Applying Blood Glucose Homeostatic model towards Self-Management of IP QoS Provisioned Networks

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Abstract. Due to the rapid growth of the Internet architecture and the complexities required for network management, the need for efficient resource management is a tremendous challenge. This paper presents a biologically inspired self-management technique for IP Quality of Service (QoS) provisioned network using the blood glucose regulation model of the human body. The human body has the capability to maintain overall blood glucose level depending on the intensity of activity performed and at the same time produce the required energy based on the fitness capacity of the body. We have applied these biological principles to resource management, which includes (i) the ability to manage resources based on predefined demand profile as well as unexpected and fluctuating traffic, and (ii) the ability to efficiently manage multiple traffic types on various paths to ensure maximum revenue is obtained. Simulation results have also been presented to help validate our biologically inspired self-management technique.

1 Introduction

Biological processes have tremendous capabilities to adapt to environmental changes due to their robust characteristics. This essential capability is largely due to fluctuating environment that living organisms must face in order to maintain survivability. Due to this reason a number of biological analogies have been applied towards communication networks (e.g. sensor networks, MANETS). One suitable application of biological analogies that provides an attractive solution towards supporting self-governance is autonomic network management. The current trend for network management requires autonomic capabilities that are exhibited through self-governance behaviour. One crucial requirement of self-governance is the ability for communication systems to self-manage and adapt to changes from the environment (e.g. changes in traffic demand or business goals).

In this paper we use principles of maintaining blood glucose in the human body as a mechanism to maintain network resource equilibrium. The human body maintains the blood glucose level irrespective of any behavioural changes (e.g. light activity to non-routine heavy exercises). We compare this analogy to the intensity usage of networks, such as the ability to handle routine demand traffic and unexpected traffic requests. We view the intensity usage of network resources from the different traffic types and the quantity of each traffic type (e.g. small data and multimedia is low intensity compared to large data and multimedia stream). At the same time we also consider the revenue output of the different traffic intensity and compare this to the energy production from the body, which is essentially determined from the Anaerobic and Aerobic respiration of the body. By applying these analogies we can show how networks resource management can adjust dynamically to fluctuating traffic demands to support high level business goals of Internet Service Providers (ISP).

The paper is organised into the following subsections. Section 2 reviews current related work for resource management as well as bio-inspired analogies applied to communication networks. Section 3 briefly describes the blood glucose homeostasis while section 4 describes the application of this analogy towards network resource management. Section 5 describes results from our simulation to validate our idea. Finally section 6 presents the conclusion and future work.

2 Related Work

2.1 Bio-inspired network management

Employing biological analogies towards telecommunications networks has gained tremendous popularity in recent times. Suzuki and Suda [1] applied the analogy of bee colony behavior for the bio-networking architecture for autonomous applications, where network applications are implemented as a group of autonomous diverse objects called cyber-entity (CE). Leibnitz et al [2] proposed a biological inspired model to solve the problem of multi-path routing in overlay networks by adapting the transmission packets to changes in the metrics of each path. The solution proposed using multiple primary paths to route traffic and switching between the different primary paths depending on the load on each path. However, the solution is based purely on selecting paths based on their loads and not considering fluctuations. At the same time, the proposed solution assumes equal priority between different traffic types. A number of biologically inspired mechanisms have also been applied to route management in networks, especially analogies that mimic social insect behaviour. An example is the work called *AntNet* by Di Caro and Dorigo [3] which employs a set of mobile agents mimicking ant behaviour to probe routes and update routing tables.

2.2 IP network resource management

Mantar et al [4] proposed a Bandwidth Broker (BB) model to support QoS across different DiffServ Domains. The architecture is based on a centralised controller and uses centralised network state maintenance and pipe-based intra-domain resource management scheme. However, their solution has only considered one QoS class and has not provided mechanisms to dynamically determine new paths once the original paths are congested. Gojmerac et al [5] proposed an adaptive multipath routing mechanism for dynamic traffic engineering. The solution is based on load balancing technique that uses local interactions between the devices, and disseminating congestion information through backpressure messages. Although the solution is based on decentralised control of resource management, the solution does not consider how diverting traffic due to congestion on particular links, could affect other paths which may handle traffic from the demand profile. Since, the back propagation message gets sent recursively through all the nodes, the time required to determine new paths is relatively slow and not reactive to fluctuating traffic. Yagan and Tham [6] proposed a self-optimising, self-healing architecture for QoS provisioning in Differentiated services. The architecture employs a model free Reinforcement Learning (RL) approach to counter the dimensionality problems of large state spaces found in conventional Dynamic Programming (DP) techniques. Simulation results of their work have shown that this solution is not suitable for dynamic networks.

3 Blood Glucose Homeostasis and Respiration

3.1 Blood glucose homeostasis

In this section we will describe the blood glucose analogy that we will apply towards self-management of resources for autonomic networks, where the concepts are illustrated in Fig. 1.

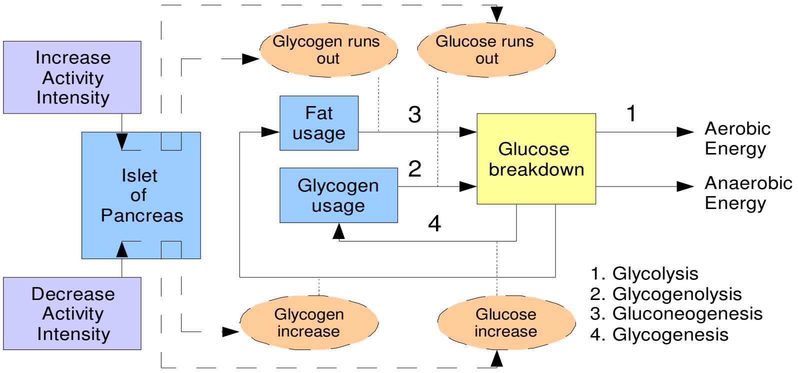

Fig. 1. Blood Glucose Homeostasis

Organisms have the ability to maintain system equilibrium, which is also known as Homeostasis [7]. The process for balancing homeostasis is through positive and negative feedback loops, where the amount of resources that is balanced is dependent on the intensity of the activity performed by the human body. When the body is going through various activities, the blood glucose is balanced in the body by obtaining glucose from various sources once current glucose storage is depleted.

These sources includes the liver, where glucose is obtained from glycogen or body fat. Glycogen is a storage form of glucose and is usually stored in the liver at large amount. Blood glucose is used to create energy through two respirations, which includes Aerobic and Anaerobic. As shown in Fig. 1, there are various chemical reactions used to maintain the blood glucose level. In the event that the intensity of body activity rises and need blood glucose to generate energy, the process of **Glycolysis** is performed. When Glucose in the blood runs out, the Glucose is obtained from Glycogen through the process of **Glycogenolysis**. The **Gluconeogenesis** is the generation of glucose from other organic molecules such as fat, and occurs once the glycogen is used beyond a specific threshold. We refer to the fat that is discovered and converted to glucose during Gluconeogenesis as “good fat”. In the event that large amount of glucose is found in the blood, the blood glucose level is reduced by transforming to glycogen through **Glycogenesis,** which usually occurs when the intensity of the body activity decreases. In the event that the amount of glycogen increases beyond a particular threshold, this is transformed into fat. Once this fat goes beyond a specific threshold, this will amount to extra fat that can lead to an unhealthy state of the body which we refer to as “bad fat”. Therefore, the glucose is obtained from various forms and used as energy depending on the intensity of the body, and in the event that the activity is reduced, this glucose is transformed back into various forms (e.g. glycogen or fat).

3.2 Respiration

Respiration is the process of creating energy by converting energy-rich molecules such as glucose into energy. There are predominantly two types of respiration, which are Aerobic and Anaerobic respiration. Aerobic respiration is more efficient than Anaerobic respiration and is the preferred method of glycogen breakdown. Aerobic respiration requires oxygen to generate energy. The resulting energy from Aerobic respiration is usually very high (2830 KJ mol-1), and is used to fuel long term high intensity body workout. Body that is usually regarded as fit will tend to have longer period of Aerobic respiration. The human metabolism process is primarily Aerobic, but during Anaerobic conditions the overworked muscles that are starved of oxygen creates very low energy, and usually occurs towards the end of maximum body intensity. The Anaerobic respiration usually leads to small amount of energy (118 KJ mol-1) compared to Aerobic respiration.

4 Network Model for Self-Management

In this section we will map the biological principles described in section 3 to the self-management of resources in core networks. Our overall model consist of two layers, which includes (i) self-management of resources using blood glucose and effective management of multiple traffic types per paths using respiration analogies, and (ii) self-organisation for decentralised control using reaction-diffusion [8]. However, the focus of this paper will only concentrate on the resource management of the network as well as traffic class management per path.

The first principle of biological analogy mapping is to the overall management of resources of the entire network (this is compared to blood glucose homeostasis), and the second mapping is used to determine the optimum ratio of data and multimedia within links of each path (this is compared to respiration).

4.1 Comparison of Blood Glucose to overall resource management

The same way that the human body self-manages blood glucose in the body depending on the activity and intensity use of the body, will be used as an analogy towards determining the mechanism that networks handle traffic at different intensity and its mechanism to manage spare resources. Our comparison to the blood glucose homeostasis feedback loop is shown in Fig. 2.

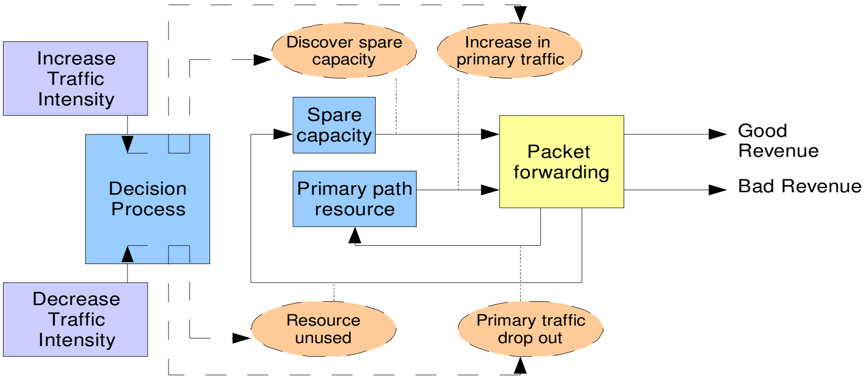

Fig. 2. Network resource self-management

We compare the usage of glucose to the normal operations of the network such as packet forwarding between nodes. The glycogen usage in the body is used once the glucose in the body is depleted; we compare this to the network using resources for load balancing and to support routine traffic from a demand profile. The demand profile contains the historical traffic statistics that is collected over a period of time and reflects the routine traffic between two edge routers (ER_i, ER_j). To support the demand profile a set of primary paths (P_n , $n = 1,..N$), where N is the total number of primary paths required for the edge pairs, are formed for the pair of edge routers. When a traffic stream t_{ER_i,ER_j} is admitted between the edge pair (ER_i, ER_j), the traffic is routed along paths P_n.

In the event that the edge routers encounter unexpected traffic requests or fluctuations that are beyond the capacity of the primary paths P_n, the Resource Manager (RM) begins to discover new path along the spare capacity of the other links within the network. When we compare this process to the blood glucose homeostasis, this is similar to the body using up all its glycogen and must begin the fat (good fat) discovery process to obtain new source of glucose. The fat on the other hand is a source of glucose that can only be accessed in rare cases and will have to be discovered from other sources. In similar way, the discovery of spare capacity $P_{SC,ERi,ERj}$ between the two edge pairs occurs in rare occasion.

An example of this process on a network is illustrated in Fig. 3. Initially we determine the amount of resource that we require with respect to a demand profile statistics. For example, if we have a demand profile between 6am to 6pm for data of 10Gb and multimedia of 10GB, then we may require total resource of 20Gb during the 12 hour period. As shown in Fig. 3, the demand profile may lead us to have two primary paths (P1 – 10Gb and P2 – 10Gb, which both gives 20Gb). Therefore, when traffic comes through the network, this resource is readily used up to support the requested traffic. When this is compared to the blood glucose model, the glycogen is broken down through **Glycogenolysis** and **Glycolysis** to support respiration and create energy. In the event that unexpected traffic comes through the network, we do spare capacity discovery (this is shown as path F1). This is similar to the human body when the body is pushed to the limit and the stored glycogen is depleted, the body discovers the fat and breaks this down to create glucose.

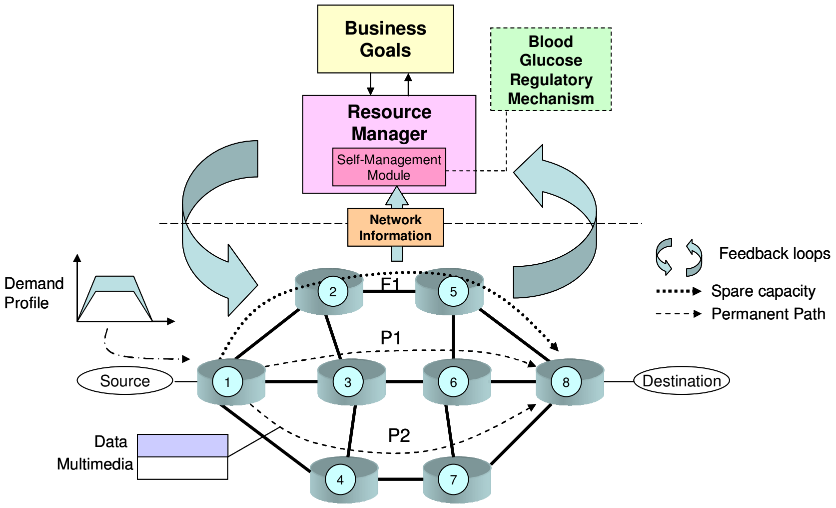

Fig. 3. Comparison of Primary streams to Spare capacity streams in network resource management

In the event that after a number of days the body tends to use the fat resource regularly, the fat is transformed into glycogen for long term use. This in turn reduces the amount of fat in the network, and is determined through a threshold T_{SPARE_USAGE}. The threshold determines the length of time the spare capacity resources is being used. This analogy fits well to the human body, where as the body is being exercised the good fat is reduced which leads to a fitter body. At the same time in the event that demand traffic starts to drop out and the 20Gb demand profile does not get used up to its full capacity, the left over resources will eventually lead to revenue loss. This is compared to the human body that has excess amount of resources leading to production of bad fat. The resulting revenue loss is an indication to the ISP of over subscription of resources. An algorithm to describe these mechanisms is shown in Fig. 4.

```
/*Determine Primary paths*/
for edge pair ($ER_i$, $ER_j$), determine total request bandwidth ($BW_{ERi, ERj}$) from Demand Profile
        Determine all possible primary paths $P_n$ ($n = 1,..N$), for $BW_{ERi, ERj}$ between edge pairs
        ($ER_i$, $ER_j$) using shortest path algorithm based on link weigh = 1/capacity

/*Routing of traffic request*/
for new traffic $t_{i,ERi,ERj}$ of request i with bandwidth $BW_{t,i}$, route through Paths $P_n$
        add $BW_{t,i}$ to used bandwidth $BW_{u,ERi, ERj}$

/*Discovery of spare capacity*/
if ( total used bandwidth $BW_{u,ERi, ERj} >= BW_{ERi, ERj}$ )
        start spare capacity discovery for new path $P_{SC, ERi, ERj}$ for ($ER_i$, $ER_j$)
        if ( time of traffic use for $P_{sc,ERi, ERj}$ , $t_{Psc} >$ threshold $T_{SPARE\_USAGE}$ )
                Add $P_{SC, ERi, ERj}$ to $P_n$

/*Determining bad fat*/
if ( used bandwidth $BW_{u,ERi, ERj} < BW_{ERi, ERj}$ for time $> T_{BAD FAT}$ )
        decrease ($BW_{ERi, ERj} - BW_{u,ERi, ERj}$) from $BW_{ERi, ERj}$
```

Fig. 4. Algorithm for overall resource management

4.2 Comparison of respiration to path ratio refinement

As described in the previous section, the mechanism for creating energy to support the activity of the user is dependent on two types of respiration, which includes Aerobic and Anaerobic respiration. Networks must support various stream types (e.g. data and multimedia), which have different requirements and at the same time outputs different revenue depending on the pricing schemes. However, this is also dependent on how much ratio has been allocated for each type of traffic, which in turn depends on monitoring the demand and adjusting according to demand changes. We compare the revenue output of the networks based on different traffic types and their intensity, to the energy output from the body depending on the respiration capabilities, which is illustrated in Fig. 5

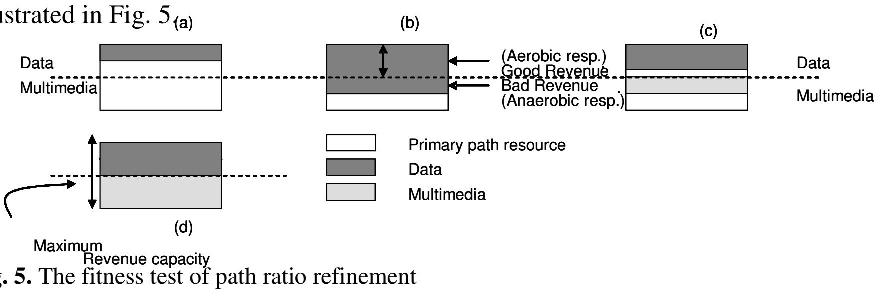

Fig. 5. The fitness test of path ratio refinement

Fig. 5 provides an illustration of our proposed solution for path ratio refinement, where the cross section of each path and the ratio of data and multimedia per path are shown. The same way that we measure the fitness of the human body to generate energy depending on the activity, we compare this to the fitness of the paths allocated in the network by the ISP subscription for a pair of edge routers. Our definition when compared to the human body is the ability for the body to maximise Aerobic respiration to the point that oxygen runs out and switches to Anaerobic respiration. Therefore, we refer to the ability for specific allocated resources to support the same type of traffic as good revenue (R_{GOOD}), but when different type of traffic uses resource allocated to different traffic, this in turn gives bad revenue (R_{BAD}). We compare this to the oxygen supply to permit Aerobic respiration (Fig. 5b shows this comparison), where our aim is to maximise Aerobic respiration. An algorithm of our process is shown in Fig. 6.

```
/*Accept traffic stream and allocate right resource*/
for new traffic t request admission
            if ( traffic of type data $t_{D,i,ER_i,ER_j}$ between edge routers ($ER_i$, $ER_j$) &&
                $Data_{current\_Resource} < Data_{Threshold}$ )
                        Allocate into data buffer and transmit along link
                        Update Good Revenue $R_{Good} = R_{Good} + BWt_{D,i,ERi,ERj}$
            else if ( traffic of type multimedia $t_{M,i,ER_i,ER_j}$ between edge routers ($ER_i$, $ER_j$) &&
                    $Multimedia_{current\_Resource} < Multimedia_{Threshold}$ )
                        Allocate into multimedia buffer and transmit along link
                        Update Good Revenue $R_{Good} = R_{Good} + BWt_{M,i,ERi,ERj}$

/*Allocating traffic stream to different resource*/
for new traffic request admission
            if (traffic of type data $t_{D,i,ER_i,ER_j}$ between edge routers ($ER_i$, $ER_j$) &&
                $Data_{current\_Resource} > Data_{Threshold}$)
                        Allocate into multimedia buffer and transmit along link
                        Update Bad Revenue $R_{BAD} = R_{BAD} + BWt_{D,i,ERi,ERj}$
            else if  ( traffic of type multimedia $t_{M,i,ER_i,ER_j}$ between edge routers ($ER_i$, $ER_j$) &&
                    $Multimedia_{current\_Resource} > Multimedia_{Threshold}$)
                        Allocate into data buffer and transmit along link
                        Update Bad Revenue $R_{BAD} = R_{BAD} + BWt_{M,i,ERi,ERj}$

/*Changing link ratio*/
for new traffic request admission
            if ( time at Bad Revenue, $T_{Bad\ Revenue} > T_{refinement}$ )
                        Calculate new ratio = $BWt_{D,i,ERi,ERj}/BW_{Pn}$
                        Change scheduling based on new ratio
```

Fig. 6. Algorithm for path ratio fitness

An example of allocated resource being used by the corresponding traffic is shown in Fig. 3a, c, and d, where the amount of resource usages is at its optimum because the revenue output is at its optimum (e.g. only R_{Good} - all Aerobic and no Anaerobic respiration). In Fig. 3d, the maximum revenue is obtained when all the resources are being used for their allocated traffic type (e.g. $R_{MAX.\ Allocated} = R_{Good}$), indicating the maximum fitness of the path. When the network is at its maximum fitness, this indicates to the ISP providers that maximum revenue is being obtained. The ISP providers can determine the amount of fitness from historical readings to determine if they are receiving maximum Aerobic respiration (full fitness), slight Anaerobic and Aerobic respiration (slight unfitness), or usage of fat (unfit network that needs more resources to prolong fitness).

Fig. 3b shows an example of a particular type of traffic that has spilled over the allocated threshold, which means that the allocated resource is being used by a different traffic type. Fortunately, the multimedia resource allocated is currently under utilised allowing the extra data to use this resource. However, since the resource being used is of a different type, this has resulted in R_{BAD} (e.g. $\mathrm{R}_{\mathrm{MAX.\ Allocated} \geq}\,\mathrm{R}_{\mathrm{BAD}}$). If this behaviour continues, the Resource Manager will transform the ratio and possibly change charging schemes to maximise good revenue. This could lead to ISP changing the threshold of the allocated resources. In the event that this resource usage is short term, then there is no effect in long term changes.

5 Simulation Experiments

We have performed simulation work to validate our Bio-inspired resource management algorithms. The topology used in our simulation is shown in Fig. 7, and the routing paths are shown in Table 1. The simulation we have performed is to test the effectiveness of managing the resources within the network based on demand profile and the ability to handle fluctuations. The simulator follows our algorithm where initially from the demand profile we determine the possible routes from the different source and destination pairs. In our particular case, we have three pairs, which includes (S1 – D1), (S2 – D2), and (S3 – D3). We will concentrate on the performance of pair S1 – D1, where the other two pairs will be used to transmit background traffic in the network. The demand traffic that we inject into the network is shown in Fig. 8, while Fig. 9 shows the amount of resources utilized by each of the paths. Initially, the paths are pre-determined using our shortest path algorithm based on inverse bandwidth (link weight = 1/capacity).

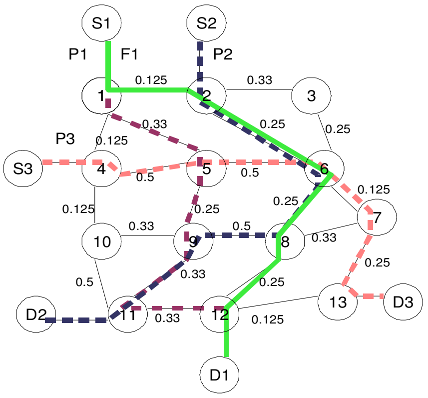

Fig. 7. Simulated Topology

Paths	Route
P1 (S1 – D1)	1 – 5 – 9 – 11 – 12
P2 (S2 – D2)	2 – 6 – 8 – 9 – 11
P3 (S3 – D3)	4 – 5 – 6 – 7 – 13
F1 (S1 – D1)	1 - 2 – 6 – 8 – 12

Table 1. Simulated Routing paths

Each of the paths corresponds to a path for a pair of edge nodes. For example path P1, is routed through paths *1 – 5 – 9 – 11 – 12* with maximum bandwidth of 0.25 Mbps. As shown in Fig. 8, the streams that are transmitted through the network increases with time for all paths. At time 15, the amount of resource usage for path 1 exceeds the maximum capacity of 0.25Mbps (combination of data and multimedia stream), where at time 15 a new multimedia stream of 0.03 Mbps that is not part of the demand profile is injected into the network. At this point in time, the shortest path algorithm is executed to determine new spare capacity that is available between edge routers 1 and 12. Fig. 9 shows this process as the *S1-D1 Spare* line*,* which begins at time 15.

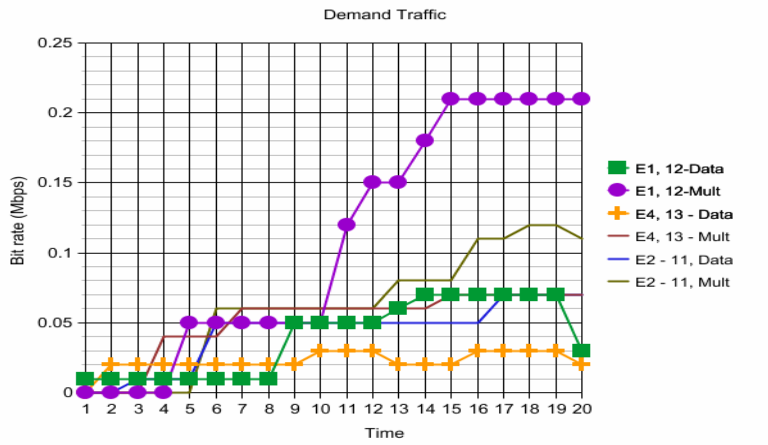

Fig. 8. Simulated demand traffic

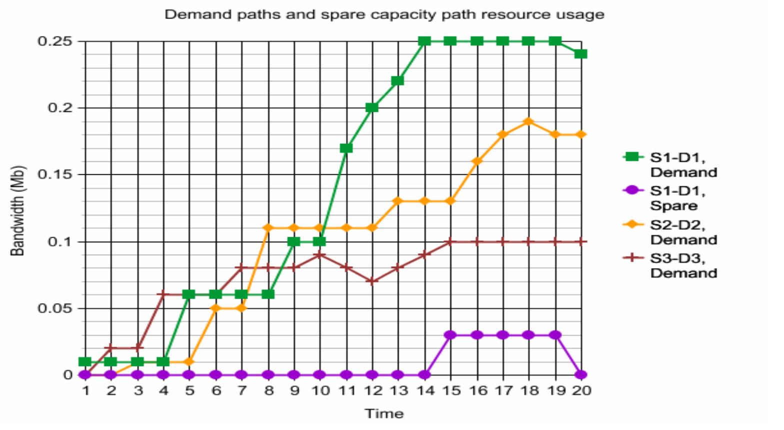

Fig. 9. Demand path and spare capacity path resource usage

As shown in table 1, this new path (F1) takes on the path *1 – 2 – 6 – 8 – 12*. The amount of time that the path F1 is alive supports the need for the ISP to purchase more resources to handle the new traffic demand. We have set the minimum threshold of spare capacity usage (T_{SPARE_USAGE} = 2 time units) to determine how much fluctuation is permitted before this new spare capacity is added to new permanent path between S1-D1. As shown in Fig. 9, the paths between S2-D2 and S3-D3 do not have traffic requests that go beyond their capacity, and therefore does not require spare capacity discovery. As described in the previous section, we also test the fitness of the paths to determine the effective ratio between data and multimedia traffic on each path. This is shown in Fig. 10, which illustrates the good and bad revenue generated from the different paths.

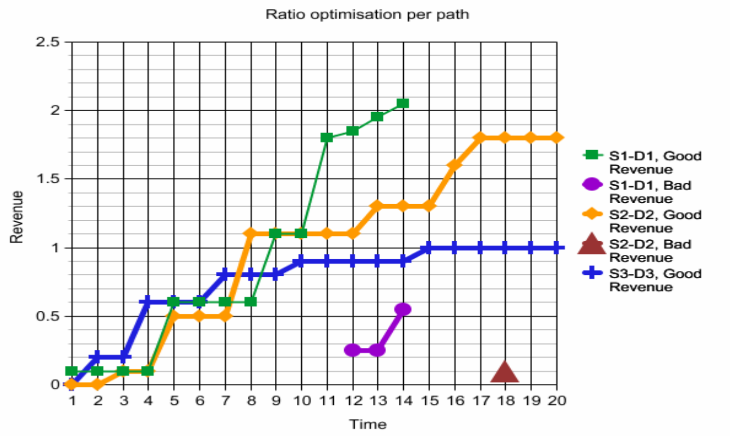

Fig. 10. Ratio optimization refinement for each path

Initially, we set the ratio for each path to 0.5 for both data and multimedia. During the simulation we injected new traffic to demand profile to see how effective our system will react to fluctuations. As shown in Fig. 10 at time 12, the amount of multimedia traffic exceeded the 0.5 threshold, resulting in multimedia traffic having to use resources allocated for data traffic. We have set our time threshold for ratio refinement ($T_{Refinement}$ = 2 time unit), which triggers the algorithm to re-calculate the ratio of the path. Once the ratio is evaluated (e.g. multimedia traffic of 0.18 Mb from 0.25 Mb capacity), the new ratio for S1-D1 is changed to 0.72. At the same time, traffic on path S2-D2 also fluctuated slightly and resulted in small amount of bad revenue as shown at time 18. However, the fluctuation time is low compared to the $T_{Refinement}$ threshold. Therefore no permanent changes are made on the ratio (0.5). Path S3-D3 had no fluctuations during the entire simulation resulting in no ratio refinement.

6 Conclusion and Future Work

Due to the immense complexities that are resulting from the accelerated growth of IP networks, efficient resource management is crucial towards maintaining overall stability. In this paper we have proposed mechanisms used for maintaining blood glucose as a technique towards maintaining overall stability in managing network resources for multiple traffic types. We have applied two biological principles towards our resource management scheme, which includes (i) management of permanent paths based on demand profiles and the ability to discover spare capacity for unexpected or fluctuating traffic, and (ii) management of multiple traffic classes on each path to support maximum revenue for ISP providers. The paper has also presented simulation results to demonstrate our idea for both points.

This paper has described preliminary results and findings for our autonomic network management program. Future work will include integrating blood glucose computational models and determining the effectiveness of the body's ability to manage resources as a comparison to test the effectiveness of our model used for network resource management. The future work will also include extending the current self-management mechanism to fully de-centralised control.

References

1. J. Suzuki, T. Suda, "A Middleware Platform for a Biologically Inspired Network Architecture Supporting Autonomous and Adaptive Applications", IEEE Journal on Selected Areas in Communications, vol. 23, No. 2, February 2005.
2. K. Leibnitz, N. Wakamiya, M. Murata, "Biologically inspired Self-Adaptive Multi-path routing in overlay networks", Communications of the ACM, vol. 49, no.3, March 2006.
3. G. Di Caro, M. Dorigo, "AntNet: Distributed stigmergetic control for communication networks", Journal of Artificial Intelligence Research 9, 1998, pp 317-365.
4. H. A. Mantar, J. Hwang, I. T. Okumus, S. Chapin, "A Scalable Intra-Domain Resource Management Scheme for Diffserv Networks", Proceedings of 2nd International Working Conference on Performance modeling and evaluation of heterogeneous networks, West Yorkshire, UK, July 2004.
5. I. Gojmerac, T. Ziegler, F. Ricciato, P. Reichl, "Adaptive Multipath Routing for Dynamic Traffic Engineering", IEEE Globecom, San Francisco, USA, December 2003.
6. D. Yagan, C.-K. Tham, "Self-Optimizing Architecture for QoS Provisioning in Differentiated Services", In Proceedings of the Second International Conference on Autonomic Computing (ICAC' 05), Seattle, WA, USA, June 2005.
7. P. Raven, G. Johnson, J. Losos, S. Singer, "Biology", 6th edition, McGraw-Hill, 2002.
8. S. Balasubramaniam, W. Donnelly, D. Botvich, N. Agoulmine, J. Strassner, "Towards integrating principles of Molecular Biology for Autonomic Network Management", Accepted for Hewlett Packard Open View University Association (HPOVUA) conference, Nice, France, May 2006.