http://dx.doi.org/10.5755/j01.eee.18.8.2640 ELEKTRONIKA IR ELEKTROTECHNIKA, ISSN 1392-1215, VOL. 18, NO. 8, 2012

Quality of Experience and Users Elasticity Considerations for Modelling Competition between Service Providers in NGN

V. Radonjic, A. Kostic Ljubisavljevic, M. Stojanovic
University of Belgrade,Faculty of Transport and Traffic Engineering, Vojvode Stepe 305, 11000 Belgrade, Serbia, phone: +381 11 3091322
v.radonjic@sf.bg.ac.rs

***Abstract*—In next generation networks, service providers should take into consideration not only quality of service but also quality of users' experience aspects. In this paper we propose Cournot game for modelling competition between two service providers offering the same NGN service to users classified according to elasticity criterion. The proposed model includes quality of service parameters within users' utility functions and total users' demand as a function of quality of experience parameters. For this model we have analyzed the price setting through three distinctive cases. The numerical results have shown that service providers' profits are greatly affected by both quality of experience and users' elasticity.**

***Index Terms*—Game theory, next generation network, quality of experience, quality of service, utility theory.**

I. INTRODUCTION

Next Generation Networks (NGN) presents packet-based networks, which can support various types of telecommunication services, including telephony, data transmission, video, multimedia etc [1]. Large numbers of service providers (SPs) are competing with each other for users. With increasing number of SPs, competition in telecommunication markets becomes significant, so it is essential for SPs to position themselves effectively. In NGN environment, where two or more providers can carry traffic with end to end Quality of Service (QoS) guarantees, new settlement models are expected to initiate [2]. However, it appears that QoS differentiation in NGN will not offer a suitable economic framework for the trade-off between quality carried by the SP and user's motivation to pay. Quality of Experience (QoE) is an optional framework for pricing service quality according to users' perception.

In this paper we propose Cournot game for modelling the competition between two SPs offering the same NGN service. In this model we apply the classification of users' utility functions according to their elasticity. The model includes QoS parameters within users' utility functions and total users' demand as a function of QoE parameters.

The rest of the paper is organized in the following way. The most important features distinguishing QoE from QoS concept in NGN are given in next section. After that we propose Cournot duopoly model for which SP's profit function is modified by including total users' demand. Finally, numerical results and conclusions are given.

Manuscript received March 17, 2012; accepted May 12, 2012.
This work is partially supported by the Ministry of Education and Science of Serbia with the project TR32025.

II. QUALITY CONCEPTS IN NGN

The NGN concept takes into consideration new realities in the telecommunication industry such as the need to converge and optimise the operating networks as well as the extraordinary expansion of digital traffic. There are several key techno-economic drivers for NGN [3]:

- Due to huge hardware technology changes, capital and operational costs are greatly reduced;
- Since users are free to choose between large number of competing SPs and a wide range of services, price to performance ratio is significantly improved;
- Standards are rapidly evolving and supporting interoperability;
- NGN is considered to encourage rapid introduction of new and different services.

Considering highly diverse network traffic in NGN, QoS concepts are of great importance for ensuring proper support for many types of applications with different QoS requirements. NGN should provide service differentiation with packets serviced depending on their value. Providing service with strong QoS guarantees keeps users satisfied and thereby maintains their confidence in the SP. Although QoS provides a valuable framework for a provider, it is not necessarily usable in specifying performance requirements for particular network technologies [1], [2]. It is necessary to take into account the user experience and business indicators. While QoS is related to service performances that can be measured and controlled, QoE relates to the experience realized by a user when using the service. QoE takes into consideration users' satisfaction with a technology, subjective evaluation and degree of users' expectations fulfilment [1], [4].

In addition to SPs' striving to ensure the required QoS to their users, profitability is of the most importance to SPs. Users should be encouraged to choose the service that meets their needs in most adequate manner, which can be most effectively achieved through pricing [5], [6]. It is expected that competition will force SPs to rapidly create and deploy different pricing concepts in order to achieve a trade-off between providing satisfying user's utility and SP's revenue, still supporting implementation efficiency and feasibility [7]. Various models from game theory can be applied for pricing NGN. In this paper we focus on Cournot game for modelling related issues.

III. Cournot Duopoly Model

Cournot game is appropriate for modelling the strategic choices of SPs at the market of telecommunication services with a small number of SPs that focus on the quantity of supplied service. From a game theory point of view, the Cournot model assumes providers act simultaneously. In this one-round game model it is necessary that each SP determines in advance his strategy without knowing strategic choices of other SPs. We consider the case of Cournot game with two players, i.e. Cournot duopoly: two competing SPs who offer the same service to their users. This game describes how these two players can settle on their respective output levels to maximize their own profits. The proposed model takes into consideration SPs revenues of providing NGN services and expenditures that both SPs have to the network service provider (NSP) for using his resources. Modelling this as a one-round game, each SP must choose an amount of bandwidth for providing the service, and then, as a function of both SPs choices, receive a pay-off (that is his profit). Clearly, SP*i*'s profit is equal to its revenue minus its cost. In our model, we propose the following SP*i*'s profit function

$$\Pi_i = (P_i - C_i)\theta_i, \tag{1}$$

where θ_i – bandwidth occupied by SP*i*, P_i – price per bandwidth unit that end users pay, C_i – SP*i*'s cost to the NSP for using his network resources. We assume that $C_i = C$ for all i, $i = 1, 2$.

If one SP*i* occupy θ_i bandwidth for providing the service, the total bandwidth amount is $\theta = \theta_1 + \theta_2$ and the resulting price in the market will be $P(\theta)$. Price per bandwidth unit can be formulated in the following manner

$$P_i = \alpha - \tfrac{p}{\pi}\theta_1 - \tfrac{p}{\pi}\theta_2 = P \text{ for all } i,\ i = 1, 2, \tag{2}$$

where p is a maximum price per bandwidth unit θ, average user is willing to pay, π is maximum bandwidth average user requires, α is a constant such that $\alpha > \tfrac{p}{\pi}(\theta_1 + \theta_2)$. In this interpretation, α represents marginal price.

With the aim of finding Nash equilibrium in the Cournot game we determined the first order conditions

$$\frac{\partial \Pi_i}{\partial \theta_i} = 0. \tag{3}$$

These conditions define the reaction curve $\theta_i(\theta_j)$ for each SP*i*, that is, his optimal choice of output as a function of his belief about the other SP's output θ_j. The equilibrium point can be found in the intersection of these curves. Nash equilibrium in this game is a pair of outputs (θ_1*, θ_2*) with the property that if SP*i* chooses θ_i* then there is no incentive for SP*j* to choose other than θ_j*, where $i, j \in \{1,2\}$ $i \neq j$. Hence, there is a unique equilibrium point given by the solution of the two equations

$$\theta_1 = \tfrac{1}{2}\left[\tfrac{\pi}{p}(\alpha - C) - \theta_2\right],\ \theta_2 = \tfrac{1}{2}\left[\tfrac{\pi}{p}(\alpha - C) - \theta_1\right]. \tag{4}$$

Solving this system of equations, we find Nash equilibrium of the Cournot game

$$\theta_1^* = \theta_2^* = \tfrac{1}{3}\tfrac{\pi}{p}(\alpha - C). \tag{5}$$

The total occupied bandwidth in this equilibrium is $\theta_1^* + \theta_2^* = \tfrac{2}{3}\tfrac{\pi}{p}(\alpha - C)$. Therefore, the equilibrium price per bandwidth unit is

$$P^* = \alpha - \tfrac{p}{\pi}(\theta_1^* + \theta_2^*) = \tfrac{1}{3}(\alpha + 2C). \tag{6}$$

Cournot's analysis suggests that as the number of SPs increases, i.e. the market structure becomes less concentrated, equilibrium price decreases. Thus, structure influences performance.

IV. Users' Demand and Utility Considerations

Total demand for bandwidth has great influence on SP*i*'s profit. Therefore, it is important to determine total demand for the service for each SP in NGN market. We have modified SP's profit function by including demand such that:

$$\Pi_i = D_i(P_i - C_i)\theta_i \tag{7}$$

User's demand *D* to accept a service is actually its satisfaction probability, which depends on the trade-off between QoS and price. Therefore, it is a function of user utility *U* and price *P*. We choose a specific shape of a user's demand function, which is defined as [8]

$$D(P) = 1 - e^{-U_n^A P^{-B}}, \tag{8}$$

where *A* and *B* are positive constants that reflect the sensitivity of users' satisfaction to the QoS/price trade-off: *A* indicates user's sensitivity to the QoS and *B* denotes user's sensitivity to the price. For example, increasing *A* makes the users more sensitive to the QoS, while increasing *B* does the same to the price. As distinct from parameter θ, which is QoS parameter, *A* and *B* are QoE parameters. The equation (8) is very general and it points the intuitive behaviour that the satisfaction of a user increases as the quality increases and/or the price decreases. For the purpose of utility function assessment, we propose elasticity criterion whereby users are classified into three categories: elastic, partially elastic and inelastic users. Users' preferences may be modelled with utility functions, which describe users' sensitivity to changes of QoS. We have assumed that users' utility functions vary in accordance to the elasticity feature of a user (Fig. 1–Fig. 3). A user's utility is expressed as a function of available network resource offered to a user, which indicates a user's sensitivity to changes in QoS. For all users' types, QoS is defined by bandwidth, θ obtained from the SP and the law of diminishing marginal utility ensures that a user derives the same amount of satisfaction from any bandwidth more than the maximum π.

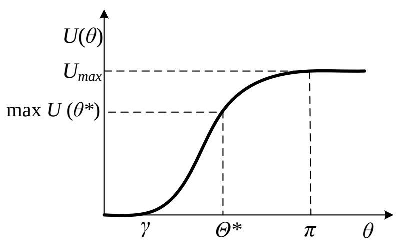

Fig. 1. Utility function of inelastic users [11].

Inelastic users have strict requirements in terms of delays, but they are more tolerant to losses. Their bandwidth demands vary at a specified interval (between γ and π). Less bandwidth than γ on average is of no utility to the user. Inelastic user's utility has been most commonly described by the sigmoid function (Fig. 1)

$$U_n = \frac{p}{1 + e^{\left(\frac{\gamma + \pi}{2} - \theta\right)}}, \ \gamma \le \theta \le \pi . \tag{9}$$

A utility function, which best models elastic and partially elastic users' behaviour, is a generalization of the logarithmic function [10]. Elastic users do not tolerate losses but can accept delay to some extent [11]. Partially elastic users are also not tolerant of losses but they have stronger requirements in respect to delay [6].

Depending upon the QoS requested, each partially elastic user would require a minimum bandwidth γ [12]. Partially elastic user's utility function (Fig. 2) is

$$U_n = p\,\gamma\left(\log\left(\theta/\gamma\right)+1\right), \ \gamma \le \theta \le \pi . \tag{10}$$

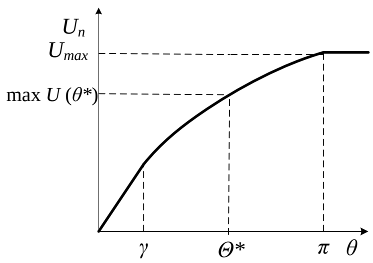

Fig. 2. Partially elastic user's utility function [6].

For elastic users (Fig. 3) only the maximum required bandwidth, π is defined. As opposed to inelastic and partially elastic users, bottom bandwidth limit doesn't have to be defined. Mathematical formulation of elastic user's utility function can be expressed as follows

$$U_n = p\,k_s \log\left(1+\theta\right) \quad 0 \le \theta \le \pi \ , \ k_s = 1/\log\left(1+\pi\right) . \tag{11}$$

We assume that the shapes of these functions (shown in Fig. 2–Fig. 4) are the same for all users within the same elasticity type. On the other hand, γ, π and p can be different for different users even if they belong to the same elasticity type.

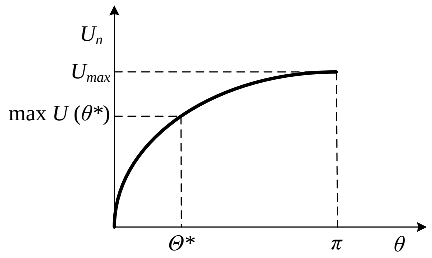

Fig. 3. Elastic users' utility function [9].

V. NUMERICAL RESULTS

For the purpose of analyzing the proposed model we have developed software in Visual Basic for determining the optimal price solution. Input parameters are p_i, γ_i, π_i, α, C_i, A_i and B_i for i = 1, 2. The additional input parameter is the proportion of inelastic, partially elastic and elastic users for each SP. All those parameters can be varied in certain range. As an illustration of the proposed model, we analyse three distinctive cases here. Fig. 4–Fig. 6 present equilibrium prices and corresponding SPs' profit values for discrete bandwidth outputs as the solutions of the proposed Cournot model. In the first analyzed case, we have assumed that two SPs attract users with different QoE parameters: A_1=0.6, B_1=0.4, A_2 = 0.4 and B_2 = 0.6. All other input parameters are set to be equal for both SPs: $p_1 = p_2$ = 5.5÷10MU, $\gamma_1 = \gamma_2$ = 10Mbit/s, $\pi_1 = \pi_2$ = 5.5÷10Gbit/s, α = 6.4 ÷ 10MU and $C_1 = C_2$ = 0.3 ÷ 3MU. MU is interpreted as money unit. In this case we have also assumed an equal number of inelastic, partially elastic and elastic users for each SP. According to the results for this case (Fig. 4), profit maximization of SP with users which are more sensitive to QoS then price, i.e. SP_1 is achieved for two price and bandwidth allocations: P_1 = 5MU, θ_1 = 2.3Gbit/s and P_1 = 5.33MU, θ_1 = 2.33Gbit/s. For the other SP which attract users that are more sensitive to price than to QoS, i.e. SP_2, profit maximization is achieved for P_2 = 3MU and θ_2 = 2.1Gbit/s. In this case, neither provider could enhance its profit by offering more bandwidth (for higher price). This is obvious for SP_2 because its profit decreases with increasing price (and bandwidth), but this is very likely for SP_1 too due to stagnation of its profit for price higher than 5MU (and bandwidth higher than 2.3 Gbit/s).

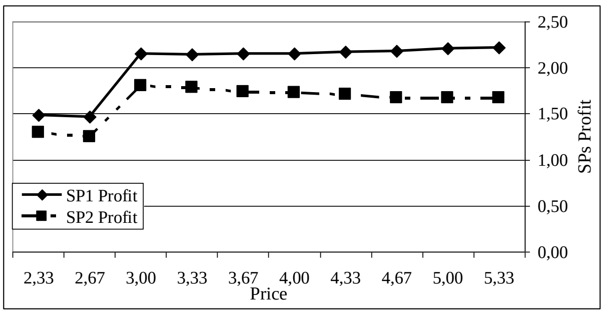

Fig. 4. SPs' profits as functions of price in the first case.

In the second analyzed case, we have used the same input parameters as in the first case with a difference in distribution of inelastic, partially elastic and elastic users. We have assumed an equal number of inelastic, partially elastic and elastic users for SP_1, such as in the first analyzed case, but for SP_2 this proportion is: 50% elastic users, 25% partially elastic and 25% inelastic users. According to the results in this case (Fig. 5) prices and bandwidth maximizing SP_1 and SP_2 profit are the same as in the first case. However, it can be noticed that SP_2 has improved its profit due to higher number of elastic users.

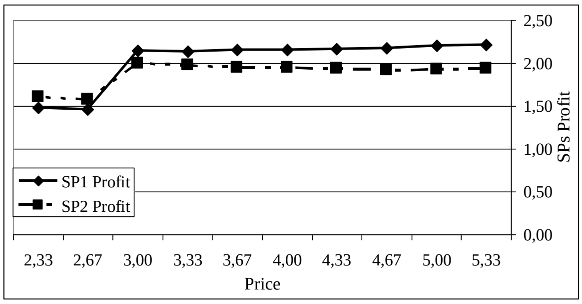

Fig. 5. SPs' profits as functions of price in the second case.

In the third case, we have assumed equal QoE parameters for both SPs, i.e. $A_1 = A_2 = B_1 = B_2 = 0.5$. All other input parameters remain the same as in the second case. Here SP_1 achieve profit maximization for P_1 = 3MU and θ_1 = 2.1Gbit/s, while values maximizing SP_2 profit are: P_2=5.33MU and θ_2=2.33Gbit/s). Considering improvement in SP_2's profit and lower profit for SP_1 (Fig. 6), in comparison with previous cases it is clear that greater number of elastic users means higher profit for the SP.

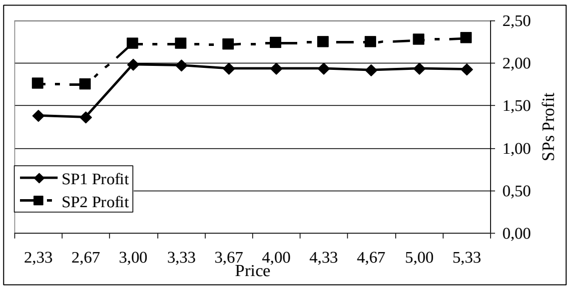

Fig. 6. SPs' profits as functions of price in the third case.

From all analyzed cases, it is obvious that SPs' profits are directly dependent on QoE parameters and users' elasticity.

VI. CONCLUSIONS

Considering increasing importance attached to users' experience in NGN, SPs strive to attract more users by offering favourable trade-off between QoS and price. Therefore, special attention should be given to users' utility and demand defining. In this paper we propose Cournot game for modelling the competition between two SPs in NGN. We have analyzed behaviour of SPs' profit functions depending on QoE parameters and users' elasticity. The classification according to users' elasticity criteria can be appropriate for a SP to estimate his future revenue based on demand function that incorporates variety of users' behaviours.

REFERENCES

[1] *ITU-T NGN FG Proceedings Part II,* ITU, 2005. [Online]. Available: www.itu.int/ITU-T/ngn/files/NGN_FG-book_II.pdf

[2] *ITU-T E.800-series Recommendations - Supplement 8, "Guidelines for inter-provider quality of service",* Geneva, 2009.

[3] *Next Generation Networks: Migration from Circuit to Packet – An Overview (white paper).* [Online]. Available: http://www.tekelec.com/ss7/ NGN-Overview.pdf

[4] *ITU-T Delayed Contribution D.197, Definition of Quality of Experience, Source: Nortel Networks,* Canada (P. Coverdale), 2004.

[5] V. Radonjic, V. Acimovic-Raspopovic, A. Kostic- Ljubisavljevic, "Quality of Experience in Cournot Competition Model for Pricing Next Generation Networks", in *Proc. of the 5th International Quality Conference*, 2011, pp. 363-370.

[6] V. Radonjić, V. Acimovic-Raspopović, "Responsive Pricing Modeled with Stackelberg Game for Next Generation Networks", *Annals of Telecommunications*, vol. 65, no. 7–8, pp. 461-476, 2010. [Online]. Available: http://dx.doi.org/10.1007/s12243-010-0174-2

[7] B. M. Ninan, M. Devetsikiotis, "Game-Theoretic Resource Pricing For The Next Generation Internet", *Performance Evaluation and Planning Methods for the Next Generation Internet*, pp. 141–163, 2005.

[8] L. Badia, S. Merlin, A. Zanella, M. Zorzi, "Pricing VoWLAN Services through a Micro-Economic Framework", *IEEE Wireless Commun*, vol. 13, no. 1, pp. 6–13, 2006. [Online]. Available: http://dx.doi.org/10.1109/MWC.2006.1593519

[9] S. Sengupta, M. Chatterjee, "Differentiated Pricing Policies in Heterogeneous Wireless Networks", *Heterogeneous Wireless Access Networks Architectures and Protocols*, pp. 393–417, 2008.

[10] S. Shenker, "Fundamental design issues for the future Internet", *IEEE Journal on Selected Areas in Communications*, vol. 13, no. 7, pp. 1176–1188, 1995. [Online]. Available: http://dx.doi.org/10.1109/49.414637

[11] F. P. Kelly, "Charging and rate control for elastic traffic", *European Transactions on Telecommunications*, vol. 8, pp. 33–37, 1997. [Online]. Available: http://dx.doi.org/10.1002/ett.4460080106

[12] X. Wang, H. Schulzrinne, "Pricing network resources for adaptive applications in a differentiated services network", in *Proc. of the Twentieth Annual Joint Conference of the INFOCOM*, vol. 2, pp. 943–952, 2001.