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Preference Based PSO for Utility Optimization in Broadband Digital Economy

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Abstract: **Efficient data transfer in broadband networks is the anchor point of digital economy in modern era. One of 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. This problem is economically defined as a utility optimization issue aiming to maximize user profits. In this paper, we present an adaptive framework for the problem of optimal utility optimization of bandwidth allocation to broadband services. We used first an online optimization for the allocation based on user preferences and Network Utility Maximization. Our second solution is a particle swarm optimization method in order to consider both parameters at the same time to find an optimal allocation pattern. Simulation results showed satisfactory bandwidth allocation patterns in different scenarios according to the network utility and user preferences in SLA.**

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

I. INTRODUCTION

The digital economy which is indeed the use of ICT in 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. Digital economy benefits should be considered in macro and micro levels:

A. Digital economy benefits in macro levels

1) Productivity

Productivity is use of more and better tools and in knowledge-based economy, the most effective tools in raising productivity are ICT-based ones. These digital tools which are more than simply the Internet, include hardware, software applications, and telecommunication networks. ICT has enabled the creation of a host of tools to create, manipulate, organize, transmit, store and act on information in digital form in new ways and through new organizational forms. Its impact is pervasive as it is being used in virtually every sector, from farming to manufacturing to services to government. ICT is what economists call a ‘general purpose technology’(GPT). GPTs undergo rapid price declines and performance improvements; become pervasive and an integral part of most industries, products, and functions; and enable downstream innovations in products, processes, business models, and business organization [3]. In fact, nearly all scholarly studies since the mid-1990s through to 2014 have found positive and significant effects of ICT on productivity [4]. The positive impacts of ICT on productivity have been found across different levels and sectors of economies, from firms to industries to entire economies, and in both goods- and services-producing industries [5].

2) Innovation and competitiveness

Innovation is acknowledged as an important source of competitiveness for business. It can do so in many ways: by reducing production costs, by enhancing existing products and leading to the creation of new ones, or by presenting and selling products more effectively [6]. In other words, ICT makes firms to be more innovative and competitive. According to a study in Netherland, ICT investment and broadband use are important drivers of innovation in service sector and in manufacturing as well [7]. Also, a study on a range of OECD countries including the UK, Italy, Spain, and the Netherlands, has been shown that ‘ICTs act as an enabler of innovation, particularly for product and marketing innovation, in both manufacturing and services.’[8]. Another study found that Dutch firms that invested more in ICT not only enjoyed faster productivity growth but also produced more innovations.[9]

3) Employment

As it is mentioned above, ICT increases the productivity and 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 [10].

B. Digital economy benefits in micro levels

Firm level studies have found that ‘Firms with high levels of ICT are more likely to grow (in terms of employment) and less likely to [go out of business].’ [11]. Use of ICT can create new business models, as it creates virtual stores and companies, digital goods and services and so on. Also it should improve operating models by automation in process, use of smart infrastructure, etc.

An important issue in using ICTs in economy is to incite households and business desire for connectivity and more and better use the connectivity; ICT demand [12]. 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, the optimized use of resources and resource management has a key role to provide ICT services with better quality of services. Bandwidth allocation in the multiservice communication networks presents a very important problem to resource management. In more detail, 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. 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. 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 two algorithms for optimizing bandwidth allocation by classifying broadband traffic into three categories based on their utility functions. First, 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. Second algorithm is based on a PSO optimization approach which achieves better results.

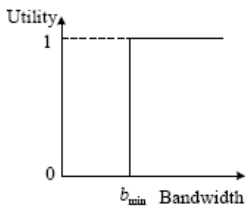
The rest of this paper is structured as follows. Section 2 describes the utility-based traffic model including the concept of utility function and the characteristics of traffic used in our study. In section 3, we discuss the matter of optimal bandwidth allocation, based on the network traffic’s utility. In section 4 based on our proposed model, we have allocated the

bandwidth to broadband services in Iran in such a way that the network user 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.

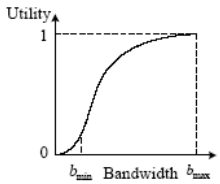
II. Traffic Categories and Related Utility Functions

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 [13].

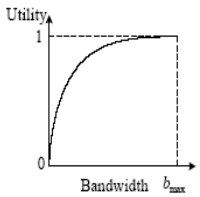
The concept of users utility is also introduced in IP network traffic. Based on different utility functions, there are three main traffic categories: CBR (constant bit rate) traffic, VBR (variable bit rate) traffic and UBR (unspecified bit rate) traffic.



CBR Traffic



VBR Traffic



UBR traffic

Shenker [14] 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 sindicates, 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 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 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. IPTV[4] 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 [15]:

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

u(b): User utility

b: Allocated bandwidth to the service

k_1 and k_2: The parameters which determine the form of function in a way that utility function equals 1 when maximal required bandwidth was provided.

UBR [5] Traffic: Ning Lu and John Bigham [2] and Zimmerman [16] 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:

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

[1] Constant Bit Rate

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

[3] Variable Bit Rate

[4] Internet Protocol Television

[5] Unspecified Bit Rate

u(b): User ب 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 ب 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 [17].

Total network users ب 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 ب s utility functions has been taken into account as the objective. [18] and [19]. Harks [20] 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 [21] 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 [19] 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 ب utility.

In [19], 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 ب 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 ب 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: VOD[6], VOIP[7] 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 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 weighted utility function can be represented in this form:

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

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 ب utility. Therefore, solving the following non-linear programming problem, the total network utility will be maximized (NUM) [22]

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

St:
$R \times bw \le C$
Where:
M: number of the users
ki: number of services requested by i-th user
j: number of the applied links

[6] Video On Demand
[7] Voice Over IP

L: total number of network links
T_{ik}: type of traffic for the k-th requested service by i-th user
U_{Tk}: user ب sutility from the traffic of type T for k-th requested service
C: 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 [23] 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 two efficient solutions for bandwidth allocation to broadband services officially introduced in Iran. First we presented an online computational framework called POUM which stands for preference based online utility optimization. It can be seen also as a modified non-linear programming approach. 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. It is worth remembering that this problem is a multi-criteria optimization one, therefore the solution have to consider different variables at the same time for finding the optimal point. The POUM procedure 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). 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.

This process is repeated for all the users (4 users in this simulation), and finally the total users ب utility is evaluated. The summation of users ب 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 ب utility will be selected. Now we have to consider another preference ordering for the allocation to find a local optima subject to the utility values.

At the second part in order to find an optimal allocation pattern satisfying at the same time the user preferences and utility values we used the Particle Swarm Optimization method as powerful optimization approach. The former is an online real time solution where the latter remains useful for offline applications.

- **Particle Swarm Optimization**

Particle swarm optimization algorithm was first introduced by Kennedy and Eberhart in 1995 [24]. In PSO, each member of population is called a particle. In fact particle swarm optimization is consisted of certain number of particles. For each particle a position and a velocity is defined and are modeled by a position vector and a velocity vector. At first, these values are randomly initialized. These particles move in multi-dimensional search space repeatedly. They calculate the fitness of different points and find optimum points without searching the whole space. Dimension of search space is equal to number of parameters of function that must be optimized. A memory is used to store the best position that has been founded by each particle and another one for the best position among all the particles. By using this information, particles decide how to move in next iteration. In every iteration, all particles move in multi-dimensional search space till the global optimal point is founded. Particles update their velocities and positions according to local and global best answers.

Each particle i in the swarm hold the following information: (i) the current position x_i, (ii) the current velocity v_i, (iii) the best position, the one associated with the best fitness value the particle has achieved so far $pbest_i$, and (iv) the global best position, the one associated with the best fitness value found among all of the particles $gbest$. In every iteration, each particle adjusts its own trajectory in the space in order to move towards its best position and the global best according to the following equations:

$$v_{ij}^{t+1} = wv_{ij}^{t} + c_1 r_{1j}^{t}(pbest_{ij}^{t} - x_{ij}^{t}) + c_2 r_{2j}^{t}(gbest_{j}^{t} - x_{ij}^{t}) \quad (1)$$

$$x_{ij}^{t+1} = x_{ij}^{t} + v_{ij}^{t+1} \quad (2)$$

for $j \in 1..d$ where d is the number of dimensions, $i \in 1..n$ where n is the number of particles, t is the iteration number, w is the inertia weight, r_1 and r_2 are two random numbers uniformly distributed in the range [0,1], and c_1 and c_2 are the acceleration factors.

Afterwards, each particle updates its personal best using the equation (assuming a minimization problem):

$$pbest_i^{t+1} = \begin{cases} pbest_i^t & if \quad f(pbest_i^t) \le f(x_i^{t+1}) \\ x_i^{t+1} & if \quad f(pbest_i^t) > f(x_i^{t+1}) \end{cases} \quad (3)$$

Finally, the global best of the swarm is updated using the equation (assuming a minimization problem):

$$gbest^{t+1} = \arg\min_{pbest_i^{t+1}} f(pbest_i^{t+1}) \quad (4)$$

where *f(.)* is a function that evaluates the fitness value for a given position. This model is referred to as the *gbest* (global best) model.

V. Implementation and Simulation Results

In the literature one can find other PSO based methods for bandwidth allocation like [25, 26] but they are basically different in the way they formulated the algorithm. In order to map the PSO algorithm to the problem of bandwidth allocation we assumed the velocity of particle *j* to be a weighted utility as sum of products of service preferences and utility obtained by allocated bandwidth as introduced before:

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

It is also supposed that x_j the position of particle *j* is initialized by the first bandwidth allocated values according to the above mentioned algorithm and other parameters w, c_1, c_2, r_1, r_2 are tuned as presented in [27]. 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 usersپ 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 پVideo-Phone پVoIP پ VoD پ Email پ Data on Demand Conferencing (DoD)پ and پFile Transferپ 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	$u(b)=\begin{cases}0 & b<30\\ 1 & b\ge 30\end{cases}$
Video-Phone: S_2	256	1800	CBR	$u(b)=\begin{cases}0 & b<30\\ 1 & b\ge 30\end{cases}$
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 [28].

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					SUM
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	60
Bw2 (Kbps)	0	0	0	0	800	800
Bw1 (Kbps)	30	200	0	256	0	486
∑ Bw)Kbps(	30	200	60	256	800	1346
Service utility	1.00	0.99	1.00	1.00	0.52	4.51
SPref*Utility	**1**	**0.28**	**2.43**	**1**	**1.47**	**6.19**

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:

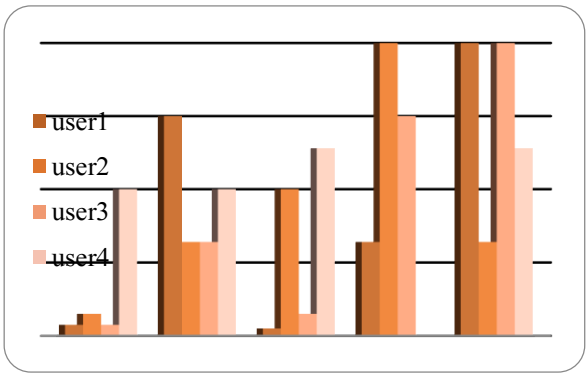


Figure 1. Users بbandwidth allocation according to SPref values and traffic types

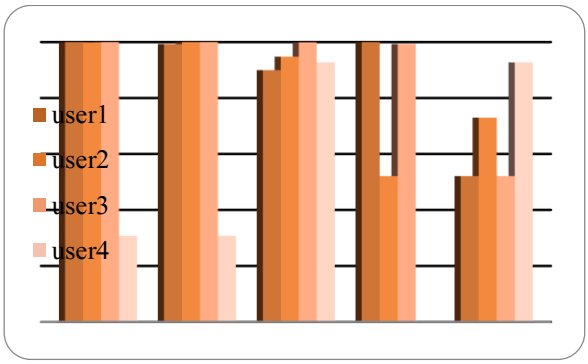


Figure 2. Users بweighted utility according to SPref values and traffic types

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 بs 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
SPref*Utility	**3**	**.84**	**.81**	**2**	**2.21**	**8.86**

C. PSO based method

The above-mentioned two experimentations can be viewed as a simplified Linear Programming approach which tries to maximize the usersب utility regarding first his/her preference and second the utility of each service. The results were also partly reported in [29]. In this paper we extended the idea by using a PSO technique to improve the results. Contrary to the POUM approach, PSO considers all constraints at the same time and iteratively improves its trajectory to a local optimum. We implemented the method for two previous scenarios and compared the obtained results with that of POUM method. Figure 3 shows little improvements for weighted utility for all users.

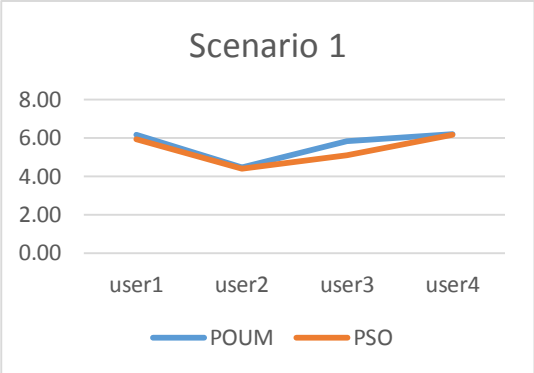


Figure 3. Usersب Weighted utility for POUM and PSO in scenario 1

We also applied the PSO method to 2nd scenario and compared the results with that of previous method in figure 4, showing again notable improvements for all users.

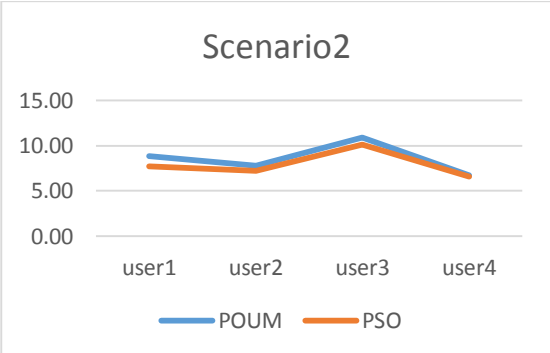


Figure 4. Usersب Weighted utility for POUM and PSO in scenario 2

As a last experimentation we carried out the comparison in a cummulative approach for 3 different scenarios (according to ITRC recommendations). The results are shown in figure 5 which are also satisfying achievements. Although the rate of improvement is different for any user but it is globally prefered comparing to the previous method by maximizing social welfare which is in turn very intersting for bandwidth service provider.

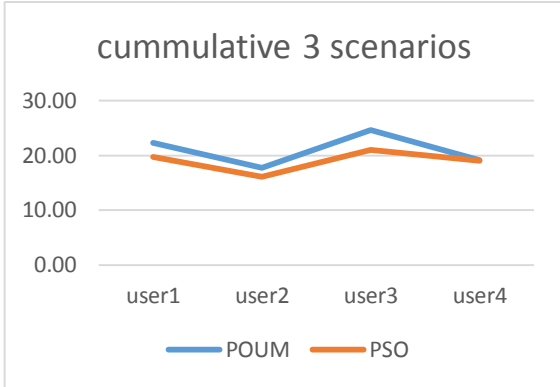


Figure 5. Comparing POUM and PSO by cummulative usersب Weighted utility for 3 scenarios

VI. Utility Analysis and Comparison

According to the theory of micro economics [30], utility indicates user satisfaction. As stated before, it is very difficult to have a fair comparative analysis with other methods because the usersب preference is usually a qualitative parameter as symbolically cited in SLA by Gold, Silver, etc. An optimal usersب preference means to formulate utility functions through extensive subjective surveys, in which users are asked to judge the performance under a wide range of network conditions. A detailed description of such subjective studies can be obtained in [31]. According to the literature, the weighting (or quantization) mechanism is very different based on not only the type and the quality of services presented by service providers but also on the needs and preferences of users varying from home users to huge telecommunication enterprises. Thus quantitative results and comparison can seldom be seen in the literature [23, 25-28].

In order to be able to roughly compare our results with that of the similar works, we used the approach proposed in [23] claiming that a logarithmic curve traces the actual survey results most closely. According to this paper the utility function for the j_{th} traffic class can be considered as:

$$U_j(x_j) = w_j \log \frac{x_j}{b_j} = 1 \qquad where \quad x_j \in 0, b_j$$

where wj, is a dynamic weight assigned to each traffic class to ensure fairness. This weight changes according to traffic load conditions of the traffic class to which flow i belongs to and the QoS requirement of traffic class is detailed in [23]. Since, the objective is to maximize the overall system utility (TotUtil); the resource allocation problem is formulated as the following optimization problem [32]:

$$TotUtil = \max(\sum_{j=1}^{N}(w_j \log \frac{x_j}{b_j} = 1))$$

Subject to the constraints:

$$\sum_{j=1}^{N} x_j \le BW_T \qquad x_j \in 0, b_j$$

Where BW_T represents the total bandwidth available and N indicates the number of traffic classes.

We implemented our algorithm with the above mentioned measure to compare the obtained results with that of two other papers. The first selected benchmark, saying one of the most similar methods, is the work of

Geetha et al. [23] in which they used a dynamic weighting mechanism to have a quantitative evaluation of total network utility. The second method is that proposed by sundarambal [26] for performance evaluation of bandwidth allocation in ATM networks. We implemented the three previous scenarios according to the above methods and obtained the results depicted in table V.

TABLE V. TOTAL UTILITY OBTAIND BY 4 DIFFERENT METHODS

TotUtil	Scen1	Scen2	Scen3	Sum
POUM	78.23	85.88	88.92	253.03
PSO	75.12	80.45	80.67	236.24
Geet	80.13	81.21	78.62	239.96
Sund	65.05	75.54	72.24	212.83

As it can be seen the preference based approach outperforms slightly other methods and it is because the weighting mechanism is appropriately selected according to user's preferences. The graphical representation is showed in figure 6.

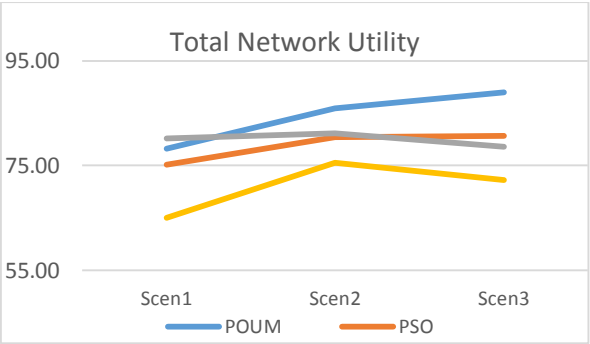


Figure 6. Network overal utility for 4 methods in 3 scenarios

VII. CONCLUSIONS AND FURTHER STUDIES

In this paper, we have first 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 a near 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. Secondly we proposed a PSO based algorithm which aimed to optimize the required bandwidth while respecting the user preferences according to their SLA. The results were very promising comparing to previous experimentations. It is worth noting that the latter solution is an iterative method that cannot be used in real time but it is indeed a powerful method for offline purposes which are also widely used in industry.

In this paper, 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.

To be able to compare our approach with some other methods, we chose a well known logarithmic utility function presented in similar literature and also an optimization function for overall network utility. Experimentations in this step showed also a better performance comparing to two other methods.

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 to the routing based on utility maximization as well as the technical obligations; these subjects can be investigated in future researches.

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