Vertical Handoff Algorithms for Heterogeneous 3G Networks

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***Abstract*—One of main challenges of fourth generation wireless networks (4G) will be the integration of various mobile technologies such as CDMA 1xEV-DO RA, UMTS/HSDPA and WiMAX. In this paper, the interoperability between the CDMA 1xEV-DO RA and the UMTS/HSDPA in the 4G context is investigated. New algorithms for vertical handoff traffic acceptance are proposed considering the link occupation, the buffer occupation, the radio signal strength (RSS) or the quantum size (DRR) of each 3G system, taken individually or in combination of them, as inputs for decision of vertical handoff process. Different algorithms are evaluated through QoS metrics such as the average packet delay and the loss percentage in function of vertical handoff traffic load. The results showed that depending on the chosen algorithm it is possible to assure the QoS of 1xEV-DO RA and UMTS/HSDPA systems and still to accept a good amount of vertical handoff traffic.**

I. Introduction

The fourth generation of mobile systems (4G) aims to integrate different access technologies in order to provide multimedia services to its users at anytime, anywhere and with any technology. It is expected to integrate various mobile systems such as the CDMA 1xEV-DO RA (Code Division Multiple Access 1x Evolution Data Optimized) [1], the UMTS/HSDPA (Universal Mobile Telecommunications System / High Speed Downlink Packet Access) [2] and the WiMAX (Worldwide interoperability for Microwave Access) [3].

The integration of 4G networks is achieved through new handoff mechanism in order to offer communication among users regardless of access networks. This mechanism is known as vertical handoff [4] that allows to users migrate among heterogeneous access networks, for example, the migration of users from CDMA 1xEV-DO RA system to UMTS/HSDPA system.

In [7], a new vertical handoff algorithm which evaluates the SINR of different access networks (WLAN,WCDMA) in order to make a decision on handoff process according to some restrictions of QoS is proposed. The analytical and numeric results demonstrated that algorithm based on SINR provides higher throughputs than algorithm based on RSS. In another study [5], a network selection algorithm based on mathematical techniques in order to guarantee its users the choice of the best network available is presented. However, the simulation results revealed that the proposed mechanism could not work efficiently for an UMTS/WLAN system. In [6], a new algorithm for vertical handoff between WiFi and WiMAX is proposed. This algorithm combines data rate and channel occupancy in order to provide a fair balance for users in the two networks.

In this paper, new vertical handoff algorithms are proposed in order to distribute vertical handoff traffic between 3G systems to avoid overloading or underutilizing of systems and still to assure QoS in both 3G systems. The algorithms are proposed considering the RSS, the buffer occupation, the link occupation or the quantum size of each 3G system as inputs for vertical handoff decision. The efficiencies of proposed algorithms are verified through the 3G systems CDMA 1xEV-DO RA and UMTS/HSDPA. The following QoS metrics are evaluated: the average packet delay and the loss percentage, all in function of vertical handoff traffic load. The data scheduler Proportional Fair (PF) is adopted in both systems to provide equal resource distribution for all users.

The rest of paper is organized as it follows. In the Section II, the basics of 3G CDMA 1xEV-DO RA and 3G UMTS/HSDPA systems are presented. The vertical handoff algorithms to distribute traffic between 3G systems are proposed in the Section III. The simulation model and adopted scenario are described in Section IV. In the Section V the results obtained in computing simulations and their analyses are presented. Finally, the main conclusions are presented in the Section VI.

II. 3G Basics

A. UMTS/HSDPA System

The air interface HSDPA standardized by 3GPP group (3rd Generation Partnership Project) is capable of transmitting data rates up to 14.4 Mbps in the downlink for a carrier bandwidth of 5 MHz. In this paper the HSDPA air interface was chosen as target in reference to UMTS/HSDPA downlink.

Table I shows the main characteristics of UMTS/HSDPA downlink according to 3GPP Release 5. In the Inter-TTI column each unit is equivalent to 2 ms. The coverage probability (Cov. Prob) column will be detailed in the Section IV.

B. CDMA 1xEV-DO RA System

The basic access technique in the 1xEV-DO RA system is the CDMA. Besides, it is also used the Time Division Multiplexing (TDM) technique in the downlink [8]. The forward link (from BTS to the mobile device) is structured to maximize

TABLE I
MODULATION TYPE PER DATA RATE - UMTS/HSDPA DOWNLINK

HS-DSCH Category	Rate (Mbps)	Bits/ Packet	Inter TTI	QPSK/ 16QAM	Code	Cov. Prob
Cat.1	**1.2**	7300	3	Both	5	3%
Cat.2	**1.2**	7300	3	Both	5	3%
Cat.3	**1.8**	7300	2	Both	5	4%
Cat.4	**1.8**	7300	2	Both	5	13%
Cat.5	**3.6**	7300	1	Both	5	12%
Cat.6	**3.6**	7300	1	Both	5	14%
Cat.7	**7.2**	14600	1	Both	10	18%
Cat.8	**7.2**	14600	1	Both	10	15%
Cat.9	**10.2**	20432	1	Both	15	8%
Cat.10	**14.4**	28776	1	Both	15	4%
Cat.11	**0.9**	3650	2	QPSK	5	2%
Cat.12	**1.8**	7300	1	QPSK	5	4%

the overall data throughput of a given sector. The 1xEV-DO RA uses a CDMA carrier of 1.25 MHz bandwidth. Each frame in forward link has length of 26.67 ms and it is subdivided into 16 Time Slots (TS), each one having duration of 1.67 ms.

The data rates supported by forward link can vary from 38.4 kbps up to 3072.0 kbps by a sector of a cell. One of three modulation schemes QPSK, 8PSK and 16QAM is used depending on data rate. Moreover, different quantities of TSs are allocated for each data rate. In Table II the data rates in function of modulation, number of TSs and packet length are shown in details. The coverage probability (Cov. Prob) column will be detailed in the Section IV.

TABLE II
MODULATION TYPE PER DATA RATE - 1XEV-DO RA DOWNLINK

Class	Rate (kbps)	Bits/ Packet	Time Slots	Modulation	Code	Cov. Prob
1	**38.4**	1024	16	QPSK	1/5	2%
2	**76.8**	1024	8	QPSK	1/5	3%
3	**153.6**	1024	4	QPSK	1/5	8%
4	**307.2**	1024	2	QPSK	1/5	15%
5	**614.4**	1024	1	QPSK	1/3	20%
6	**921.6**	3072	2	8PSK	1/3	14%
7	**1228.8**	2048	1	QPSK	1/3	13%
8	**1536.0**	5120	2	16QAM	1/3	10%
9	**1843.2**	3072	1	8PSK	1/3	8%
10	**2457.6**	4096	1	16QAM	1/3	4%
11	**3072.0**	5120	1	16QAM	1/3	3%

III. VERTICAL HANDOFF ALGORITHMS

The algorithms for vertical handoff traffic acceptance proposed in this paper provide the roaming among heterogeneous systems considering the states of the systems, so that the overloading or underutilization of systems is minimized. Four different vertical handoff algorithms are examined.

A. Equivalent Power

In the vertical handoff algorithm based on equivalent RSS, both 3G data rates are converted into equivalent powers and compared to each other. So, it is selected 3G system that presents the highest equivalent power. After power conversion in case of equal powers, the 3G UMTS/HSDPA system is chosen to receive packet in vertical handoff process. The power conversion is performed according to mapping shown in Table III.

TABLE III
EQUIVALENT POWER MAPPING

HS-DSCH Category	Rate (Mbps)	Equivalent Power	Class	Rate (kbps)
Cat.11	0.9	**1**	1	38.4
Cat.1	1.2	**2**	2	76.8
Cat.2	1.2	**3**	3	153.6
Cat.12	1.8	**4**	4	307.2
Cat.3	1.8	**5**	-	-
Cat.4	1.8	**5**	5	614.4
Cat.5	3.6	**6**	6	921.6
Cat.6	3.6	**7**	7	1228.8
Cat.7	7.2	**8**	8	1536
Cat.8	7.2	**9**	9	1843.2
Cat.9	10.2	**10**	10	2457.6
Cat.10	14.4	**11**	11	3072

```
If equivalent powers are different
    Schedule the 3G system with the highest equivalent power
Else If equivalent powers are equal
    Schedule the 3G UMTS/HSDPA system
End equivalent powers
```

B. Mix Occupation

This vertical handoff algorithm is a combination of buffer occupation and link occupation parameters in order to increase fairness in the resource distribution between 3G systems [11]. The mix occupation algorithm works as follows:

```
If link occupations are lower than 30%
    Schedule the 3G system with the lowest link occupation
Else If link occupations are higher or equal to 30%, verify
    If the difference between occupations is lower or equal to 10%
        Schedule the 3G system with the lowest buffer occupation
    Else If the difference between occupations is higher than 10%
        Schedule the 3G system with the lowest link occupation
    End difference
End link occupations
```

C. Mix Power & Link Occupation

This vertical handoff algorithm is another combination of equivalent power and link occupation in order to guarantee a fair balance between 3G systems. The mix power and link occupation algorithm works as follows:

```
If link occupations are lower than 30%, verify
    If equivalent powers are different
        Schedule the 3G system with the highest equivalent power
    Else If equivalent powers are equal
        Schedule the 3G UMTS/HSDPA system
    End equivalent powers
Else If link occupations are higher or equal to 30%, verify
    If the difference between occupations is lower or equal to 10%
        If equivalent powers are different
            Schedule the 3G system with the highest equivalent power
        Else If equivalent powers are equal
            Schedule the 3G UMTS/HSDPA system
        End equivalent powers
    Else If the difference between occupations is higher than 10%
        Schedule the 3G system with the lowest link occupation
    End difference
End link occupations
```

D. Deficit Round Robin - DRR

In DRR scheduler the server works in cyclic order where in each cycle a packet of a queue is processed [12]. In this model the vertical handoff traffic is stored in the 4G queue and server is represented by 4G scheduler as illustrated in

Figure 1. For each 3G system is attributed a quantum value in bits to be processed by 4G server. Furthermore, there is also a deficit counter value for each 3G system. When the first packet in vertical handoff pointed by round robin pointer is directed to 3G system a quantum value is added to the deficit counter value. The packets are routed to 3G system while deficit value remains higher than zero and the 4G queue is not empty. This deficit value is zeroed when there are no packets in queue.

```
While there are packets in vertical handoff do
    If 4G queue is not empty then
        cycle = cycle + 1;
        DeficitCounter = quantum + DeficitCounter;
        While (DeficitCounter - PacketSize) > 0
            DeficitCounter = DeficitCounter - PacketSize;
            Schedule the 3G system; (*/HSDPA or 1xEV-DO RA*/)
            Increase counter
            If 4G queue is empty then
                DeficitCounter = 0;
                break; (*/skip while loop*/)
            End If 4G queue
        End While DeficitCounter
    End If 4G queue
End While packets in vertical handoff
```

IV. Simulation Model and Evaluated Scenario

For the evaluation of proposed vertical handoff algorithms a simulation platform was developed. The whole platform is developed in Matlab software tool. The two chosen 3G heterogeneous systems are UMTS/HSDPA and CDMA 1xEV-DO RA. The performances of these two systems are evaluated in function of vertical handoff traffic, i.e., for the UMTS/HSDPA system is considered vertical handoff traffic the traffic coming from CDMA 1xEV-DO RA system and vice-versa.

A. 4G Simulation Model

Figure 1 illustrates the 4G simulation model adopted in this study. In this figure, the new element named here 4G scheduler will be responsible for distributing vertical handoff traffic between 3G mobile systems according to proposed vertical handoff algorithms. Moreover, each 3G system has its own PF data scheduler, its own buffers, its own internal traffic and its own horizontal traffic. The packets are classified into four types of priorities and separated in different buffers, one for each priority in accordance with the DiffServ architecture.

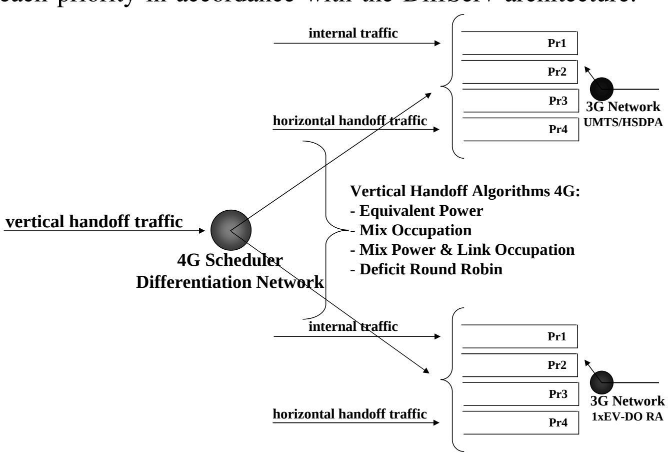

Fig. 1. 4G Simulation Model

The following assumptions are adopted. The HTTP sources and the IP packets (1500 bytes and 576 bytes) used in this study are the same as proposed in [9]. At some moment, the priorities are associated with IP packets before arriving at data scheduler. The buffer of each queue has finite size and the IP packets are stored according to (First In First Out) FIFO scheme. In this handoff model the noise and interferences from others cells are disregarded. The output handoff traffic (vertical handoff or horizontal handoff) of 3G cells are not considered due to high flow of input handoff traffic. The overhead existing in the physical layers of 3G systems when considered the vertical handoff process is disregarded for simplifying 4G system model.

The coverage classes adopted are distributed according to the estimates shown in the Tables I and II. The deterministic values, i.e., fixed values used in the coverage probability distribution are not real data but estimated values that consider higher percentages in the intermediate rates and lower percentages in the high or low rates.

B. Evaluated Scenario

The probability distribution of priorities adopted in this study is only an estimate based on larger proportions for low priority traffic and lower proportions for high priority traffic. This distribution represents the scenario where there are fewer users wishing to pay more for differentiated services. Besides, the Table IV exhibits the buffer size for each type of priority, i.e., the maximum number of IP packets allowed in the buffer for each priority. In case of DRR scheduler, the quantum sizes associated with UMTS/HSDPA and 1xEV-DO RA systems are 5 Mbits and 0.6 Mbits, respectively.

TABLE IV
Priority Distribution X Buffer Size

Priority	**Proportion**	**Buffer**
1	10%	20
2	25%	50
3	30%	60
4	35%	70
Total	100%	200

The evaluated scenario keeps a fixed number of internal HTTP sources and horizontal handoff sources of 3G systems and it is increased the number of HTTP sources in vertical handoff ranging from 2 up to 280 sources. Tables V and VI show the scenario evaluated. Note that the number of vertical handoff HTTP sources is the same in both 3G systems. The definition of what 3G system will serve the packet in vertical handoff only happens in run-time determined by vertical handoff algorithm used. Thus, the number of HTTP sources in vertical handoff was included in the tables only for the purpose of comparison between 3G systems.

TABLE V
Scenario Evaluated - UMTS/HSDPA

Internal Traffic	47%	20%	10%	5%
Horizontal Handoff Traffic	47%	20%	10%	5%
Vertical Handoff Traffic	6%	59%	80%	90%
Internal HTTP Sources	16	16	16	16
Horizontal Handoff HTTP Sources	16	16	16	16
Vertical Handoff HTTP Sources	2	47	125	280
Total of HTTP Sources	34	79	157	312

TABLE VI
SCENARIO EVALUATED - CDMA 1xEV-DO RA

Internal Traffic	40%	7%	3%	1%
Horizontal Handoff Traffic	40%	7%	3%	1%
Vertical Handoff Traffic	20%	85%	94%	97%
Internal HTTP Sources	4	4	4	4
Horizontal Handoff HTTP Sources	4	4	4	4
Vertical Handoff HTTP Sources	2	47	125	280
Total of HTTP Sources	10	55	133	288

V. RESULTS ANALYSIS

In this section the simulation results of the performances of UMTS/HSDPA and CDMA 1xEV-DO RA systems are presented. The equivalent power, mix occupation, mix power and link occupation and deficit round robin algorithms are identified in the figures as acronyms EqPow, MixOcp, MixPowOcp and DRR, respectively. Finally, the numbers at the end of each acronym are associated with the priority of each type of traffic ranging from 1 to 4, i.e., from highest priority to lowest priority. In all graphics it is considered the buffer condition of Table IV. The simulation average standard deviation was 4.49% and 95% confidence interval was 2.75% of the average value.

The priority 1 average packet delay for HSDPA system in function of vertical handoff traffic is shown in Figure 2. The highest average packet delays are obtained by the algorithm DRR with average delays from 4 ms up to 289 ms due to large quantum size of 5 Mbits applied for this system. The others algorithms EqPow and MixPowOcp present intermediate performances with delays ranging from 9.6 ms to 260 ms, but these delays are sensitive to increase in vertical handoff traffic. The algorithm MixOcp shows low delays varying from 1.5 ms up to 65 ms. However, these good results are associated with bad utilization of link occupation in the HSDPA system.

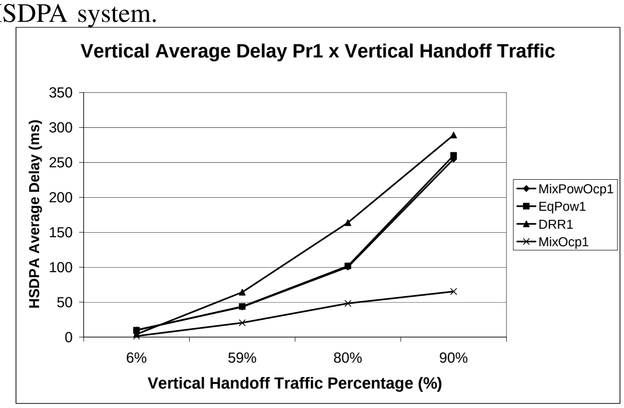

Fig. 2. HSDPA Average Packet Delay Priority 1 in Function of Vertical Handoff Traffic

In case of priority 4 the average packet delay for HSDPA are similar to Figure 2 but due to low priority users the average packet delays are increased from 2 ms up to 1025 ms for the worst case of the MixPowOcp algorithm. The lowest average packet delays are again assigned to MixOcp algorithm due to low link occupation of the HSDPA system.

Figure 3 shows the priority 1 average packet delay for 1xEV-DO RA system in function of vertical handoff traffic. It can be observed the excessive average packet delay for all algorithms evaluated as a result of incapacity of 1xEV-DO RA to provide enough bandwidth to serve all high priority users. The highest average packet delays are related to the MixPowOcp algorithm ranging from 127.8 ms up to 1641 ms. The EqPow algorithm shows an intermediate performance with average packet delays varying from 107.5 ms up to 1371 ms. The other algorithm DRR presents a good performance with average packet delay varying from 161.8 ms up to 1064 ms because the 1xEV-DO RA system is not overloaded by vertical handoff traffic. The best result is obtained by algorithm MixOcp with maximum delay of 875 ms although the 1xEV-DO RA system is not used efficiently.

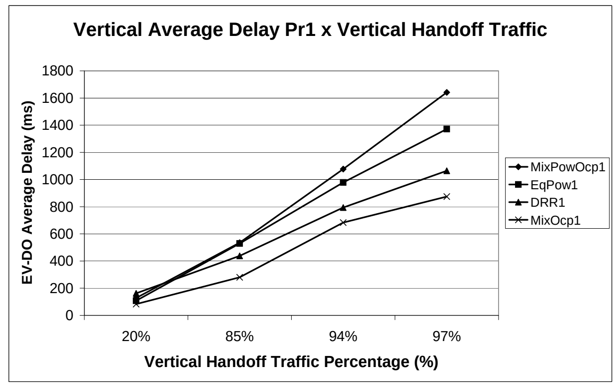

Fig. 3. 1xEV-DO RA Average Packet Delay Priority 1 in Function of Vertical Handoff Traffic

In Figure 4 the priority 4 average packet delay in function of vertical handoff traffic for 1xEV-DO RA system is exhibited. The very large average packet delays obtained by all algorithms evaluated it demonstrates mainly the weakness of the 1xEV-DO RA system since this system does not offer enough bandwidth to serve the high demand of low priority vertical handoff traffic. Moreover, the higher proportion of priority 4 users and buffer size reduce the performance of the 1xEV-DO RA system. Thus, the MixPowOcp algorithm reaches unacceptable average packet delays and in the worst case, 4234.8 ms. The delays are reduced when it is used the EqPow algorithm but the delays remain high with a minimum of 368 ms and a maximum of 3768 ms. The algorithm DRR presents intermediate performance with delays lower than 3729 ms in the worst case. The best results are achieved by the MixOcp algorithm with average packet delays ranging from 294 ms to 2546 ms however this algorithm presents high loss percentages as shown in Figure 6.

Figure 5 exhibits the priority 4 loss percentage in function of vertical handoff traffic for HSDPA system. The highest loss percentage is obtained by the DRR algorithm with losses ranging from 0% to 7.6%. This performance is a result of quantum size of the HSDPA system that increases the waiting time of Pr4 users and consequently loss percentage. The algorithms MixPowOcp and EqPow also present high loss percentages with 7.32% in the worst case. The lowest loss percentages are obtained by MixOcp algorithm ranging from 0% to 2.54%. However, this result is consequence of underutilization of HSDPA system.

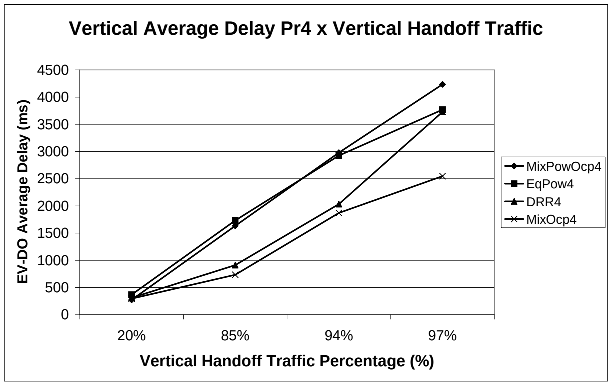

Fig. 4. 1xEV-DO RA Average Packet Delay Priority 4 in Function of Vertical Handoff Traffic

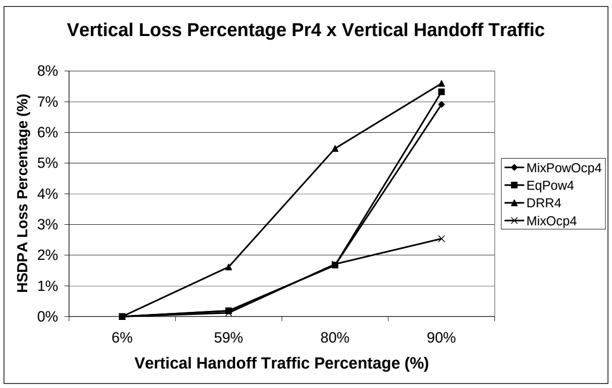

Fig. 5. HSDPA Loss Percentage Priority 4 in Function of Vertical Handoff Traffic

Finally, in Figure 6 the priority 4 loss percentage in function of vertical handoff traffic for 1xEV-DO RA system is shown. The highest loss percentages are obtained by algorithm MixOcp varying from 0% up to 2%. In the other algorithm MixPowOcp the performance of 1xEV-DO RA system has little improvement with maximum loss percentage of 1.96%. The algorithm EqPow presents an intermediate performance ranging from 0% up 1.4% during simulation. Finally, the best results are associated with algorithm DRR whereas loss percentages are lower than 0.79%.

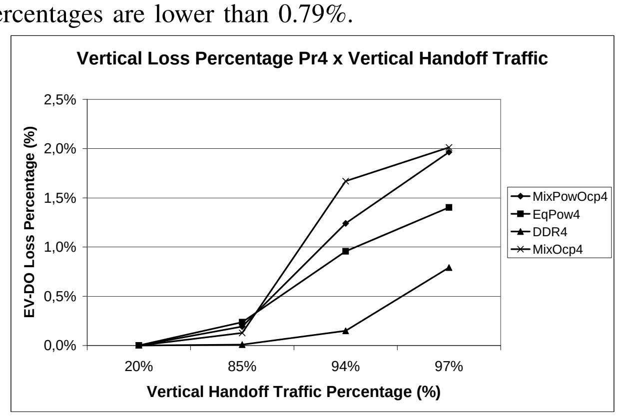

Fig. 6. 1xEV-DO RA Loss Percentage Priority 4 in Function of Vertical Handoff Traffic

VI. Conclusions

In this paper, new algorithms for vertical handoff traffic acceptance were proposed and evaluated in the 3G UMTS/HSDPA and 1xEV-DO RA systems in conjunction with PF data scheduler in order to assure the QoS of each 3G system and minimize the performance degradation caused by the increase of vertical handoff traffic in 3G systems. The impacts of these algorithms for traffic acceptance together with PF data scheduler were evaluated through computer simulations using Matlab software tool. The average packet delay and the loss percentage were studied in function of vertical handoff traffic load.

In the new scenario of heterogeneous 3G networks integration, the MixOcp algorithm which is a combination of buffer occupation and link occupation parameters presented a good performance in terms of average packet delay and loss percentage among the algorithms evaluated. However, such performances are related to inefficiency in the resource allocation of 3G networks with underutilization of the 1xEV-DO RA system and the HSDPA system. The other MixPowOcp algorithm showed high loss percentages and high average packet delay in both 3G systems.

The algorithm EqPow showed an intermediate performance in all QoS metrics evaluated. However, high latencies in 3G systems obtained by this algorithm not satisfactorily served all users. On the other hand, the DRR algorithm ensured satisfactorily QoS in the most of all evaluated performance metrics. Moreover, this performance can be improved by reducing of quantum size in the HSDPA system, i.e., the quantum size in both 3G system are flexible according to operator need.

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