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QUALITY OF EXPERIENCE IN COURNOT COMPETITION MODEL FOR PRICING NEXT GENERATION NETWORKS

Abstract: *In next generation networks, providers want to support pricing different quality of services classes and must take into consideration quality of users' experience aspects. In this paper, besides defining quality of service parameters, we also define quality of experience parameters for modelling the competition between two service providers offering the same service. The proposed model is based on Cournot game and is verified through numerous simulations.*
Keywords: *Quality of service, Quality of experience, Next generation networks, Cournot duopoly model.*

1. INTRODUCTION

Next Generation Networks (NGN) are packet-based networks that can support all types of services, including basic voice telephony services, data, video, multimedia, advanced broadband and management applications [8].

NGN should be operated by large number of service providers (SPs) competing with each other for users and cooperating at the same time. With increasing competition in telecommunication markets, it will be essential for SPs to position themselves appropriately and to prepare for the emerging NGN environment.

In NGN environment, where traffic with Quality of Service (QoS) guarantees can be carried end to end by two or more providers, new settlement models are expected to start up [7]. However, it appears that in NGN QoS differentiation will not provide a suitable economic framework for the trade-off between quality delivered by the SP and willingness to pay from the user's side. Quality of Experience (QoE) is an alternative framework for pricing service quality according to the user perception [16].

In this paper we propose Cournot game for modelling the competition between two service providers offering the same NGN service. We define user's utility function which includes QoS parameters and in addition we define total users' demand as a function of QoE parameters.

This paper is organized in the following way. An overview of pricing issues in NGN and the most important features which distinguish QoE concept from QoS are given in Section 2. In Section 3 some game theoretic approaches that can be applied for pricing and quality differentiation in NGN are discussed. For the Cournot duopoly model proposed in Section 4, we modified SPs' profit functions by including total users' demand which is explained in Section 5. Simulation results are analyzed in Section 6 and concluding remarks are given in Section 7.

2. PRICING, QUALITY OF SERVICE, NETWORK PERFORMANCE AND QUALITY OF EXPERIENCE IN NGN

Generally, the concept of pricing implies the process of determining tariffs which should be based on appropriate pricing model and controlled by a pricing policy. Charging combines the tariffs and the results of metering needed for the charge of users. The output of charging process is the charge per party (customer, service provider, content provider). The billing process produces an invoice on the basis of the charge per party [1]. The process can be configured by means of the billing policy, e.g., how often a bill is sent to a user. The payment process results in the actual transfer of money, based on an invoice as input.

A wide range of different schemes is likely to be applied for pricing services in NGN [12, 14]. It is expected that competition will force service providers to rapidly create and deploy different pricing concepts. Pricing model should fulfil a trade-off between providing satisfying user's utility and provider's revenue, still preserving implementation efficiency and feasibility. User's utility can be expressed as a function of available network resource offered to a user which indicates a user's sensitivity to changes in QoS.

By introducing QoS differentiation users are encouraged to choose the service that is most appropriate for their needs, which can be most effectively achieved through pricing. Considering highly diverse network traffic in NGN, QoS concepts play a crucial role in ensuring proper support for many types of applications with different QoS requirements. It is suggested for NGN that the basic best-effort architecture should be left intact with QoS schemes solely reserved for resource intensive high quality real-time services [8].

NGN should provide service differentiation with packets serviced depending on their value. QoS is defined in Recommendation E.800 as: "collective effect of service performance which determines the degree of satisfaction of a user of the service". This definition encompasses many areas of research, including subjective user satisfaction. QoS provides a valuable framework for network provider, but it is not necessarily usable in specifying performance requirements for particular network technologies (e.g. IP, MPLS, etc.). However, in [8] the aspects of QoS are restricted to the identification of parameters that can be directly observed and measured at the users' access point.

Recommendation I.350 defines Network Performance (NP) as "NP is measured in terms of parameters which are meaningful to the network provider and are used for the purpose of system design, configuration, operation and maintenance. NP is defined independently of terminal performance and user actions". NP ultimately determines the user observed QoS, but it does not necessarily describe that quality in a way that is meaningful to users.

QoE is subjective in nature, i.e. depends upon user actions and subjective opinions. It includes the complete end-to-end system effects (client, terminal, network, services infrastructure, etc). QoE, also referred to as "perceptual QoS", is defined as "a measure of the overall acceptability of an application or service, as perceived subjectively by the end-user" [6, 8].

QoE is a multidimensional concept with many factors affecting it. Therefore it is difficult to be defined or measured in a simple unified manner. It takes into consideration not only a technology performance in terms of QoS, but also users' satisfaction with that technology, subjective evaluation, degree of their expectations fulfillment and in what context they use it or intend to [3].

The definition of QoS, NP and QoE should make mapping clear in cases where there is not a simple one-to-one relationship among them. Table 1 shows some of the characteristics which distinguish QoS, NP and QoE.

Table 1. Distinction between QoE, QoS and NP [8]

QoE	QoS	NP
User oriented		Provider oriented
User behaviour attribute	Service attribute	Connection/Flow element attribute
Focus on user-expected effects	Focus on user-observable effects	Focus on planning, development (design), operations and maintenance
User subject	Between (at) service access points	End-to-end or network elements capabilities

NP definition includes transmitting time and response time. Transmitting time is the time interval during which a packet is transmitted between two network nodes. Response time is the time interval between the requirement sending and the receiving of required data. In this paper we did not particularly observed those parameters. The analyzed service model reflects elastic users for whom the QoS can be determined solely as a function of the average bandwidth. We defined QoE parameters through positive constants that regulate the sensitivity of users' satisfaction to the QoS/price trade-off.

3. GAME THEORETIC APPROACHES FOR PRICING AND QUALITY DIFFERENTIATION IN NGN

Game theory is a field of applied mathematics that describes and analyzes interactive decision making situations and consists of a set of analytical tools that predict the outcome of complex interactions among rational players [13, 18].

Basic components of a game are players, the possible strategies of the players and consequences of the chosen strategies. The players are decision makers and their strategy choices result in a consequence or outcome. The players try to ensure the best possible consequence according to their preferences. The preferences of a player can be expressed either with a utility function, which maps every consequence to a real number, or with preference relations, which define the ranking of the consequences.

The most fundamental assumption in game theory is rationality. Rational players are assumed to maximize their payoff. If the game is not deterministic, the players maximize their expected payoff. It is also assumed that the players know the rules of the game well.

In game theory, a solution of a game is a set of the possible outcomes. A game describes what strategies the players can take and what the consequences of the strategies are. The solution of a game is a description of outcomes that may emerge in the game if the players act rationally and intelligently. Generally, a solution is an outcome from which no player wants to deviate unilaterally.

In telecommunications game theory can be applied for solving a wide range of problems such as congesting control, resource allocation, routing, QoS provisioning, network security, sharing radio-communication spectrum and pricing telecommunication services. Various game models are proposed for pricing telecommunication networks. Some of the most appropriate game models for solving problems of pricing telecommunication services are Nash bargaining game, Stackelberg leader-follower game, Bertrand game and Cournot game.

Nash bargaining game concerns the choice of a point within a bargaining set. In this type of game two cases can be distinguished: 1. players have equal bargaining power and 2. players have unequal bargaining powers. The solution of such a game relates on that.

In Stackelberg game model at least one player is defined as the leader who chooses a strategy before other players defined as followers. Stackelberg game can be played with either price leadership or quantity leadership. They can provide a good base for defining prices in NGN especially in case of network congestions.

In the Cournot model each player announces as his strategic choice the quantities of services that he intends to supply. Prices adjust in response to the aggregate supply, so that all the production can be sold, and each player obtains a proportional amount of the consumers' outlay. The Cournot duopoly describes how two players selling the same service (or other products) can settle on their respective output levels so as to maximise their own profits.

Like the Cournot duopoly, the Bertrand duopoly is a static game, but one in which the two players compete in terms of the price they charge users, rather than production levels. Thus, in the Bertrand duopoly, the strategic variable is the price charged in the marketplace. The players simultaneously decide their pricing structures and market forces then decide about demand share for each player [9].

In this paper we propose Cournot game for modelling competition between two service providers.

4. COURNOT DUOPOLY MODEL

Cournot game is appropriate for modelling the strategic choices of service providers at the market of telecommunication services with a small number of service providers that focus on the quantity of supplied service. Service prices are adjusted according to total supply, so the entire bandwidth can be used and each SP receives revenue which is proportional to the amount of bandwidth consumption. In this one-round game model it is necessary that each SP determines in advance his strategy without knowing strategic choices of the other SPs.

We consider the case of Cournot game with two players: two competing SPs who offer the same service to their users. First, we present a general formulation of SPi profit and equilibrium solutions for two players in Cournot game.

If one SPi 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 $P(\theta)$. Assumption is that SPi has expenditure to Network Service Provider (NSP) of C_i. Modelling this as a one-shot 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). The profit of SPi can be written

$$\Pi_i(\theta_1,\theta_2) = P(\theta_1+\theta_2)\theta_i - C_i(\theta_i) \quad (1)$$

Equilibrium in this game is a pair of outputs (θ_1*, θ_2*) with the property that if firm i chooses θ_i* then there is no incentive for firm j to choose other than θ_j*, where $i, j \in \{1,2\}$ $i \neq j$. This implies the first order conditions:

$$\begin{aligned} \partial\Pi_1(\theta_1,\theta_2)/\partial\theta_1 &= P(\theta_1+\theta_2) + P'(\theta_1+\theta_2)\theta_1 - C'_1(\theta_1) = 0 \\ \partial\Pi_2(\theta_1,\theta_2)/\partial\theta_2 &= P(\theta_1+\theta_2) + P'(\theta_1+\theta_2)\theta_2 - C'_2(\theta_2) = 0 \end{aligned} \quad (2)$$

These conditions define for each SPi his reaction curve $\theta_i(\theta_j)$, 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. Next, we propose a specific model formulation.

We assume two SPs offering their prices at the same time. The proposed model takes into consideration SPs revenues of providing NGN services and expenditures that both SPs have to the network provider for using his resources. Clearly, SPi's profit is equal to its revenue minus its cost. In our model we propose the following SPi's profit function:

$$\Pi_i = (P_i - C_i)\theta_i \tag{3}$$

θ_i – bandwidth occupied by SPi,

P_i – price per bandwidth unit that end users pay,

C_i – SPi's cost to the NSP for using his network resources.

We assume that $C_i = C$ for all i, $i = 1, 2$.

Price per bandwidth unit can be formulated in the following manner:

$$P_i = \alpha - \frac{p}{\pi}\theta_1 - \frac{p}{\pi}\theta_2 = P \text{ for all } i,\ i = 1, 2. \tag{4}$$

where: p is a maximum price per bandwidth unit θ, average user is willing to pay, π is maximum bandwidth average user requires[1], α is a constant measured in money units such that $\alpha > \frac{p}{\pi}(\theta_1 + \theta_2)$.

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

$$\frac{\partial \Pi_i}{\partial \theta_i} = 0 \tag{5}$$

For the case with two SPs, there is a unique equilibrium point given by the solution of the two equations:

$$\theta_1 = \tfrac{1}{2}\left[\tfrac{\pi}{p}(\alpha - C) - \theta_2\right] \tag{6}$$

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

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

$$\theta_1^* = \theta_2^* = \tfrac{1}{3}\tfrac{\pi}{p}(\alpha - C) \tag{7}$$

The same result can be found graphically as it is shown in Figure 1. The total occupied bandwidth in this equilibrium is $\theta_1^* + \theta_2^* = \frac{2}{3}\frac{\pi}{p}(\alpha - C)$. Hence, the equilibrium price per bandwidth unit is:

$$P^* = \alpha - \tfrac{p}{\pi}(\theta_1^* + \theta_2^*) = \tfrac{1}{3}(\alpha + 2C). \tag{8}$$

From (7) and (8) it can be noticed that average user requirements for maximum bandwidth (π) and price (p) affect the equilibrium bandwidth, but have no influence on the equilibrium price. The result could be different if we apply appropriate pricing scheme that takes into account user's feedback, such as responsive pricing [4, 11, 14].

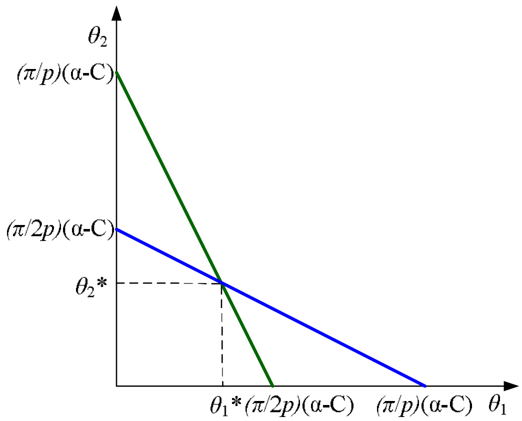

Figure 1 – The reaction curves and equilibrium point in Cournot game with two service providers

[1] The law of diminishing marginal utility ensures that the user derives the same amount of satisfaction from any bandwidth more than the maximum π [15].

5. ELASTIC USER'S UTILITY AND BANDWIDTH DEMAND

Total demand for bandwidth has great influence on SPi's profit. Therefore, it is important to determine total demand for the service for each provider.

We assumed that users of the observed service are more tolerant to delays, but not tolerant to losses, which are characteristics of elastic users [5, 10]. A utility function which best models elastic user's behaviour is the logarithmic function (Figure 2). QoS is defined by bandwidth obtained from the SP. It is considered that any price beyond the maximal price p per unit of bandwidth θ reduces the user's desired bandwidth to zero [17]. Mathematical formulation of elastic user's utility function is:

$$U(\theta) = p \cdot k_s \cdot \log(1+\theta),\ 0 < \theta < \pi \quad (9)$$

$$k_s = 1/\log(1+\pi)$$

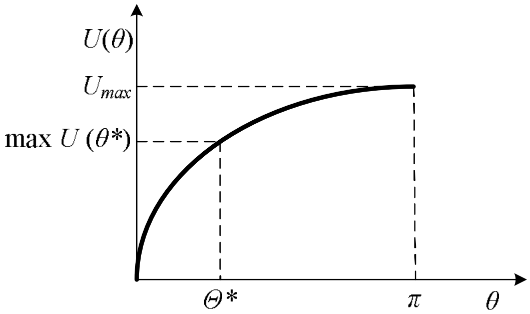

Figure 2 – Elastic users' utility as a function of bandwidth

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. It can be defined as [2]:

$$D(P) = 1 - e^{-U_n^A P^{-B}}, \quad (10)$$

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. This equation 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.

As distinct from parameter π and θ, which are QoS parameters, A and B are QoE parameters.

Next, we modify SP's profit function by including demand such that:

$$\Pi_i = D_i(P_i - C_i)\theta_i \quad (11)$$

6. SIMULATION RESULTS

First, we analyzed the case when two SPs attract users with different QoE parameters. For $p_1=p_2=5.5$, $\pi_1=\pi_2=5.5$, $\alpha=1\div10$, $C_1=C_2=0.3\div3$, $A_1=0.6$, $B_1=0.4$, $A_2=0.4$ and $B_2=0.6$, results are shown in Figure 3. SP with users which are more sensitive to QoS then price, i.e. SP_1, has higher revenues comparing to other SP, i.e.SP_2.

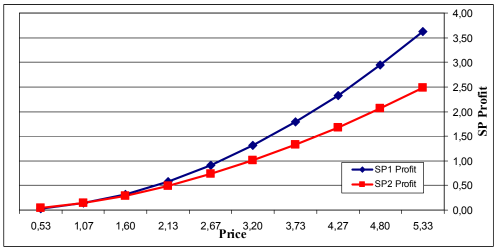

Figure 3 – SP Profits as functions of price for two providers with different QoE parameters

In second case we supposed the same QoE parameters for both SPs (i.e. $A_1=A_2=B_1=B_2=0.5$), but different maximal price elastic user is willing to pay for a unit of bandwidth (i.e. $p_1=5$ and $p_2=5.5$) and all other parameters the same as in previous example. In this case, SP_1 also has higher revenues, as it is shown in Figure 4.

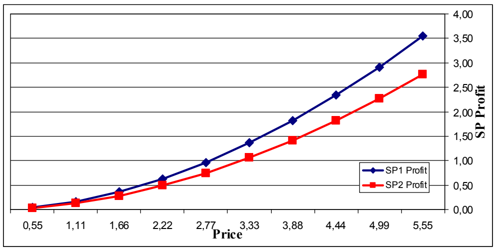

Figure 4 – SP Profits as functions of price for two providers with different parameters of maximal price user is willing to pay

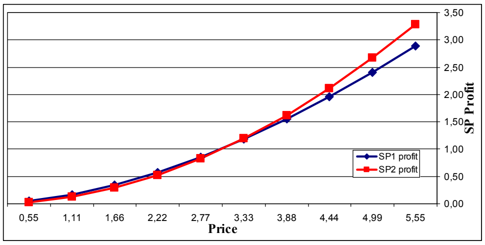

Figure 5 – SP Profits as functions of price for two providers with different QoE parameters and maximal price user is willing to pay

In third case, we supposed different QoE parameters as in the first case, but in reverse order, i.e. A_1=0.4, B_1=0.6, A_2=0.6 and B_2=0.4, with the same maximal prices per bandwidth unit as in the second case (i.e. p_1=5 and p_2=5.5). π, α and C remained the same (i.e. π_1=π_2=5.5, α=1÷10, C_1=C_2=0.3÷3). In this case, SP_2 is provider with users who are willing to pay higher maximum price per bandwidth unit and are more sensitive to QoS then price. Profits of SP_1 are slightly higher than SP_2 for lower prices. With increasing price, profit of SP_2 increases more rapidly.

7. CONCLUSION

In NGN there is a clear need for distinguishing QoE concept from QoS. Considering that end users experience the resulting performances of services, special attention should be given to QoE. Unlike QoS which is based on technology performances, QoE covers users' satisfaction with the technology, subjective evaluation, degree of their expectations fulfillment and context of usage. Encouraging users to choose the service that provides them with appropriate QoE can be most effectively realized through pricing.

In this paper we propose the Cournot game model for determining prices of the NGN service two SPs offer to their users. Defined SPs profit functions depend not only on the trade-off between QoS and price but also QoE parameters can significantly affect the profit. We analyzed behaviour of providers profit functions depending on QoE parameters and price changes.

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