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Performance Analysis of QOS-aware Resource Scheduling Strategies in LTE Femtocell Networks

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***Abstract*—OFDMA based-Long-term evolution (LTE) femtocells represent a very promising answer to the ever rising bandwidth demand of mobile applications. Femtocells, standardised as HeNBs, are end user deployed network nodes for indoor environment with a network backhaul provided by the digital subscriber line (DSL) or cable modem. The base station called as Femtocell Access Point can be easily deployed in adhoc manner. Femtocells improve the coverage in indoor scenarios and provide better user experience, thereby increasing the network capacity.**

Resource allocation strategies play a key role in distributing radio resources among different stations, with fine time and frequency resolutions by taking into consideration the channel conditions as well as QoS requirements. The present paper provides performance comparisons of radio resource scheduling strategies such as Proportional-Fair (PF), Modified Largest Weighted Delay First (MLWDF), Exponential Rule, Exponential/PF (EXP/PF), LOG Rule and Frame Level Scheduler (FLS) with stress on QoS provisioning capabilities in the context of heterogeneous urban scenario with both macro and femtocells.

***Keywords*— LTE, OFDMA, Femtocells, Heterogeneous Networks, QOS, Downlink Scheduling, Radio-Resource Management**

I. Introduction

LTE uses orthogonal frequency division multiple access (OFDMA) in the downlink and is designed to provide enormous bandwidth with more efficient use of the radio network. It supports a broad range of multimedia and Internet services even in high mobility scenarios reduced latency, and significantly lower cost per bit [1].

However, there is a need to enhance the system capacity in order to improve the indoor coverage as well as to provide high-data-rate services to the users in a cost-effective manner as more than 50% of voice calls and significant amount of data traffic is expected to originate from indoor users [2]. Basically this problem can be solved by increasing the node deployment density. Moreover, due to the penetration losses, the indoor user demands high power from the serving Base Station (BS). It leads to significantly low power for other users and as a result the overall system throughput is reduced. The signal originating from the macrocell attenuates due to high frequency range of the signals used in 3G systems and deteriorates swiftly once the signal reaches indoors.

Challenges associated with indoor coverage and capacity enhancement can be overcome by the installation of Home base stations with lower transmit power i.e. Femtocells or Femto Access Points (FAPs). FAPs are small, short-ranged (10-30 m) access points that are installed by the end users. FAPs can be connected to the operators' core network through users' DSL, optical fibre cable or through a broadband connection [2], [3]. A network that comprises combination of macrocells and low-power nodes (femtocells) is referred to as a *heterogeneous network* (HeNets) which is illustrated in Fig. 1.

The present paper discusses the resource scheduling in HeNets and is organized as follows: Section II describes the resource allocation in LTE. QOS-aware scheduling algorithms with mathematical expressions are presented in Section III. Then, Section IV provides the simulation outcomes. At last, conclusions are provided in Section V.

II. Downlink Resource Allocation in LTE

The LTE heterogeneous network composed by macro and small range femtocells; consists of two parts: the radio access network, i.e., the evolved-universal terrestrial radio access network (E-UTRAN), and the packet switched core network, known as Evolved Packet Core. From the network side, the evolved NodeB (eNB) is the major node of the E-UTRAN which is in charge of providing network connectivity through the air interface to all user equipments (UEs) in the cell.

At the physical layer, LTE allows variable bandwidth from 1.4 MHz up to 20 MHz and provides radio spectrum access based on the Orthogonal Freq. Division Multiplexing (OFDM) scheme. The air interface uses OFDMA and Single Carrier Frequency Division Multiple Access (SC-FDMA) for the downlink and uplink respectively.

Radio resources in LTE are apportioned into the time/frequency domain [4]. Along the time domain they are assigned every Transmission Time Interval (TTI), each one lasting 1 ms which further consists of 2 time slots each with length 0.5 ms. In particular, the time is split in frames, each one composed of 10 consecutive TTIs. Each TTI consists of 14 OFDM symbols in the default configuration with normal cyclic prefix.

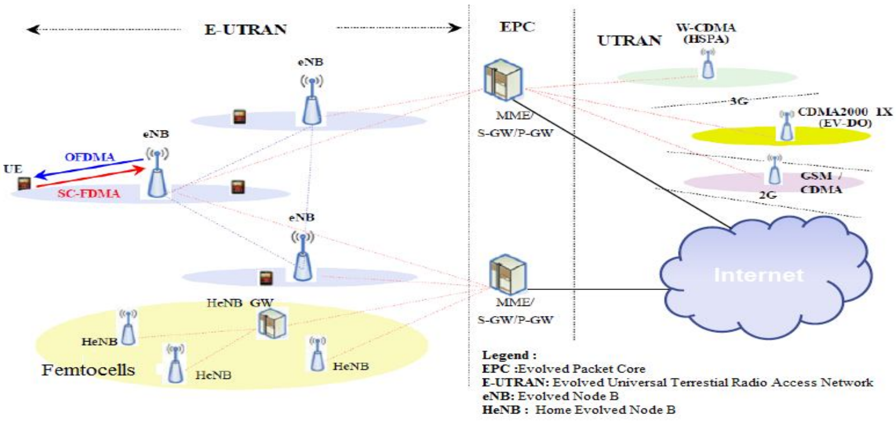


Fig 1 Heterogeneous network topology using combination of macro and HeNBs [3]

In the frequency domain, the total bandwidth is divided in sub-channels of 180 kHz. Each sub-channel further comprises of 12 consecutive equally spaced OFDM sub-carriers. The minimum allocable resource unit is called *Resource Block* (RB) which is formed by the intersection between a sub-channel in frequency domain and one TTI in time domain.

Spectrum portions should be apportioned every TTI among the users. Packet schedulers work in the time and frequency domain with coarseness of one TTI and one RB respectively. The fastest scheduling is required to be done within 1ms according to the symbol length of RB.

The per-RB metrics' comparison that serves as the transmission priority of each user on a specific RB is taken into account for resource allocation for each UE. For example the *k*-th RB is allocated to the *j*-th user if its metric $m_{j;k}$ is the largest one among all i-UEs, i.e., if it satisfies the equation:

$$m_{j;k} = \max_i \{m_{i;k}\} \quad (1)$$

The whole process of downlink scheduling can be divided in a sequence of operations that are repeated, in general, every TTI:

1) The Evolved Node B formulates the list of downlink flows having packets to transmit. It prepares the list of flows which can be scheduled in the current sub-frame.

2) Each UE after decoding the reference signals, reports CQI (Channel Quality Indicator) to eNB which helps to estimate the downlink channel quality.

3) Then the preference metric is computed for each flow according to the scheduling strategy using the CQI information. The UE that shows the highest metric is assigned with the sub-channel.

4) The size of transport block during the current TTI is calculated by eNB for each scheduled flow. The AMC (Adaptive Modulation and Coding module) at MAC layer selects the best MCS (Modulation and Coding Scheme) by tailoring the modulation order (QPSK, 16-QAM, 64-QAM) and coding rate for each UE in the cell, depending on the downlink channel conditions.

5) PDCCH (Physical Downlink Control Channel) is used to send the information about the users, the assigned Resource Blocks, and the selected Modulation and coding scheme to terminals in the form of DCI (Downlink Control Information).

6) Each UE reads the PDCCH payload .If a particular UE has been scheduled; it will try to access the PDSCH payload.

The users are prioritized by packet scheduler on the basis of a scheduling algorithm being used which while making scheduling decisions, takes into account the instantaneous or average channel conditions, Head of Line (HOL) packet delays, status of receiving buffer or type of service being used. At each TTI, a user may be allocated one or multiple RBs [5].

III. RESOURCE SCHEDULING ALGORITHMS FOR 3GPP DOWNLINK

In LTE networks, the problem of finding low complexity algorithms able to distribute time slots and frequency carriers to users demand much attention. A good scheduling algorithm should be optimal in throughput maximization, QOS provision and fairness provided to the users. The ensuing text discusses the most relevant resource scheduling algorithms in brief:

A. *Proportional Fair*

The Proportional Fair (PF) scheduler is a channel dependent scheduler. Here, the terminals are ranked according to the priority function. It serves the user with the maximum Relative Channel Quality Indicator (RCQI) which is defined as the ratio between the instantaneous maximum data rate supported by the UE based on the CQI value and the average data rate of the UE's previous transmission till the present TTI. The priority metric is obtained by merging the metrics of MaxT and BET and is given as [6]:

$$m^{PF}_{i,k} = m^{Max-T}_{i,k} \cdot m^{BET}_{i,k} = \frac{d^{i}_{k}(t)}{\overline{R^{i}}(t-1)} \quad (2)$$

$d_k^i(t)$ is the estimation of supported data rate of terminal i for the resource block k. $\overline{R^i}(t-1)$ is the average data rate of terminal i over a windows in the past.

If T_{PF} is the windows size of average throughput, then $R^i(t)$ i.e. the instantaneous value of data rate at time instant t is given as:

$$\overline{R^i}(t) = \{\left(1-\frac{1}{T_{PF}}\right)\cdot\overline{R^i(t-1)} + \frac{1}{T_{PF}}\cdot R^i(t) \quad \text{if i-th terminal is selected} \quad (3)$$

$$\{\left(1-\frac{1}{T_{PF}}\right)\cdot\overline{R^i(t-1)} \quad \text{if i-th terminal is not selected} \quad (4)$$

B. Modified Largest Weighted Delay First

The Modified Largest Weighted Delay First (M-LWDF) combines both channel conditions and the state of the queue with respect to delay in making scheduling decisions. It ensures that the probability of delay packets does not exceed the discarded bound below the maximum allowable packet loss ratio i.e.

$$\Pr(D_{HOL,i} > \tau_i) \leq \delta_i$$

Non-real and real-time flows are treated differently by MLWDF according to the metric [7]:

$$m_{i,k}^{MLWDF} = \alpha_i \cdot D_{HOL,i} \cdot \frac{d_k^i(t)}{\overline{R^i}(t-1)} \quad (5)$$

Where $D_{HOL,i}$ is waiting time of the packet at the head of the line and $\alpha_i = -\log \delta_i / \tau_i$

δ_i represents the maximum probability for HOL packet delay to exceed the delay threshold of user i. and τ_i defines Target Delay for the i-th user.

C. Exponential/PF Algorithm

EXP/PF is a QOS aware extension of PF. It can support both Non-Real Time and Real Time flows at the same time. When calculated for real-time flows, the metric is given as [7]:

$$m_{i,k}^{EXP/PF} = \exp\left(\frac{\alpha_i \cdot D_{HOL,i} - \chi}{1+\sqrt{\chi}}\right) \cdot m_{i,k}^{PF} \quad (6)$$

Where $\chi = \frac{1}{N_{RT}} \cdot \sum_{i=1}^{N_{RT}} D_{HOL,i}$ and N_{RT} is the number of active downlink real-time flows.

The metric when calculated for Non-real-time flows is given as:

$$m_{i,k}^{EXP/PF} = \frac{w(t)}{M(t)} \cdot \frac{d_k^i(t)}{\overline{R^i}(t-1)} \quad (7)$$

Where w(t)={ w(t-1) - ε...........$(D_{HOL})_{max} > \tau_{max}$

{w (t-1) + ε /p.......$(D_{HOL})_{max} < \tau_{max}$

where $M(t)$ is the average number of RT packets waiting at e-Node B buffer at time t, ε and p are constants, $(D_{HOL})_{max}$ is the maximum HOL packet delay of all RT service users and τ_{max} is the maximum delay constraint of RT service users.

In the EXP/PF algorithm, RT users are prioritized over NRT users when their HOL packet delays are approaching the delay deadline. If HOL delays of all users are about the same, the exponential term in (6) is close to 1 and EXP/PF behaves like PF. If one of the user's delays becomes large, the exponential term in (6) will override the left term in (6), which reflects channel states, and dominate the selection of a user.

D. Exponential Rule Algorithm

EXP rule can be considered as modified form of the above mentioned EXP/PF and its priority metric is calculated as:

$$m_{i,k}^{EXP-Rule} = b_i \cdot \exp\left(\frac{\alpha_i \cdot D_{HOL,i}}{c+\sqrt{\left(\frac{1}{N_{RT}}\right)\sum_j D_{HOL,j}}}\right) \cdot \Gamma_k^i \quad (8)$$

Where Γ_k^i represents Spectral efficiency for the user i over the k-th RB and the optimal parameter set according to [8] is:

{ $a_i \in [(5/0.99\ \tau_i\ , 10/0.99\ \tau_i)]$,

$b_i = 1/E[\Gamma^i]$ and $c=1$

E. Logarithmic Rule Algorithm

LOG Rule algorithm has been described in [9]. For the LOG rule *priority function* is:

$$m_{i,k}^{LOG-Rule} = b_i \cdot \log\left(c + \alpha_i D_{HOL,i}\right)\Gamma_k^i \quad (9)$$

where b_i, c, and a_i are tuneable parameters; Γ_k^i represents the spectral efficiency for the i-th user on the k-th RB. Optimal parameters are given as :

$b_i = 1/E[\Gamma^i]$, $c = 1.1$, and $a_i = 5/0.99\ \tau_i$

F. Frame Level Scheduler

Frame Level Scheduler proposed by Prio *et al.*, is a two-level downlink scheduling algorithm for real-time flows [10]. At the upper level, a discrete time linear control law is applied every LTE frame (i.e.10 ms). It calculates the total amount of data that real-time flows should transmit in the following frame in order to satisfy their delay constraints. When FLS finishes its task, the lowest layer scheduler works every TTI to allocate radio resources using the PF algorithm. PF considers the bandwidth requirements imposed by the FLS. Firstly, the lowest layer scheduler assigns RBs to those UEs that experience the best channel quality and then the remaining ones are considered. If any RBs left free, they would be allocated to best-effort flows.

IV. PERFORMANCE EVALUATION

A. Simulation Scenario

To investigate the performance of resource scheduling strategies, a realistic cell scenario of 500 m layout overlapped with 25 femtocells has been developed. A Downlink BW of 5 MHz is assured by distributing frequencies of first operative

LTE Bandwidth i.e. DL [2110-2170 MHz] and UL [1920 -1980 MHz] in FDD Mode.

A downlink traffic composed by one video flow, one VoIP flow, and one best effort flow, is assumed to be active for each UE. For the video application, we used a traffic trace obtained from a test sequence (i.e., "foreman.yuv") available at [11]. It sends packets based on realistic video files. The VoIP application generates G.729 voice flows as ON-OFF simulations with source data rate of 8 kbps [12]. Finally, for the best effort flows infinite buffer application has been considered which models an ideal greedy source that has endless packets to send.

For channel model, a propagation loss model for an urban cell has been considered for macrocell structure according to [4]. It takes into account all phenomena influencing channel conditions: (i) the path loss, (ii) the shadowing, (iii) the loss due to penetration and (iv) the fast fading effect due to the multipath propagation. In particular, the path loss, *PL*, is given by the expression $PL = 128{:}1 + 37{:}6 \log d$, where d is the distance between the eNodeB and the UE, in kilometers. The large scale shadowing fading has been modeled through a log-normal distribution with 0 mean and 8 dB of standard deviation. The penetration loss has been set to 10 dB. Finally, the time-frequency correlated signal multipath is modeled by using the Rayleigh fading channel model. Moreover, in order to cope with the peculiar features of femtocells, the path loss model i.e. Femtocell Urban Area Model has been considered which also takes into account an additional attenuation factor while calculating the path loss i.e. external wall attenuation with default value of 20 dB.

An indoor structure composed by 25 apartments, each one delimiting the area of a given femtocell located over a 5 × 5 grid has been developed. Femtocells operate in open access mode. Main simulation parameters are summarized in Table 1.

B. Results and Discussions

1) Packet Loss Ratio: In context of QOS provisioning, PLR is an important parameter of real time flows.PLR increases when scheduler is unable to timely serve the real time packets. It is evident from fig 2 that PLR increases with the rise in number of UEs due to higher network load. Moreover , QOS –aware strategies perform better than PF because QOS schemes discard those packets that violate delay deadline (i.e. 0.1 s).Since the real time application has no advantage in receiving the expired packets and retransmitting them after delay deadline means sheer wastage of radio resources. Fig 2 shows that ability to limit PLR decreases with at high cell load.FLS has achieved the lowest PLR but by sacrificing the available resources for BE flows (see Fig.4).Exp- Rule performs better than MLWDF and LOG-rules since EXP Rule grows faster at exponential rate with respect to argument than logarithmic behavior and more quickly delivers the packets with delays nearly approaching the transmission delay budget or deadline.

TABLE 1
SIMULATION SUMMARY

Parameter	Value
Physical Detail	Carrier Frequency : 2GHz ; Downlink Bandwidth : 5MHz; Frame structure :FDD; Frequency Reuse scheme :cluster of 4 cells; eNB : Total Power Transmission :43dBm; Propagation Model :Macro-cell Urban scenario; #Path loss Model: $128.1+37.6\log_{10}R$ HeNB : Power Tx :20 dBm ; #Prop. Model : Femtocell –Urban Area Model , Modulation Scheme :QPSK,16 QAM and 64 QAM with all available coding rates; Target BLER:10 %
Macrocell radius	0.5 km
Indoor Structure	Building Type : (5 *5) Grid type ; # Apartment Size :100 m^2 No. of Femtocell :25; Activity Ratio : 1.0 ; Access policy :Open Access
CQI	Full bandwidth ;# periodic reporting with measurement duration:2 ms;
Control Overhead	RTP/UDP/IP with ROCH compression: 3 bytes ; PDCP: 2 bytes; MAC and RLC: 5 bytes; CRC: 3 bytes PHY: 3 symbols
User Mobility	Mobility model: Random –Direction; UE speed: 30 km/h
Traffic	Real time traffic type :Video (242 kbps), VOIP ; Best Effort flows :Infinite Buffer

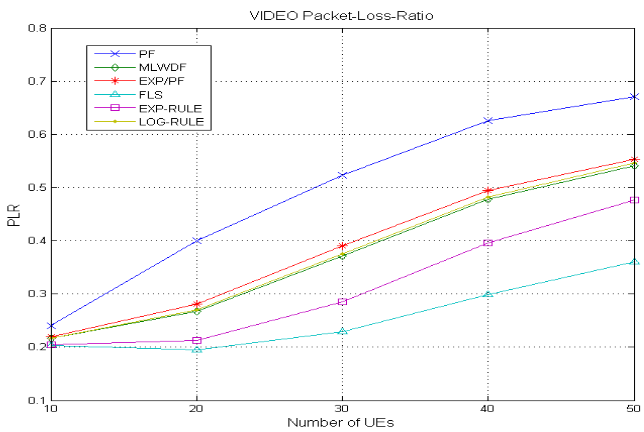


Fig. 2 PLR of Video Flows with QOS-aware schemes

The VOIP flows experience significantly lower PLRs than Video Flows as illustrated in Fig. 3.The reason behind this is that VOIP having lower source bit rate as compared to Video flows; has smaller PDUs. Thus get high priority from scheduler.

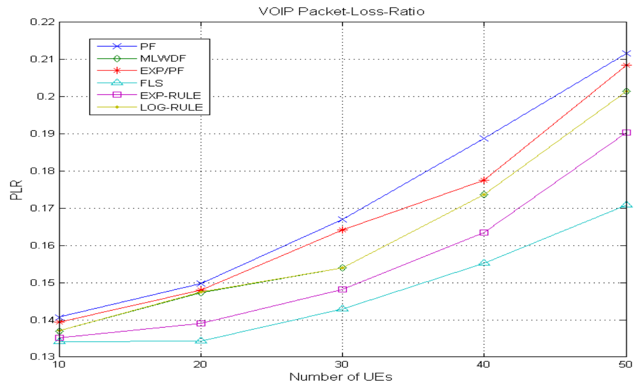


Fig. 3 PLR of VOIP Flows with QOS-aware schemes

2) Throughput: Fig .4 shows the average user throughput experienced by BE flows. It is worth to note that the throughput for all the strategies decreases as the number of UE increases. Obviously, now same amount of resources has to be shared among higher number of candidates; thereby causing dip in the throughput. Moreover, when the cell is fully charged, note that, for EXP –Rule and LOG Rule algorithms, higher throughput is obtained with respect to the FLS algorithm. This result was expected because earlier ,(Fig. 2 and 3) LOG and EXP Rule provide worse service to multimedia flows leaving a high quota of BW for BE flows.FLS shows low throughput since in FLS real-time flows are prioritized over BE flows.PF which aims at maximizing throughput for NRT flows along with MLWDF and EXP/PF registers high throughput.

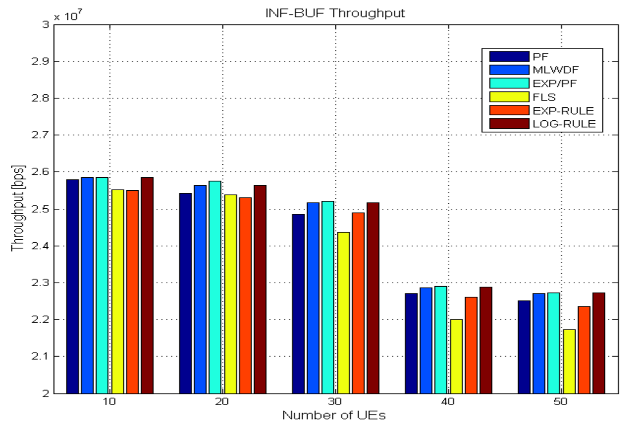


Fig.4 Average User Throughput of BE Flows

Fig.5 shows the average user throughput of Video flows that tend to fall with increase in cell load.FLS registers rise in throughput at full cell load which indicates that video service is still acceptable. Whereas EXP ,MLWDF ,LOG Rules can support only 30-35 UEs.PF gives worst performance with ~50 % decline in throughput as compared to FLS at full load ; which means that it is unsuitable to handle real time Video Flows.

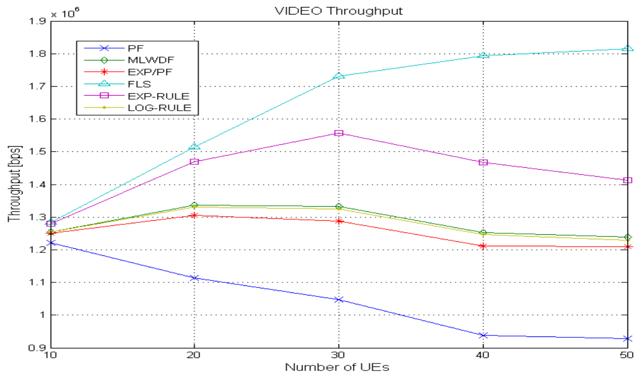


Fig.5 Average User Throughput of Video Flows

3) Fairness: A resource scheduling strategy should optimally scale between fairness and spectral efficiency in order to ensure minimum performance also to the cell-edge users.

Table 2 represents the fairness index values of considered scheduling strategies for Video flows. Initially, all the QOS-aware strategies show comparable level of fairness closer to 0.8 that tend to decrease thereafter. FLS not only presents the highest throughput (see fig.5) but also shows the highest fairness index here. The M-LWDF scheduler degree of fairness performance is higher compared to PF, EXP/PF and LOG-Rule scheduler. Owing to optimization between spectral efficiency and fairness QOS-unaware PF presents lowest fairness index that falls after 20 users only. Table 3 presents the fairness index experienced by VOIP flows. All the considered strategies show fairness equal to 0.8 at all cell loads.

TABLE 2
FAIRNESS-INDEX FOR VIDEO FLOWS

VIDEO Fairness Index						
UE	**PF**	**MLWDF**	**EXP/PF**	**FLS**	**EXP**	**LOG**
10	0.7871	0.8490	0.8385	0.8599	0.8498	0.8448
20	0.6667	0.8016	0.7921	0.8375	0.8341	0.7998
30	0.6093	0.7363	0.7220	0.8167	0.7969	0.7318
40	0.5918	0.6836	0.6722	0.7818	0.7371	0.6779
50	0.5987	0.6674	0.6609	0.7623	0.7036	0.6655

TABLE 3
FAIRNESS-INDEX FOR VOIP FLOWS

VOIP Fairness Index						
UE	**PF**	**MLWDF**	**EXP/PF**	**FLS**	**EXP**	**LOG**
10	0.8789	0.8803	0.8803	0.8803	0.8803	0.8803
20	0.8217	0.8220	0.8221	0.8225	0.8224	0.8220
30	0.8203	0.8217	0.8217	0.8217	0.8217	0.8217
40	0.8115	0.8116	0.8115	0.8118	0.8117	0.8115
50	0.8104	0.8112	0.8112	0.8116	0.8115	0.8112

Table 4 shows that Fairness Index experienced by best-effort flows is lesser than real time flows. Fairness decreases when number of UE increases because of the low priority level of best-effort flows. PF shows quite good fairness index due to its "*proportional fair* quality. FLS prioritizes real time flows over

BE flows, hence shows minimal fairness index among all QOS-aware strategies.

TABLE 4
FAIRNESS-INDEX FOR BE FLOWS

Best- Effort (Inf-Buf)Fairness Index						
UE	PF	MLWDF	EXP/PF	FLS	EXP	LOG
10	0.7995	0.8021	0.8034	0.7862	0.7998	0.8037
20	0.7936	0.7951	0.7963	0.7695	0.7954	0.7959
30	0.7882	0.7881	0.7875	0.7613	0.7874	0.7884
40	0.7829	0.7849	0.7842	0.7586	0.7837	0.7840
50	0.7772	0.7792	0.7796	0.7552	0.7751	0.7785

4) Delay: The delay of the system accounts for Head of Line (HOL) packet delay and is calculated as an average of the total time delay difference between the arrival time of packet in queue and its release time instant from the service queue to UE.

Figure 6 shows the delay experienced by video flows. The lowest delay is performed by EXP/PF algorithm because of inclusion of exponential function of end-to-end delivery delay in its preference metric. PF shows a stable delay when there are less than 20 users in the cell, the delay increases when the cell is charged.

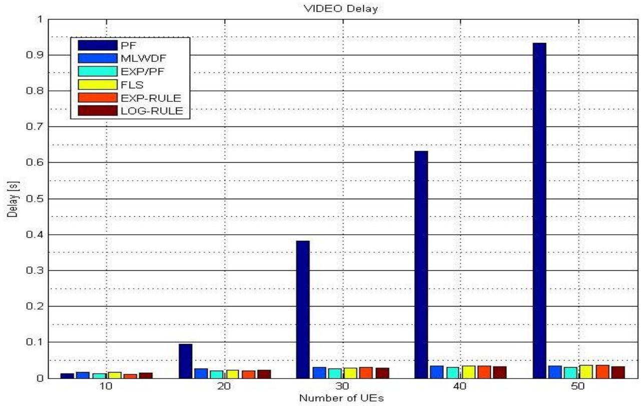


Fig.6. Delay Value for Video Flows

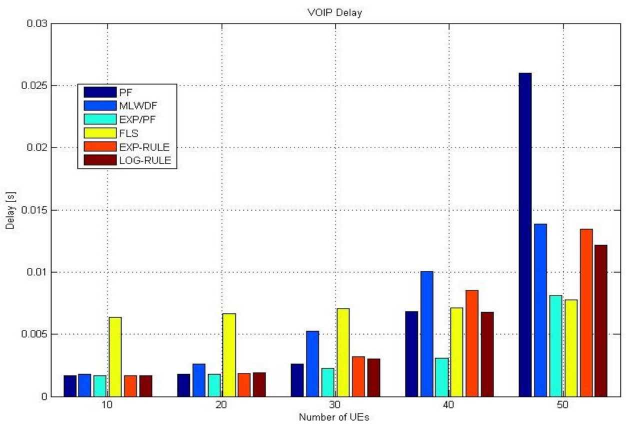
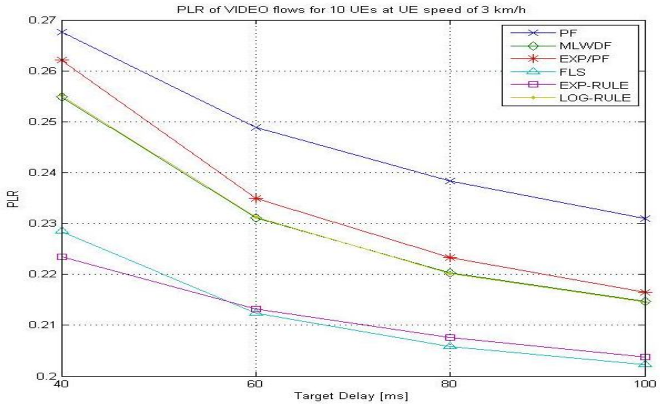


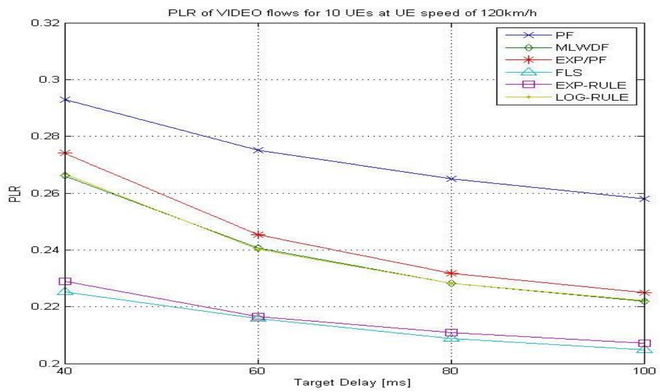
Fig.7. Delay Value for VOIP Flows

Figure 7 shows the delay experienced by VOIP which is significantly less than delay experienced by video flows. EXP/PF presents the lowest delay, also FLS shows comparable delay. PF shows a fair performance when the cell has less than 35-40 users, this value is sufficiently good. The delay will always be a constant value of 0.001 ms in case of best effort flows modeled by an infinite buffer model, for all scheduling strategies.

Figs. 8 and 9 show the PLR achieved for video flows projected against the target delay both in pedestrian (i.e. with UE speed =3km/h) and vehicular scenarios (i.e. UE speed =120 km/h). It is possible to observe that the PLR increases with the number of UEs changed from 10 to 50, due to the higher network load. Moreover, a lower value of the target delay implies a higher value of PLR due to a larger quota of packets violating the deadline .We also note that users with the highest speed equal to 120 km/h in vehicular scenario achieve the greatest PLR as compared to pedestrian users. Actually, when the user speed increases, there is high likelihood of channel quality changes in two consecutive sub frames which may lead to more frequent errors in MCS (Modulation and Coding Scheme) selection.

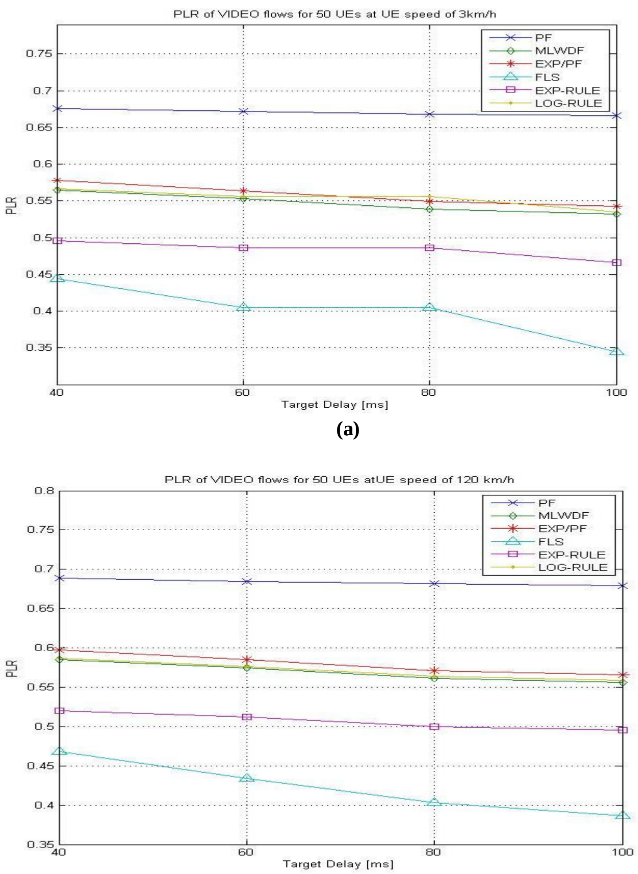


(a)



(b)

Fig.8. PLR for Video flows in (a) Pedestrian and (b) Vehicular scenarios for 10 UEs



(b)

Fig.9. PLR for Video flows in (a) Pedestrian and (b) Vehicular scenarios for 50 UEs

Now, we investigate the impact of the femtocell deployment in urban environments. For this, a traditional urban environment without femtocells and urban environment with femtocells deployed (Assumed to be working on the same operative bandwidth of macrocell) are compared.

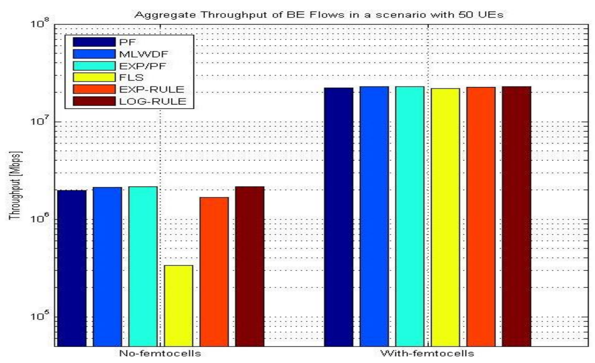


Fig.10. Aggregate Throughput Enhancement

Figure 10 demonstrates that performance of users improves in terms of average user throughput .This is mainly due to the macrocell unloading effect contributed by the adoption of femtocells .In other words, it can be said that certain number of users is served by HeNBs and the amount of resources available for remaining outdoor users consequently increases.

V. CONCLUSION

This paper has investigated the properties of the various resource scheduling strategies both for real-time and best effort services.QOS Aware Resource allocation strategies outperform PF in terms of PLR, Throughput, Delay and Fairness for RT Traffic. For RT Traffic, PF shows the highest Packet loss ratio value, the lowest achieved throughput and a high delay when the cell is charged; therefore this algorithm could be a good solution only for non-real-time flows but is unsuitable to handle real time multimedia services. We found that FLS always reaches the lowest PLR in all simulated scenarios, among all those strategies that aim to guarantee bounded delay but at the cost of reducing resources for best effort flows. Adoption of femtocells leads to rise in Overall system throughput.

REFERENCES

[1] 3GPP, Technical Specifications Group Radio Access Network - Requirements for Evolved UTRA (E-UTRA) and Evolved UTRAN (E-UTRAN), 3GPP TS 25.913. [Online]. Available: http:// www.3gpp.org

[2] V. Chandrasekhar and J. Andrews, “Femtocell networks: A survey,” *IEEE Communication Magazine,* vol. 46, no. 9, pp. 59–67, Sep. 2008.

[3] Damnjanovic., Montojo J., Yongbin Wei, Tingfang Ji; Tao Luo, “A survey on 3gpp Heterogeneous Networks” , *IEEE Communication Magazine,* Vol. 18,Issue 3,pp. 1-3 , June 2011.

[4] 3GPP, Technical Specifications Group Radio Access Network - Physical channel and Modulation (release 8), 3GPP TS 36.211.

[5] F Capozzi, G Piro, La Grieco, G boggia, P Camarda, “Downlink packet scheduling in lte cellular networks: Key Design Issues and A survey,” *IEEE Commun. Surv. Tutorials,* 2012.

[6] Rabie K. Almatarneh , Mohamed H. Ahmed, Octavia A. Dobre,” Performance analysis of Proportional Fair Scheduling in OFDMA Wireless Systems, *“in proc. of 72nd IEEE Vehicular Tech. Conference*, 6-9 Sept., 2010.

[7] R. Basukala, H. Mohd Ramli, and K. Sandrasegaran, “Performance analysis of EXP/PF and MLWDF in downlink 3GPP LTE system,” in *Proc. of first Asian Himalayas International Conference on Internet,* Nepal, Nov. 2009, pp. 1 –5.

[8] B. Sadiq, R. Madan, and A. Sampath, “Downlink Scheduling for Multiclass Traffic in LTE,” *Eurasip Journal of Wireless Communications Netw.*, vol. 2009, 2009.

[9] Bilal Sadiq, Seung Jun Baek,”Delay-Optimal Opportunistic Scheduling and Approximations: The Log Rule”, *IEEE/ACM Transactions on Networking*, Vol. 19, April 2011.

[10] Piro, L. Grieco, G. Boggia, R. Fortuna, and P. Camarda, “Two-level Downlink Scheduling for Real-Time Multimedia Services in LTE Networks,” in *IEEE Trans. Multimedia,* vol. 13, no. 5, Oct. 2011.

[11] Video test sequence. [OnLine] Available:[http://www.hlevkin.com/]

[12] G Boggia, P Camarda, LA Grieco, S Mascolo, “Feedback-based Control for Providing Real-time Services with the 802.11e MAC,” in *IEEE/ACM Transactions. Netw.* 2007.