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An Optimized Bandwidth Allocation in Broadband Digital Economy

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***Abstract*— Efficient and optimized data transfer in broadband is the anchor point of digital economy in modern era. One the most challenging issues for providing different services in broadband is the bandwidth allocation. That is a real-time multi dimensional problem solving requiring to satisfy QOS and SLA constraints at the same time. In this paper, we present a real-time adaptive framework for the problem of optimal bandwidth allocation to broadband services in Iran. Our approach for the allocation is based on Network Utility Maximization. In this way, the optimal bandwidth is the one which maximizes network users' utility. For this purpose, the bandwidth is dynamically allocated to the services with highest importance for the user (according to the SLA) and the remaining bandwidth is most appropriately allocated to the less important services. Each service has its own (non-linear) utility function which is considered in each allocation cycle. The utility values are calculated in real-time and the bandwidth allocation pattern which maximizes the total users' utilities is selected. Simulation results showed satisfactory bandwidth allocation patterns in different scenarios according to the network utility and user preferences in SLA.**

Keywords-component; Digital Economy, Network Utility Maximization (NUM); Network traffic Categories; Bandwidth Allocation; QoS; Broadband Services.

I. Introduction

The digital economy is developing rapidly worldwide. It is the single most important driver of innovation, competitiveness and growth, and it holds huge potential for entrepreneurs and small and medium-sized enterprises (SMEs) [1]. As data is the key point of digital economy, transferring large amount of them at highest possible speed is crucial. This is why policy makers set certain goals for broadband availability (such as those in the Digital Agenda for Europe) [2] and encourage investment in broadband infrastructure.

Broadband is of significant interest in its own right in telecommunication but also because of its role as a facilitator of main economic outcomes such as growth (in GDP), productivity and employment (in long run). Broadband deployment increases the income generated by Internet-related activities and which is called GDP static effects. Moreover, broadband increases the productivity of internet related activities, it makes again to increase GDP called GDP dynamic effects. Finally broadband would have effects beyond GDP, like consumer surplus generated by Internet activities [3].

Broadband Increases the productivity as it decreases the transaction and communication cost as well. This increase in productivity will displace some jobs, thereby having a negative effect on employment, at least that of lower-skilled workers. However a large number of economists believe that the increased competitiveness of firms, particularly in the more dynamic sectors of the economy, and the development of new services will outweigh any negative effects of job losses by creating new jobs, and that broadband thus has a net positive effect on employment. This may be particularly true in service industries with high labor intensity [3].

Digital economy have two sides: supply side and demand side. The supply side includes investment and supplying ICT infrastructures: access to broadband and telecommunication services, wired and wireless coverage, telecommunications companies, data centers, and data. The demand side indicates ICT take up: households and business desire for connectivity and how to use the connectivity [4]. Cloud services, e-commerce, e-government services and app use are the main examples of ICT demand. Note that supply with better quality leads to higher demand and stronger demand increases incentive to more investment in ICT, so higher supply. In other words, better quality of services (QoS) improves users' satisfaction and it in turn drives up demand. For example in China, spending on the media and entertainment sector has increased because the broadband experience has improved, creating high demand. With more people using mobile broadband to access digital entertainment services, the market is expected to be worth US$800 million by 2018.

Thereby, broadband as a main element in supply side is not sufficient without reinforcing the quality of services provided on broadband in demand side. In other word, providing broadband access without paying attention to the quality of services delivered on, should not necessarily improve demand, and so do not foster digital economy.

The internet applications have been found beyond transferring of simple data, as they are supposed to meet users' exceeding requirements for high-speed transfer of audio and video files. Currently voice, video and data traffic (triple-play services) is separately forwarded by broadband networks.

A critical issue which all the ISPs have to deal with in facilitating broadband quality of services is how to schedule traffic and allocate bandwidth for triple-play services on a same terminal device. To this end, most of existing researches have concentrated on utility-based solutions; i.e the bandwidth allocation is optimized when network user's utility is maximized.

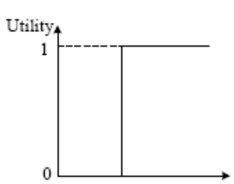
In this paper, we proposed an algorithm for optimizing bandwidth allocation by classifying broadband traffic into three categories based on their utility functions. In each class, according to three levels of quality of service (QoS) defined in service level agreement (SLA), the bandwidth is allocated to each user in such a way that the utility of all users is maximized.

The rest of this paper is structured as follows. Section 2 describes the utility-based traffic model including the concept of utility function and the characteristics of traffic used in our study. In section 3, we discuss the matter of optimal bandwidth allocation, based on the network traffic's utility. In section 4 we Based on the model proposed by Hajer Derbel, we have allocated the bandwidth to broadband services in Iran in such a way that the network user's utility is maximized and for this purpose, a simulation code was is written. Section 5 describes the concluding remarks and identify issues for further research.

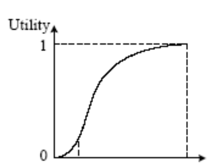
II. Traffic Categories and Related Utility Functions

The concept of utility was originally used in economics for analyzing consumer behavior. The economic concept of utility refers to the level of satisfaction of an individual gained by consuming some quantities of a good or service at a particular point in time [1].

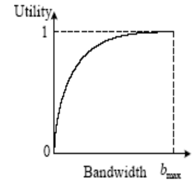
The concept of users' utility is also introduced in IP network traffic. Based on different utility functions, there are three main traffic categories: CBR (constant bit rate) traffic, VBR (variable bit rate) traffic and UBR (unspecified bit rate) traffic.



CBR Traffic



VBR Traffic



UBR traffic

Shenker [2] introduced for the first time the concept of users' utility in IP network traffic classification. The problem was that Internet structure originally supported the "best-effort" level in supplying web services. In other words, the Internet made no guarantee for the time elapsed for data delivery to the destination. As a result, the data may have remained waiting in certain nodes in the case of traffic overloads. Although, this structure could result in less dissatisfaction for classic data transfers, but for audio or video services the delay in delivering some packets might cause serious disorder in multimedia packets.The data may have been delivered partially and the rest might be received after a long delay causing corrupted streaming and inacceptable quality of the provided services.

CBR[1] Traffic refers to the applications like VoIP which is extremely sensitive to packet delay and loss caused by bandwidth insufficiency.

As Shenker's indicates, users' utility function of real-time services, like multimedia services, is different from that of non-real-time ones such as e-mail or data transfer services.

$$\pi(b) = \begin{cases} 0 & b < b_{\min} \\ 1 & b \geq b_{\min} \end{cases}$$

$\pi(b)$: User's utility from a services

b: The allocated bandwidth to the service

b min: Minimal required bandwidth for providing a service

The utility will be 100% if the allocated bandwidth is equal to the required bandwidth for the certain services (for Voice: 64Kbps[2]) and therefore, the audio file is transferred without delay. Otherwise, audio file will be delivered with remarkable delay and thus, user's utility from the respective service will be zero.

VBR[3]Traffic: Unlike the abovementioned services, non-real-time services have less sensitivity to packet delay (like video on demand). If the allocated bandwidth is somehow lower than the required bandwidth, the larger percentage of the respective file is downloaded; the users' utility will be higher. Ultimately, when the file is completely downloaded, utility reaches its maximal value. This type of traffic is specific for multi-media services which are flexible against the different network loads. In other words, their sensitivity level to b min is less than CBR traffic, and in the case of network overloads and hence lowering of bandwidth, the transfer rate can be equilibrated in such a manner that users feel no reduction in the service quality.

[1] Constant Bit Rate

[2] 64Kbps: Standard of voice encoding rate in most wired phone communications.

[3] Variable Bit Rate

IPTV4 service is an example of this traffic. Its utility function resembles the traffic which was formerly discussed; the difference is where IPTV and similar services can remarkably compensate the potential delay and packet losses using adaptive coding technology and also jitter control. In this way, the users would feel no bottlenecks in the delivered service. The following formula shows the utility function for VBR traffic [3]:

$$u(b) = 1 - e^{\frac{-kb^2}{k_2+b}}$$

u(b): User’s utility
b: Allocated bandwidth to the service
k1 and k2: The parameters which determine the form of function in a way that utility function equals 1 when maximal required bandwidth was provided.

UBR5 Traffic: Ning Lu and John Bigham [2] and Zimmerman [4] proposed another version of traffic entitled UBR. This version is related to data transfers having less sensitivity to delay in data delivery. In case of overload, the data remain waiting inside a network node and are then gradually sent at a slower rate. The following relation is the utility function of this type of traffic:

$$u(b) = 1 - e^{\frac{-kb}{b_{\max}}}$$

u(b): User’s utility
b max: Maximal bandwidth
k: The parameter indicating the form of function
In this type of traffic, the minimal bandwidth is not needed because the users are not highly sensitive to delays. So long as bandwidth equals b max, utility function assumes its maximal value which is unity. The following figure illustrates the form of utility function for UBR traffic.

III. Network Utility and Bandwidth Allocation

Based on the network traffic’s utility, we can solve the congestion-phased bandwidth allocation issue from the objective of Network Utility Maximization (NUM). Researches in academia have mainly concentrated on utility-based solutions [5].

Total network users’ utility is obtained from utility sum for all requested services. Different models have been proposed so far in the field of application method of utility functions in optimal bandwidth allocation among the various provided services. In some models, maximization of the summation of user’s utility functions has been taken into account as the objective. [6] and [7]. Harks [8] considered another assumption instead of network utility maximization: fairness among the users signifying the available bandwidth must be allocated among the users so that all of them would have the same utility, and for utility of a user, the utility of others shall not be reduced. Massoulie [9] suggested algorithms commensurate with each of the following assumptions:

1. Max-min fairness among users
2. Establishing relative fairness among the users
3. Delay minimization

Ning Lu and John Bigham [2] proposed an algorithm for optimizing bandwidth adaptation in wireless networks to achieve two objectives: all calls belonging to the same class (UBR, CBR and VBR) receive fair utility and the utility sum of all different classes of calls is maximized.

Changbin Liu discussed the matter of optimal bandwidth allocation in next generation networks. He divided these services into five categories and defined a separate utility function for each one considering the type of network traffic in the respective services. The optimal bandwidth in this model is the one that maximizes the total network users’ utility.

In [2], It is assumed that utility function in each traffic class is equal for all users, while the users in reality do not have similar tastes and requirements. In overload hours, the allocated bandwidth to all users is reduced declining the data transfer rate. If a home user requests a service such as IPTV, he may give up and ask for it later if he/she feels slowness in service delivery. On contrary, a commercial user who has requested this service for using in a distant video-conference is highly sensitive to receiving it at the same moment. As a result, it is proved that the significance level is not the same for both users and therefore, its impact is not the same on their satisfaction and utility. Thus, the service quality parameters (QoS) should be taken into account in the model based on which several different quality levels are presented for each service; each level has a specific price depending on its quality. The service applicants select one of the quality levels commensurate with their sensitivity and requirements; they would pay higher prices (for better quality) and lower price (for lower price).

Hajer Derbel et al proposed a model for optimal bandwidth allocation in packet-based networks. Base on this approach, the optimal bandwidth is the one which maximizes the total users’ utility: Network Utility Maximization (NUM). In this study, total network utility is divided based on 3 traffic types; UBR, CBR and VBR. The objective is to maximize the total network utility (summation of all network users’ utility functions). The advantage of this method emerges as the service provider is assumed to supply diverse services, and according to this assumption, different utility functions are proposed considering the type of network traffic of each service. In addition, quality of service parameter is introduced into the model which guarantees allocative efficiency. In other words, the bandwidth, particularly in overload times, is allocated to those individuals who value the services most and consequently are willing to pay higher price for it. SPref parameter inputs the significance level that users consider for the service. For instance, suppose two users who request 3 services: VOD6, VOIP7 and File Transfer but they do not have the same preferences. VOD service is the most important for the first user and hence he accepts to pay higher price to receive this service in very high

[4] Internet Protocol Television
[5] Unspecified Bit Rate
[6] Video On Demand
[7] Voice Over IP

quality. In contrast, the first priority of the second user is VOIP service. Therefore, SPref parameter which has a numerical value is defined as follows:

$SPref \in [1,2,...QL]$

The user utility function can be represented in this form:

$$\sum_{i=1}^{k} S\Pr ef(T_i)U_{Ti}(bw_i)$$

Where:

k: the number of activated services,

SPref(Ti): the significance level of i-th service,

Ti: type of service (e.g. Video on Demand, VOIP, etc)

bwi: the allocated bandwidth to i-th service

The available bandwidth must be allocated among the numerous services so as to maximize the total users' utility. Therefore, solving the following non-linear programming problem, the total network utility will be maximized (NUM) [10]

$$\max \sum_{i=1}^{M} \sum_{k=1}^{ki} S\Pr ef(T_{ik}) \sum_{j=1}^{L} U_{Tk}(bw_{ikj})$$

St:

$R \times bw \leq C$

Where:

M: number of the users

ki: number of services requested by i-th user

j: number of the applied links

L: total number of network links

Tik: type of traffic for the k-th requested service by i-th user

UTk: user's utility from the traffic of type T for k-th requested service

Bu: total allocated bandwidth to a user; this factor is normally mentioned in the initial contract signed by service provider and the customer (SLA: Service Level Agreement)

S.Geetha et al [11] have proposed a utility based resource allocation mechanism for WiMAX radio access networks based on the IEEE 802.16e, with dynamic weight adjustment that takes into account varying traffic load conditions. Based on the stringent nature of the QoS requirements, traffic classes are classified into higher and lower priority traffic classes. Each traffic flow is assigned a weight, depending on the type of traffic it belongs to. The weight assigned to different traffic classes should take into account QoS requirement and queue length (which depends on load conditions) of the traffic class. So the proposed dynamic weight assignment mechanism allocates bandwidth by taking into account:

- Traffic load in each traffic class and
- Priority of traffic class

The model propose a framework for bandwidth allocation in IEEE 802.16e broadband wireless networks with multiple classes of traffic flows. Although it seems that it may support other types of networks.

IV. OUR PROPOSED APPROACH

Knowing the fact that there is no deterministic real-time solution for optimal bandwidth allocation problem, we inspired by the model proposed by Derbel and implemented an online computational framework for bandwidth allocation to broadband services officially introduced in Iran. Here for the sake of simplification, only a limited number of users and services have been taken into account, but this approach is calculative rational and scalable.

Since the total bandwidth purchased by any user is a limited amount, the maximal required bandwidth may not be provided for each of the requested services in most of the cases. Only a portion of maximal bandwidth is allocated to the service. The program decides on which service receives the maximal required bandwidth and which one is received only a portion of it. Generally the importance degree of each service from the view point of each user is specified in the SLA: (Service Level Agreement) as gold, silver and bronze (SPref in the model). So the QoS parameters (amongst them bandwidth) is first allocated to the service with highest importance for the user and the remaining bandwidth is allocated to the services with less importance (silver and then bronze).

This process is iterated for all the users (4 users in this simulation) by the code, and finally the total users' utility is evaluated. The summation of users' utilities is computed in each cycle of bandwidth allocation to all requested services of the network. Subsequently, the obtained utility values are evaluated and the bandwidth allocation which maximizes the total users' utility will be selected.

We assume that there are totally 6 services supplied by service provider and each of the users simultaneously demands 5 of them. The total number of users is 4. Also, the customers valuate the requested services based on the related QoS levels (SPref); i.e. numbers 1, 2, 3 are respectively assigned to very high, high and moderate quality of service level. The aforementioned levels are in fact equivalent for service qualities presented by providers, namely gold, silver and bronze levels. The user requests gold level for the service which is most important for him/her (and therefore he/she will pay higher price). In this case, utility function is input in the model with coefficient of 3, and greater bandwidth is allocated for this service in the model output.

The capacity of links purchased by any of the users plays an important role in the selection of presentable services. For example, it is not possible to provide IPTV services for the links with capacity of 1.8 Mbps because these kind of services need higher bandwidth. Therefore, two distinctive scenarios are devised: In the first scenario, it is assumed that the capacities of all users' links are 1.8 Mbps, therefore the services requiring the bandwidth less than 1.8 Mbps are selected. In the second scenario, we assumed that the capacity of user links are 10 Mbps; consequently, services like IPTV which requires higher bandwidth are chosen.

A. *First Scenario*

Out of all services proposed in broadband pilot plan and also in broadband services package by Iranian Research

Institute for ICT (ex ITRC), six services were chosen as models for simulation. As indicated in the following table, these services include “Video-Phone”, “VoIP”, “VoD”, “Email”, “Data on Demand Conferencing (DoD)”, and “File Transfer”. For services with CBR traffic type, such as VoIP and Video-Phone, only the minimum bandwidth is needed because the maximum bandwidth is meaningless. Third column shows the maximal permissible bandwidth which is in fact capacity of the link possessed by the user.

TABLE I. SERVICES AND TRAFFIC TYPES IN FIRST SCENARIO

Services	Min BW (Kbps)	Max BW (Kbps)	Traffic Type	Utility Function
VoIP: S_1	30	1800	CBR	$u(b)=\begin{cases}0 & b<30\\ 1 & b\geq 30\end{cases}$
Video-Phone: S_2	256	1800	CBR	$u(b)=\begin{cases}0 & b<30\\ 1 & b\geq 30\end{cases}$
VoD: S_3	1-6M	1800	VBR	$u(b)=1-e^{\frac{-10.54b^2}{0.166+b}}$
Email: S_4	0-20	1800	UBR	$u(b)=1-e^{\frac{-4.6b}{0.04}}$
DoD: S_5	0-512	1800	UBR	$u(b)=1-e^{\frac{-4.6b}{0.9}}$
File Transfer: S_6	0-10M	1800	UBR	$u(b)=1-e^{\frac{-4.6b}{5}}$

Note that values of parameters in utility functions have been extracted from reference [12].

It is assumed that the first user respectively requests services: S1, S3, S4, S2, and S6. Three QoS level is: 3, 3, 1, 2, 3. It means the first user has selected Gold or excellent quality for VoIP and VoD (S3) services. Email (S4) as the third service is assigned a Bronze or moderate quality level. The information concerning the type of requested services by 4 users along with the selected quality levels are included in the parentheses under the following diagram.

user1: S= (S1, S3, S4, S2, S6) , SPref=(1,1,3,1,2)
user2: S= (S4, S2, S3, S6, S5) , SPref=(1,1,1,2,2)
user3: S= (S1, S2, S4, S3, S6) , SPref=(1,3,1,2,1)
user4: S= (S6, S6, S5, S4, S5) , SPref=(1,2,3,1,2)

TABLE II. BANDWIDTH ALLOCATION TO USER1

User	User 1				
i^{th} request	*1*	*2*	*3*	*4*	*5*
service requested	S_1	S_3	S_4	S_2	S_6
SPref	1	1	3	1	2
Bw3 (Kbps)	0	0	60	0	0
Bw2 (Kbps)	0	0	0	0	800
Bw1 (Kbps)	30	200	0	256	0
∑ Bw (Kbps)	30	200	60	256	800
Service utility	1.00	0.99	1.00	1.00	0.52

Where in the above table:
Bwj: Bandwidth allocated based on the SPref for each service
j: round of allocating Bw; in the first round, Bw is allocated to the services with highest quality level requested (SPref) and so on.

The table indicates the bandwidth allocated to user for each of the five requested services based on the selected quality levels.

The allocated bandwidth and total network utility are illustrated in the following diagrams:

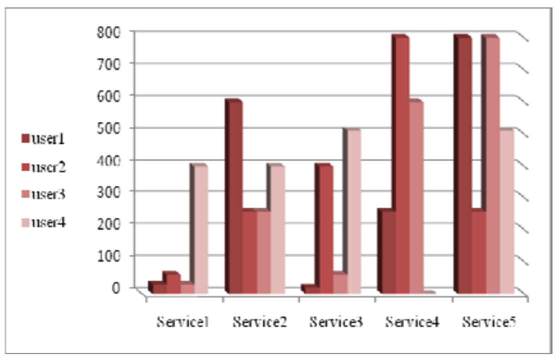


Figure 1. Bandwidth allocation according to SPref values and traffic types

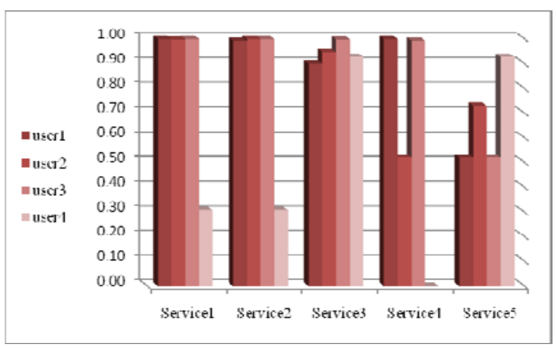


Figure 2. User utility according to SPref values and traffic types

B. *Second scenario*

Here, the assumption implies that the capacities of links of each user is 10 Mbps (Maximum bandwidth in the following table) and six services are selected. The services such as IPTV requiring higher bandwidth are chosen.

TABLE III. SERVICES AND TRAFFIC TYPES IN SECOND SCENARIO

Service	Bw requiered (Kbps)	Bw Allocated (Kbps)	Max BW (Kbps)	Traffic type	Utility
s1= VoIP	64	64	10000	CBR	$u(b)=\begin{cases}0 & b<30\\ 1 & b\geq 30\end{cases}$
s2=Video -Phone	256	256	10000	CBR	$u(b)=\begin{cases}0 & b<30\\ 1 & b\geq 30\end{cases}$
s3= VoD	1.5-6M	1500	10000	VBR	$u(b)=1-e^{\frac{-10.54b^2}{0.166+b}}$
s4= IPTV	1.5-20M	1500	10000	VBR	$u(b)=1-e^{\frac{-10.45b}{0.566}}$
s5=DoD	24-10000	5000	10000	UBR	$u(b)=1-e^{\frac{-4.6b}{0.9}}$
s6= Internet Service	0-4M	200	10000	UBR	$u(b)=1-e^{\frac{-4.6b}{6.9}}$

Similar to the first scenario, the bandwidth is allocated via an amended process so as to maximize the total utility and also to allocate the maximal permissible user's link capacity. The figure below shows the allocated bandwidth to each service besides the total utility.

TABLE IV. BANDWIDTH ALLOCATION TO USER1

User / i^{th} request	User 1					
	1	*2*	*3*	*4*	*5*	*SUM*
service requested	S_1	S_3	S_4	S_2	S_6	
SPref	3	3	1	2	3	
Bw3 (Kbps)	30	600	0	0	1600	2230
Bw2 (Kbps)	0	0	0	256	0	256
Bw1 (Kbps)	0	0	20	0	0	20
∑ Bw (Kbps)	30	600	20	256	1600	2506
Service utility	1.00	0.99	1.00	1.00	0.52	4.51

V. CONCLUSIONS AND FURTHER STUDIES

In this paper, we have presented an adaptive real-time framework for resource allocation in broadband networks. Since data transfer in broadband is expected to serve beyond simple data interchanges, and numerous multimedia services are being provided; we divided network services in three categories each of which follow a specific utility function. The utility functions and their numerical values are determined for the selected services independently. Using a computer simulation we obtained an optimal bandwidth allocation for each services while maximizing total network utility. It is worth noting that the proposed solution is based on QoS requested in SLA. So the limited bandwidth purchased by each user is first allocated to the services with higher degree of importance specified in the SLA.

In this approach, the users' utility is considered as a function of bandwidth, while other parameters of service quality such as jitter, etc can also affect the level of users' utility.

Although, multitude of links was regarded in the proposed model but it was assumed that only one of the links is occupied for provision of a certain service. However, in next generation network, it will be possible to benefit from several consecutive and sometimes irrelevant links for supplying a service to the user. Decision concerning the type of links is dependent on the routing based on utility maximization as well as the technical obligations; these subjects can be investigated in future researches.

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