INVESTIGATING THE PERFORMANCE OF SCHEDULING SCHEMES IN HSDPA SYSTEM

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***ABSTRACT*: *This paper focuses on evaluating the performance of scheduling schemes in HSDPA system. The investigation is performed with the aid of system level simulator developed for this purpose. The investigation focuses on four scheduling schemes namely Maximum C/I, Proportional Fair, Fair Throughput and Round Robin. The investigation is performed in terms of service throughput, and fairness at network level. Moreover, the investigation is also performed over the user level in terms of user average throughput, retransmissions percentage and SPDU transfer delay.*

***Key Words**: HSDPA, Performance, UMTS, Max C/I, Proportional Fair, Round Robin, Fair Throughput, Fairness*

1 INTRODUCTION

An evolution to the Universal Mobile Telecommunication System (UMTS) has been introduced known as “High Speed Downlink Packet Access” (HSDPA) in Release 5 specifications of Third Generation Partnership Program (3GPP). HSDPA is introduced to provide multimedia services to the users with much high speed and to improve spectral efficiency as compared to UMTS. The theoretical maximum downlink data rate is achievable up to 14.4 Mbps [1, 2]. However, in practical conditions, the achievable downlink data rate is limited up to 10 Mbps. These high data rates have become possible as a result of inclusion of new technologies like Link Adaptation, Hybrid Automatic Repeat Request (HARQ) Retransmissions, and Fast Packet Scheduling. The inclusion of these new features in UMTS is bundled as HSDPA in 3GPP specifications. In HSDPA, a new downlink transport channel “High Speed Downlink Shared Channel (HS-DSCH)” is also introduced for this purpose. The transmission time interval (TTI) is shortened from 10ms to 2ms. This leads to better match of the transmission parameters with the user’s channel conditions, thus leading to improved spectral efficiency. Also, the packet scheduler is moved from Radio Network Controller (RNC) to Node B to minimize the delays introduced during retransmissions at Radio Link Control (RLC) layer. The relocation of packet scheduler from RNC to Node B opens new ways in defining scheduling strategies for scheduling packet data over the air interface [1].

Any scheduling scheme would have to fulfill two goals while allocating resources to users in a cell. These include providing fairness among users in a cell during allocation of resources between them and achieving maximum cell throughput [1]. To figure out which scheduling scheme achieves the above mentioned two goals, various studies had been made in the past. Different scheduling schemes are compared with each other in HSDPA system [3, 4, 5]. However, these studies only anticipate the performance of scheduling algorithms in a constrained environment. For instance, only single cell is considered in [3] and dynamic inter-cell interference is ignored in [4] which are not in compliance with the real world scenario. In [5], the mobility and traffic model is absent and comparison is performed in single cell. Moreover, the channel condition indicator values are self generated and only limited number of users is taken into account. In these, the performance of scheduling schemes in HSDPA system has been studied over a single cell layout without taking into consideration the dynamic variation in the channel conditions and users mobility in multi cellular scenario of Wideband Code Division Multiple Access (WCDMA) systems. Moreover, these studies have been done using a simple traffic model in which users have always data to be transmitted. In this paper, we have conducted a comprehensive study over the performance of scheduling schemes in HSDPA system by using a dynamic system level simulator in multi-cellular environment by including all the essential features of HSDPA system which affects radio channel and link conditions in a dynamic way throughout the simulation run and 3GPP recommended traffic models. The performance metrics taken into account includes service throughput, fairness, user average throughput, retransmission percentage, Session Protocol Data Unit (SPDU) transfer delay etc.

The paper is organized as follows. Section 2 describes various scheduling schemes and their principle. Section 3 discusses the dynamic systems level simulator developed for this study. Section 4 discusses the results obtained and finally some conclusions are drawn in Section 5.

2 OVERVIEW OF SCHEDULING SCHEMES

In this paper, we have performed a comprehensive study on the performance of scheduling schemes such as Maximum Carrier to Interference, Proportional Fair, Fair Throughput, and Round Robin in multi cellular environment in HSDPA system.

Maximum Carrier to Interference (Max C/I) is also known as Maximum Throughput or Maximum SIR scheduling scheme. It is one of the most opportunistic scheduling schemes. It exploits the user’s channel condition by taking into account the radio channel conditions of the users during scheduling process. It selects the user having best channel conditions among all in the scheduling pool. Scheduling pool comprises of users whom are eligible for being scheduled in the subsequent TTI. The advantage of this scheduling scheme is that it increases system throughput. However, the price of this advantage is paid in terms of fairness. It lacks fairness among users in terms of throughput and time [1]. The Proportional Fair (PF) scheduling scheme was first described in [6] and was proposed for High Data Rate (HDR) Code Division Multiple Access (CDMA) Systems. This scheme prioritizes users in a given cell based on the ratio of user's instantaneous supportable data rate and average throughput. The user having highest priority is selected for scheduling in the subsequent TTI. This scheme tries to serve those users in a cell which has good radio channel conditions relative to their average channel conditions or throughput observed. In this way, fairness is maintained in a proportional manner among users in terms of throughput [1, 6, 7]. Fair throughput (FTH) scheduling scheme comes in the category of channel independent scheduling schemes. It doesn't consider the users channel conditions while making scheduling decisions. The goal of this scheduling strategy is to provide all the users, the same throughput irrespective of their channel conditions. There are several ways to implement this scheduling scheme. However the strategy used in this paper involves the scheduling of user per TTI on the basis of its average throughput. The user having lowest average throughput is scheduled in the subsequent TTI. This satisfies the max-min fairness criteria as all the users have equal distribution of throughput. Round Robin (RR) is among one of the simplest scheduling schemes. It a channel independent scheduling scheme. It doesn't take into account the channel condition of the users while making scheduling decision. It schedules users in a cyclic fashion [7].

3 SIMULATION MODEL

The performance of scheduling schemes in HSDPA system has been evaluated using a dynamic system-level simulator. The system model used in simulation comprises of 24 cell sites with a hexagonal layout using omni-directional antennas. Users are created in each cell site randomly and at random locations from centre of the cells using uniform distribution. The site-to-site distance is equal to 2.8 Km.

3.1 Traffic Model

An ETSI WWW traffic model based on [8] that has been modified for HSDPA traffic [9] has been implemented. The WWW browsing session comprises of one or more packet sessions. Each packet session comprises of one or more packet calls depending upon the type of application [8]. Table 1 lists the attributes of the packet session model [9].

Table 1**.** Parameters for ETSI WWW Browsing Model [9]

Process	Random Variable	Parameters
Packet Call Size	Pareto with cut-off	α=1.1, k=4.5 kbytes, m= 2 Mbytes (Average 25 kbytes)
Time between packet calls	Geometric	5 seconds
Datagram Size	Segmented based on MTU size	1500 octets
Datagrams per Packet Call	Deterministic	Based on Packet call size and Packet MTU
Datagram Inter-arrival time	Geometric	= MTU size/ peak link speed = (1500 octets *8)/2Mbps=6ms

3.2 Mobility and Handover

In order to model the mobility of the users with in a system, synthetic mobility models have been considered in this paper. There are many synthetic mobility models such as Random Walk Model, Random Waypoint Model, and Random Direction Model etc [10]. Out of these, Random Direction Model has been used [11]. Once the user speed is determined, it is not changed throughout the simulation time. Moreover, the probability of changing direction of movement is equal to 20 percent [8]. In order to avoid edge effects, users are wrap-around after reaching at system boundaries. For mobility between the cells, hard handoff is also supported for HSDPA users.

3.3 Interference

In WCDMA based networks, interference plays an important role in the performance. It is the interference due to which power control and other features have been implemented in WCDMA networks. The total interference being received at the receiver is the sum of intra-cell and inter-cell interference. Intra cell interference accounts to the interference that occurred within a cell site whereas inter-cell interference accounts to the inference that is caused by the neighboring cell sites [12]. In the dynamic simulator, the intra-cell and inter-cell interference are taken as variables which keep on changing due to user's mobility, their transmitted power levels and load conditions. That is why we consider them to be important for evaluation of packet scheduling schemes which lacks in other published results. Moreover, the large scale path loss using Suburban Okumara-Hata model [8], shadow fading [13], and multipath fading has been modeled.

The power of Node B is distributed among common channels and High Speed Downlink Shared Channel (HS-DSCH). A portion of available power for HSDPA operation is allocated to HS-DSCH. This power is further distributed between High Speed Physical Downlink Shared Channels (HS-PDSCHs) and High Speed Shared Control Channel (HS-SCCH). A total of 5 HS-PDSCHs are allocated per Node B. No code multiplexing is used in the simulation. Thus all the available resources (codes and power) are at the disposal of a scheduled user in a given TTI.

3.4 CQI Report

Channel Quality Indicator (CQI) report consists of an integer value estimated by the User Equipment (UE) for the Node B. It tells the Node B about the instantaneous channel condition of the UE. The CQI value is determined from the Signal to Interference Ratio (S/I) which is estimated at the UE side. The S/I ratio is estimated using following formula [1]:

$$S/I = SF \frac{P_{HSDPA}}{(1-\alpha)I_{intra} + I_{inter}} \qquad (1)$$

Where P_{HSDPA} is the received HSDPA power estimated from the received Common Pilot Channel (CPICH) power. SF is the spreading factor of High Speed Physical Downlink Shared Channel (HS-PDSCH) which is equal to 16, I_{intra} and I_{inter} is the intra-cell and inter-cell interference respectively. Once the SIR is estimated, it is translated into CQI value by utilizing the following equation [14]:

$$CQI = \lfloor S/I\,[dB] + 3.5 \rfloor \qquad (2)$$

CQI value generated at UE is processed at Node B after 3 subframes or 6ms corresponding to CQI processing delay.

3.5 HSDPA MAC Related Entities

The simulator comprises of full Medium Access Control (MAC) layer entities (Node B and UE side) as specified in [15] such as flow control, reordering mechanism, Hybrid Automatic Repeat Request (HARQ), packet scheduler, disassembly entity etc. A Credit based flow control mechanism [12] has been implemented in which the RNC sends an amount of Protocol Data Units (PDUs) to Node B depending upon the credit request being made by Node B. It is implemented at the high speed Medium Access Control (MAC-hs) Node B side. In case of HARQ entity which is present at both sides of MAC-hs entities [15], Chase Combining method [1] has been used in which once the retransmission is requested by the UE, the same copy of the Protocol Data Unit (PDU) is send to the UE by Node B. Moreover, a total of three retransmissions can be requested by UE to Node B for a particular PDU. In order to send the PDUs received at UE side to higher layer in orderly manner, a reordering mechanism [15] known as "Sliding Window" has been implemented.

A summary of important simulation parameters is given in Table 2.

Table 2. Simulation Parameters

Parameter	Value
Cell Layout	24 hexagonal single sector
Site to Site Distance	2.8 Km
BS Max Power	44 dBm
HS-DSCH Power	39 dBm
CPICH Power	33 dBm
Other Channels Power	33 dBm
Carrier Frequency	2000 MHz
Handover Type	Hard Handover
Propagation Model	Suburban Okumura Hata
Packet Scheduler	Node B Packet Scheduler
Shadow Fading	Mean 0 dB Std deviation 8dB
# HS-PDSCHs	5
# HS-SCCHs	1
HARQ Method	Chase Combining [1, 7]
Max Retransmissions	3
Flow Control	Credit based
Reordering Mechanism	Sliding Window
Terminal Speed	3 km/hr
Orthogonality Factor	0.6
Simulation Time	50,000 TTI

4 RESULTS AND DISCUSSION

In the simulation model, we have considered the performance of scheduling schemes in the HSDPA system at network level and user level.

4.1 Network Level

The Maximum C/I scheduling scheme corresponds to high average service throughput as compared to all the other scheduling schemes being simulated. The service throughput is defined as "*the average number of information bits that are successfully decoded during unit time T_s*" [16]. It is calculated as:

$$\phi_s = \frac{\sum_{i}^{N_{sec}} D_i \Big/ N_{sec}}{T_s} \qquad (3)$$

where D_i is the information bits successfully decoded in each sector. N_{sec} is the number of sectors in which transmission has occurred.

Figure 1 shows the average service throughput attained by various scheduling schemes being simulated. The distinction between the channel dependent scheduling schemes and channel independent scheduling schemes can be seen easily seen in the figure. Channel dependent scheduling schemes such as Max C/I and PF takes into account the channel conditions of the users while scheduling. Thus, they exploit the user's channel conditions by scheduling the users whose channel conditions are most favorable among all. In this way, the service throughput attained by such schemes is higher than channel independent scheduling schemes such as Round Robin and Fair Throughput. Channel independent scheduling such as Round Robin and Fair Throughput doesn't take into account the channel conditions of the users while performing scheduling decisions. Thus they have lower service throughput.

Service throughput with Max C/I scheme is higher than PF scheme as it schedules user having better channel conditions among all. In this way, it exploits the channel conditions of the user more as compared to PF. On the other hand, the PF scheme tries to provide fairness to all users in the cell site thus lowering attained service throughput. In case of Fair Throughput (FTH) and Round Robin (RR) schemes, the RR has higher service throughput than FTH. It is because it schedules users in cyclic fashion giving each user an equal share of resources. Whereas, the FTH scheme tries to provide equal throughput share to all the users in the cell site irrespective of their geographical locations. Thus its service throughput is lowered than RR.

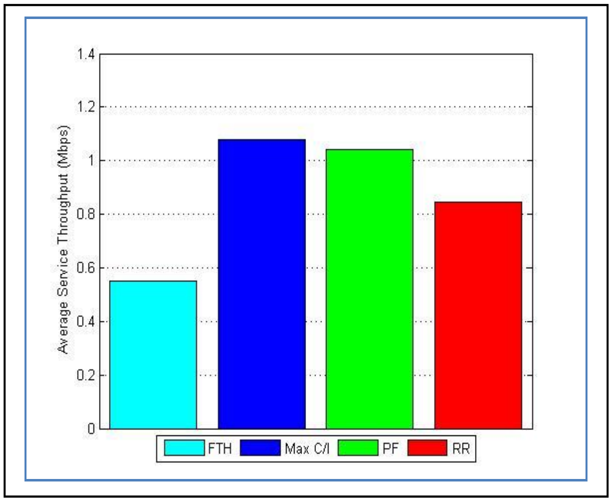

Figure 1. Average Service Throughput for various Scheduling Schemes

Fairness, an important parameter when comparing the performance of scheduling schemes with each other. In this paper, Jain fairness index defined in [17] has been used to determine the fairness achieved by each scheduling scheme. It is calculated as:

$$Index = \frac{\left\{\sum_{i=1}^{N} x_i\right\}^2}{N\left\{\sum_{i=1}^{N} (x_i)^2\right\}} \quad (4)$$

where x_i denotes the throughput of user i and N is the number of users.

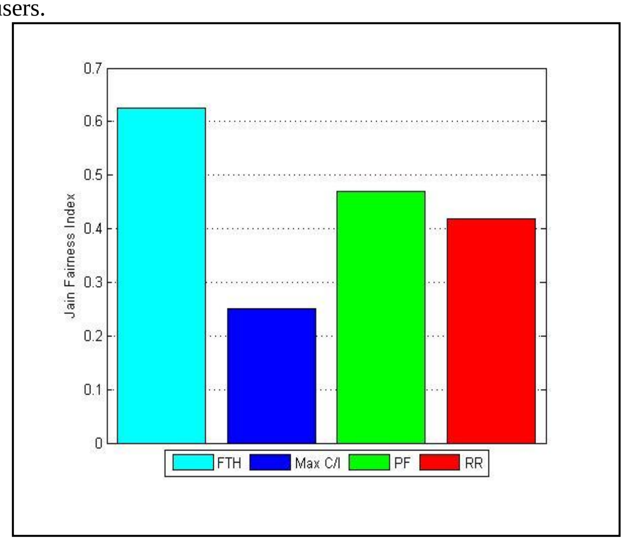

Figure 2. (a) Total Network Fairness (Throughput)

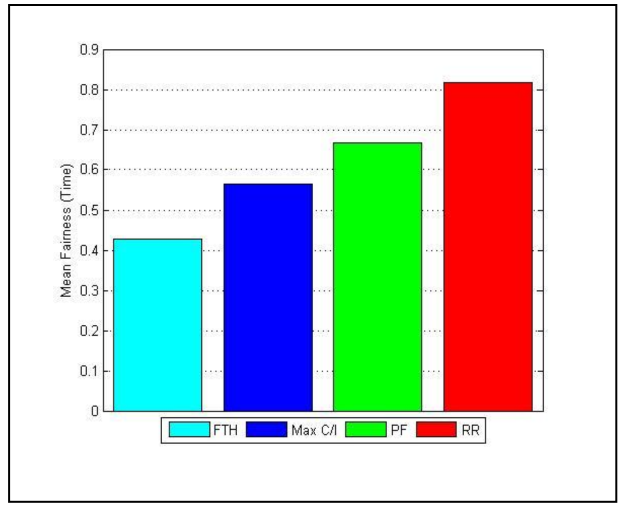

Figure 2. (b) Total Network Fairness (Time)

Figure 2 shows the average fairness in terms of throughput achieved by each scheduling scheme. It can be seen that the fairness achieved by Maximum C/I scheme is the least among all. This is because it tries to schedule user having better channel conditions, thus neglecting users having poor channel conditions. In this way, unequal distribution of throughput is attained. In case of Fair throughput scheme, it has the highest fairness in terms of throughput than other schemes because it tries to give each and every user an equal share of throughput. On the other hand, Round Robin has high fairness in terms of time allocation which can be seen in Figure 2. This is as it gives equal time share to all the users in the cell.

4.2 User Level

The scheduling scheme performance over user level is also studied in a broader manner. Each cell in a network comprises of different number of users and the performance of scheduling scheme is different in each cell. The same is true in case of a single user. Thus, we have considered the effect of scheduling scheme on user over a network level. Moreover, each user is classified into ten classes based on the normalized distance from the Node B. It can be seen in Figure 3 that the users close to the Node B are more privileged by the Max C/I scheme than PF, FTH and RR. This is because Max C/I scheme schedules user having highest CQI value among all indicating better channel condition. They have higher throughput than other schemes. However, as the normalized distance is greater than 0.6-0.7, the user throughput using the Proportional Fair scheme is larger than Max C/I scheme. One can witness the fairness achieved by FTH in figure 3 as it tries to gives equal throughput to all the users in the cell regardless of their location.

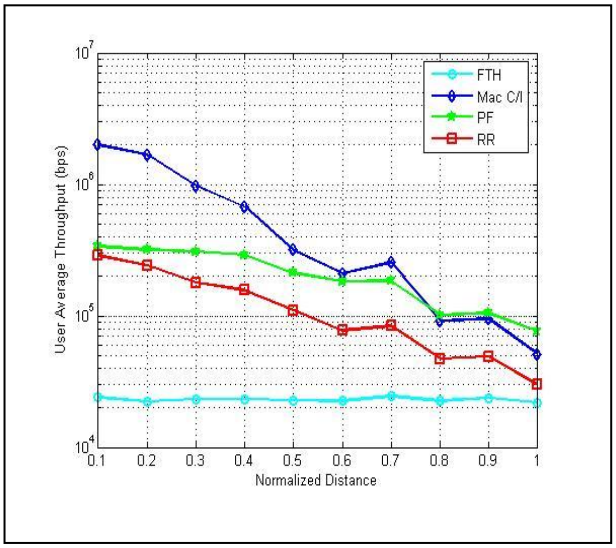

Figure 3. Average User Throughput vs Normalized distance from Node B

Moreover, the Session Protocol Data Unit (SPDU) transfer delay as a function of normalized distance from Node B is shown in Figure 4. It is evident that users close to the Node B have less average SPDU transfer delay as compared to the users far from the Node B. With FTH scheme, the SPDU transfer delay is greater than Max C/I, PF and RR scheme since it tries to maintain fairness among user by scheduling schedules users in random fashion and having less average throughput among all. Moreover, the fairness achieved by FTH can also be seen in the figure below as the SPDU transfer delay with respect to normalized distance from Node B is linear. In case of Max C/I scheme, users close to the Node B have lower SPDU transfer delay as compared to the PF and RR scheme. As the normalized distance increases from 0.6, the SPDU transfer delay of users with Max C/I scheme increases compared to the PF scheme. This indicates that users far from the Node B are less privileged by Max C/I scheme than PF scheme. The SPDU transfer delay with RR scheme is also shown below. From it, one can deduce that user close to the Node B enjoying better channel conditions have less SPDU transfer delay than users located far as it schedules users in cyclic fashion doesn't taking into account the variations in the channel conditions of the users.

The user average retransmissions percentage vs normalized distance from Node B is also shown in Figure 4. It is observed that the users close to the Node B have fewer retransmissions as compared to the users far from the Node B. It can be seen that as the distance from Node B increases, the number of retransmissions increases. This is due to the fact that user far from the Node B has more channel variations as compared to users close to the Node B. Also, the CQI processing delay causes the retransmissions to occur. It is also observed that retransmissions percentage is higher for channel independent scheduling schemes as compared to channel dependent scheduling schemes.

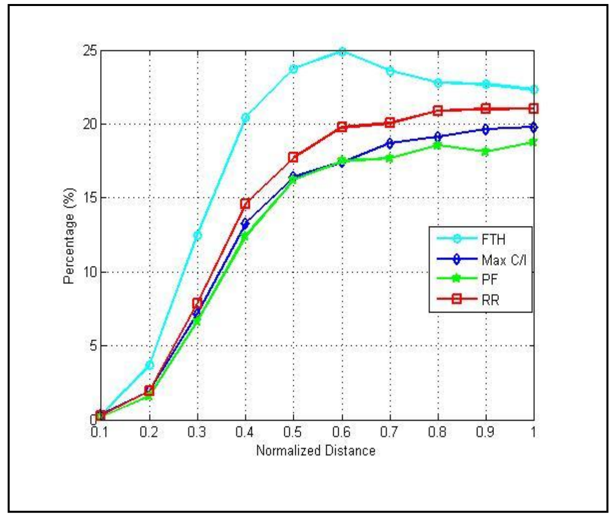

Figure 4. (a) Average User Retransmission vs Normalized Distance from Node B

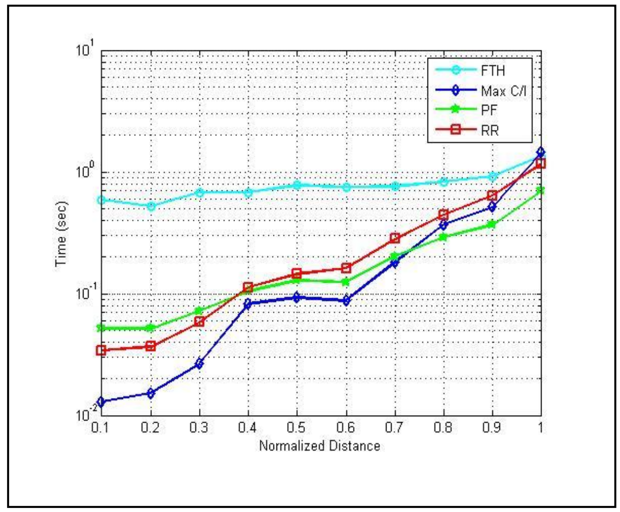

Figure 4. (b) SPDU Transfer Delay vs Normalized Distance from Node B

5 CONCULUSIONS

In this paper, we have analyzed the performance of HSDPA system under various scheduling schemes focusing on service throughput, fairness, average user throughput, SPDU transfer delay, and retransmissions using computer simulations. Four packet scheduling schemes were considered namely Maximum C/I, Proportional Fair, Fair Throughput and Round Robin. It has been observed that the average service throughput per Node B is higher for channel dependent scheduling schemes as compared to non-channel dependent or channel independent scheduling schemes. It has been observed that the user average throughput decreases with the increase its distance from Node B. Although the Max C/I scheme has higher service throughput, However, the PF scheme performs well as compared to Max C/I scheduling scheme in terms of giving throughput to user located far from the Node B. Moreover, the FTH scheme gives equal throughput share to all the users irrespective of their geographical locations. In case of SPDU transfer delay, the same effect is viewed in terms of delay. The PF scheme outperforms in terms of retransmissions as compared to other schemes.

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REFERENCES

1. *Holma, H., and Toskala, A. HSDPA/HSUPA for UMTS. John Wiley and Sons, 2006*
2. *Holma, H., and Toskala, A. WCDMA for UMTS (3rd ed.). John Wiley and Sons, 2004*
3. *Malkowski, M., Kemper, A., and Wang, X. Performance of Scheduling Algorithms for HSDPA. In Proceeedings of Second International Conference on Communications and Networking in China, CHINACOM '07*, 1052-1056, 2007
4. *Haider, A., and Harris, R. A Novel Proportional Fair Scheduling Algorithm for HSDPA in UMTS Networks. In Proceedings of The 2nd International Conference on Wireless Broadband and Ultra Wideband Communications*, AusWireless 2007, 1-7, 2007
5. *John, J. U., Trianon, A. M., and Pillay, S. A Study on the Characteristics of the Proportional Fairness Scheduling Algorithm in HSDPA. In Proc. of The 4th Student Conference on Research and Development, Selangor, Malaysia, SCOReD 2006*, 33-37, 2006
6. *Jalali, A., Padovani, R., and Pankaj, R. Data Throughput of CDMA-HDR a High Efficiency- High Data Rate Personal Communication Wireless System. In Proc. of The IEEE 51st Vehicular Technology Conference Proceedings, 2000. VTC 2000-Spring Tokyo*, **vol. 3,** 1854-1858, 2000
7. *Ameigeiras, P. (2003). Packet Scheduling And Quality of Service in HSDPA. PhD Thesis, Institue of Electronic Systems, Aalborg University, Denmark*
8. *ETSI/SMG2. Evaluation Report for ETSI UMTS Terrestrial Radio Access (UTRA). ITU-R RTT Candidate Submission*, Tdoc SMG2 260/98, September 1998
9. *Members of 3GPP TSG-RAN Working Group 1. Common HSDPA System Simulation Assumptions. 3GPP*, TSGR1#15(00)1094, August 2000
10. *Musolesi, M., & Mascolo, C. Mobility Models for Systems Evaluation A Survey. Book Chapter in B. Garbinato, B., Miranda, H., & Rodrigues, L., Middleware for Network Eccentric and Mobile Applications. Springer*, 2009
11. *Alexander, K. A Survey of Mobility Models in Wireless Networks (Description, Algorithm, Analysis, Videos),* http://www.routingprotokolle.de/Routing/mobility_main.htm, 2008
12. *Enhanced UMTS Radio Access Network (EURANE) Extensions for NS2*. http://eurane.ti-wmc.nl/eurane/, June 2010
13. *Gudmundson, M. Correlation model for shadow fading in mobile radio systems. Electronics Letters* , **vol. 27**, issue 23, 2145-2146, 1991
14. *Members of 3GPP TSG-RAN Working Group 4. Revised HSDPA CQI Proposal. 3GPP*, Technical Report R4-020612, April 2002
15. *3GPP Technical Specification Group Radio Access Network. Medium Access Control (MAC) Protocol Specifications*. 3GPP TS 25.321, Release 5, V5.14.0, 2008
16. *Ofuji, Y., Morimoto, A., Abeta, S., and Sawahashi, M. Comparison of Packet Scheduling Algorithms Focusing on User Throughput in High Speed Downlink Packet Access. In Proc. of The 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC 2002*, **vol. 3**, 1462-1466, 2002
17. *Jain, R., Chiu D., and Hawe, W. A Quantitative Measure of Fairness and Discrimination for Resource Allocation in Shared Computer System. Technical Report, Digital Equipment Corporation, DEC-TR-301*, (1984)