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Rate Allocation for Mixed Traffic Users in Relay Based Communication Network

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Abstract: In this paper, a rate allocation technique for mixed traffic users in relay based communication network is discussed. Network utility maximization (NUM) approach is utilized for resource allocation to mixed traffic users. Mixed traffic users are running network applications either elastic traffic type or inelastic traffic type. Proposed technique allocates rates to users under a maximum rate constraint. Proposed technique adaptively allocates rates between elastic traffic users and inelastic traffic users based on value of maximum rate constraint. As maximum rate constraint is increasing, elastic traffic users get higher rate in comparison to inelastic traffic users. Proposed technique consider a relay node as an elastic traffic user, so that relay node will get higher rate at higher maximum rate constraint. After allocation the rate to relay node, relay node reallocates rates to cell edge users in its surrounding network using network utility maximization approach. Proposed technique guarantees that no user either central user or cell edge user will be left without getting rate allocation. It provides minimum rate to all users while satisfying QoS for inelastic traffic (real time) corresponding users. It provides higher throughput along with fairness at cell edge users. Results of the proposed rate allocation technique validates advantages of the proposed technique.

Keywords: Utility function, proportional fairness, adaptive rate, throughput, logarithmic function, Sigmoidal like function.

1 Introduction

In the last decade, major enhancement has been seen in telecommunication network generation. Starting from a normal voice based services to currently at QoS supporting high throughput services are major enhancement in communication system. Shift in telecommunication network generation happened due to increasing of demand for high data rate services and fulfillment of their demand through continuous research on various communication technologies [1-2]. Radio resource allocation is one of the important key areas in which number of research works have been done. A resource scheduling technique should be design such that it improves overall communication performance i.e. data rate, fairness, delay, packet loss rate etc. For resource scheduling, different key parameters are utilized such as channel condition, packet queue length, head of the line delay, number of carriers, past throughput etc. Literature survey papers [3]-[5] suggest basic resource scheduling techniques, such as round robin, maximum throughput, proportional fairness, delay based scheduling etc. These techniques are broadly classified in to channel unaware strategies and channel aware strategies, and QoS unaware strategies and QoS aware strategies. Each strategy provides a priority scheduling metric and accordingly resources are scheduled. Priority scheduling metric prioritizes users as par values of key scheduling parameters. Research paper [6] shows priority scheduling metrics for round robin and proportional fair scheduling techniques and then compares its performance results. It suggests that proportional fairness technique provides high fairness to users as it allocates resources based on past throughput and current channel condition. Proportional fair technique is a technique based on trade-off between the fairness and data rate as suggested in [7]. Exponential proportional fairness technique is disclosed in [8], which utilizes features of exponential function for proportional fairness scheduling. Most of these techniques do not consider traffic type of network applications running at user ends for resource scheduling. Research papers [9] - [10] suggest resource allocation techniques for mixed traffic i.e. real time traffic and non-real time traffic. Research paper [9] suggest dynamic packet scheduling in which services are categorized in different classes and then priority based scheduling algorithm is utilized for resource allocation. Research paper [10] discusses Hebbian learning process and Kmean clustering algorithm for scheduling after categorizing services in different classes. Different research papers [11]-[14] suggest resource allocation technique based on utility function maximization. Research paper [11] suggests a utility-based resource scheduling technique for different types of traffic. It suggests a heuristic algorithm for resource scheduling for hybrid traffic users in which real time traffic users get required QoS, whereas non real time traffic users has to deal with trade off between data rate and fairness. Similarly, research papers [13]-[14] proposed utility proportional fairness based rate allocation method for mixed traffic users. Different utility functions (i.e. logarithmic and sigmoid function) are utilized for elastic traffic users and inelastic traffic users. It allocates rates to all users such that no users have zero rate allocation. It has been seen that most of these techniques improves communication performance for centralized users in network of base station. However, it does not improves communication performance for user's located at edge of the cell. Some paper, such as research paper [15] discloses a technique of enhancing performance of user's at cell edge through inter cell interference reduction technique. However, it does not improves fairness among cell edge users. Research paper [16] a technique for selecting a relay and then allocating resources by way of dual decomposition and sub-gradient method. However, this also does not improve fairness of cell edge users. A relay node is node which is located in between a base station and users which are far away from each other. In LTE, a relay node receives resource data from the base station and after enhancing resource data, it sends resource data to users in its network [17].

Current paper suggest a method of enhancing performance especially fairness of cell edge users through a relay node in the network. In proposed technique, it has been considered that users are running different types of services, such as real time services (inelastic traffic) or non real time services (elastic traffic). Priority is given to inelastic traffic running users, however, it guarantees at least minimum throughput for all users. Proposed technique utilizes network utilization maximization method for rate allocation. Logarithmic utility function is defined for elastic traffic and sigmoidal-like utility function is defined for inelastic traffic.

2 Utility Function

In field of the economics, a utility is defined as a measurement of preferences over a set of goods and services. Its value indicates a degree of user satisfaction from the goods and services [18]. Similarly, in communication network, utility indicates a degree of satisfaction of user in terms of received rate and experienced QoS. These users can be performing of any type of communication services i.e. elastic traffic services and inelastic traffic services. As name suggest, elastic traffic are delay tolerant services and adaptable with variable throughput rate whereas inelastic traffic are rigid with respect to delay and throughput. Inelastic traffic services perform poor when it experience lower QoS. Practical examples for the elastic traffic are non-real time services such as email communication, messaging, web browsing etc. and for the inelastic traffic are real time services, such as voice calling, video calling, streaming etc. These traffic types can be modeled in different utility functions. Research paper [19] shows different utility curves for elastic traffic and for inelastic traffic. Research papers [11] and [12] reveal different utility functions for elastic traffic and inelastic traffic. Research papers [15] and

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[14] also disclose utility functions for elastic traffic and inelastic traffic. It shows logarithmic function for inelastic traffic and sigmoidal like elastic traffic. To satisfy users in the network, network utility maximization (NUM) approach is suggested in research paper [20]. Research paper [20] has a major contribution in all devised techniques related to network utility maximization (NUM) approach. Proposed technique also utilizes network utility maximization (NUM) approach for throughput rate allocation to users. In this paper, utility functions disclosed in [11] - [14] are utilized for throughput rate allocation.

1) Utility functions for elastic traffic are:

- For HTTP application type

$$U_n(x_n) = \frac{\log\left(\frac{x_n}{x_{min}}\right)}{\log\left(\frac{x_{max}}{x_{min}}\right)} \tag{1}$$

- For FTP application type

$$U_n(x_n) = \frac{\log\left(\frac{\tau_n x_n + 1}{\tau_n x_{max} + 1}\right)}{\log\left(\frac{x_{max}}{x_{min}}\right)} \tag{2}$$

2) Utility functions for inelastic traffic are:

- For streaming application type

$$U_n(x_n) = \frac{1}{1 + e^{-\alpha_n(x_n - \beta_n)}} \tag{3}$$

- For voice/video communication application type

$$U_n(x_n) = \gamma_n\left(\frac{1}{1 + e^{-\alpha_n(x_n - \beta_n)}} - \delta_n\right) \tag{4}$$

Where $\gamma = \frac{1+e^{\alpha_n \beta_n}}{e^{\alpha_n \beta_n}}$ and $\delta = \frac{1}{1+e^{\alpha_n \beta_n}}$

All these utility functions have following features.

- $U_n = 0$ and $U_n(x_n)$ is an increasing function of x_n
- $U_n(x_n)$ is twice continuously differentiable in x_n

In fig.1, plot of logarithmic utility function (parameter τ) and sigmoidal like utility function (parameters α, β) are displayed with respect to increasing in x_n.

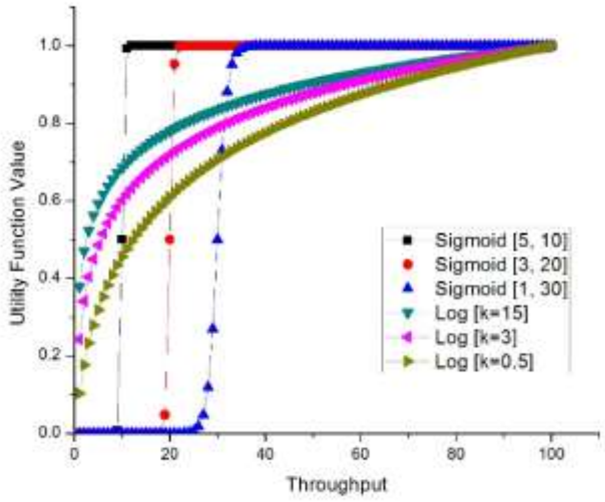

Fig. 1. Plots of logarithmic utility function and sigmoidal-like utility function at increasing in $\boldsymbol{x_n}$.

3 Scheduling design formulation

Parameters of network utility maximization problem are defined as below: let a set $\phi = \{n: n = 1,2,3, \dots N\}$ of users are situated in a coverage area of a base station B_s. Each user running either elastic traffic behaving network applications or inelastic traffic behaving network applications. Out of N users, let n^{th} user is a relay node RN in the network, which is treated as elastic traffic type application running user. The RN itself works as a base station and allocates resources to users located in its network. Let, a set $\psi = \{s: s = 1,2,3, \dots S\}$ of users are present in network of RN and are located at cell edge area of the network of B_s. The RN allocates only those number of resources to users which are allocated to it by base station B_s. Proposed rate allocation techniques has two steps. In one step, base station B_s allocates rates to users (including RN as a user) and in second step, relay node RN allocates rates to cell edge users.

A. First step: Rate Allocation by Base Station B_s: −

1) Network utility maximization Problem at Base Station B_s: Let, each user in network of B_s receives a throughput x_{mn} over a set $\Omega = \{m: m = 1,2,3, \dots M\}$ of carriers. Total throughput is received by a user is x_n over set of carriers allocated to it, which is calculated as per equ.5.

$$x_n = \sum_m x_{mn} \tag{5}$$

Network applications running at each user n can be represented by a utility function $U_n(x_n)$. Utility function $U_n(x_n)$ of a user is shown in equ.1 to equ.4 as per type of network application i.e. elastic traffic or inelastic traffic is currently running at user end.

Objective: The objective of the proposed scheduling technique is to increase overall sum of utilities of users, which is defined by equ.6, subject to maximum throughput T_{max} constraints. The network utility maximization problem is given as below:

$$max_x \prod_{n=1}^{n=N} (U_n(x_n)) \tag{6}$$

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Subject to

$$\sum_{n=1}^{n=N} x_n \leq T_{max} \tag{7}$$

2) Global optimal solution: Current problem shown in equ.6 can be rewritten as equ.8 by converting multiplication of utility function in to summation of natural logarithm of utility function.

$$max_x \sum_{n=1}^{n=N} \log\left(U_n(x_n)\right) \tag{8}$$

subject to

$$\sum_{n=1}^{n=N} x_n \leq T_{max} \tag{9}$$

For global optimal solution, a Lagrange multiplier (Λ) based optimization solution is utilized, where Λ is greater than 0. The penalty function based on Lagrange multiplier (Λ) is defined for the equ.8 as in equ.10:

$$L(x, \Lambda) = \sum_{n=1}^{n=N} \log\big(U_n(x_n)\big) - \Lambda\left(\sum_{n=1}^{n=N} x_n + \mathrm{z} - T_{max}\right) \tag{10}$$

$$L(x, \Lambda) = \sum_{n=1}^{n=N} (\log\big(U_n(x_n)\big) - \Lambda x_n) + \Lambda(T_{max} - z) \tag{11}$$

$$L(x, \Lambda) = \sum_{n=1}^{n=N} L_n(x_n, \Lambda) + \Lambda(T_{max} - z) \tag{12}$$

Here, z is a slack variable and Λ is a Lagrange multiplier. Let Λ represents price per unit bandwidth and price demand for n^{th} user is given by Θ_n. It can be represented as $\Theta_n = \Lambda x_n$ and $\sum_n(\Theta_n) = \Lambda \sum_n(x_n)$. In equ. 10, $x_n)$ is separable in $\sum_{n=1}^{n=N} (\log\big(U_n(x_n)\big) - \Lambda x_n)$. So, we can write $max_x(\sum_{n=1}^{n=N} (\log\big(U_n(x_n)\big) - \Lambda x_n))$ = $\sum_{n=1}^{n=N} max_x(\log\big(U_n(x_n)\big) - \Lambda x_n))$. The primal problem defined in equ.10 can be solved by duality based optimization solution. Duality problem objective function can be written as equ.13:

$$D_\Lambda = max_x L(x, \Lambda) \tag{13}$$

$$D_\Lambda = \sum_{n=1}^{n=N} max_{x_n} (\log\big(U_n(x_n)\big) - \Lambda x_n) + \Lambda(T_{max} - z) \tag{14}$$

$$D_\Lambda = \sum_{n=1}^{n=N} max_{x_n}(L_n(x_n, \Lambda)) + \Lambda(T_{max} - z) \tag{15}$$

The dual problem is given by

$$min_\Lambda D_\Lambda \tag{16}$$

subject to $\Lambda \geq 0$ So, we have

$$\frac{\partial D_\Lambda}{\partial \Lambda} = T_{max} - \Lambda \sum_{n=1}^{n=N} x_n - z \tag{17}$$

$$\frac{\partial D_\Lambda}{\partial \Lambda} = 0 \tag{18}$$

$$T_{max} - \Lambda \sum_{n=1}^{n=N} x_n - z = 0 \tag{19}$$

Substituting $\sum_n(\Theta_n) = \Lambda \sum_n(x_n)$, we have

$$\Lambda = \frac{\sum_{n=1}^{n=N} \Theta_n}{T_{max} - z} \tag{21}$$

Hence the global optimization problem solution is divided in to two simpler optimization problems based on the duality. First is maximizing of $(\log(U_n(x_n)) - \Lambda x_n$ and second is determining $\Lambda = \frac{\sum_{n=1}^{n=N} \Theta_n}{T_{max}-z}$.

B. Second step: Rate Allocation by Relay Node RN: −

1) Network utility maximization Problem at Relay Node RN: A set ψ= $\{s: s = 1,2,3, \dots S\}$ of users are located at cell edge. These users are situated in a coverage area of relay node RN. These users are running different network applications of either elastic traffic type or inelastic traffic type defined by utility function $U_s(x_s)$. From the first step, base station B_s allocates rate X_{rn} to relay node. Now, the relay node as a pseudo base station allocates received rate X_{rn} to cell edge users S. Network utility maximization problem at RN is given as below:

$$max_x \prod_{s=1}^{s=S} U_s(x_s) \tag{22}$$

Subject to

$$\sum_{s=1}^{s=S} x_s \leq X_{rn} \tag{22}$$

2) Global Optimal Solution: NUM problem shown in equ.22 with constraint shown in equ.23 is same type as that of base station B_s. Therefore, approach for problem solution can be same as that of base station B_s. Based on such solution, users located at cell edge will get high throughput rate with improved in fairness performance.

Proposed Scheduling Algorithm:-

Proposed scheduling algorithm is a distributed scheduling algorithm which will be run in iterative manner. In each iteration, a user transmits its price demand to a station (such as base station B_s or relay node RN station) and it allocates rates to users based on received price demand. Proposed scheduling algorithm provides proportional fairness for all users in the network while it satisfying QoS and minimum throughput rate for users. Proposed scheduling algorithm has two parts (a & b), one at user side and another at station side.

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- *Part a i.e. proposed scheduling algorithm at the base station side:* Base station receives price demand $\Theta_{n,k}$ of all users in the network in each iteration. It compares current price demand $\Theta_{n,k}$ of users to previous price demand $\Theta_{n,k-1}$ of users. If difference is less than a predetermined threshold ε, then scheduler at the station allocates rates according to the current price demand $\Theta_{n,k}$. However, if difference is greater than determined the predetermined threshold ε then scheduler at station calculates Λ_k based on received price

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demands from all users i.e. $\sum_n(\Theta_{n,k})$and maximum throughput T_{max}. The updated value of Λ_k is provided to all users in the network in each iteration. The k is an index for number of iterations.

- *Part b i.e. proposed scheduling algorithm at user side:* In each iteration, each active user n transmits its price demand $\Theta_{n,k}$ for rate allocation x_n to station when the user does not receive stop command from the station. Price demand $\Theta_{n,k}$ is calculated based on $\Theta_{n,k} = \Lambda_k x_{n,k}$, where value of Λ_k provided by station is updated in each iteration. When the user receives stop command from the station, then user allocated rate $x_{n,k}$ will be calculated as per current price demand $\Theta_{n,k}$ and Λ_k. The k is an index for number of iterations.

4 Simulation results and analysis

Proposed rate allocation technique is simulated in MATLAB environment. Different network application types, which are running at user's end, are characterized by different utility functions defined in equ.1 to equ.4. Table I shows different values of parameters utilized for utility functions.

Table 1. Parameters for Utility functions

Parameter	Value
T_{max}	>60
T_{min}	0
α	Variable with T_{max}
β	[10, 20, 30]
τ	[15, 3, 0.5]

Analyzing performance results:

- Rate allocation by base station at $T_{max} > 60$: Here, six users are taken in the network of base station B_s for current simulation. Out of six users, three users are running elastic traffic behaving network applications and three users are running inelastic traffic behaving network applications. Relay node RN is treated as one of the elastic traffic running user as relay node serves cell edge users which gets resources in best effort manner. Base station B_s allocates resources to users with priority given to inelastic traffic (real time) users. Result in fig.2 shows rate allocation to different users while maximum rate constraint T_{max} is varying from 60 to 200. It can be seen that in fig.2, as maximum rate constraint T_{max} is increasing, rate allocation to inelastic traffic (real time) users are getting required QoS while rate allocation to elastic traffic (non real time) users are continuously increasing. Required QoS for real time users is determined by $sum(b_n)$. Proposed technique schedules resources with QoS satisfaction and additional rate is allocated to non real time users. Thus, relay node (sixth user) gets additional rates after rate allocation to real time users as shown in fig.2.

- Rate allocation by relay node at $T_{max} > 300$: Relay node receives rate $X_{rn} = 100$ at $T_{max} > 300$ as shown in fig.2. So, it allocates resources to cell edge users with maximum rate constraint $X_{rn} = 100$. Here also, six cell edge users are taken in the network of relay node RN for current simulation. Out of six cell edge users, three cell edge users are running elastic traffic behaving network applications and three cell edge users are running inelastic traffic behaving network applications. Relay node allocates resources to cell edge users with priority given to inelastic traffic (real time) users. Result fig.3 shows rate allocation to different cell edge users while maximum rate constraint $X_{rn} = 100$. It can be seen that in fig.4, rate is proportionally allocates to all cell edge users. As shown in fig.3, each inelastic traffic running cell edge user is getting QoS rate, while no cell edge user is getting zero rate allocation. Thus, proposed technique guarantees minimum rate allocation to all cell edge users such that no cell edge users will be left without getting resource allocation.

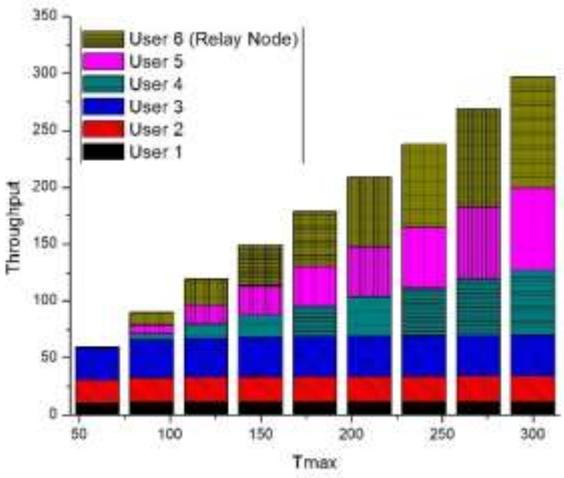

Fig. 2. Plot of throughput allocation v/s number of iterations by base station.

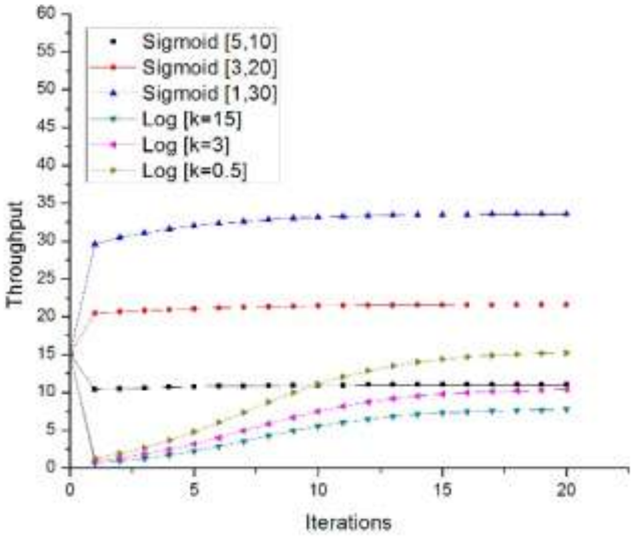

Fig. 3. Plot of throughput allocation v/s number of iterations by relay node.

5 Conclusion

Current paper discusses a rate allocation technique for mixed traffic users in relay based network. It utilizes network utility maximization approach for resource allocation to users, which are running network application either elastic traffic type or inelastic traffic type. Proposed technique treats relay node as an elastic traffic user and allocates rate to relay node when maximum rate constraint increases. Relay node provides utility proportional fairness in cell edge users and also provides higher throughput. Results of the proposed rate allocation technique clearly show the improved communication performance of cell edge users. Current technique does not consider other scheduling parameters for resource allocation, such as queue size, packet delay. It future, rate allocation in relay based network with considering these scheduling parameters can be utilize.

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