Strict Priority Scheduler for Rate Controlled Transmission

Lukasz Chrost and Agnieszka Brachman
Silesian University of Technology
Gliwice, Poland
lukasz.chrost@polsl.pl, agnieszka.brachman@polsl.pl

***Abstract*—The paper proposes a modification to the strict priority scheduler, to guarantee the Quality of Service (QoS) of a network with variable and undetermined bandwidth capacity. The proposed modifications make it possible to accomplish QoS along the path. The presented solution allows providing the minimum guaranteed transmission rates for all active flows with the respect to their priorities and to provide the fair share of the additional bandwidth. The scheduler also rejects flows, for which the minimum rate requirements exceed the available bandwidth. Moreover, a simple algorithm for mapping the WiMAX traffic classes to the strict n-priority scheduler bands is described. This allows providing WiFi - WiMAX internetworking with the QoS support. The presented test results show that the proposed scheduler preserves the defined, minimum transmission rates and improves the performance of the delay and throughput.**

***Keywords*-packet scheduling; strict priority scheduler; Quality of Service; wireless network.**

I. Introduction

Nowadays, the real-time traffic occupies a significant percentage of the available bandwidth and Internet must evolve to support the new applications. For the newly developed applications and services such as VoD (Video on Demand), VoIP (Voice over IP), VTC (Video-Teleconferencing), interactive games, distributed virtual collaboration, remote classrooms, grid computing, etc., the best effort delivery is unacceptable, since in case of a congestion the Quality of Service (QoS) and Quality of Experience (QoE) declines to an unsatisfactory level. Therefore, the main and crucial objective of the future Internet is to change the best effort network into the Quality of Service controlled network.

Various applications may have different, sometimes stringent requirements in terms of throughput, packet losses and/or delays. It brings out the necessity to provide different priorities to different applications, users or data flows, or to guarantee a certain level of performance to a data flow; in short, to provide the Quality of Service (QoS). Some real time traffic application will not be commercially viable without the QoS guarantees. Enabling the differentiated resource allocation is also very important from the providers point of view. The predominant form of pricing currently in practice in the Internet is per achievable throughput. A fee is charged for the amount of bandwidth to access the network. Therefore, the ability to provide the exact, required part of the available bandwidth is crucial. Accomplishing this task may seem easy, however the problem arises in case of the unpredictable and variable environment.

Providing the minimum transmission rates is particularly difficult in the wireless networks. The varying conditions of the wireless channel lead to the unpredictable transmission channel parameters, i.e., the available bandwidth. The physical radio transmission is based on the emission of the electromagnetic waves. Radio waves decrease in the amplitude as they propagate and pass through the obstacles. In the urban environments the large throughput variations may arise even in a Line-Of-Sight (LOS) conditions. This happens especially due to the moving vehicles in the radio path as well as due to the multi-path effect.

WiFi [1] and WiMAX [2] are two common, low cost technologies for providing the ubiquitous wireless Internet access. WiFi provides high data rates up to 100 Mbps, within the short ranges, usually used within buildings. WiMAX is designed to offer throughput up to 70 Mbps, in 5 km range, used for covering the large outdoor locations. Integrating these two technologies is considered for the next generation network technology [3]. To provide the WiMAX-WiFi internetworking a new solution for the last WiFi hop is necessary.

WiFi is especially prone to the bandwidth degradation due to the varying conditions in the transmission channel, due to the modulation changes. The knowledge of the currently available bandwidth is crucial for providing the guaranteed rates and/or delays. The bandwidth estimation algorithms try to provide an accurate estimation of the available bandwidth. However, due to the high variability of the wireless channel throughput, most current techniques produce relatively inaccurate results and long convergence times.

The main contribution of this paper is the strict priority scheduler designed to provide the minimum guaranteed transmission rate for all active flows with the respect to their priorities and to provide fair share of the additional bandwidth. The scheduler also rejects flows, for which the minimum rate requirements exceed the available bandwidth. The proposed solution is applicable for the WiFi wireless network, to accomplish QoS along the path. It is simple to implement and does not require the bandwidth estimator. Additionally, we provide a simple algorithm for mapping the WiMAX traffic classes to the strict n-priority scheduler in order to provide the WiFi - WiMAX internetworking with

 ISBN: 978-1-61208-183-0

the QoS support.

The rest of the paper is organized as follows. Section II reviews the similar solutions and the priority schedulers designed for the real-time services and link-sharing service provisioning. In Section III, the proposed strict priority scheduler is presented and the proof-of-concept tests are depicted and explained. Section IV is devoted to the description of mapping of WiMAX classes to the strict n-priority scheduler band. Finally, the paper is concluded and the future work perspectives are presented in Section V.

II. Related work

Scheduling algorithm determines the allocation of the bandwidth among the users, flows or the service classes. Packet scheduling algorithms are widely discussed in the literature.

The QoS and packet scheduling are addressed by the DiffServ (Differentiated Services) architecture [4]. For the DiffServ several queuing and scheduling methods are associated, namely the priority scheduling and the Weighted Fair Queuing (WFQ).

The methods based on the priority scheduling are described in [5], [6]. Priority scheduling can reduce the packet, delay, jitter and loss for the high priority traffic. The Strict Priority (SP) scheduling is a simple and common solution. It provides the preferential treatment for the high priority classes, however at the cost of starving the lower priority traffic. The SP serves the high priority traffic queue, until it is empty and then moves to the lower priority queues. SP discipline itself is not controllable, therefore it cannot handle the starvation problem. Several modifications have been proposed to alleviate this problem. Authors in [7] propose to assign a parameter to each priority queue, which determines the extent, to which the priority queue is served. Their Probabilistic Priority (PP) discipline provides the minimum average throughput and the delay guarantees. However the algorithm does not assume that the resources may be scarce.

WFQ attempts to provide a share of bandwidth for each class or flow in proportion to their specified rates. WFQ and its variants are described in [8]–[11].

The Weighted Fair Queuing (WFQ) [9] is a packetized Generalized Processor Sharing (GPS) algorithm [9], [12], which works as follows. All traffic is classified into the so-called traffic classes i. Classes can be either individual flows or a bunch of flows with similar transmission requirements. Each class is assigned a positive weight ϕ_i, which specifies the minimum share of the available bandwidth C. This weight is also used for the distribution of the excess capacity, when a particular class does not fully use its bandwidth's share. Each backlogged traffic class, i.e., the class that has the packets waiting for the transmission in its queue or class, which packet is in service, receives the guaranteed service rate r_i:

$$r_i = \frac{\phi_i}{\sum \phi} C,$$

where $\sum \phi$ is the sum of the weights for all traffic classes.

GPS offers the protection among traffic classes, along with the full statistical multiplexing. GPS is an idealized scheduler, based on the assumption, that the capacity is infinitely divisible, which means that several packets can be served at the same time. Since in reality, the traffic is composed of the discrete packets sent in sequence, GPS cannot be implemented in a real system.

The packet scheduling is crucial for providing any QoS guarantees for the multiple service classes or priorities. Majority of proposed solutions requires information concerning the current bandwidth. The knowledge of bandwidth capacity is elementary. If it is not possible to guarantee the required, adequate performance, i.e., of a voice conversation, it is more beneficial to block the call rather than accept and experience excessive delays and packet drops. Therefore rejecting unfitting flows is a desired feature. To provide the efficient and stable transmission through the heterogeneous network, rate control, applied to all active flows, is necessary.

Providing Qos in WiMAX-WiFi integrated network is very challenging. WiMAX standard incorporates QoS features into the Media Access Control (MAC) layer. It implements the signalling and bandwidth allocation algorithms, thanks to which, the traffic with the different QoS requirements may be jointly regulated to make the best use of the available bandwidth. On the other hand, WiFi provides only the prioritized QoS introduced by the 802.11e enhancement [13], without any bandwidth-share guarantees.

The problem of the WiMAX and WiFi integration is discussed in [14]. Authors present an integrated Access Point, which combines the WiMAX subscriber station and WiFi Access Point. However the authors do not provide any scheduling strategy. In [15], an integration model based on the traffic mapping and signalling is presented. The authors describe the scheduling algorithm, which provides the QoS in terms of the delay bound for the real time traffic and the buffer bound for the non real time traffic. Nonetheless, they do not consider the bandwidth variations.

III. Strict priority scheduler with the minimum and maximum rates guarantees

The proposed strict priority-based scheduler with the minimum and maximum rates guarantees is designed to provide the following:

- Enforcement of the minimum guaranteed transmission rates for the existing flows, according to their priority.
- Rejection of the non-provisioned flows.
- Equal distribution of the additional bandwidth among active flows, up to their maximum transmission rates.
- Fast detection of the bandwidth capacity degradation.

 ISBN: 978-1-61208-183-0

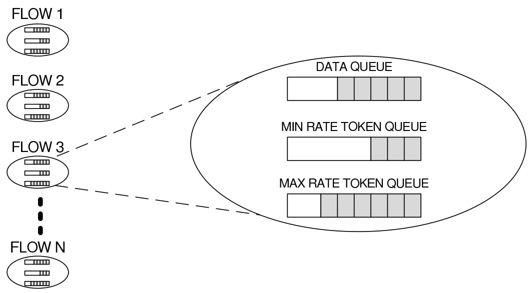

Figure 1. Strict priority based system

The aforementioned functionality is especially important for variable transmission channels, i.e., wireless networks. This method also allows passive estimation of the available bandwidth, however only if the link utilization is high.

The strict priority based system consists of the data queue and two virtual token bucket queues (the minimum rate token queue and the maximum rate token queue) for each transmission flow. The schematic representation of the algorithm is depicted in Figure 1. The virtual token queues are the standard TBF (Token Bucket Filter) queues. Tokens are added to the bucket every $1/rate_{min}$ and $1/rate_{max}$ seconds. If there is no $rate_{max}$ defined, the corresponding queue is always full. The parameters $rate_{min}$ and $rate_{max}$ are determined by the external system. All queues have size limits.

Every cycle requires up to three passes and ends if the packet is dequeued. The first two passes start from the queue with the highest priority. The first pass searches for the packets belonging to the flow with the non-empty minimum rate token bucket queue. The second (optional) pass looks for the packets belonging to the flows, with non-empty minimum rate token bucket queue, which were previously rejected (if the system supports re-enabling rejected transmissions). Third pass picks the packets belonging to the flows with the empty minimum rate token bucket queue and the non-empty maximum rate token bucket queue. This pass may be scheduled according to the round robin algorithm or any other algorithm, which may provide fair share of additional bandwidth regardless of the flows' priorities. In the proposed solution the modified Round Robin (RR) mechanism is used. The modified RR scheduler selects the packets in the third pass, however only from the queues, which were left nonempty in the earlier pass. RR does not provide any fairness, therefore if necessary, another algorithm may be applied, i.e., Deficit Round Robin (DRR).

When the packet of n bytes is dequeued, n tokens are removed from both token buckets - if the packet is selected in the first or in the second pass - or from the maximum rate token bucket - if packet is selected in the third pass. Subsequently, the packet is sent to the network.

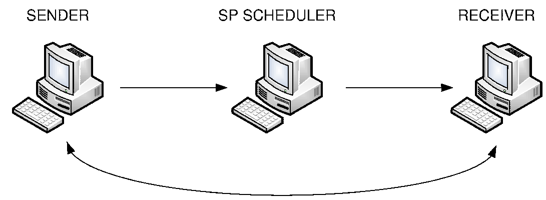

Figure 2. Scheduler testbed

The system is designed for handling flows with the unique priority. If there are two or more identical priorities, several approaches are possible, that is: random priorities, hash priorities or priorities set successively, according to the arrival time. The Type of Service (TOS) field in the IPv4 header may be used to identify and store the packets' priorities.

Implementation is based on the Linux kernel 2.6.39. The priority scheduler and the token bucket filter are implemented as the Traffic Control modules.

A. Test results

Proof-of-concept tests were run to verify the scheduler performance. The test environment is depicted in Figure 2.

SENDER is a station with a single Pentium III 800 MHz under Linux 2.6.39 with the modified traffic control module, described in the previous Section. 150 service flows with the unique priority were governed by SP SCHEDULER. Each queue has capacity for 10ms of traffic with regard to their minimum transmission rates. The overall bandwidth is $\sim$ 90 Mbps. Traffic is generated using D-ITG on VMware to avoid throttles.

Figures 3 and 4 present the results for the test with traffic pattern composed of 150 UDP connections, sent with constant bit rate 1200 kbps each and the packet size set to 1400 B. All flows start at the same time. The minimum rate was set to 600 kbps (fig. 3) and 950 kbps (fig. 4). In the first case all flows fit to the overall bandwidth, in the second approximately the first 90 flows are able to achieve the minimum transmission rate.

When the minimum rates of all flows fit to the overall bandwidth, the minimum transmission rate is provisioned for all flows and the additional bandwidth is shared according to the modified RR algorithm. The average, experienced delay is similar for all provisioned flows.

Under the over-provisioned scenario around 60% of all flows achieves the desired transmission rate. The non-served flows experience large delays till they are blocked.

Figures 5 and 6 present results for a similar test but with the TCP transport protocol.

Since TCP implements its own rate control using the window-based mechanism, it adjusts the sending rate. Flows adjust the transmission rate to the offered bandwidth share.

 ISBN: 978-1-61208-183-0

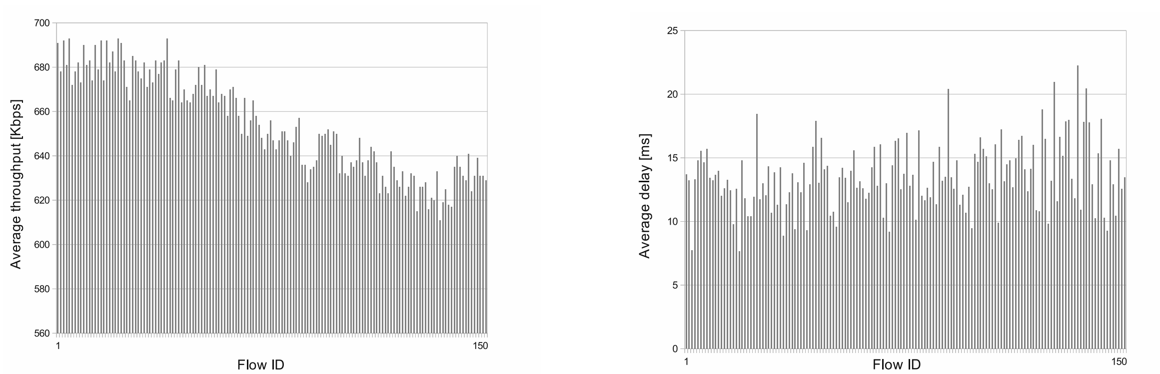

Figure 3. Average throughput and delay for 150 UDP connections, CBR = 1200 Kbps, packet size = 1400B, minimum rate = 600 Kbps

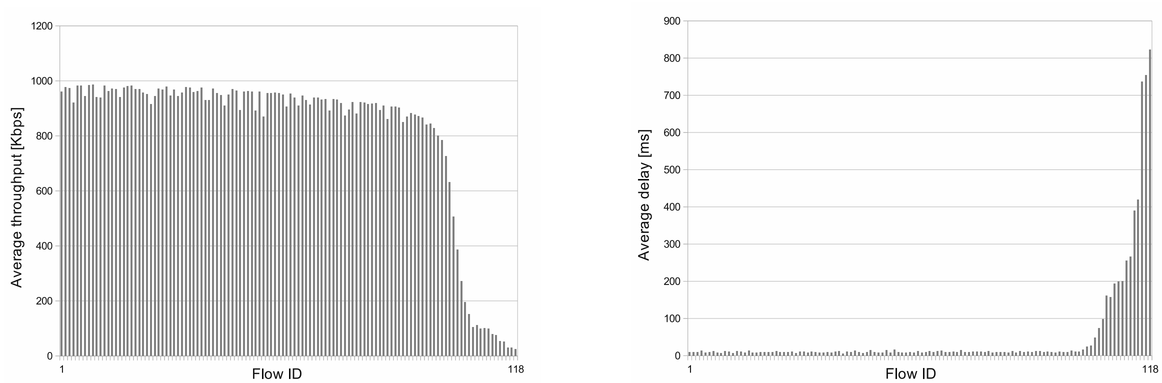

Figure 4. Average throughput and delay for 150 UDP connections, CBR = 1200 Kbps, packet size = 1400B, minimum rate = 950 Kbps

The flows with higher priority experience lower delays in both cases.

IV. Mapping of WiMAX classes to strict n-priority scheduler band

As shown in the previous section, the multi-pass strict priority scheduler can provide good bandwidth for multiple streams with low jitter. However, in case of the heterogeneous networks, a single, consistent QoS configuration system is required. WiMAX already contains an expanded QoS definition set describing different types of traffic classes. However, the classes are not usable neither in the standard WiFi network, nor, directly, in the strict-priority extended one. Fortunately, a simple class-to-priority mapping is possible.

The prosed algorithm provides a simple means of mapping the WiMAX traffic class to the strict n-priority scheduler band. To achieve that, we introduce a Φ vector describing scheduler bands. The $\Phi_i <> 0$ if the particular band has a WiMAX QoS SF mapped, and 0 otherwise. The actual mapping is done by an external, system-wide mechanism with the regard to several rules:

1) The 1's have to form continuous series inside Phi vector, with i denoting the first, and j denoting the last mapped position.
2) For n bands and m classes, $i = n/2 - m/2$, that is the '1' should occupy the central part of the Phi vector.
3) The incoming classes are mapped to the position k, where $(i-1) < k < (j+1)$.
4) If the SF leaves the system, its class should be unmapped.
5) In case of the mapping/unmapping, the vector shift may be required to fulfil 2. The chosen direction shall require the minimum number of bands to be remapped.

The actual mapping is based on WiMAX's QoS class hierarchy described in Table I of ϕ values. The decimal fraction is set according to the maximum delay parameter for a given service flow, while the whole part is defined by its class, i.e., UGS service flow with the maximum delay of 3ms has a ϕ value of 0.003.

The external mechanisms selects new k to form an increasing sequence of $\Phi_{i..j,k}$ SF vector mappings, where $\Phi_k = \phi$.

A schematic diagram depicting mapping process of in-

 ISBN: 978-1-61208-183-0

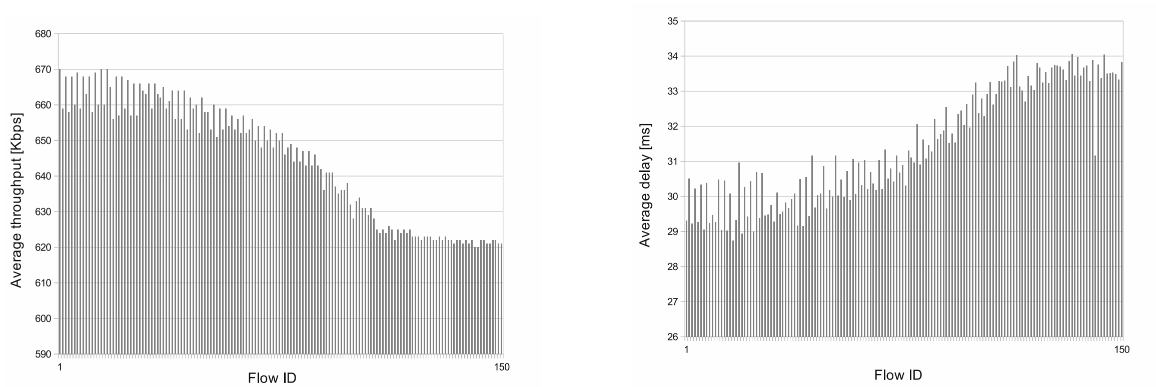

Figure 5. Average throughput and delay for 150 TCP connections, packet size = 1400B, minimum rate = 600 Kbps

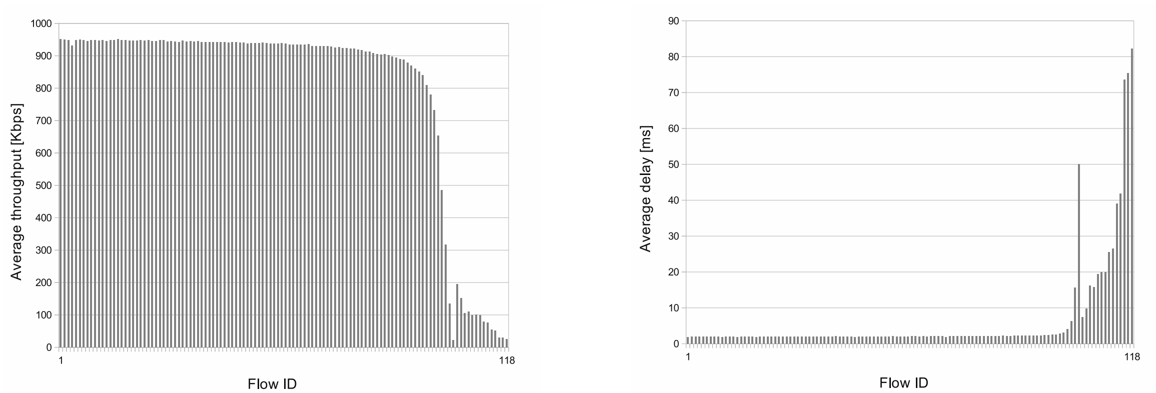

Figure 6. Average throughput and delay for 150 TCP connections, packet size = 1400B, minimum rate = 950 Kbps

Class	ϕ value
Unsolicited Grant Service (UGS)	0.0
Extended Real-Time Polling Service (ertPS)	0.0
Real-Time Polling Service (rtPS)	2.0
non-Real-Time Polling Service (nrtPS)	4.0
Best Effort	4.0

Table I
MAPPING OF THE WIMAX QOS TRANSPORT CLASSES TO ϕ PARAMETER VALUE. THE FRACTION PART IS DEFINED BY THE MAXIMUM DELAY PARAMETER DESCRIBING SPECIFIC SF.

coming SF has been presented in Figure 7. The mapping process requires a k value to be selected for the new SF.

V. CONCLUSION AND FUTURE WORK

The paper proposed a modification to the strict priority scheduler, which provides the minimum and maximum transmission rates for all active flows. Various tests were performed, which include the performance measurements for the UDP and TCP traffic in the provisioned and over-provisioned scenarios. The designed solution has been shown to distribute the available bandwidth according to the predefined requirements.

The main disadvantages of the proposed solutions are: packet-based operation and performance-related concerns - each cycle requires, at worst case, passing each queue three times. Another problem arises if the scheduler rejects the flows and there is no backward communication. In such a case, the rejected flows waste bandwidth up to the hop with the strict priority scheduler.

In further studies, we plan to enhance the scheduler to satisfy the delay requirements using adequate buffer sizing. The proposed scheduler needs also verification under more sophisticated scenarios including: varying bandwidth rate to imitate transmission in the wireless network, varying packet size and diversified minimum rate requirements.

ACKNOWLEDGMENT

The material is based upon work supported by the Polish National Science Centre under Grant No. N N516 479240.

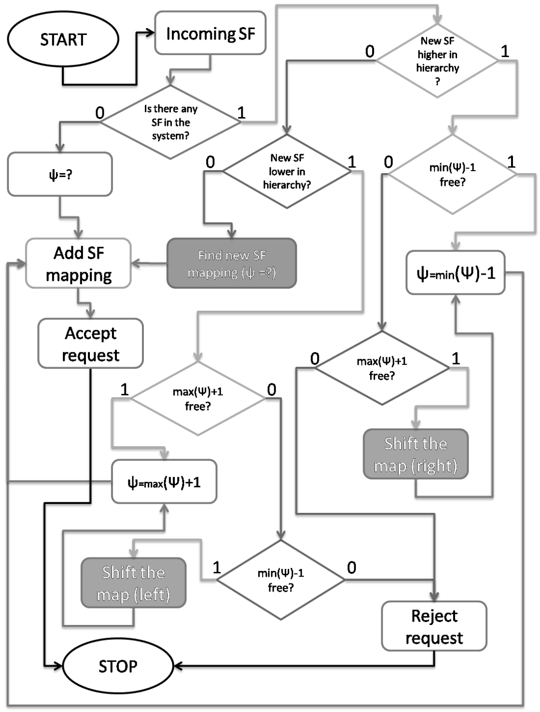

Figure 7. Diagram depicting the process of mapping incoming WiMAX service flow to multi-pass strict priority scheduler band.

REFERENCES

[1] "IEEE standard for information technology-telecommunications and information exchange between systems-local and metropolitan area networks-specific requirements - part 11: Wireless LAN medium access control (MAC) and physical layer (PHY) specifications," *IEEE Std 802.11-2007 (Revision of IEEE Std 802.11-1999)*, pp. C1–1184, December 2007.

[2] "IEEE Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems," *IEEE Std 802.16-2004 (Revision of IEEE Std 802.16-2001)*, pp. 0 –857, 2004.

[3] M. Jamil, S. Shaikh, M. Shahzad, and Q. Awais, "4G: The future mobile technology," in *TENCON 2008 - 2008 IEEE Region 10 Conference*, nov. 2008, pp. 1 –6.

[4] S. Blake, D. Black, M. Carlson, E. Davies, Z. Wang, and W. Weiss, "An Architecture for Differentiated Service," RFC 2475 (Informational), Internet Engineering Task Force, Dec. 1998, updated by RFC 3260.

[5] Z. Rosberg and F. Sabrina, "Rate control of multi class priority flows with end-to-end delay and rate constraints for QoS networks," *Computer Networks*, vol. 53, no. 16, pp. 2810–2824, Nov. 2009.

[6] A. E. Kamal and H. S. Hassanein, "Performance evaluation of prioritized scheduling with buffer management for differentiated services architectures," *Computer Networks*, vol. 46, no. 2, pp. 169–180, Oct. 2004.

[7] Y. Jiang, C. Tham, and C. Ko, "A probabilistic priority scheduling discipline for high speed networks," in *2001 IEEE Workshop on High Performance Switching and Routing*. IEEE, 2001, pp. 1–5.

[8] A. Demers, S. Keshav, and S. Shenker, "Analysis and simulation of a fair queueing algorithm," *SIGCOMM Comput. Commun. Rev.*, vol. 19, pp. 1–12, August 1989.

[9] A. Parekh and R. Gallager, "A generalized processor sharing approach to flow control in integrated services networks-the multiple node case," in *INFOCOM '93. Proceedings.Twelfth Annual Joint Conference of the IEEE Computer and Communications Societies. Networking: Foundation for the Future. IEEE*, 1993, pp. 521–530 vol.2.

[10] J. Bennett and H. Zhang, "WF2Q: worst-case fair weighted fair queueing," in *INFOCOM '96. Fifteenth Annual Joint Conference of the IEEE Computer Societies. Networking the Next Generation. Proceedings IEEE*, vol. 1, Mar. 1996, pp. 120–128 vol.1.

[11] J. F. Lee, M. C. Chen, and Y. Sun, "WF2Q-M: Worst-case fair weighted fair queueing with maximum rate control," *Computer Networks*, vol. 51, no. 6, pp. 1403–1420, 2007.

[12] A. Parekh and R. Gallager, "A generalized processor sharing approach to flow control in integrated services networks-the single node case," in *INFOCOM '92. Eleventh Annual Joint Conference of the IEEE Computer and Communications Societies, IEEE*, May 1992, pp. 915–924 vol.2.

[13] "IEEE Standard for Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements Part 11: Wireless LAN Medium Access control (MAC) and Physical Layer (PHY) Specifications Amendment 8: Medium Access Control (MAC) Quality of Service enhancements," *IEEE Std 802.11e-2005 (Amendment to IEEE Std 802.11, 1999 Edition (Reaff 2003)*, pp. 1 –189, 2005.

[14] S. Frattasi, E. Cianca, and R. Prasad, "An Integrated AP for Seamless Interworking of Existing WMAN and WLAN Standards," *Wirel. Pers. Commun.*, vol. 36, pp. 445–459, March 2006.

[15] G. Prasath, K. Raghu, and M. Ma, "Integration of WLAN and WiMAX with base station assisted QoS," in *Wireless and Optical Communications Networks, 2008. WOCN '08. 5th IFIP International Conference on*, may 2008, pp. 1 –5.