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Effect of Adaptive Modulation and Coding Schemes on Scheduling Algorithms for LTE Downlink

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ABSTRACT

Long Term Evolution (LTE) network uses Radio Resource Management (RRM) mechanisms such as Scheduling and Adaptive Modulation and Coding (AMC) for realizing Quality of Service (QoS) requirements and optimizing system performance. Scheduling is the process of dynamically allocating physical resources to User Equipments (UEs) based on scheduling algorithms implemented at MAC sublayer of the LTE base station. Whereas AMC is Link Adaptation functionality of LTE Physical layer to enhance higher system performance. AMC scheme adopted in LTE Downlink depends on the channel quality Index (CQI) feedback from User Equipments. Hence in this paper, an attempt has been made to study and compare the performance of Blind Equal Throughput (BET), Maximum Throughput (MT) and Proportional Fair (PF) scheduling algorithms for Downlink connections with AMC (64 QAM, 16 QAM and QPSK regions) for Constant Bit Rate (CBR) traffic scenario. Performance metrics considered for simulation studies are throughput, delay, jitter and fairness. From the simulation results it is evident that the throughput, delay, jitter and fairness performances of the considered scheduling algorithms are better in 64QAM region. Also, MT scheduling algorithm achieves better throughput and BET scheduling algorithm achieves better fairness.

General Terms

LTE, Scheduling Algorithms, AMC

Keywords

Blind Equal throughput, Maximum Throughput, Proportional Fair.

1. INTRODUCTION

Long Term Evolution (LTE) is a Broadband Wireless Access network technology which aims at providing higher data rate and system throughput to deal with increasing demand for multimedia applications such as mobile TV, video streaming, VoIP and online gaming. To achieve these goals, the Radio Resource Management (RRM) block exploits a mix of advanced MAC and Physical functions like resource sharing, Channel Quality Indicator (CQI) reporting, link adaptation through Adaptive Modulation and Coding (AMC). Scheduling is a crucial RRM mechanism which divides and allocates radio resources among different users while maintaining QoS to optimize system performance. Whereas AMC is Link Adaptation functionality of LTE Physical layer to enhance higher system performance based on Channel Quality Feedback (CQI) from User Equipments in LTE Downlink. The scheduling in downlink is carried out by scheduler present at the Medium Access Control (MAC) sublayer of eNodeB (eNB). Since scheduling algorithm for eNB MAC scheduler is not standardized, LTE network designers have proposed scheduling algorithms which results in significantly different levels of user and system performance. In addition LTE supports different modulation and coding schemes (MCS) to maximize the supported throughput with a given target Block Error Rate (BLER) considering CQI reporting from UEs.

Hence in this paper, an attempt has been made to study and compare the performance of Blind Equal Throughput (BET), Maximum Throughput (MT) and Proportional Fair (PF) scheduling algorithms for Downlink connections with AM (64 QAM, 16 QAM and QPSK regions) for Constant Bit Rate (CBR) traffic scenario.

The rest of the paper is organized as follows. Section 2 gives a brief insight of Downlink Resource Allocation in LTE and Section 3 describes Scheduling Algorithms in LTE. AMC in LTE is described in Section 4. Section 5 describes the throughput and Jain index of fairness performance metrics. Simulation studies and results are given in section 6 and Section 7 concludes the paper.

2. DOWNLINK RESOURCE ALLOCATION IN LTE AGE

LTE has been designed as a highly flexible radio access technology in order to support several system bandwidth configurations (from 1.4 MHz up to 20 MHz). Since LTE uses Orthogonal Frequency Division

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Multiple Access (OFDMA) based air interface in the downlink, resource allocation can be made in time-frequency domain as shown in figure 1. In time domain, LTE frame is composed of ten consecutive Transmission Time Intervals (TTIs) of 1ms duration. A TTI consists of two equally sized time slots of 0.5ms where each slot contains 7 consecutive OFDMA symbols (including 1 control and 6 data symbols) for normal cyclic prefix. In frequency domain, the system bandwidth is divided into sub channels of 180KHz consisting of 12 consecutive subcarriers. One sub channel and the corresponding time slot is called a Resource Block (RB) and a group of two consecutive RBs in a TTI is the minimum scheduling unit which can be allocated to a user. Available RBs can be shared between multiple users at every TTI based on scheduling policy implemented at eNBs.

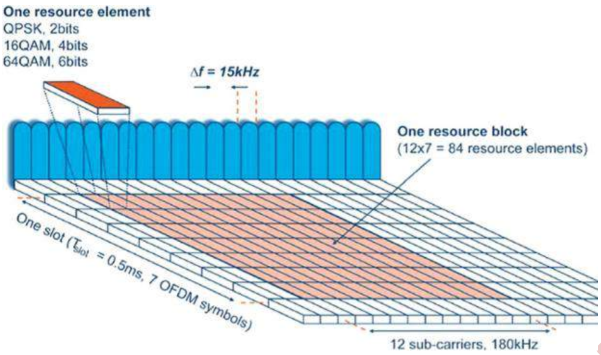

Fig 1: Time-Frequency radio resources grid [1]

3. SCHEDULING ALGORITHMS IN LTE

Scheduling algorithm is employed to select different users in time domain and different RBs in frequency domain depending on the channel conditions and bandwidth requirements of the user while ensuring fairness, stability and throughput optimality. Several scheduling algorithms have been designed for efficient scheduling based on the following three properties: low complexity, bounded delay and fairness to optimize system performance [2]. In this section BET, MT and PF scheduling algorithms are described.

3.1 Blind Equal Throughput (BET)

Please Throughput Fairness can be achieved with Blind Equal Throughput (BET) which considers the past average throughput achieved by each user and uses it as metric [3]. BET metric for the i^{th} user is calculated as in (1)

$$m_{\mathbf{i,k}}^{\mathbf{BET}} = \frac{1}{R^{\mathbf{i}}(t)} \qquad (1)$$

Where $R^{\mathbf{i}}(t)$ is given in (2).

$$R^{\mathbf{i}}(t) = (\beta) R^{\mathbf{i}}(t-1) + (1-\beta) r^{\mathbf{i}}(t) \qquad (2)$$

Where $0 \le \beta \le 1$ and $r^{\mathbf{i}}(t)$ is the data rate achieved by the i^{th} user at time t. The factor $R_i(t)$ represents the past average throughput experienced by the i^{th} user at time t which is calculated as a moving average and it is updated every TTI.

BET scheduling algorithm allocates resources to users with lower past average throughput at each TTI and the user with lowest throughput will be served till same throughput as that of other users in the cell is achieved. In particular, users with bad channel conditions are allocated more often leading to consequent fairness improvement.

3.2 Maximum Throughput (MT)

MT scheduling algorithm aims at maximizing the overall throughput by assigning radio resources to the user that can achieve the maximum throughput in the current TTI. MT metric for ith user is calculated as in (3)

$$m_{\mathbf{i,k}}^{\mathbf{MT}} = d_{\mathbf{k}}^{\mathbf{i}}(t) \qquad (3)$$

Where $d_k^i(t)$ is expected data rate for i^{th} user at time t on the k^{th} RB is given in (4)

$$d_{\mathbf{k}}^{\mathbf{i}}(t) = \log(1 + SINR_{\mathbf{k}}^{\mathbf{i}}(t)) \qquad (4)$$

MT scheduling algorithm maximizes cell throughput, on the other hand it performs unfair resource sharing since users with poor channel conditions (e.g., cell-edge users) will only get a low percentage of the available resources.

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3.3 Proportional Fair (PF)

The PF scheduling algorithm provides a good tradeoff between system throughput and fairness by selecting the user with highest instantaneous data rate achievable relative to its past average throughput. PF metric is given in (5)

$$m_{\mathbf{i,k}}^{\mathbf{PF}} = \frac{d_{\mathbf{k}}^{\mathbf{i}}(t)}{R^{\mathbf{i}}(t)} \qquad (5)$$

Where $d_k^i(t)$ is expected data rate for the i^{th} user at time t on the k^{th} RB given in (6)

$$d_{\mathbf{k}}^{\mathbf{i}}(t) = \log(1 + SINR_{\mathbf{k}}^{\mathbf{i}}(t)) \qquad (6)$$

The factor $R^i(t)$ represents the past average throughput experienced by the i^{th} user until time t, is calculated as a moving average and it is updated every TTI for each user. $R^i(t)$ is given in equation (2). Since the past average throughput act as a weighting factor of the expected data rate, users in bad conditions will be served within as certain amount of time. The parameter β is related to the time window T_f, over which fairness wants to be imposed, according to the relation (7)

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$$T_f = \frac{1}{1-\beta} \quad (7)$$

Intuitively, for $\beta = 0$ the past average throughput results to be equal to the last instantaneous rate and the fairness window T_f would be equal to one TTI. On the other hand, for β approaching to 1, the last achieved rate would never be included into the past throughput calculation and the fairness window would theoretically become infinite [4].

4. ADAPTIVE MODULATION AND CODING IN LTE

AMC is one of the most important RRM mechanisms that has been used to improve system capacity. AMC adapts the modulation and coding scheme (MCS) according to the channel condition. The channel condition can be reported back by the UE by using Channel Quality Indicator (CQI). Various modulation schemes supported in LTE downlink are listed in table 1. AMC regions considered for performance study are shown of figure 2.

Table 1. Modulation Schemes [4]

CQI	Modulation Scheme
1-6	QPSK
7-9	16QAM
10-15	64QAM

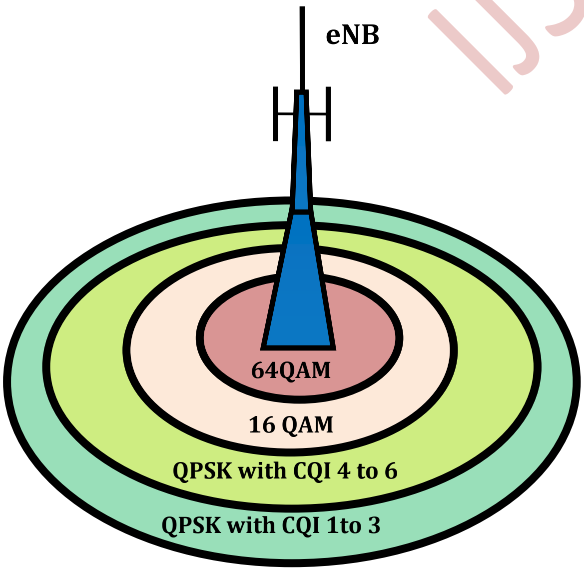

Fig 2: AMC regions considered for Simulation studies

5. THROUGHPUT AND JAIN INDEX OF FAIRNESS

Scheduling Algorithms should maximize the system throughput by utilizing fast variations in channel conditions while still satisfying some degrees of fairness. Hence in this paper throughput and Jain index of fairness are considered as performance metrics along with delay and jitter for evaluating performance of scheduling algorithms. Throughput and Jain fairness index metrics are explained below

Throughput is defined as in (8):

$$\text{throughput} = \frac{(\text{TBR} * 8)}{(t_L - t_F)} bps \quad (8)$$

where TBR –Total Bytes Received, t_L and t_F are time at which last packet received and first packet received respectively.

The Jain index of fairness, FI, is defined as (9):

$$FI = \frac{(\sum_i^K T_i)^2}{K * \sum_i^K T_i^2} \quad (9)$$

Where T_i is the throughput achieved of user i (i[th] connection) and K is the total number of users. If all T_i are equal, then FI is equal to 1 [5,6].

6. SIMULATION STUDIES AND RESULTS

The performances of BET, PF and MT scheduling algorithms for CBR traffic are evaluated using QualNet 7.1 simulator by considering an eNB and ten UEs in a single cell environment. Two ray path loss model with constant shadowing is considered for the simulation studies. The remaining simulation parameters are listed in table 2

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Table 2. Simulation Parameters

Property		Value
Simulation-Time		100S
Simulation-Area		5Km X 5Km
Downlink-Channel-Frequency		2.4GHz
uplink-Channel-Frequency		2.5GHz
Propagation-Model		Statistical
Shadowing mean		4dB
Channel-Fading-Model		Rayleigh
Channel-Bandwidth		10MHz
Antenna-Model		Omnidirectional
eNB	PHY- Tx-Power	23dBm
	PHY- Num-Tx-Antennas	1
	Antenna-Height	12m
	MAC-Tx-Mode	1(SISO)
UE	MAC- Scheduler-Type	Simple-Scheduler
	PHY- Tx-Power	12dBm
	PHY- Rx-Antennas	1
	Antenna-Height	1.5m

6.1 Scenario 1

The snapshot of the scenario designed for simulation study using QualNet 7.1 simulator is shown in figure 3. In the scenario designed, ten downlink CBR connections of data rate 3.2 Mbps are established

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between eNB and ten stationary UEs. Simulation has been carried out for BET scheduling algorithms by placing ten UEs at 64QAM region and performance metrics such as aggregate throughput, average delay average jitter and Jain fairness index are recorded. Simulation studies are repeated by changing placement of all the UEs to 16QAM, QPSK with higher CQI from 4 to 6 and QPSK with lower CQI value from 1 to 3.

Simulation studies are also repeated for MT and PF scheduling algorithms and performance metrics are measured.

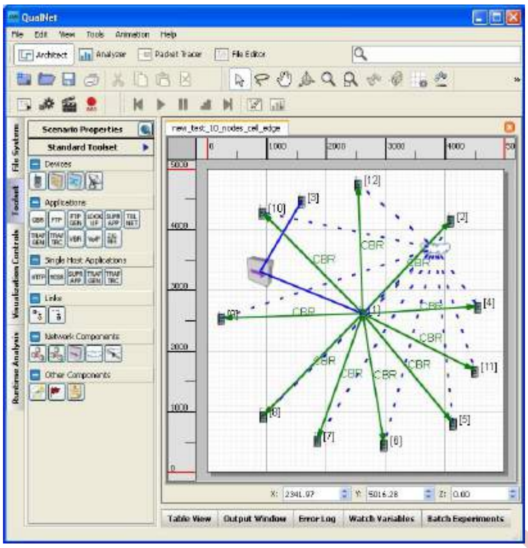

Fig 3: Snapshot of the Scenario designed for simulation study

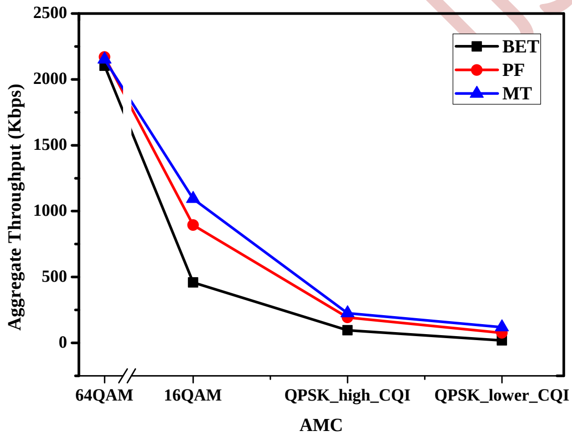

Fig 4: Throughput performance with AMC

Figure 4 shows throughput performance of different scheduling algorithms with AMC. It is observed from figure 4 that throughput performance of BET, MT and PF scheduling algorithms are similar in all AMC regions. Also, throughput performance is higher in 64QAM region and decrease as position of UEs is moved from 64QAM region towards QPSK region. This is because 64QAM uses 6 bits/symbol compared to 16QAM and QPSK which uses 4, 2 bits/symbol respectively. Further in QPSK region, throughput achieved is better for QPSK with higher CQI compared to QPSK with lower CQI. Since better CQI ensures higher coding rates leading to higher throughput in an AMC region [7]. Figure 4 also illustrates that throughput performance of MT is better than all other scheduling algorithms. Since MT assigns resources to a user with better channel quality, throughput achieved is higher [8, 9].

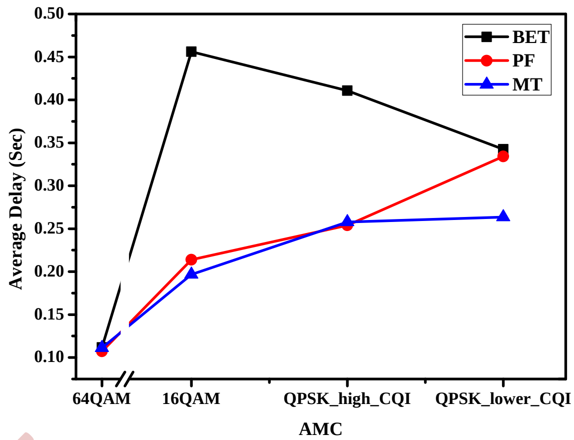

Fig 5: Delay performance with AMC

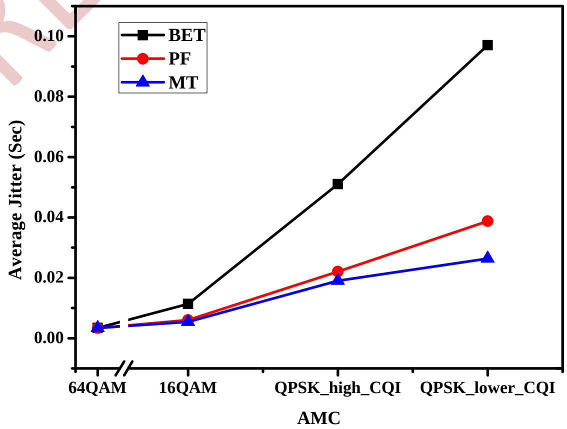

Fig 6: Jitter performance with AMC

The delay and Jitter performances of scheduling algorithms considered for performance study with AMC are shown in figure 5 and 6. Figure 5 and 6 depicts that the delay and jitter performances of MT scheduling algorithm are better than other scheduling algorithms and BET scheduling algorithm shows least performance.

Figure 7 shows the fairness (Jain Fairness Index) performance of PF, MT and BET scheduling algorithms with AMC. Figure 7 depicts that the fairness performance of all scheduling algorithms is better in 64QAM region and decreases as the UEs are moved from 64QAM region to QPSK region. It is also evident from figure 7 that Jain fairness index is higher for BET scheduling algorithm than PF and MT scheduling algorithms.

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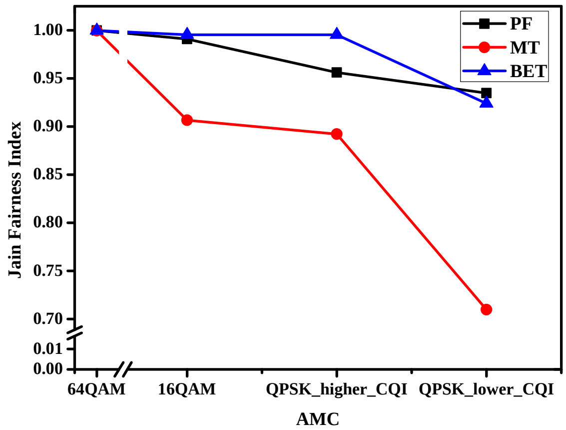

Fig 7: Fairness performance with AMC

6.2 Scenario 2

In Scenario2, UEs are placed randomly throughout the cell (Six UEs at cell edge and Four UEs in cell center). The snapshot of the scenario designed for simulation study using QualNet 7.1 simulator is shown in figure 8. Simulation study is carried out for MT scheduling algorithm with ten downlink CBR connections of data rate of 3.2 Mbps established between the eNB and ten stationary UEs. Aggregate throughput, average delay, average jitter and Jain fairness index are measured. Further, simulation studies are repeated for BET and PF scheduling algorithms.

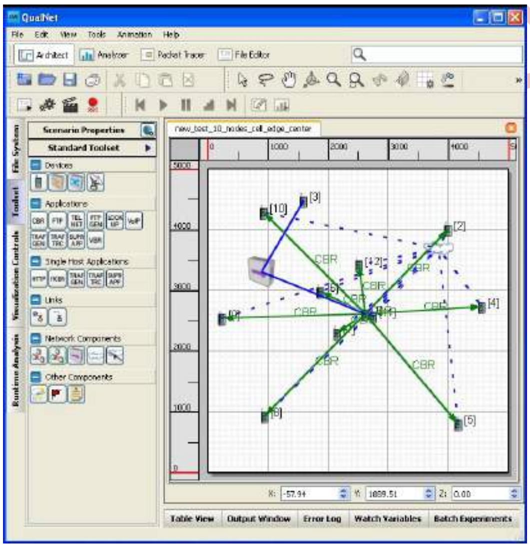

Fig 8: Snapshot of the Scenario designed for simulation study

Figure 9 shows aggregate throughput performance of MT, PF and BET scheduling algorithms. From figure 9 it is evident that aggregate throughput performance of MT scheduling algorithm is better compared to PF and BET scheduling algorithms, since MT algorithm assigns resources to a user with better instantaneous channel quality which can achieve maximum throughput in each TTI. Whereas BET scheduling algorithm achieves lesser throughput since it assigns radio resources to user with lower past average throughput which is independent of instantaneous channel quality. Also from figure 9 it is evident that aggregate throughput performance of PF scheduling algorithm is intermediate between performances achieved with MT and BET scheduling algorithms, since PF algorithm assigns resources to user with maximum ratio of instantaneous data rate achievable to past average throughput achieved [7,8].

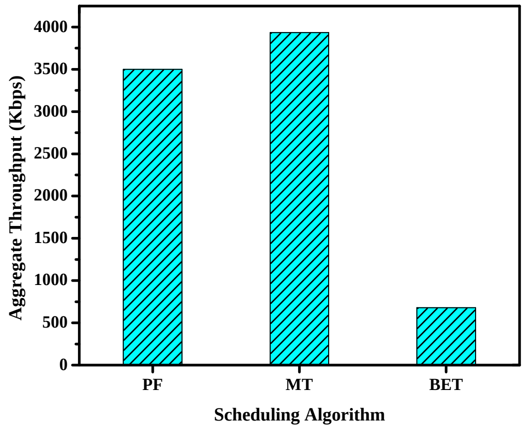

Fig 9: Throughput performance of different scheduling algorithms

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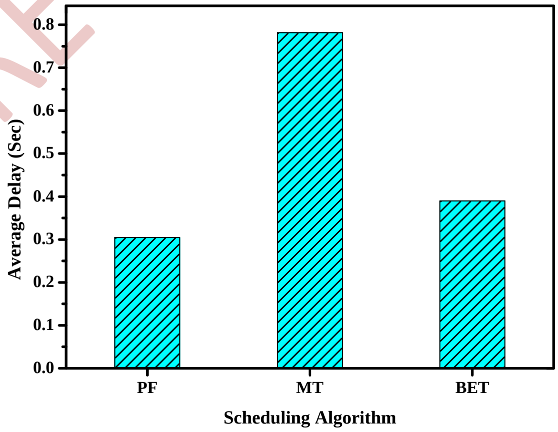

Fig 10: Delay performance with of different scheduling algorithms

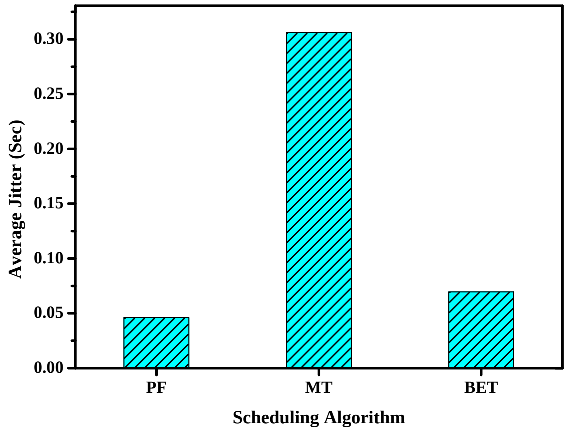

Fig 11: Jitter performance with of different scheduling algorithms

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The delay and Jitter performances of scheduling algorithms considered for performance study with AMC are shown in figure 10 and 11. Figure 10 and 11 depicts that the delay and jitter performances of PF scheduling algorithm are better than other scheduling algorithms and MT scheduling algorithm shows least performance

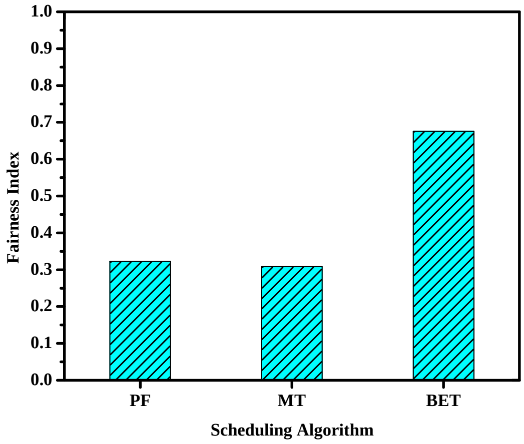

Fig 12: Fairness performance of different scheduling algorithms

Figure 12 shows the fairness (Jain Fairness Index) performance of scheduling algorithms considered for performance studies. It is evident from Figure 12 that the fairness performance of BET scheduling algorithm is better compared to MT and PF scheduling algorithms since it assigns radio resources to user with lower past average throughput at each TTI leading to fair resource allocation. MT and PF scheduling algorithms assign resources to users based on instantaneous channel conditions resulting in higher throughput for cell center users and lower throughput for cell edge users leading to unfair resource allocation [7,8].

7. CONCLUSION

In this paper, performance of BET, MT and PF scheduling algorithms with AMC is evaluated through simulation studies using Qualnet network simulator 7.1. When the UEs are placed in 64QAM region, scheduling algorithms under study achieve better throughput, delay and jitter performance. Also, as the UEs move towards QPSK region, throughput decreases with increase in delay and jitter.

However when the UEs are distributed throughout the cell, MT scheduling algorithm achieves higher throughput and PF scheduling algorithm achieves better delay and jitter performance. Also, BET scheduling algorithm achieves better fairness compared to other scheduling algorithms.

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