Tetcos White Paper

LONG TERM EVOLUTION (LTE) PROTOCOL

Verification of MAC Scheduling algorithms in NetSim^{TM}

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1. Abstract

In this paper, we compare NetSim's LTE performance metrics with the equivalent NS 3 test suite. The scenario involves multiusers in downlink using different MAC scheduling algorithms, namely Round Robin and Proportional fair scheduling. (NetSim, in addition also has a custom implementation of the maximum throughput scheduling algorithm, but NS3 test vectors do not exist for this algorithm)

2. Introduction to LTE

LTE, an acronym for Long Term Evolution, commonly known as 4G LTE, is a standard for wireless communication of high-speed data for mobile phones and data terminals. It is based on the GSM/EDGE and UMTS/HSPA network technologies, increasing the capacity and speed using a different radio interface together with core network improvements.

LTE uses new multiple access schemes on the air interface: OFDMA (Orthogonal Frequency Division Multiple Access) in downlink and SC-FDMA (Single Carrier Frequency Division Multiple Access) in uplink. Furthermore, MIMO antenna schemes form an essential part of LTE. In the long term evolution (LTE) cellular communication system scheduling the user transmission on the downlink is the biggest challenge.

2.1 Requirement of MAC scheduling

In LTE Radio Resource Management (RRM) is a challenging task as many operators nowadays offer unlimited data plans and different services. One of the key RRM functions in LTE is MAC scheduling, which coordinates the access to shared radio resources. In OFDMA-based LTE systems, this coordination generally considers two distinct dimensions, the time dimension (allocation of time frames) and the frequency dimension (allocation of subcarriers or subcarrier groups). A key challenge in setting parameters for a MAC scheduler is to optimize resource efficiency, while satisfying the users' QoS requirements and achieving a certain degree of fairness.

The network scheduler logic is similar to a statistical multiplexer wherea packet to be forwarded next is stored in a buffer which works as a queuing system. The buffer space is divided into many queues, each of which is used to hold the packets of one flow, defined for instance by source and destination IP addresses. In each case the network scheduling algorithm determines how the network scheduler manages the buffer.

2.2 Round Robin

Round Robin is the simplest scheduler which distributes the resources equally to all the users. It works by allocating the resource blocks to the non-empty Radio link control (RLC) queues in cyclic order. These non-empty RLC queues are also referred as active flows. If all the flows are allocated to some RBGs (Resource block Group) then they all are transmitted in the same sub frame. Otherwise, if some of the flows are left unassigned then the allocation in the next frame will start from the last flowthat was not allocated. The modulation and coding scheme for different transmission channels are allocated according to the received Channel Quality Indicator (CQI).

2.3 Proportional Fair Scheduling

The Proportional Fair (PF) scheduling supports high resource utilization while maintaining good fairness among network flows.A user is likely to be scheduled when its instantaneous channel quality is high relative to its own average channel condition over time. Let M_i be the Modulation and Coding Scheme Index (MCS) assigned to a user depending upon the corresponding CQI. Using the Transport Block Size (TBS) mapping, $S\left(M_j, B\right)$ be the transport block size as defined in 3GPP standard TS36.213 where B is the number of resource blocks used. Number of resource blocks is decided according to the bandwidth of transmission channel. Let $T_j(t)$, be the past average throughput of the user j. Hence the rate achievable by the user j is given by

$$R_j(k,t) = \frac{S(M_j, B)}{\tau}$$

Where τ is the transmission time interval.

Scheduling of the users is done according to the following relation.

$$\widehat{i_k}(t) = \underset{j=1,\ldots,N}{\operatorname{argmax}} \frac{R_j(k,t)}{T_j(t)}$$

The previous average throughput is given by

$$T_j(t+1) = (1-\lambda)T_j(t) + \lambda\widehat{T_j}(t), \qquad if j is scheduled$$
$$= (1-\lambda)T_j(t), \qquad otherwise$$

λisa constant which is very close to unity.$\widehat{T_j}(t)$is the actual throughput achieved by user $j$in the sub frame t.

2.4 Maximum throughput scheduling

The Maximum throughput scheduler maximizes the throughput of the base station. The maximum throughput is achieved by allocating resources on the basis of channel condition only. The user with the highest value of wideband CQI index is scheduled first. The scheduling and calculation of the throughput is very similar to that of Proportional Fair scheduling algorithm. Let i, j be the user index. $S(M_j, B)$be the size of the TB according to TS 36.213, where B is the number of resource blocks used. Achievable throughput for sub frame $t$is given by

$$R_j(k,t) = \frac{S(M_j, B)}{\tau}$$

Where τ is the TTI duration.Finally user index I to be scheduled is defined by

$$\widehat{i_k}(t) = \underset{j=1,\dots,N}{\operatorname{argmax}} R_j(k,t)$$

Thus it selects the user with maximum throughput.

3. Introduction to NetSim

NetSim, developed by Tetcos, is a popular discrete event, network simulation software used for Network Research and Development. NetSim's development environment platform allows users to develop custom codes, simulate their models and statistically analyze performance metrics. MAC scheduler with LTE in NetSim incorporates three different scheduling algorithms named Round Robin (RR), Proportional Fair (PF) and Maximum throughput scheduling. In this paper we explain the implementation and then compare the results against standard NS 3 test vectors.

4. Implementation

We incorporated a generalized algorithm to implement all three of the scheduling types. Steps to be followed are listed below.

1. Initialize the number of user set
2. Find the maximum priority among the users
3. Assign priority as per the criteria mentioned in the equation
4. Sort all the users according to their priority value
5. Continue allocating the resources as usual

Consider the given expression

$$\widehat{i_k}(t) = \underset{j=1,\dots,N}{\operatorname{argmax}} \frac{R_j(k,t)^{\alpha}}{T_j(t)^{\beta}}$$

$R_j(k,t)$is the required throughput by a user j and $T_j(t)$ is the previous average throughput of the same user. α and β are constants.

Previous average throughput is calculated by the following formula

$$T_j(t+1) = (1-\lambda)T_j(t) + \lambda \widehat{T_j}(t), \qquad if j is scheduled$$

$$= (1-\lambda)T_j(t), \qquad otherwise$$

λ is a constant which is very close to unity.

For proportional fair scheduling $\alpha = 1$and $\beta = 1$, which implies that both the previous and current possible throughput are considered for scheduling. Round Robin algorithm is implemented by taking $\alpha = 0$and $\beta = 1$, that is only previous throughput is used for scheduling. Maximum throughput algorithm uses $\alpha = 1$ and $\beta = 0$, which implies that the user with highest possible throughput will get scheduled first irrespective of earlier throughputs.

5. Testing

For the testing of Round Robin and Proportional fair scheduling algorithm following scenarios have been considered

5.1 Round robin throughput scheduling algorithm

Scenario

In the scenario considered here, a single base station (eNB) is connected to several UEs. All UEs have same channel conditions. Now for different number of users, the distance of these UE from base station is varied is varied and application throughputs for all UEs are recorded.

Due to same channel conditions as the distance increases, SNR decreases and throughput will also go down. The test consists of checking that the resultant throughput is distributed equally among the users and sums up to a reference throughput value obtained according to the SNR perceived by a single user.

The test vector is obtained according to the values of transport block size reported in table 7.1.7.2.1-1 of TS36.213, considering an equal distribution of the physical resource block among the users using Resource Allocation Type 0 as defined in Section 7.1.6.1 of TS36.213.

Let τ be the TTI duration, N be the number of UEs, B the transmission bandwidth configuration in number of RBs, G the RBG size, M the modulation and coding scheme in use at the given SINR and $S(M,B)$ be the transport block size in bits as defined by 3GPP TS 36.213. We first calculate the number L of RBGs allocated to each user as

$$L = \left\lfloor \frac{B}{NG} \right\rfloor$$

The reference throughput T in bit/s achieved by each UE is then calculated as

$$T = \frac{s(M, LG)}{8\,\tau}$$

The test passes if the measured throughput matches with the reference throughput.

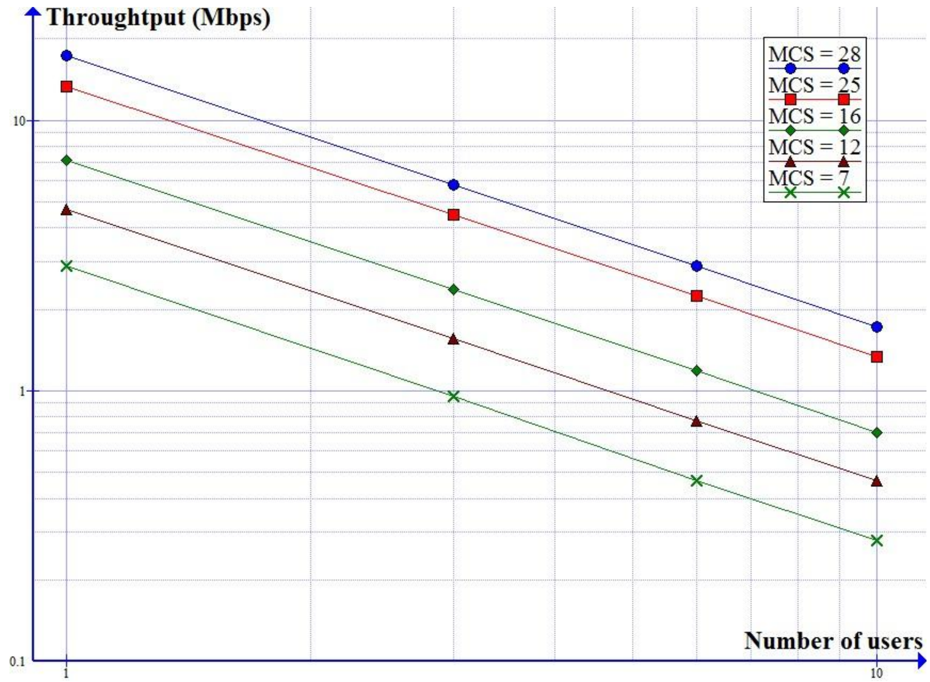
Results and verification:

The experiment is carried out with 5 MHz bandwidth. The TTI is 1 ms.MCS vs. Distance for a single user for different MCS index is given as below

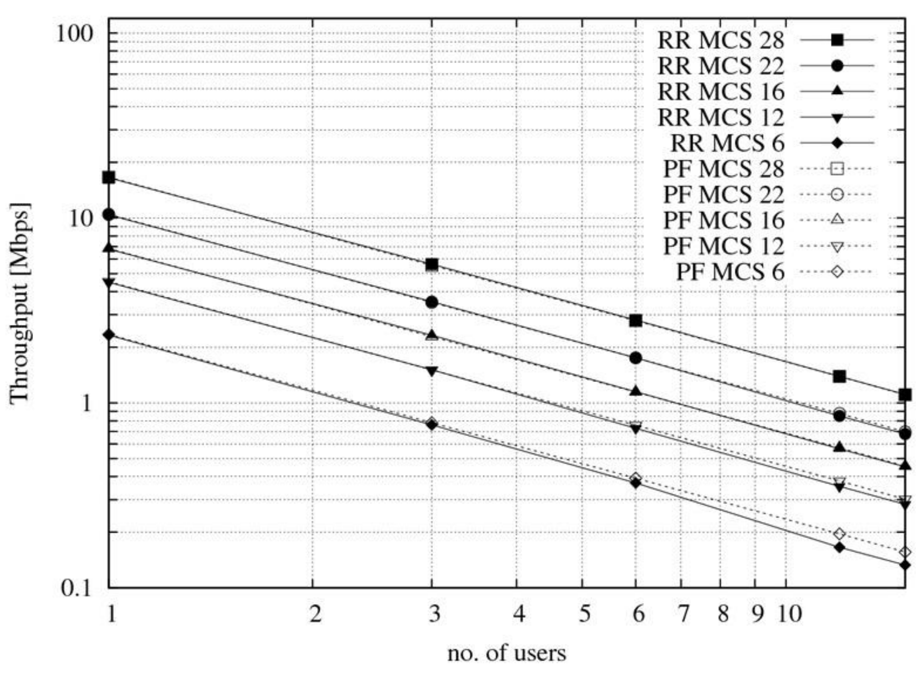
Distance (m)	MCS Index
100	28
2000	27
2400	25
2600	23
3100	20
3500	16
4000	14
4600	12
6000	9
7000	7

	Throughput (Mbps)				
Users / MCS	28	25	16	12	7
1	17.3097	13.3385	7.1014	4.672	2.8966
3	5.79328	4.4617	2.3593	1.5651	0.9577
6	2.8966	2.2425	1.1913	0.7708	0.4672
10	1.72864	1.3315	0.7008	0.4672	0.2803

NetSim Output Plot



NS3 test Suite Result (Ref: NS3 Website)



5.2 Proportional fair scheduling algorithm

Two scenarios have been considered to test the performance in terms of adaptive channel conditions and to check its fairness perspective.

Scenario 1

In this scenario, all UEs are kept at a constant distance from the only eNBthat they are connected to. Now the PF scheduling is used and throughput for different number of user at different distance is recorded. The test consist of checking that obtained throughput performance matcheswith expected throughput.

The PF should perform similar to round robin, since SNR for each of UE is same. Every user should get an equal fraction of throughput which a single user should have achieved when using all the resources.

Expected throughput$T$for each user is given by

$$T = \frac{S(M,B)}{\tau N}$$

Where τ is the TTI duration, M is the MCS index, $B$is the number of blocks to be used, $N$is the number of UEs and $S(M,B)$ is the TB size defined in TS 36.213.

Results and verification:

The result gives the same graph as obtained for Round Robin scheduling, which is correct since each user have same radio bearer conditions.

Scenario 2:

A test case with one eNB and UEs $i = 1, \ldots, 5$ those are located at a distance from the base station such that they will use respectively the MCS index $28, 25, 16, 12, 7$.

In this scenario, the SNR for every UE is different; hence they have different channel conditions. So the distribution of the bandwidth for each user will be proportional to the capacity achieved by it alone considering its SNR. So the ratio for each user is calculated as follow

Let there be N users. Mi is the MCS index of user I (determined by the SNR of UE). R_i is the achievable rate and T_i is the throughput achieved. Then Achievable rate ratio $\rho_{R,i}$ and achieved rate $\rho_{T,i}$

$$\rho_{R,i} = \frac{R_i}{\sum_{j=1}^{N} R_j}$$

$$\rho_{T,i} = \frac{T_i}{\sum_{j=1}^{N} T_j}$$

The test consists of checking that the following condition is verified:

$$\rho_{R,i} = \rho_{T,i}$$

If so, it means that the throughput obtained by each UE over the whole simulation matches with the steady-state throughput expected by the PF scheduler according to the theory.

Results and verification

The bandwidth is chosen to be 20MHz and SISO mode is used.

Users	MCS Index	Distance (m)
UE1	28	100
UE2	25	1600
UE3	16	2200
UE4	12	3500
UE5	7	5000

Obtained Throughput Ratio

User	Throughput(Mbps)	Ratio*
UE1	14.903	0.4015
UE2	11.341	0.3055
UE3	6.038	0.1626
UE4	3.118	0.0840
UE5	1.716	0.0462
Total	37.1190	

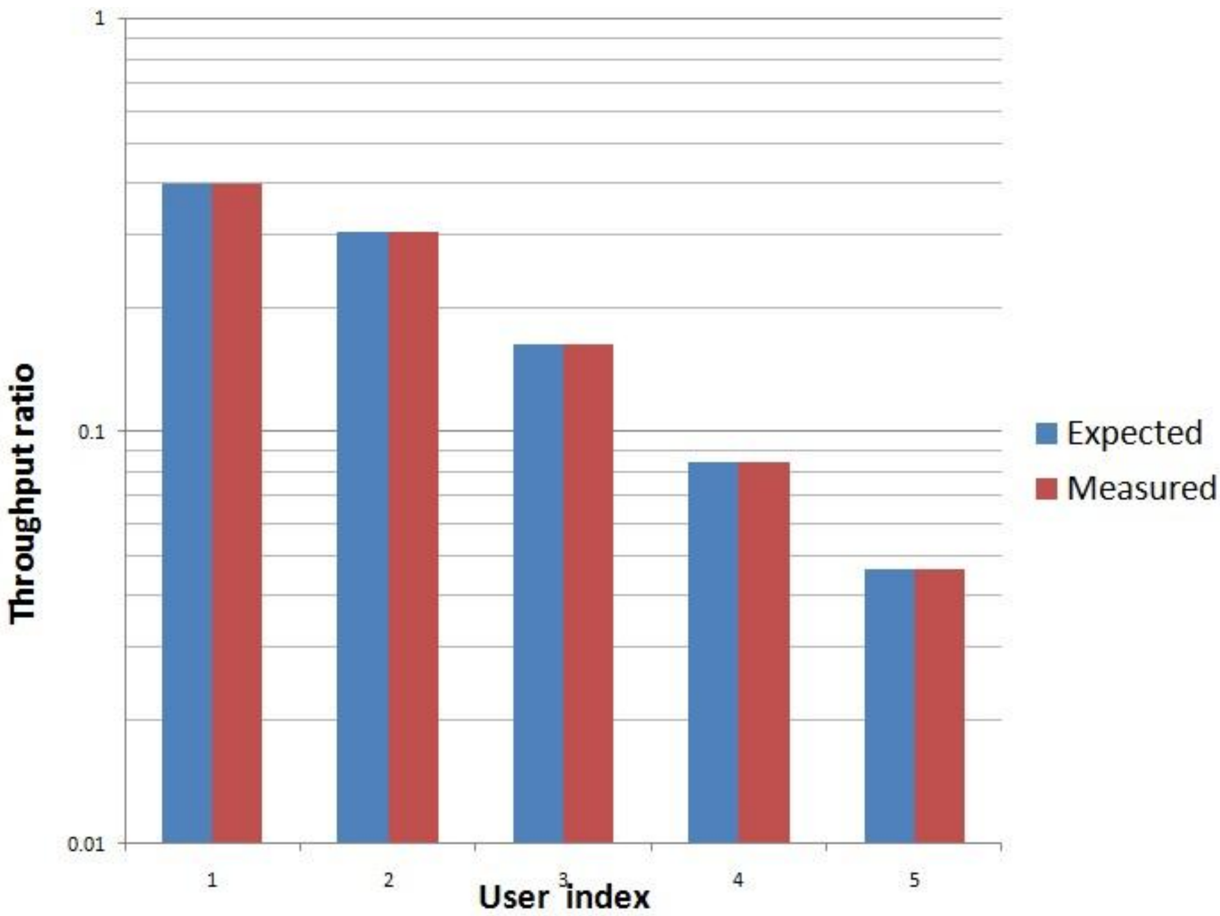
*Ratio = throughput / total throughput

Expected Throughput Ratio

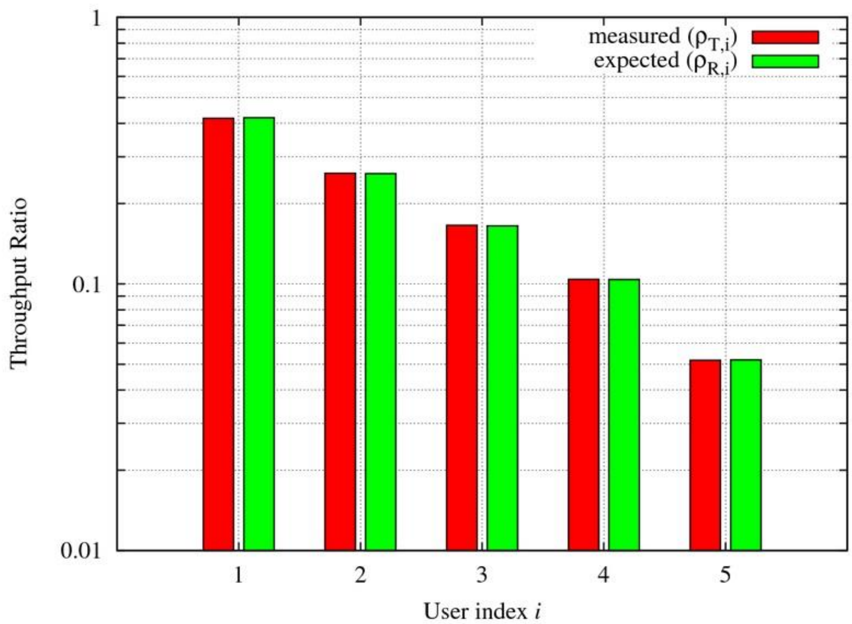
User	Throughput (Mbps)	Ratio*
UE1	74.4716	0.4013
UE2	56.648	0.3052
UE3	30.1928	0.1627
UE4	15.6278	0.0842
UE5	8.6315	0.0465
Total	185.5718	

*Ratio = throughput / total throughput

NetSim Output Plot



NS3 Test Suite Result



6. Reference

- 3GPP TS 36.413
- 3GPP TS 36.300
- 3GPP TS 36.331
- 3GPP TS 36.213
- NS3 Documentation

7. Appendix

Table 1 : SNR – CQI Index mapping

Range of SNR values		CQI Index
Lower limit	Upper limit	Value
-5	-4.42	1
-4.42	-3.40	1
-3.40	-1.70	2
-1.70	-0.19	3
-0.19	1.34	4
1.34	2.64	5
2.64	5.16	6
5.16	6.71	7

6.71	8.18	8
8.18	10.43	9
10.43	11.84	10
11.84	13.32	11
13.32	15.53	12
15.53	16.20	13
16.20	22.38	14
Greater than 22.38		15

Table 2: CQI – MCS mapping

CQI	MCS	Modulation
1	0	QPSK
2	0	QPSK
3	2	QPSK
4	5	QPSK
5	7	QPSK
6	9	QPSK
7	12	16QAM
8	14	16QAM
9	16	16QAM
10	20	64QAM
11	23	4QAM
12	25	64QAM
13	27	64QAM
14	28	64QAM
15	28	64QAM

Table 3: MCS – TBS index mapping

MCS Index	Modulation Order	TBS Index
0	2	0
1	2	1
2	2	2
3	2	3
4	2	4
5	2	5
6	2	6
7	2	7
8	2	8
9	2	9

10	4	9
11	4	10
12	4	11
13	4	12
14	4	13
15	4	14
16	4	15
17	6	15
18	6	16
19	6	17
20	6	18
21	6	19
22	6	20
23	6	21
24	6	22
25	6	23
26	6	24
27	6	25
28	6	26
29	2	Reserved
30	4	
31	6	

Table 4: TBS to Transport Block Size

I_{TBS}	N_{PRB}			
	97	**98**	**99**	**100**
21	48936	48936	48936	51024
22	52752	52752	52752	55056
23	55056	55056	57336	57336
24	59256	59256	61664	61664
25	61664	61664	63776	63776
26	63776	63776	66592	75376