Real-Time Data Analytics in Support of Network Resource Management Protocols

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***Abstract-* Communications Networks Resource Management (RM) functions such as dynamic and static resource usage monitoring, real time resource reservation as well as advance resource reservation have been widely studied in the past few years. Research has been investigating variant techniques for addressing RM problems in different fixed and wireless networks. One of the key observations is that with the increased complexity of these networks, the function of providing real-time OAM&P has resulted in an ever increased network element MIB attribute polling resulting in a data mountain. The key issue is to extract intelligence from this data using data analytical tools in an efficient manner if it is to have any impact on optimising real-time network resource utilisation as a function of demand. This paper reviews some of the recent techniques conducted in RM for different domains. We discuss data management (DM) in telecommunications and try to depict its role to support our real-time data analytics within the OAM&P functions. The main purpose of this paper is to investigate RM components in groups of networks (ATM, MPLS, Wireless, EPONs) and indicate recent solutions for each group.**

Keywords: Resource Management, Data Mining, Optimisation, Next Generation Networks

I. INTRODUCTION

In a typical IP network managing resources such as bandwidth (capacity), connection identifiers, CPU time and buffer memory in an efficient way not only results in reducing total network cost for the network provider but it can guarantee the Quality of Service (QoS) for end users. As traffic profiles change with no predefined pattern over selected time periods adding more resources to cover resource demand increases is not a cost effective way to guarantee resource availability for all end users in network peak time. Employing Resource Management (RM) protocols, techniques and algorithms to achieve optimal use of available resources is the process of controlling and measuring (and predicting) communications traffic on a network to avoid flooding resource capacity, resulting in congestion and poor Quality of Service (QoS). These challenges are more significant in Next Generation Network (NGN) [8], Fig.1 [20]. In this paper, we will discuss different RM protocols and techniques in variant domains and highlight opportunities to extract knowledge from the management control plane using data management techniques. We will also summarise the use of potential optimisation tools to provide further levels of accuracy.

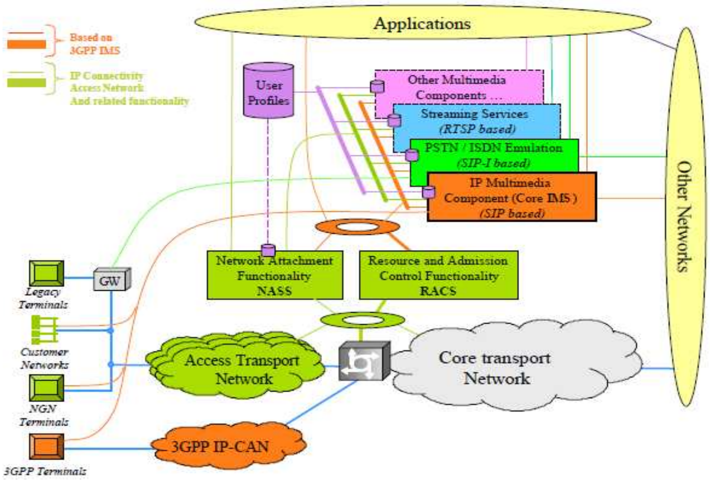

Fig.1 [20]: Next Generation Network (Component/Packaging viewpoints)

II. QOS AND RESOURCE MANAGEMENT

The term QoS has been used to describe different techniques to provide better service for specific traffic in a typical network. QoS methods include: Traffic Shaping, Priority Queuing, Congestion Monitoring, Resource Management, Admission Control (AC), Routing, Application Specific, etc. AC is QoS procedure which determines how resources allocate to application streams with different requirements so it should be implemented between network edges and the access-core to control traffic entering the network [1]. Before determining resource allocation, AC may abide by policies embedded within the network management control plane as part of any Service Level Agreement (SLA) to provide required QoS for each stream. QoS mechanisms are selected and configured according to user application-specific QoS attributes resource availability and resource management policy.

III. REVIEW OF TYPICAL RM PROTOCOLS

RM Protocols should negotiate necessary resources along the path from sender to receiver. Here we can consider two available resource reservation protocols named as Reservation Protocol (RSVP) [23] and Stream Protocol Version 2 (ST-2). Other RM protocols are highlighted in Table (1). ST-2 follows a hard state approach which means at connection set up time its agent establishes a distribution tree from source to

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all destinations. This tree is almost fixed so it avoids the problem of changing routes when the transmission starts. This property makes ST-2 complex while RSVP uses soft state features. Having soft state property means the route between source and destination may change which requires updating of route nodes periodically whenever each part of route changes. This process adds overhead to the network. Moreover, while RSVP is receiver-based which means the receiver is responsible for establishing the reservation as well as distinguishing tear-down message to finish reservation process. ST-2 is sender-based reservation protocol in which the sender is responsible for starting and finishing reservation requests [19]. One serious problem with RSVP which has not been solved so far is the soft state features which let routes get changed during reservation. This means that over the reservation period if a route changes, reservations should be processed again on new links. So in the worst case scenario if resources are not available towards a new path, the RM will refuse a request so the reservation will be cancelled. This requires a new approach. More details about RSVP and ST-2 protocols can be found in [4].

Assume a user application issued a resource reservation request. For each condition we try to depict the requirement of having Real Time Optimization Protocol for handling each situation. *Case1:* User does not want to use reserved resource. *Case2:* User releases the resources before reservation time expired. In case one and two the reserved resources or fraction of them remain unutilized. By having a Real Time Resource Management Protocol we can offer those unutilized resources to either real-time or to advance reservation requests. Any new protocol should be able to accommodate extra resource requests to achieve real time allocation when demands arrive. *Case 3:* User wants to extend reservation when their current connection is still active. *Case 4:* User wants to extend their reservation immediately after reservation time expired. In case three and four regarding to available amount of resources as well as resources released in case one and case two a Real Time RM Protocol can decide on time whether to accept request extension without degrading QoS of current and future reservations.

TABLE (1)
RESOURCE MANAGEMENT PROTOCOLS

Name	Layer/ Technology	Good points	Weak points
IntServ (RSVP)	Layer 3	-It works well when all the routers towards path support RSVP. -Good treatment for high priority traffic.	-It is not good when traffic is heavy or network is large. -It consumes many resources on each router.
DiffServ [24]	Layer 3	-It allocates resources to classes of traffic instead of specifying resource for each stream. -It defines same policy for each class of traffic. -Most WAN vendors use it.	-Sharing resources is not possible between different classes of traffic. -It cannot manage resources just serves them with best effort on each class which is not good when the traffic is heavy and resources are limited.
IP Precedence	Layer 3	-It is a simple method which gives priority to IP packets. -Good when routers do not support DiffServ.	-Most routers support DiffServ so there is not any advantage using IP Precedence.
ATM	WAN	-Flexible in resource allocation. -DiffServ categories could be translated to ATM categories on network edges. -Simple routing. -Multiplexing different range of traffic. -Fast cell switching. -It can measure and policy resources. -Flow control. -Media specification.	-Overhead of ATM cells. -Resource overflow in ATM switches results in dropping ATM cells.
MPLS	WAN	-Flow control. - WAN technology. -Recognized on routers by using MPLS tags. -It has fixed number of classes and mapping code could have been done between DiffServ and MPLS in core.	-It is still a technology which is not supported by all vendors.

IV. DATA MANAGEMENT IN TELECOMMUNICATION

Data Management in telecommunications deals with all aspects from the FCAPS model. In a typical IP network data could be categorised into following groups: 1) From real time applications such as voice and video, games. 2) From non real time application like email. 3) Generated from malicious activities. 4) generated by network provider for purpose of changing network configuration, monitoring network activity, recovering devices, etc. 5) added by different protocols travelling along network for variant purposes. 6) Generated by agents in manageable network devices such as Access Points, Routers, Switches, etc. to initiate trap for specific events such as device failure, buffer overflow, and malicious activity or to respond to the requests from management node. Regarding the above classifications challenges such as data security, access, accuracy, mining and integration are revealed. Using data management tools and techniques is a solution for those challenges which can help network managers and PBNM autonomic protocols make real time decision and offers the potential of supporting prediction by employing real time data analytics. It is important that any techniques adopted can cope with the real-time pressures and the vast amounts of data generated whilst at the same time minimizing the amount of computation overhead caused.

Review of Some Data Analytical Techniques

Data analytical techniques could be categorized into three groups as follow: 1) User-customized scripts in a language such as Perl to parse data and produce useful information. 2) Machine learning which is the subfield of artificial intelligence and based on different data analysis algorithms such as Fuzzy, Decision Tree, Neural Networks, etc, [15]. 3) Visualization methods which provides data displays and analysis tools. Table (2) is comparison between them.

TABLE (2)
DATA ANALYTICAL TECHNIQUES

Name	Good points	Weak points
User -customized scripts	-Easy and cheap to develop.	-Compatibility and security issues in different domain and components.
Machine learning	-Highly automated. -It could be implemented in different domains.	-Waste human time to analyze. -Not able to recognize new and unexpected events.
Visualization methods	-Very powerful. -Direct process of data. -Visually analyze data and indicate events. -Alarm unexpected event such as malicious activity or congestion. -Human friendly.	-Need powerful CPU and huge memory.

In [3] authors designed a visualization system to analyze network traffic rapidly and validate it by performing analysis of real-time and network traffic from several domains. It is able to scan network traffic quickly and detect anomaly event such as intrusion detection. However, it does not directly apply to resource management.

V. GENERAL SEARCH ON OPTIMIZATION

Operational Research (OR) or optimization is a group of mathematical modelling, statistical techniques and algorithms which result in optimum or near optimum solutions for complex problems. These solutions could be applied to industry or even non industry fields to achieve profit maximization and budget (like cost and time) minimization [2]. Telecommunication, energy, transportation and manufacturing are the fields in which optimization techniques could be utilized. Regarding to availability of high speed computers, optimization techniques are becoming more popular in engineering world [9]. In general terms, to apply these techniques regarding different engineering problems the first step is to identify important variables that could be changed during defined scenario while the other items keep as the fixed parameters. The second step is formulating the constraints. The third step is formulating an objective function with minimum or maximum functions. The last step is to solve objective function by finding limitations for variables [9].

A. Optimization Techniques

To solve optimization problems there are different techniques which could be categorized as follow: Linear Programming, Integer Programming, Dynamic Programming, Network Programming, Nonlinear Programming, Heuristic Methods and Stochastic Optimization Algorithms [2]. In this literature review we consider some of them as follows:

(A) *Linear Programming (LP:)* it is an optimization technique for a linear objective function subject to linear equality and linear inequality constraints which determines the optimum solution such as maximum profit or minimum cost. Linear programming models can apply to industries such as transportation, energy, telecommunication and manufacturing. (B) *Dynamic Programming (DP):* in this method optimization problem breaks up in to simpler problems like dividing it in to different stages, then for each stage we try to find out the optimal solution which is output to the next stage or sub problem. At the end by solving the last sub problem we can find out optimum solution for the entire problem space. Dynamic Programming has two methods to solve optimization problems named as Forward Recursion (going from source to destination) and Backward Recursion (going from destination to source) [2]. (C) *Heuristic Method*: this method is able to produce an acceptable solution to a problem but there is no formula proof of its correctness [2]. We use heuristic methods when there is no previous or known method to give us optimum or near optimum solution. Today using Heuristic Methods is a very common solution for different fields such as telecommunication which gives an acceptable solution. Some Heuristic Methods could be named as Simulated Annealing (SA), Tabu Search (TS), Genetic Algorithm (GA) and Artificial Neural Network (ANN), e.g. *Tabu search* is a meta-heuristic algorithm that can be used to find solutions for combinatorial optimization problems like travelling salesman problem (TSP). It uses a local or neighbourhood search procedure to move from solution (x) to solution (y) until some stopping criterion has been satisfied. Tabu Search (TS) started with an initial solution which could be generated by neighbourhood algorithm to create new algorithm. (D) *Genetic Algorithm (GA)* is another heuristic method inspired by evolutionary biology such as inheritance, mutation, selection and crossover. In GA binary strings of fixed length are the code parameters. It has genetic operators such as *Coding, Initialization, Evaluation, Reproduction, Crossover, Mutation* and *Terminating condition.* Binary strings evolve to the next generation by selection, crossover and mutation. To evaluate each binary string it uses fitness function and selection operator which allows strings with higher fitness to appear with higher probability in the next generation. Crossover exchanges parents' parameters to make new generation; crossover point is randomly selected. Mutation flips single bit in a string. GA operations are fully described in [25], [16]. Table (3) is comparison between LP, DP, TS, GA and ANN. The challenge for us is to investigate and compare the application of these various approach in an example scenario such as link bandwidth allocation and protection.

TABLE (3)
COMPARISON BETWEEN SOME OPTIMIZATION METHODS

Method	Good points	Weak points
LP	-Reliable	-Only applicable for linear objective function. -Needs to define upper and lower bounds for all variables. -Variables could not be infinite or negative. -Uses slack, surplus for non-equivalents which add extra variables which need to be solved. -Needs very details information.
DP	-Fast -Reliable -Solve each sub problem only once.	-Not applicable if a problem changes over time. -Not applicable if a problem is not stationary.
TS	-Good for solving combinational optimization like travelling sale man.	-To start working needs to determine potential solution, e.g. solution generated from neighbouring algorithm.
GA	-Robust -Solving complex problem. -Requires little information to search -Useful for non-linear problems.	-Slow -Could not find best solution when the population is small and long waiting time for significant improvement when the population is very big. -Could not find best solution when the mutation is too low or too high.
ANN	-Could model complex relationship between inputs and outputs to find patterns in data. -Real time operation. -Self organization. -Able to learn how to do the task via initial examples.	-Its operation can be unpredictable as it finds solutions for the problem itself. -Cannot be programmed to perform specific task. -As it learns by example, if the example is not selected carefully it will be very slow.

B. Optimization Applied to Telecommunications

What follows is a summary review of various methods deployed to provide bandwidth management in different transport networks.

Here, we have a literature review of heuristic methods like Genetic Algorithms (GA) for Asynchronous Transfer Mode (ATM) [22] networks and Linear Programming for 3G networks. In reviewed papers almost all GA approaches are proposed for ATM, so here we try to consider GA solutions for ATM problems starting by area definition and problem specification. ATM has been widely deployed in telecommunication systems to transport data, video and voice at a very high speed. The following are problems with ATM networks which could be solved by GA approaches: (*1):* Design ATM in an optimal way (cost effective and QoS aware), (*2):* Routing cells dynamically in ATM networks to achieve less average cell delay which is an indirect factor for buffer memory as a network resource (*3):* Bandwidth optimization in ATM network.

C. Sample RM Optimization Techniques in ATM / 3G

In [18] bandwidth and buffer memory are resources to optimize. They proposed a HYBRID approach using GA and Tabu Search (TS) to solve dynamic routing problem in ATM networks and to optimize both buffer memory and bandwidth. TABU is less time consuming than GA. In ATM networks buffer overflow probability is related to average queue length, average queue length is related to average delay, so we can say average packet delay is an indirect factor related to buffer overflow probability. Therefore, by managing average packet delay we can manage buffers indirectly. They tried to combine both features of TABU and GA to find solutions for dynamic routing problem in ATM which result in buffer and bandwidth optimization. They implemented ATM over virtual paths (VPs) and appointed equal capacity for each VP to reduce the cost of physical installations between each pair. Following formula (1) is considered for average cell delay which should be minimized using GA.

$$\text{Minimize } T = 1/\lambda \sum_{m-1}^{m} \frac{Fm}{Cm-Fm} \qquad (1)$$

Subject to: $Fm < Cm$ for all VPm in network.
To start optimization using GA the first step is to encode parameters that should be optimized by string, characters or numbers. The encoded string is named as the Configuration String (CS). In [18] for the encoding method they used a coding procedure which is depicted in Fig.2 [18] in which each bit in the string is representing random number of 'Router No' from route table which is corresponding a random possible path between two ATM nodes. Initialization, evaluation and selection are three GA operators which are used in [18]. At the end it output the best solution which is the one with minimum cell delay from TABU list.

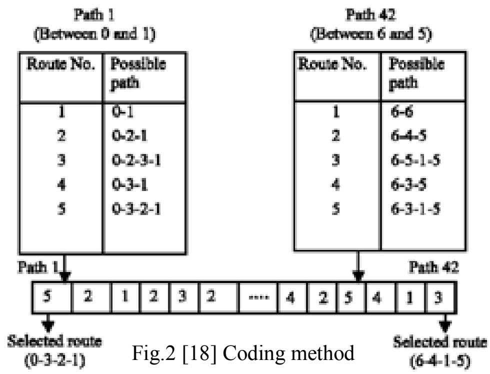

Fig.2 [18] Coding method

In [17] authors used Linear Programming (LP) based techniques for allocating resources in third generation networks (3G) which reduced resources from running applications for hand-off and new applications by considering the highest priority for real time hand-off over non real time. The problem depicted in linear programming formula (2). They used 'Ω' as reduction parameter which reduces resources such as bandwidth and buffer memory from running application to provide required resources for both hand-off and new applications without degrading the QoS of running applications. To solve this LP problem first they converted it to equivalent LP then used Neural Networks to solve LP problem. The number of neuron depends on the number of variables in equivalent LP. The LP based resource reduction, significantly improved the average percentage acceptance of requesting applications. They used artificial neural networks (ANN) to generate solutions for LP problems which results in a faster control decision. The simulation result from [17] show that the proposed algorithm based on LP resource reduction increases the percentage of acceptance to requesting applications and considers fairness between applications with different priorities such as hand-off and new applications.

$$\begin{aligned} &\text{maximize} && \textstyle\sum_{j=1}^{q}\sum_{i=1}^{r} c_{ij}R_{ij} \\ &\text{subject to} && \textstyle\sum_{i=1}^{r} R_{ij} \le (1-\Omega_j)(P_j-\Theta_j) \\ & && R_{ij}^{\min} \le R_{ij} \le R_{ij}^{\text{alloc}} \\ & && R_{ij} \ge 0 \qquad \forall i \in [1,r], \forall j \in [1,q] \end{aligned} \tag{2}$$

D. Sample RM Optimization Techniques for EPON

In [13] authors used heuristic methods for optimal use of available bandwidth in EPON networks. Sample EPON includes single Optical Line Terminal (OLT) and a couple of Optical Network Units (ONUs) working in two directions: point to multi-points, from OLT to ONUs and multi points to point, from ONUs to OLT [5]. As upstream bandwidth is common between multi-point of ONUs and single point of OLT, they needed to allocate shared bandwidth to ONUs efficiently to avoid congestion in data transmissions. To address this problem in [13] there are formulas for collecting extra bandwidth from lightly loaded ONUs and then granting increased bandwidth between heavy loaded ONUs depicted in following three formulas (3) which show how OLT calculates quantity of granted bandwidth to different bandwidth requests. In this process the OLT must wait for REPORT messages to arrive and ONUs wait for OLT calculation which results in idle time during which upstream channel is not utilized. More details of this process could be found in [13].

$$B_{excess} = \sum_{i \in l} [B_{\min}(i) - B_{req}(i)], \quad B_{\min}(i) > B_{req}(i)$$

$$B_{granted}(i) = B_{\min}(i) + B_{excess}(i)$$

$$B_{excess}(i) = \frac{B_{req}(i)}{\sum_{k \in H} B_{req}(k)} \times B_{excess}$$

To cover the idle time problem during which upstream channel left unutilized, paper [5] introduced an efficient Dynamic Bandwidth Allocation (DBA) method using multipoint control protocol (MPCP) by utilizing unused bandwidth of light ONUs for heavy ONUs. In [5] the proposed algorithm is able to save ending time of the last time slot (T_end) in a tracker which will be used in ONU scheduling. Then, if the requested bandwidth is smaller than the minimum granted bandwidth OLT will grant it immediately otherwise OLT will defer the granted process if the tracker value is smaller than the idle time and the arrival time of the next REPORT is earlier than (T_end – RTT/2). This process is more detailed in [5]. Generally in [5] authors presented a new DBA for using increased bandwidth of light ONUs to meet required bandwidth needs.

E. Sample RM Optimization Techniques in WIMAX

In [6] authors proposed an adaptive bandwidth allocation algorithm in fixed and mobile WiMAX for delivery of voice and data based on Adaptive Custom Queuing (ACQ) in which they used Priority Queuing (PQ) and Custom Queuing (CQ) features and a soft threshold feature to give bandwidth guarantees to both voice and data. In ACQ although higher priority will be given to voice and it is served first, but if voice demands increase ACQ can protect data. In [6] this portion is 70% for voice and 30% for data. For better system performances an ACQ scheduler makes available spare bandwidth on different zones. Simulation results in [6] show that by applying the ACQ algorithm in down link schedulers, ACQ allocates bandwidth efficiently by allowing voice and video to borrow spare bandwidth from their zones and performing fairness between them.

F. Sample RM Optimization Techniques for MPLS

Label Switching Routers (LSRs) are available on both ingress and egress edge of MPLS [21] networks which help non-LSR connected to MPLS cloud and makes a Label Switch Path (LSP) reachable for MPLS packets [10]. In [7] authors proposed an efficient distributed bandwidth management for MPLS fast reroute between different service of LSPs. They also proposed efficient signalling algorithm to distribute/collect additional data to maximize bandwidth sharing among back up paths. Sharing bandwidth among same back up LSPs has been published by the Internet Engineering Task Force (IETF) RFC 4090 [12]. IETF fast reroute defines two methods for MPLS fast reroute named as: *one-to-one back up method* which creates back up for each and every protected service LSP failures and discuss in [7] and *facility backup method* which creates tunnels to protect failure points [10]. In [7] to minimize total restoration bandwidth they used heuristic methods. Sharing possibility among reserved back-up bandwidth helps to reduce overall restoration bandwidth. In [7] authors used RSVP Traffic Engineering (RSVP –TE) protocol [11] which allows signalling messages (PATH, RESV and PATHTEAR) to be explicitly routed from source to destination and used the CSPF algorithm to find shortest path between them to utilize minimum possible bandwidth. Generally in [7] authors proposed an optimum mechanism to share back-up bandwidth between different service of LSPs and introduced three new signalling messages between neighbours to distribute and collect extra information.

In [14] authors presented a new bandwidth allocation schema named as Dynamic Bandwidth Partitioning for multiservice IP networks by emphasising the suitability for MPLS and Virtual Private networks. In this method each network link is partitioned dynamically into a number of sub links then each of them serving a single traffic class which could be implemented in area with limited capacity (e.g. access networks) but not for core networks when large quantity of bandwidth is available and required.

VI. INTEGRATED OF DATA ANALYTICS WITH OPTIMIZATION FOR RM

Regarding to availability of variant data management techniques which are able to capture and analyze data in real time through a typical IP network, challenges such as speed of execution, data access, accuracy, mining and data integration must be efficient. Moreover, analyzing traffic patterns in real time does allow for in-line profiling taking place and mappings to be given against current and expected load. However, identifying the behaviour of network components and quantity of free and utilized resources such as buffer memory and bandwidth (capacity) along network is always difficult. On the other hand, as the RM responsibility is controlling and measuring communications (traffic and packets) on a network to avoid congestion build up in queues and at per-hop nodes capacity could take advantages of data management techniques if they are implemented with a fast execution footprint at key points along the access and core pathway. If we can identify the attributes of key importance in a specific node (e.g. router or DSLAM) and extract traffic patterns from the MAC and PHY layers we do then have an opportunity to investigate how we can deploy real time optimization techniques as highlighted in section V with the specific aim of protecting and allocating bandwidth efficiency. Therefore, feeding RM with real time data which captured by data management tools and techniques not only provides real time optimization for network resources but it can eliminate RM computational requirements and reduce network overhead significantly.

VII. CONCLUSION AND FURTHER WORKS

In managing different resources such as bandwidth (capacity), connection identifiers, CPU time and buffer memory, resource management must operate with variant techniques and protocols to have an impact into allocating resources in advance or in response to real time resource demands. We discussed some optimization techniques and available resource reservation protocols which help resource allocation issues and spotted the necessity of having Real Time Optimization Protocol for Resource Management that could give common approaches in different IP networks. Our current work is to further explore the technical and functional characteristics for an in-line data analytic tool that can operate in real time and that can support the use of optimization techniques for bandwidth management in NGNs thus providing more efficient monitoring and use of available network resources.

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