Quality of Service Differentiation Measurements in 4G Networks

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Abstract*:* *Quality of Service (QoS) differentiation measurement provides the ability to evaluate different level of QoS support in 4G networks such as Long Term Evolution (LTE) and Worldwide Interoperability for Microwave Access (WiMAX). Many research studies around the world have addressed the QoS Differentiation (QoS-Diff) considerations, however, to the best of our knowledge, only a few have attempted to make measurements and evaluate the level at which each QoS solution could provide differentiated services to users and applications in demand. In this study, we provide a method to evaluate such differentiated level of service by means of User as well as Service Provider satisfaction levels, and use a new parameter to measure them. By simulation results, we show that this parameter could provide detailed information about QoS-Diff measurements and how users and service providers perceive their service delivery experience.*

Keywords: *QoS differentiation, Satisfaction, Fairness*

1. Introduction

Radio Resource Management (RRM) techniques in 4th Generation (4G) of wireless technologies provide differentiated level of Quality of Service (QoS) support to various users and applications. Service levels are traditionally measured using parameters such as throughput, delay, jitter, and packet loss ratio. RRM strategies achieve QoS differentiation (*QoS-Diff*) among Real Time (RT) and None-RT (NRT) applications using different Packet Scheduling (PS) and Bandwidth Allocation (BA) schemes. Among RT applications, resources are concerned with their priority orders while for NRT applications services are satisfied when they are treated with fairness. Achieving QoS requirements in differentiated levels led us to the motivation for this study in twofold: (i) once the resources are distributed among a group of RT or NRT applications differently; one could develop parameters to "*measure*" the differences among the differentiated levels of QoS support. (ii) Develop parameters to evaluate the efficiency of the entire system with respect to both RT and NRT application service differentiation levels simultaneously.

In this study we take a broad view of QoS requirements of the entire network, by differentiating the QoS requirements and deliveries of different service classes, and by comparing QoS experiences of those classes. For the first time we introduce a parameter to "quantify" *QoS-Diff* thus allowing us to measure the ability of a RRM scheme in differentiating the service level deliveries. We adopt the RRM framework presented in [1], which guarantees improvement in fairness and utilization. This will allow us to improve the fairness for NRT applications, while keeping the priority of RT applications intact by increasing system utilization.

We introduce a new *QoS-Diff* parameter called Service Differentiation Satisfaction (SDS). SDS provides a comparative analysis for QoS parameters such as throughput and delay, and it is a good indication of *QoS-Diff* ability of the PS scheme. The scheme used in [1] differentiates traffic in Intra- and Inter-Class levels, and measures fairness in both levels. We further develop a scheme to quantify *QoS-Diff* levels, and measure the ability of the PS scheme to differentiate the level of QoS guarantees.

The rest of this paper is in the following order. Section 2 provides a literature review on QoS provisioning and *QoS-Diff*. Section 3 presents the proposed *QoS-Diff* parameter and equations to calculate SDS. Section 4 presents the concept of quantifying QoS-Diff. and how we could measure differentiated levels of QoS support. Section 5 outlines the simulation and results, and finally Section 6 presents conclusions and future studies.

2. Literature Review

Qo-Diff issues have been discussed in variety of topics in the literature. However, only a few studies [2-4] have tried to evaluate the differentiated levels and perform comparative analysis with respect to QoS support levels that their schemes provide. The authors in [5] proposed a QoS scheme including packet classifier and scheduler to provide service differentiation over WiMAX networks. The authors have tested their proposed solution using a set of QoS oriented scenarios to show that their model is capable of differentiating traffic classes defined by WiMAX standard. They verified behavior of the implemented WiMAX QoS classes by testing several topologies to see traffic differentiation by different values obtained for QoS parameters such as latency, delay, bandwidth usage. Within different topologies a minimum transmission is guaranteed for all classes. However, different performances were observed due to prioritization, and to the modified round robin scheduler, which does not serve lower priority queues in the case of network overload with high priority services.

The authors in [6] proposed *QoS-Diff* approaches on the contention-based bandwidth request (*bw-req)* schemes. The *bw-req* is served by assigning different channel access parameters or by bandwidth allocation priorities to different services. They further proposed an analytical model to study effects of the *QoS-Diff* approaches used for the configuration and optimization of the *QoS-Diff* services. They showed by simulation and results that the services are differentiated with initial back-off window in terms of throughput and channel access delay.

The authors in [7] proposed a framework that includes a packet classification mechanism and a cross-layer scheduling algorithm designed based on user's prioritization and radio resources optimization. In order to verify their scheme for different network topologies and providing *QoS-Diff* between different classes, they implemented their solution using new traffic sources, where the Best Effort (BE) traffic contained a variable packet size (512 to 1024 bytes) and interval to emulate FTP and web traffic, and the UGS traffic contained a constant transmission rate (300 bytes) to emulate T1/E1 constant bit rate. They showed by simulation and results that the throughput achieved for UGS was satisfactory, with a reduced latency, jitter, and packet loss; and concluded that *QoS-Diff* was obtained by prioritizing UGS over the BE packets.

QoS-Diff Adaptive Retransmission Limits ARQ (QDARL-ARQ) is proposed in [8] to improve the efficiency of retransmission in conventional Selective Repeat ARQ (SR-ARQ) for the IEEE 802.16e networks. The proposed scheme dynamically adjusts the retransmission limits for services with different characteristics by considering both their QoS requirements and the current system status. The proposed scheme tries to lower packet error rate while controlling end-to-end delay in comparison with SR-ARQ. Several performance metrics such as throughput, delay, and packet loss ratio (PLR) are investigated. The authors in [8] have introduced new metric called retransmission efficiency (since the ARQ technique is considered a trade-off between delay and PLR) to account for the PLR improvement and the resulting longer delays.

3. QoS Differentiation Mechanism

Performance evaluation parameters such as throughput and delay do not satisfy the QoS support evaluations of the new generation wireless networks. New wireless technologies support the ability to separate different traffic types, differentiate between their QoS requirements, and deliver services at those differentiated levels. 4G wireless technologies such as WiMAX and LTE networks classify various types of traffic into several different classes based on the QoS requirements of their applications, as well as their user and SP demands. We define a new parameter called Service Differentiation Satisfaction (SDS), which represent relative ratio of the allocated over requested resources. This value provides a comparative level of QoS deliveries and the level of satisfaction among various classes of service.

SDS is a parameter that evaluates the ability of the RRM scheme to deliver service requests to all classes and avoid starvation of lower priority classes. In other words, SDS is a measure of the proportion of bandwidth request that is delivered by the scheduler, or achieved by the service requester. If the available bandwidth is close to the bandwidth request by a service class, then the service request is considered to be satisfied with the service that it has received. SDS for each service class should be measured based on the resource request, available resources, and QoS requirements of all other classes.

SDS is mathematically defined as the ratio of the allocated bandwidth to a service class divided by its respective bandwidth request. SDS with respect to connection j of service class n in the i^{th} round of scheduling is calculated using Equation 1.

$$SDS_{i,n}^{j} = \frac{bwS_{i,n}^{j}}{bwReq_{i,n}^{j}} \qquad (1)$$

Where: $\mathrm{bwS}_{i,n}^{j}$ is the bandwidth allocated to connection j by the scheduler, and $\mathrm{bwReq}_{i,n}^{j}$ is the bandwidth requested by this connection. The value of SDS is a real number between 0 and 1. For a service request, as the value of SDS approaches 1, the service request is considered satisfied with respect to the delivered service. SDS is a good indication of what portion of the requested resource was granted by the PS or BA component of the RRM to the user, or the "User Satisfaction Level".

The total SDS for a service class is achieved by the ratio of bwS over bwReq of several connection IDs (CIDs) for the service class over a round of scheduling. $SDS_{i,n}$ is the satisfaction level for the request by all the connections of service class *n*, or the Intra-Class SDS, in one round of scheduling, calculated using Equation 2.

$$SDS_{i,n} = \frac{\sum_{j=1}^{J} bwS_{i,n}^{j}}{\sum_{j=1}^{J} bwReq_{i,n}^{j}} \qquad (2)$$

This represents the system SDS for all CIDs from 1 to *J*, for service class *n*, in the i^{th} round of scheduling. If we take the sum of Intra-Class SDS over a range of scheduling rounds we achieve the total system SDS towards class *n* using Equation 3.

$$SDS_{T,n} = \frac{\sum_{i=1}^{\infty} \sum_{j=1}^{J} \left(bwS_{i,n}^{j}\right)}{\sum_{i=1}^{\infty} \sum_{j=1}^{J} \left(bwReq_{i,n}^{j}\right)} \qquad (3)$$

Equations 1-3 represent satisfaction levels among different users or applications. Equation 1 represents SDS for one connection in one round of scheduling, whereas Equations 2 and 3 represent the same factor for all connections in one round of scheduling and all connections in a range of scheduling series respectively. All equations represent SDS for one class of service only.

4. Quantifying QoS Differentiation

Although the Radio Resource Management (RRM) schemes provide an effective measure to counter-affect the resource limitations in wireless networks; nonetheless, there always remains a trade-off while distributing limited resources among users. Providing services to one class of service constrains services to other classes. *QoS-diff* is used to study and analyze the trade-offs when distributing resources among service classes with diverse QoS requirements such as RT versus NRT applications. Next generation of wireless technologies such as WiMAX and LTE support both types of applications. New equipment implementing these technologies are capable of carrying traffic from both types of applications concurrently. Therefore, new parameters are required capable of differentiating RT and NRT classes, and to be able to evaluate how satisfied the requesters are with the services that they have received.

4.1 QoS differentiation capabilities

The proposed *QoS-Diff* mechanism provides detailed information about the satisfaction of users as well as Service Providers (SP), such as diversity in resource distribution among various RT and NRT applications. An important quality of 4G wireless networks is the ability to carry both types of traffic concurrently and providing QoS support to both at a reasonable level of users and SP demands. Performance analysis of such systems includes a comparison among QoS support for all service classes.

The RRM schemes have a delicate task to balance between resource distributions of RT and NRT applications in order to satisfy QoS requirements of all service classes. An important question is "how could we measure this balance?" or "how could we measure the capability of a RRM scheme in differentiating the amount of resources allocated to each service class?" *QoS-Diff* is a good indication of measuring this balance and the differences in the level of QoS support deliveries among various service classes.

Performance evaluation metrics such as throughput and delay could also be used for comparative measurements among various RRM techniques. Differentiating the QoS support levels provided to different services using a RRM strategy is significant; however, it is as critical to be able to quantify the differences. Furthermore, it is essential to be able to quantitatively evaluate capabilities of various RRM strategies. In this study, we use the SDS parameter to measure and compare those capabilities.

4.2 QoS differentiation measurements

QoS-Diff is used to study and analyze the trade-offs when distributing resources among service classes with diverse QoS requirements such as RT versus NRT applications that are multiplexed into a single flow in wireless technologies such as WiMAX and LTE. We evaluate *QoS-Diff* based on statistical measurements of *QoS-Diff* parameters. For instance, one could evaluate how well the resources are distributed among all service classes by calculating simple statistical values such as Variance ($\overline{var}$) and Standard of Deviation ($\overline{sd}$) for SDS parameter. These statistics show the variations among satisfaction level of the requester for the acquired services. If the $\overline{sd}$ (SDS) value is large, then the system satisfaction varies largely from one class to another. The smaller the value of $\overline{sd}$, the higher the overall satisfaction. Variance and standard of deviation of SDS (i.e. $\overline{var}(SDS)$ and $\overline{sd}$(SDS)) could be calculated using the general formulas as in Equations 4 and 5.

$$\overline{var}(SDS) = \ (SDS_{i,T} - \rho)^2 \tag{4}$$

$$\overline{sd}(\text{SDS}) = \left(\frac{1}{N}\right) * \sqrt{\sum_{i=1}^{N}\left(SDS_{i,T} - \rho\right)^2} \tag{5}$$

Where:

- $\overline{var}$(SDS) is the variance of the service request satisfaction
- $\overline{sd}$ (SDS) is the standard deviation of the service request satisfaction
- ρ is the mean value of service differentiation satisfaction or $\text{SDS}_i^{\text{avg}}$ for service class n
- i is the connection ID within this service class

5. Simulation and Results

We have adopted the Dynamic QoS-based Bandwidth Allocation (DQBA) framework presented in [1] for implementation in this study. The proposed framework works in two tiers and allows the traffic to be separated in both Inter- and Intra-Class levels, which makes it a suitable experimental environment to highlight the importance of *QoS-Diff* methods and to show differentiated level of services among various service classes as well as flow level service differentiation. We use the proposed RRM framework to measure QoS parameters used to evaluate overall performance of the system such as throughput and delay as well as the new proposed *QoS-Diff* parameter SDS.

RRM techniques are classified in various ways in the literature. One type of classification is based on QoS differentiation strategies. Most of the proposed solutions that we have seen in this area are divided into two major groups: fairness or priority based models. Examples of these proposals are based on Modified Deficit Round Robin (MDRR) [9, 10], and Modified Priority Queue (MPQ) [11, 12] for fairness-based versus priority-based solutions, respectively. In this study, we use DQBA for implementation of the RRM framework, and compare the results of performance evaluation from this model with those of MDRR and MPQ solutions. We further compare the *QoS-Diff* levels provided by each solution, and for the first time –to the best of our knowledge- we quantify the differentiated levels of service provided by each, and use numerical values to show "*how well the services are differentiated*".

A simple WiMAX network was simulated in OPNET modeler 14.5-PL1, including seven cellular structures, each containing one Base Station (BS) and five Subscriber Stations (SSs), and an application server, which provides five applications corresponding to five types of service classes. The users make their request through the SS, which in turn forwards the traffic through the BS and eventually to the application server.

The application server is used by requester to provide downloads for the required applications, which generate WiMAX traffic between the BS and SSs. QoS parameters, bandwidth request, throughput, and other QoS related parameters are also measured on the links between the BS and SSs in OPNET scenarios. Traffic specifications are presented in Table 1.

Figure 1 shows the throughput values achieved by various patterns in RT and NRT applications using the DQBA method presented in [1]. As illustrated in Figure 1, the throughput for RT applications stands at values in the range of 1-5 Mbps; this is substantially higher than the corresponding values for NRT applications in the ranges below 5 Kbps in the same figure. Similar results are observed for end-to-end delay; RT applications show delays in the range of 10-50 ms (Figure 2), again remarkably lower than the corresponding values for NRT service classes standing at values over 500 ms at high peaks.

Table 1: Applications and type of traffic and QoS requirement

Service class	Class 1	Class 2	Class 3	Class 4	Class 5
Traffic type	UGS	ertPS	rtPS	nrtPS	BE
Application	VoIP	Video	SSH	FTP	HTTP
Priority level	5 highest	4	3	2	1 lowest
Bandwidth requirement	5.0 Mbps	3.0 Mbps	1.5 Mbps	64 Kbps	32 Kbps
Delay Tolerance	10 ms	50 ms	50 ms	200 ms	500 ms

Diversity of the values of QoS parameters for RT versus NRT applications makes it difficult to perform a single experiment to analyze *QoS-Diff* capabilities among RT versus NRT results. For this reason, more studies that we have seen implement solutions for either RT or NRT applications, but not both concurrently. SDS, on the other hand, has relative results for the required versus granted resources, thereby having comparative values that could be evaluated for both RT and NRT applications as illustrated in Figures 4 and 5.

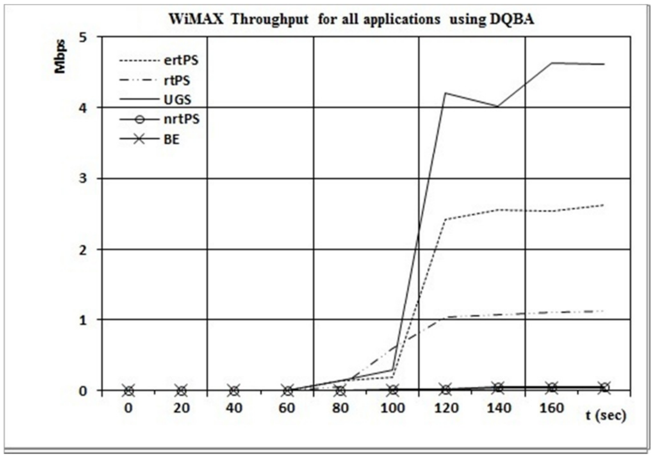

Figure 1: performance evaluation parameters, Throughput achieved for applications using DQBA

The results, like many others in the literature signify that the QoS levels are differentiated among RT and NRT applications for both throughout and delay. Both MDRR and MPQ methods [9-12] show differentiated level of service for throughput and delay achieved by various classes of service for RT and NRT classes.

As illustrated in Figures 4 and 5, SDS values for RT and NRT applications using different RRM strategies vary significantly. This could easily allow us to make comparative analysis between satisfaction levels for both RT and NRT applications depending on which RRM option was selected for QoS differentiation strategy. These values provide the system level treatment for RT and NRT applications, the values for *QoS-diff* measurements, and the capability of various RRM scheme used to provide QoS support.

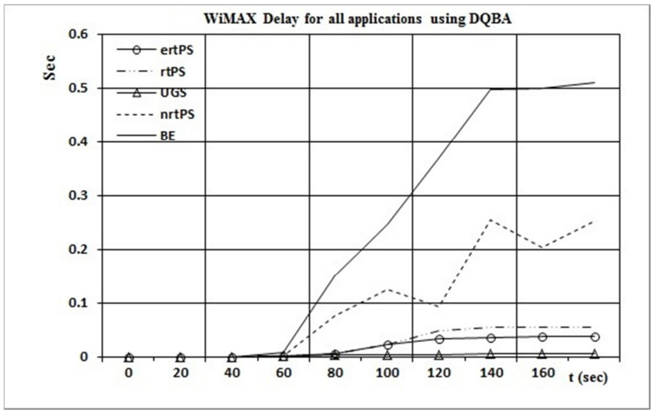

Figure 2: performance evaluation parameters, end-to-end Delay achieved by applications using DQBA

Figures 4 and 5 show the SDS values for RT and NRT applications using the three approaches. The MPQ value for SDS approaches 1 for RT applications as the simulation progresses, while the NRT applications are not satisfied using MPQ, as the value of SDS is below 0.5 in Figure 5. This is due to the fact that PQ and its affiliated scheduling disciplines are in favor of RT applications. On the other hand, the MDRR is providing a satisfaction level with respect to the NRT applications as the value of SDS approaches 1, while doing not so well with RT applications, as the value of SDS stand close to 0.8. These results are in coherence with the fairness behavior of RR and its associated scheduling proposals such as MDRR. The DAPQ keeps a good balance between the requirements of both RT and NRT applications, with both values of SDS over 0.9, which translates into higher user satisfaction by the DQBA users.

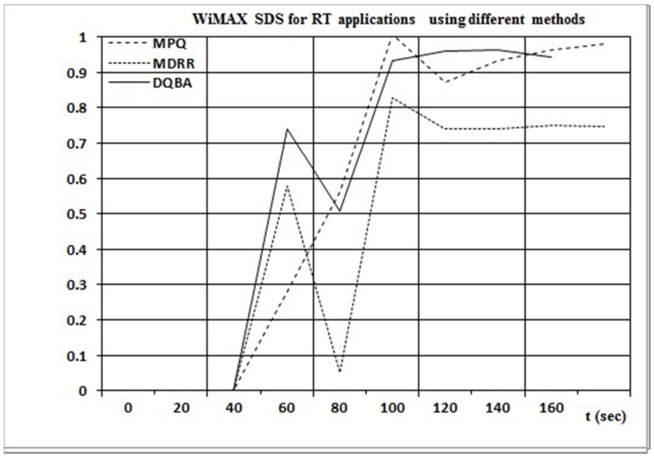

Figure 4: Service Differentiation Satisfaction for RT applications using three methods

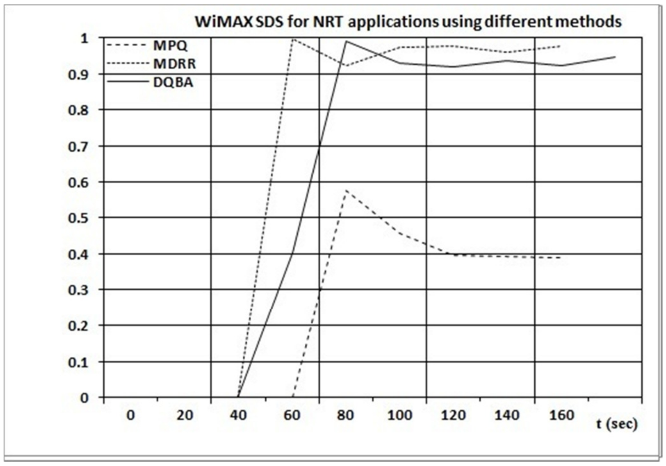

Figure 5: Service Differentiation Satisfaction for NRT applications using three methods

In the second part of the performance analysis we looked at variations in SDS, and calculated $\overline{var}$ and $\overline{sd}$ for SDS. These values are good indication of QoS differentiation measurement. Using SDS values in Figures 4 and 5, and Equations 4 and 5, we find $\overline{var}$ and $\overline{sd}$ values for the SDS in DQBA method to be 0.13 and 0.36 for RT, and 0.04 and 0.2 for NRT applications respectively. These values indicate that the variation in DQBA treatment of various RT and NRT service classes are low, which directly translates in better fairness and higher user satisfaction. In another word, the system is fair to various service classes with the correlated level of satisfaction.

The proposed scheme does not try to achieve an equal satisfaction among RT versus NRT classes. At this stage, we proposed a method to measure differentiated level of service among service classes. In future, we propose achieving specific satisfaction values by adjusting allocated resources, and improving utilization satisfaction of the system by such variations in SDS values. An increased utilization satisfaction could potentially improve performance of NRT applications without compromising on the performance of RT applications.

6. Conclusion and Future Work

We proposed quantifying QoS differentiation using new parameter called Service Differentiation Satisfaction (SDS) defined based on the level of requested and granted resources. SDS signifies the satisfaction of the system with respect to granted and obtained resources. They translate into the satisfaction level of the users and service providers with respect to the services provided to them. We have measured Inter-Class and Intra-Class satisfactions using these parameters in order to measure QoS differentiation among various service classes. By simulation results, we show that SDS values could provide more detailed information about QoS differentiation than throughput and delay, and we measured variations in the level of QoS support that various RRM models provide to service classes supported by WiMAX networks. In future, we plan to expand this study to measure other information on QoS differentiation such as system utilization, and perform more detailed statistical analysis of various QoS differentiation parameters.

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