SIMULATION ANALYSIS OF QUALITY OF BUSINESS IN IP NETWORKS

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Abstract: In this paper, we propose a simulation model for mapping Quality of Service (QoS) parameters to Quality of Business (QoBiz) in IP networks. We assume that Internet Service Provider (ISP) offers tariff packages based on the proposed QoS to QoBiz mapping and users' requirements. Available bit rate and security are chosen as the key QoS parameters, and price is selected as a main QoBiz parameter from users' perspective, while revenue singles out as the main QoBiz parameter from ISP's perspective. We also assume that ISP applies hybrid pricing so that price reduction is performed depending on QoS violation, defined through network load. The simulation model is conducted using agent-based simulation methodology. Agents can be seen as autonomous units that mutually interact in the environment. In this research, users and ISP are observed as simulation agents and IP market is seen as the environment. Output parameters in the simulation analysis are ISP's revenue and service price. The proposed model enables direct reflection of QoS violation on service prices and consequently on ISP's revenue. Simulation results show prices decrease for most of the tariff packages.

Keywords: Quality of Service, Quality of Business, Pricing, Agent-based simulation, Modelling.

1. INTRODUCTION

Considering highly diverse traffic in Internet Protocol (IP) networks, Quality of Service (QoS) differentiation has become crucial in ensuring proper support for different QoS requirements. QoS describes technical ability of network to provide a service with an assured service level [1]. In order to provide a suitable economic framework for trade-off between quality, offered and delivered by Internet Service Provider (ISP) and its financial benefit from service provisioning, Quality of Business (QoBiz) has been increasingly used. It deals with financial aspects of service provisioning that are important from both service providers' and users' perspective. Generally, QoBiz refers to all those parameters that are expressed in monetary units, such as cost, service provider's revenue, profit, service price, etc. [15].

One of the main factors affecting business operation of an ISP is pricing. Therefore, selection of an appropriate pricing scheme is very important for an ISP. A pricing scheme should make compromise between providing satisfied users' and ISP's revenue goals [3]. Considering that users' satisfaction mainly depends on changes in QoS and price, an efficient pricing scheme should include both aspects. A wide range of different pricing schemes have been applied in IP networks [10], and the simplest is static pricing scheme where users are charged independently of the resource consumption and QoS delivered. Unlike static pricing, dynamic pricing is a process of determination the price as a cost per unit of resource consumption and according to level of QoS guarantees provided for the particular service class. In this research we use a combination of static and dynamic pricing, known as hybrid pricing. It is defined as a process of applying the static price in regular network operation mode while during congestion the dynamic pricing is enforced allowing deviations from contracted tariff [11].

In order to analyze the effects on QoBiz parameters when hybrid pricing is applied, we propose a QoBiz model for which we have conducted simulation analysis. A computer simulation is a set of techniques, methods and tools used to model a real system in the form of the computer program. The developed program is the simulation model that imitates behavior of the real system [7]. Agent-based simulation (ABS) is a form of computer simulation whereby a phenomenon is simulated and modeled in terms of agents and their interactions. An agent is an autonomous computational individual or object with particular properties and actions [14]. In our paper, simulation analysis of the proposed QoBiz model is performed using ABS techniques, and the focus is on the interaction between participants (users and ISP) in an IP network. In order to understand behavior and interactions between components of the simulation model we developed a computer program with a display of animation.

The rest of the paper is organized in the following way. In Section 2, a spiral solution for mapping QoS to QoBiz is proposed as well as tariff packages (TPs), based on QoS parameters combinations and users' requirements. A simulation

model is proposed and explained in detail in Section 3. Concluding remarks are given in Section 4.

2. MODELLING QUALITY OF BUSINESS IN IP NETWORKS

Quality of IP services is characterized by a combination of following aspects: service support performance, service operability performance, service security performance and other factors specific to each service [5, 13]. Therefore, Quality of IP services can be estimated based on different aspects which describe and distinguish service provisioning [12]. Considering that ISP strives to maximize its revenue while providing users the required QoS at the acceptable price, in this research we focus on mapping QoS to QoBiz parameters.

In the proposed model we take into account only requirements, regarding QoS, that are enough significant and transparent to users and thereby relevant for ISP's QoBiz. Steps preceding the development of our model include: selecting QoS parameters that significantly affect QoBiz requirements, identifying key QoBiz parameters, and finding the most appropriate solution for mapping QoS to QoBiz [4, 9].

First, we choose the available bit rate and security as the key QoS parameters for mapping to QoBiz. Regarding available bit rate, we consider download and upload speed as separated QoS parameters. Security comprises data confidentiality, data integrity and availability of the system and its information [2].

While users consider price as one of the most significant parameters, and ISP its revenue, we take both, a service price and ISP's revenue, as the key QoBiz parameters.

For the purpose of this research, we propose a spiral solution for mapping QoS to QoBiz with different settings for each QoS parameter (Figure 1):

- download speed (s_{d1}, s_{d2}, s_{d3}, s_{d4}, s_{d5}), where $s_{d1} > s_{d2} > s_{d3} > s_{d4} > s_{d5}$

- upload speed (s_{u1}, s_{u2}, s_{u3}, s_{u4}, s_{u5}), where $s_{u1} > s_{u2} > s_{u3} > s_{u4} > s_{u5}$ and

- security (s_1, s_2, s_3, s_4, s_5), where s_1 indicates the highest level of security while each subsequent level indicates a bit lower security, so s_5 point out to the lowest level of security.

Each of these values corresponds to a specific price, as it is illustrated in Figure 1. Service with the best performances (s_{d1}, s_{u1}, s_1) is charged with maximum price, denoted as p_0. It is assumed that a price equally depends on each QoS parameter, i.e. it decreases for 5% with any QoS degradation, which implies that a service with the worst performances by all QoS parameters (s_{d5}, s_{u5}, s_5) is charged with 60% lower price compared to a service with the best performances.

Further, users are classified according to their preferences regarding to QoS and price. We assume that there are eight different types of users:

1. Users who prefer high speed Internet access with maximum download speed,
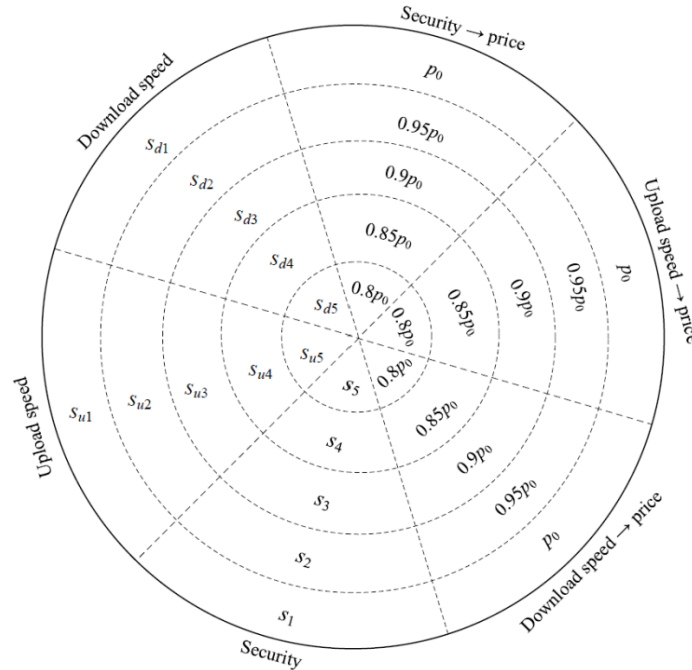
Figure 1: Spiral QoS to QoBiz mapping

2. Users who prefer high speed Internet access with maximum upload speed,
3. Users who prefer maximum security protection,
4. Users who can tolerate slightly lower download speed
5. Users who can tolerate slightly lower upload speed
6. Users who can tolerate slightly lower level of security
7. Users who are willing to pay no more than p_1 ($p_1 > 0.4p_0$) for monthly Internet usage and
8. Users who are willing to pay no more than p_2 ($p_2 \geq 0.4p_0$) for monthly Internet usage (the assumption is that $p_2 < p_1$).

Users can belong to more than one type but some types are mutually exclusive. For example, type 1 users can be at the same time type 2 and/or type 3 users but this excludes the possibility of belonging to types 4, 7 and 8. We assume that type 7 and 8 do not have any QoS preferences specified for previous types, so they will be assigned lower QoS values than the previous types, and consequently they will be charged with lower prices.

Based on QoS parameters combinations and users' requirements, ISP defines TPs, which is shown in Table 1.

Acordingly, ISP's revenue can be determined as:

QoS/ QoBiz	Download speed	Upload speed	Security	Price
TP1	s_{d1}	s_{u1}	s_1	p_{TP_1}
TP2	s_{d1}	s_{u1}	s_2	p_{TP_2}
TP3	s_{d1}	s_{u2}	s_1	p_{TP_3}
TP4	s_{d2}	s_{u1}	s_1	p_{TP_4}
TP5	s_{d1}	s_{u1}	s_3	p_{TP_5}
TP6	s_{d1}	s_{u3}	s_1	p_{TP_6}
TP7	s_{d3}	s_{u1}	s_1	p_{TP_7}
TP8	s_{d1}	s_{u3}	s_3	p_{TP_8}
TP9	s_{d3}	s_{u1}	s_3	p_{TP_9}
TP10	s_{d3}	s_{u3}	s_1	$p_{TP_{10}}$
TP11	s_{d4}	s_{u4}	s_4	$p_{TP_{11}}$
TP12	s_{d5}	s_{u5}	s_5	$p_{TP_{12}}$

Table 1: Tariff packages

$$\sum_{i=1}^{k} p_{TP_i} N_{TP_i} \tag{1}$$

where p_{TP_i} is monthly price per tariff package TP_i, N_{TP_i} is number of users per tariff package TP_i and k is the number of TPs (in this case $k=12$).

Monthly prices are determined according to spiral QoS to QoBiz mapping. Thus, $p_{TP_1} = p_0$, $p_{TP_2} = p_{TP_3} = p_{TP_4} = 0.95p_0$, $p_{TP_5} = p_{TP_6} = p_{TP_7} = 0.9p_0$, $p_{TP_8} = p_{TP_9} = p_{TP_{10}} = 0.8p_0$, $p_{TP_{11}} = 0.55p_0$, $p_{TP_{12}} = 0.4p_0$.

Finally, we assume ISP applies hybrid pricing scheme, implemented so that the monthly price is reduced by a certain percentage if users, due to excessive network load (NL), experience significantly lower speed than declared in time period longer than the defined time period (typically several minutes).

3. SIMULATION MODEL AND RESULTS

We use ABS methodology to develop our simulation model. The main components of any ABS are: *agents*, *environment* and *interactions*. Agents are the basic units of the simulation model, while the environment is the surrounding world in which the agent exists. Interactions are mutual actions that can occur between agents or between agents and the environment [14].

The simulation model is coded in C++ programming language with intensive use of Standard Template Library (STL) [8]. Since it is necessary to simulate and animate the model at the same time a *fixed increment time advance simulation mechanism* is used. Graphical user interface of the simulator is developed using Qt application framework. Qt consists of several libraries and applications and is the compelling framework for cross-platform software development [6]. All input

parameters for the simulation are located in a relational database. A database file located on a local computer is accessed through the SQLite embedded relational database management system.

In the simulation model following input parameters are chosen [16]:

- total number of users;

- QoS parameters, i.e. download speed, upload speed and security;

- TPs based on QoS parameters combinations and users' requirements;

- monthly price for each TP;

- percentage of users per each TP;

- NL and NL probability;

- variable speed depending on NL;

- time intervals with speed less than the declared;

- price reduction depending on number of time intervals with reduced speed, and

- a simulation period.

In this simulation model, we assume the following QoS setting: download speed (200 Mbit/s, 150 Mbit/s, 100 Mbit/s, 60 Mbit/s, 40 Mbit/s), upload speed (10 Mbit/s, 8 Mbit/s, 6 Mbit/s, 4 Mbit/s, 2 Mbit/s) and security (very high, high, medium, low, very low). Declared bit rates are maximal values for download and upload speed and it is assumed that up to 10% lower bit rates does not mean QoS violation. Maximum price is set to 40 EUR. Thus, for each defined TP in Table 1, concrete values for QoS parameters and prices are specified in Table 2.

Percentage of users per each TP is shown in Figure 2.

We define NL as a percentage of total number of users using Internet at the same time and propose the following NL setting observed over a period longer than 10 minutes:

- *NL1* - If NL < 60%

- *NL2* - If 60% ≤ NL < 80%

- *NL3* - If 80% ≤ NL < 90%

- *NL4* - If NL ≥ 90%

NL1 network is functioning normally, means that all QoS parameters are within defined level for each TP and there is no reduction in price. In case of *NL2*, *NL3* and *NL4*, QoS violation occurs, i.e. bit rates are lower than the declared for more than 10% during period longer than 10 minutes for:

QoS/ QoBiz	*Download speed* (Mbit/s)	*Upload speed* (Mbit/s)	*Security*	*Price* (EUR)
TP1	200	10	very high	40
TP2	200	10	high	38
TP3	200	8	very high	38
TP4	150	10	very high	38
TP5	200	10	medium	36
TP6	200	6	very high	36
TP7	100	10	very high	36
TP8	200	6	medium	32
TP9	100	10	medium	32
TP10	100	6	very high	32
TP11	60	4	low	22
TP12	40	2	very low	16

Table 2: Tariff packages with input QoS parameters and prices

- *TP1-TP9* and consequently monthly price is reduced for 1% for all users belonging to *TP1-TP9* when *NL2* occurs,

- *TP1-TP10* and consequently monthly price is reduced for 1% for all users belonging to *TP1-TP10* when *NL3* occurs and

- *TP1-TP11* and consequently monthly price is reduced for 1% for all users belonging to *TP1-TP11* when *NL4* occurs.

Price reductions are performed each time *NL2*, *NL3* or *NL4* lasts more than 10 minutes. Only for *TP12* there is no reduction on monthly price regardless of network load.

We assume that daily NLs are different for working days and weekends. Daily NL probabilities for working days and weekends are given in Table 3 and Table 5, respectively. Duration of daily NL for working days and for weekends is exponentially distributed with mean times presented in Table 4 and Table 6, respectively.

Network Load	*00-06*	*06-08*	*08-16*	*16-18*	*18-22*	*22-00*
NL1	0.99	0.95	0.9	0.85	0.75	0.8
NL2	0.01	0.05	0.1	0.1	0.1	0.1
NL3	-	-	-	0.05	0.1	0.05
NL4	-	-	-	-	0.05	0.05

Table 3: Daily network load probabilities for working days

In this simulation, we have two types of agents: user and ISP. Two main aspects that define agents are their properties and the methods that they can execute. Properties of user agents are: user's TP, TP price, and TP price after
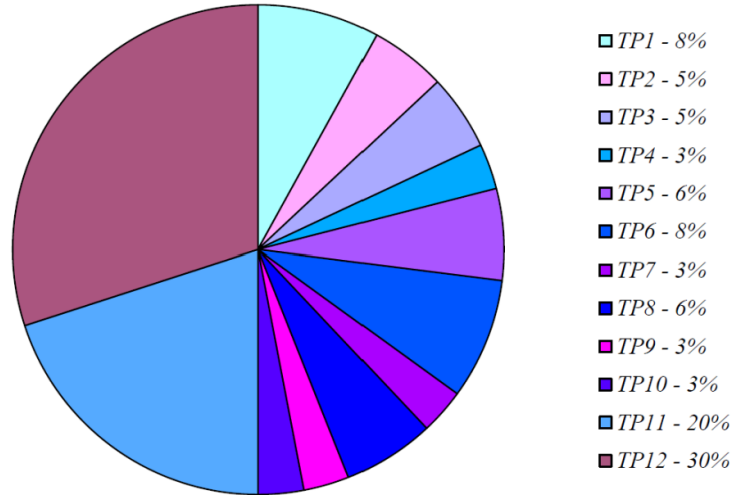
Figure 2: Tariff packages distribution

Network Load	Average duration (min)					
	00-06	06-08	08-16	16-18	18-22	22-00
NL1	180	55	235	50	100	50
NL2	4	5	6	7	8	8
NL3	-	-	-	5	7	4
NL4	-	-	-	-	5	3

Table 4: Mean time of daily network load for working days

Network Load	00-06	06-08	08-16	16-18	18-22	22-00
NL1	0.98	0.99	0.85	0.85	0.7	0.75
NL2	0.02	0.01	0.15	0.1	0.15	0.1
NL3	-	-	-	0.05	0.1	0.1
NL4	-	-	-	-	0.05	0.05

Table 5: Daily network load probabilities for weekends

reduction. A user agent has one method: *reduce TP price*. This method is used for interaction with the ISP which calls this method each time *NL2*, *NL3* or *NL4* lasts more than 10 minutes. The ISP agent has two properties: *maximal revenue*, and *revenue with hybrid pricing*. Methods of the ISP agent are: *examine network load*, and *initiate reduction of users' prices* (prices per TP). The environment is an IP network where different network loads can happen depending on day and time during the day.

Screenshot of simulator's main window with running animation is shown in

	Average duration (min)					
Network Load	00-06	06-08	08-16	16-18	18-22	22-00
NL1	180	60	230	50	95	45
NL2	5	3	5	6	9	9
NL3	-	-	-	5	6	6
NL4	-	-	-	-	5	5

Table 6: Mean time of daily network load for weekends

Figure 3. Users are presented as circles with color that depends on TP (colors of TPs are the same as in Figure 2). The background color defines network load (*NL1* - green, *NL2* - yellow, *NL3* - orange and *NL4* - red). When *NL2*, *NL3* or *NL4* duration is larger than 10 minutes, ISP initiates price reduction for users in particular TPs. These users are presented as circles with black outline.

Figure 3: Screenshot of simulator software with running animation

Simulation experiment is performed 50 times with 1000 users. For every simulation run, different seeds are used for random numbers. Selected simulation period is one year, starting from January 1st to December 31st 2019. Selected time increment is 30 seconds. Simulation results for one run are shown in Figure 4. ISP's revenue is presented annually (Figure 4a) while service prices are shown monthly for different TPs (Figure 4b). We present prices for users belonging to *TP1*, *TP2*, *TP5*, *TP8*, *TP10*, *TP11*, and *TP12*. *TP3* and *TP4* are not observed as the

price of these tariff packages is the same as *TP2* and they experience equivalent price reduction based of network load. For the same reason, we don't present results for *TP6* and *TP7*, which have the same price and price reduction as *TP5*. The same applies for *TP9*, which has the same price and price reduction as *TP8*. Although *TP10* has the same price as *TP8*, users belonging to *TP10* experience price reduction if *NL3* or *NL4* occurs, but not in case of *NL2*, which distinguishes them from *TP8* and *TP9*. Service prices are calculated for all users during the period of 600 months. On average *TP1-TP9* users achieve 11.5% price reduction on monthly price, *TP10* users achieve 4.2% monthly price reduction, while *TP11* users achieve only 0.7% monthly price reduction on average.
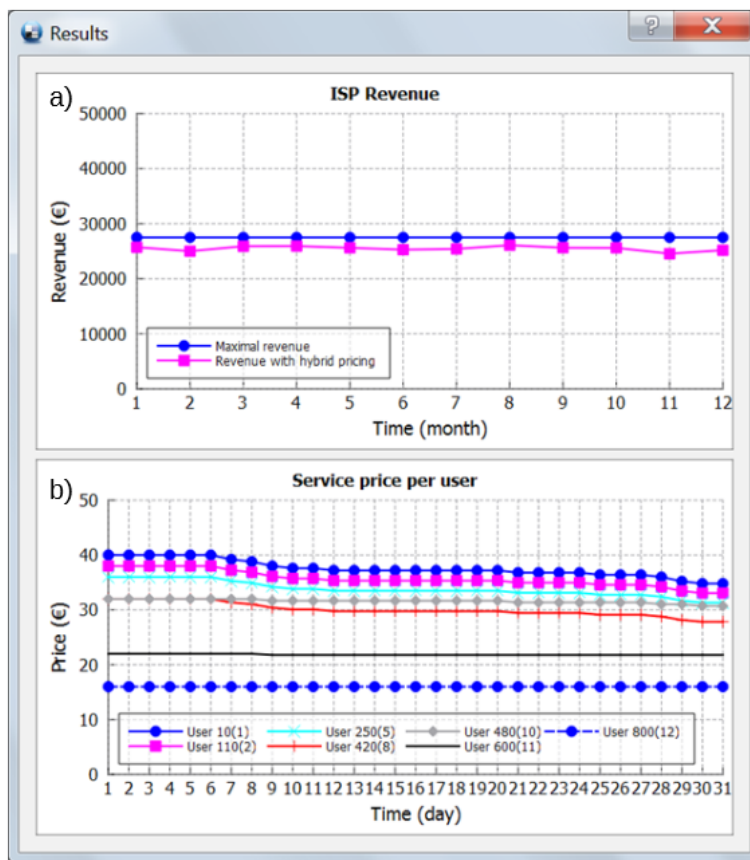

Figure 4: Simulation results: a) Maximal ISP revenue and ISP revenue with hybrid pricing, b) Reduction of service price for selected users

Applying hybrid pricing, ISP expects to gain more users and achieve maximal revenue at the same time. With this aim, based on simulation results, it is necessary for ISP to improve QoS parameters, which can be performed by expanding the network. Further cost optimization can be conducted in order to reduce costs and

to maximize its revenue.

4. CONCLUSION

In this paper we focus on ISP's revenue and service prices, which are observed as main QoBiz parameters from ISP's and users' perspective, respectively. We propose a QoBiz model, which takes into account QoS parameters, and assume that ISP applies hybrid pricing scheme. Simulation analysis of the proposed model is conducted using ABS techniques with focus on the interaction between users and ISP in an IP network.

One of the advantages of the proposed model is the transparent mapping of QoS parameters to QoBiz including direct reflection of QoS violation on service prices, and consequently, on ISP's revenue. Users are charged not only according to the declared QoS but also to the achieved QoS. Simulation results show prices decrease for most of the tariff packages. By applying hybrid pricing scheme, ISP is likely to attract new users, but in order to achieve maximal revenue, ISP should tend to improve QoS parameters, which can be accomplished by additional investments in the network.

In a future research, cost optimization for ISP can be performed in order to optimize trade-off between cost investments and expected revenue from new users. Further, the observed ISP's revenues can be simulated in cases of different tariff packages. The proposed model can be expanded to include the impact of service prices variations offered by other ISPs in the same market.

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