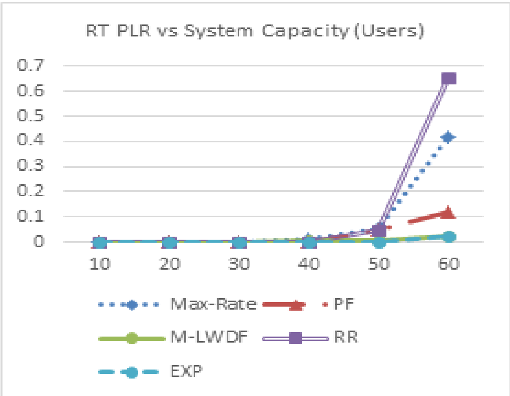

Figure 2. RT PLR vs System capacity

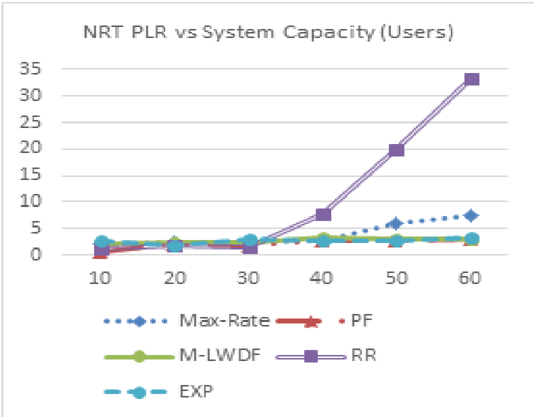

Figure 3. NRT PLR vs System Capacity

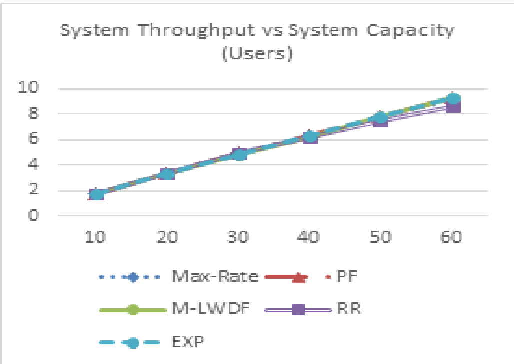

Figure 4. System Throughput vs System Capacity

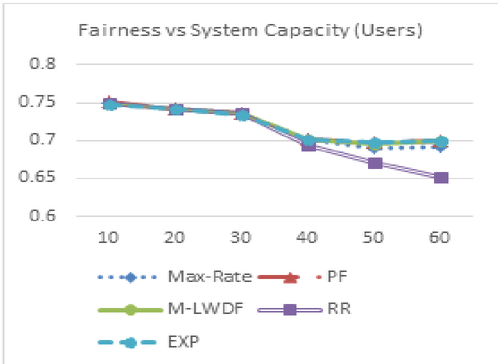

Figure 5. Fairness vs System Capacity

Based on the simulation results, it is observed that PF, M-LWDF and EXP are the algorithms that able to satisfy most of the performance metrics. However, PF is only able to provide minimal performance for RT PLR thus leaving only M-LWDF and EXP with promising performance. Given EXP's complexity, M-LWDF is seen as the better candidate for cognitive LTE-A system as it is able to provide similar performance to EXP while having less complex computation.

4. Conclusion

LTE-A network is the new mobile communication standard that is expected to meet the increasing demand of RT and NRT multimedia contents. This network is facing a challenge to provide satisfactory QoS for more mobile users due to its limited spectrum. Integrating CR into LTE-A allows improvement of spectrum availability and efficiency and therefore overcome spectrum scarcity. Furthermore, with addition of PS into the cognitive LTE-A network, QoS requirement can be guaranteed for more cognitive LTE-A users. This paper models, simulates and evaluates the performance of Max-Rate, PF, RR, M-LWDF and EXP for simultaneous support of video streaming and web browsing applications using a C++ simulation tool. The simulation results show that the M-LWDF has the best overall performance for all three metrics; RT and NRT PLR, system throughput and fairness compared to other evaluated packet scheduling algorithms. Therefore, it can be concluded based on the simulation results that the M-LWDF is the most suitable candidate for cognitive LTE-A for simultaneous support of RT and NRT multimedia contents.

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