A MEASUREMENT-BASED ADMISSION CONTROL ALGORITHM FOR RESOURCE MANAGEMENT IN DIFFSERV IP NETWORKS

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ABSTRACT

IP-based Radio Access Networks (RANs) are envisaged to be the next generation access networks in UMTS. In order to provide a satisfactory level of Quality of Service (QoS) for real-time applications, and efficient network resource utilisation in the IP-based RAN, Resource Management in Diffserv (RMD) is proposed [1]. RMD is a simple and scalable bandwidth resource management scheme that extends Differentiated Services for on-demand resource reservation and admission control. We evaluate Measurement-Based Admission Control (MBAC) algorithms for RMD. An MBAC algorithm proposed in literature was selected, namely the Time Scale Decomposition (TSD). The main reason for choosing the TSD algorithm is that this algorithm is less dependent on traffic assumptions. In the TSD algorithm, two variants are specified. The first variant is based on per flow measurement statistics (TSD-FE criterion), which is not scalable. The second one uses aggregate measurement statistics (TSD-AE criterion). The main disadvantage of TSD-AE is that it provides poor utilisation performance due to inaccurate estimation of traffic statistics. Therefore, we enhance TSD-AE to improve its utilisation performance. A performance evaluation of different variants of TSD is conducted, the results show that our proposal, the TSD-EAE outperforms TSD-AE.

I. INTRODUCTION

UMTS [2] is a third generation mobile communication system that supports multimedia applications. The Radio Access Network (RAN) part of UMTS consists of several Node Bs and Radio Network Controllers (RNCs). Initially, the Node Bs are connected to RNCs or other Node Bs by using ATM technology. However, it is envisaged that IP will be used as transport technology in the next-generation UMTS access networks.

The advantage of such a transition offers is that the IP network capacity can be shared between Node Bs and RNCs. Such a sharing of transport network leads to an increase of transport efficiency and a reduce of network costs for the operator. Moreover, IP routing management can support rerouting and load balancing, which increases the transport reliability of the IP-based RAN.

While the IP-based RAN offers these advantages, it is of paramount importance that such an IP-based RAN provides the required quality of service (QoS) guarantees. Currently, several dynamic resource management schemes are proposed for supporting QoS in IP-based networks [3]-[6]. However, it is shown in [7] that none of the existing resource management schemes is able to meet the requirements of an IP-based RAN. Therefore a new resource management scheme has been developed for IP-based RAN, which is called Resource Management in Diffserv (RMD) [8].

RMD extends the Differentiated Services (Diffserv) architecture with new resource reservation and admission control mechanisms. The admission control function in RMD is used to admit as many mobile users as possible with the requested QoS and achieve high network utilisation. Currently, within RMD one type of admission control is specified thus far, which is a reservation based type of admission control. The reservation based admission control bounds the number of flows in the network by maintaining soft-state resource reservations. The main disadvantage of this admission control approach is that it requires a lot of processing and signalling overhead due to the updates of the soft-state reservations. In addition, in this approach the mobile user is required to declare its traffic characteristics at flow setup time. This a priori traffic specification is used to determine how much resources should be reserved for this flow. However, for real-time services, the mobile user may not send traffic conforming to the a priori traffic specification, which will yield low network utilisation.

In this paper, we use a Measurement-Based Admission Control (MBAC) algorithm for RMD. The main advantage of MBAC is that it does not have to maintain any reservation states and that it requires no a priori traffic specification. Instead of using traffic specifications, the MBAC characterises the traffic through real-time measurements. We use a simulation-based performance study to evaluate the performance of the selected MBAC algorithm.

The outline of the paper is as follows. In Section II, we describe Resource Management in Diffserv. Section III gives a short description of the most relevant MBAC algorithms in literature. Section IV presents a functional evaluation of the MBAC algorithms. Section V gives a description of the selected TSD algorithm for IP-based RAN. Section VI presents a set of results obtained via simulations. Section VII concludes this paper.

II. RESOURCE MANAGEMENT IN DIFFSERV (RMD)

The Diffserv architecture [9] is a scalable IP QoS framework that classifies different flows into traffic classes. The Diffserv framework defines a Diffserv field in the IP header to classify packets into traffic classes. At each node the packets are treated according to pre-specified forwarding Per Hop Behaviours (PHBs). In this way, traffic flows get differentiated services in the IP network, where high priority flows are treated better than low priority flows.

The RMD framework is an edge-to-edge dynamic resource management scheme that is based on Diffserv. In RMD two types of protocols are specified, the Per Domain Reservation (PDR) protocol and the Per Hop Reservation (PHR) protocol. The PDR protocol is used for resource management in the entire Diffserv domain, while the PHR protocol is used for re-

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source reservation per Diffserv traffic class in each node in the communication path. Currently one type of PHR protocol is specified, which is RMD On-demand (RODA) [10]. RODA PHR protocol uses the reservation based type of admission control. The second PHR protocol is Resource management In diffserv Measurement based Admission control (RIMA) [11], which is still under development. This PHR protocol uses MBAC as admission control. Fig. 1 shows the PDR and PHR protocols in an IP-based RAN.

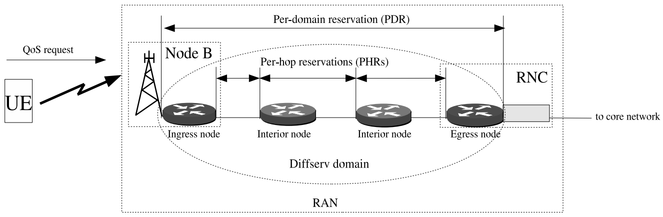

Figure 1: PDR and PHR protocols in the IP-based RAN [8]

As shown in Fig. 1, the PDR protocol is implemented in the ingress and egress nodes, while the PHR protocol is implemented in the interior nodes within the Diffserv domain. Once a QoS request arrives at the ingress node, RMD determines whether sufficient bandwidth resources are available at all nodes in the communication path between the ingress node and egress node to support the flow.

In our work we focus on MBAC for the RIMA PHR protocol. Fig. 2 shows the schematic of MBAC for RIMA PHR in an interior node.

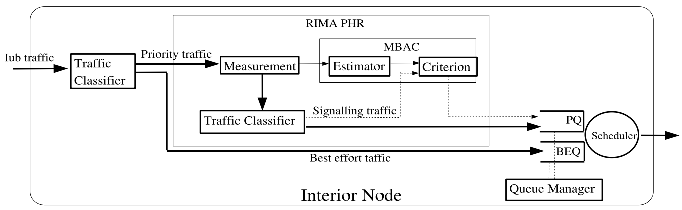

Figure 2: MBAC implementation in RIMA PHR protocol

As depicted in Fig. 2, the implementation includes several elements. The elements are: traffic classifier, queue manager, and scheduler. The other four elements are used to built MBAC for RIMA PHR protocol.

When a packet is received, a traffic classifier determines which traffic class it belongs to. After the classification, priority packets are passed to the measurement element and best effort packets to the best effort queue. The measurement element maintains a bit counter to periodically calculate the bandwidth usage. The second traffic classifier is used to identify which type of PDR signalling message is received and passes this information to MBAC. The MBAC consists of two elements: the estimator and the criterion. The estimator estimates the average bandwidth (and variance) by applying an exponential moving average filter to the measured bandwidth usage. The criterion element uses these measured quantities as inputs to estimate the packet loss rate in order to decide whether the priority flow is accepted or not.

In the next section we describe the possible MBAC algorithms for the RIMA PHR protocol.

III. Related work

A variety of different MBAC algorithms have been proposed in the recent years. Below we review the most significant ones:

- *Measured Sum (MS)* [12]: The MS algorithm checks the bound that keeps the measured mean load plus the a prior peak rate specification of the new flow less than the capacity times a load factor.

- *Hoeffding Bound (HB)* [13]: HB is developed by using the Hoeffding bound theory to compute the effective bandwidth of flows in the network. The HB admits a flow if the sum of the peak rate of the new flow and the measured effective bandwidth is less than the link capacity.

- *Chernoff Bound (CB)* [14]: CB computes the effective bandwidth from the measured traffic by using the Chernoff bounds. Four types of bounds are presented, each bound is derived by considering the tangents at a particular point in the effective bandwidth function.

- *Buffer Occupancy (BO)* [15]: The BO algorithm is based on the large deviation theory, which states that the overflow probability at the queue has an exponential decay. This algorithm approximates the packet loss ratio by measuring the queue.

- *Normal approximation (N)* [16]: This algorithm is based on mean and variance measurements of the traffic load and estimates the loss probability with the Normal approximation to bound the number of flows in the network.

- *Time Scale Decomposition (TSD)* [17]: TSD estimates the loss probability by considering mean and variance measures in the central limit theorem for bounding future calls.

- *Maximal Traffic Envelope (MTE)* [18]: This algorithm is based on a traffic envelope, which is a description of the mean and the variance of the traffic load over multiple time scales. The number of flows in the network are bounded by a maximum traffic envelope.

IV. Functional evaluation of MBAC algorithms

In this section we consider requirements for MBAC algorithms. RANs have different characteristics when compared to traditional IP networks. These characteristics impose requirements on the MBAC algorithm that will be used in the IP-based RAN. The MBAC requirements are:

- *Complexity*: The DiffServ paradigm simplifies the interior nodes in the domain for scalablity reasons. Since the MBAC is located in the interior nodes, the MBAC function should be made as simple as possible.

- *Scalability*: In RANs, traffic is generated at a large number of Node Bs and is transported over the same links in the RAN. As a result, the total number of flows in the RAN is very large. Therefore, the MBAC algortihm should not perform per-flow state management.

- *Dependency on the traffic model*: In UMTS, the RNC manages the radio resources by adjusting the mobile users sending rate at transmission time intervals. Hence, the traffic profile in the RAN is not only dependent on real-time applications but also strongly dependent on RNC management functions. Because of the dynamic character of the UMTS source, the MBAC should make little traffic assumptions as possible.

The above described requirements show that the RAN is a very dynamic environment. As such, MBAC algorithms should be simple, scalable, and make as little traffic assumptions as possible in order to be appropriate for the IP-based RAN.

The MBAC algorithms described in Section III are quantitatively assessed against the requirements. The MS algorithm characterises traffic only with the measured mean, such an algorithm is very simple to use. However, by incorporating only the mean measurement, this algorithm has difficulties in handling fast load fluctuations. Therefore, this algorithm is too optimistic for the RAN environment.

The HB, CB, and BO algorithms are mainly based on traffic assumptions, which make them not suitable for the RAN.

As for the algorithms N, TSD, and MTE, they rely on the fact that they require no knowledge about the traffic characteristics. They assume a large number of flows in the network, and are based on mean and variance measurements. The MTE algorithm measures the traffic load over several time scales. This algorithm requires a large number of measurements samples and computation iterations to compose the maximal traffic envelope. Due to the processing complexity, this algorithm is not suitable. N and TSD are more or less the same, and they differ only in the way of estimation. However, TSD is preferred over the N algorithm because it estimates the mean and variance with more accuracy.

Overall, the choice for TSD is motivated by the fact that this algorithm is less dependent on traffic assumptions, it is simple and scalable, and it is able to track traffic fluctuations at different time scales.

V. Description of the selected MBAC algorithm

MBAC algorithms consist of two parts: the estimator and the criterion. As explained earlier, the estimator is the element which estimates the current network load, and the criterion decides whether to admit or reject the new traffic flow.

A. Estimator

The estimator in the TSD algorithm estimates two traffic statistics: the traffic mean $\widetilde{\mu}(t)$ and variance $\widetilde{\sigma}^2(t)$ see (Eq. 1) and (Eq. 2), respectively. The used estimation technique is based on splitting the aggregate traffic into a slow frequency and high frequency component by using a cut-off frequency of $\frac{1}{\widetilde{T}_h}$, which is the mean flow life-time.

The mean is estimated by:

$$\widetilde{\mu}(t) = \int_0^t \left(\sum_{j=1}^{n} X_j[0, t-\tau] \right) h(\tau) d\tau. \quad (1)$$

The variance is estimated by:

$$\widetilde{\sigma}^2(t) = \int_0^t \left(\sum_{j=1}^{n} \left(X_j[0, t-\tau] - \frac{1}{n}\widetilde{\mu}(t) \right)^2 \right) g(\tau) d\tau, \quad (2)$$

where n is the system size, where X_j denotes the measured load produced by flow j at time t, and where

$$h(\tau) = \frac{1}{\widetilde{T}_h} e^{(\frac{-\tau}{\widetilde{T}_h})}, \quad (3)$$

is the low frequency filter, and where

$$g(\tau) = \frac{1}{T_s} e^{(\frac{-\tau}{T_s})}, \quad (4)$$

is the high frequency filter and $T_s = K\widetilde{T}_h$.

Note that the mean and variance estimates can simply be obtained by exponential weighting of past bandwidth measures. The estimator uses two control parameters: sampling period T_s and estimation window size T_h. The sampling period controls the sensitivity of the traffic measurement. The estimation window size controls how past bandwidths are weighted in a exponential-weighted moving average filter.

B. Criterion

Currently, two types of criteria are defined in TSD. One criterion maintains the number of flows $N(t)$ in order to use per flow measurement statistics $\widetilde{\mu}_f(t)$ and $\widetilde{\sigma}_f(t)$ in its decision. We refer to TSD with this criterion as TSD with Flow Estimation (TSD-FE). The other criterion has no knowledge about the number of active flows and it makes decisions only by using aggregate measurement statistics $\widetilde{\mu}_a(t)$ and $\widetilde{\sigma}_a(t)$. The TSD algorithm with Aggregate Estimation is refered as TSD-AE.

The criterion of TSD-FE has the form:

$$C - N(t)\widetilde{\mu}_f(t) - \widetilde{\mu}_f(t) > \alpha_{qos}\widetilde{\sigma}_f(t)\sqrt{N(t)+1}, \quad (5)$$

where, C is the capacity, and $\alpha_{qos} = Q^{-1}(p_{loss\,target})$. This criterion can be interpreted in the following way. At the left side of the formula, the estimated available spare bandwidth for a new flow is calculated. At the right side, the required spare bandwidth for traffic variance is estimated. Furthermore, it can be noted that the larger the variance or QoS parameter $p_{loss\,target}$, the stricter the criterion.

In IP-based RANs only the edge nodes are aware of the number of flows in the transmission path. Whereas, the interior nodes handle only traffic aggregates. Therefore, we will focus only on the criteria that are based on measured aggregate statistics $\widetilde{\mu}_a(t)$ and $\widetilde{\sigma}_a(t)$, such a criterion as in TSD-AE:

$$C - \widetilde{\mu}_a(t) - \hat{r} > \alpha_{qos}\widetilde{\sigma}_a(t), \quad (6)$$

where $\hat{r}$ is the peak rate of the requesting flow. The problem of criteria that use only aggregate statistics is that the measured variance $\widetilde{\sigma}_a$ is not only composed of traffic variance but also variance due to flow arrivals and departures. The next problem is that the bandwidth of the just admitted flows is not immediately reserved. Actually, it takes some time before the traffic of the just admitted flows is fully reflected in the measured load

$\widetilde{\mu}_a(t)$, approximately one round trip time plus filter response time. In [17] it is proposed to correct this by modifying the $\widetilde{\mu}_a(t)$ to $\widetilde{\mu}_a^c(t)$, i.e.,

$$\widetilde{\mu}_a^c(t) = \left(\widetilde{\mu}_a(t) + \sum_i \hat{r}\delta(t - t_i)\right) * h(\tau), \tag{7}$$

where, t_i is the time that a new flow is admitted by the admission control. The additional term in (Eq. 7) is an initial bandwidth reservation that is added with $\widetilde{\mu}_a(t)$ each time a flow is admitted and lasts until the flows traffic is fully reflected in $\widetilde{\mu}_a(t)$. By incorporating this initial bandwidth reservation the MBAC protects the resources of the just admitted flow.

Unfortunately, we indicated that TSD-AE has a poor utilisation performance. The reason for this, is that the initial bandwidth reservation effects the variance estimation. Actually, it introduces a large estimation error in $\widetilde{\sigma}_a(t)$. To solve this problem we enhanced the criterion in TSD-AE by separating the initial bandwidth reservation from the estimated mean $\widetilde{\mu}_a(t)$. In this way, the correction will be independent of the variance estimation and the MBAC still fulfils its goal to protect the just admitted flows. The enhanced TSD algorithm is called TSD-EAE and is given by

$$C - \widetilde{\mu}_a(t) - \varphi(t) - \hat{r} > \alpha_{qos}\widetilde{\sigma}_a(t), \tag{8}$$

where

$$\varphi(t) = \sum_i \hat{r}\delta(t - t_i) * h(\tau). \tag{9}$$

In the next section we evaluate the performance of TSD with different type of criteria by simulations.

VI. Performance evaluation

A. Simulation Approach

We used the Network Simulator v2 (ns2) [19] to evaluate the different variants of the TSD algorithm (TSD-FE and TSD-AE) and our enhanced algorithm TSD-EAE. Within the ns2 framework we have built an IP-RAN simulator that is based on RIMA as described in section II.

The study is conducted in two parts. First, the performance of the TSD algorithm is evaluated in the simplest case, we used the TSD in a single bottleneck link in order to investigate the maximum link utilisation and the packet drop ratio. In the second scenario, we consider a network topology where we investigate the network link utilisation. For simplicity reasons, we consider only real-time traffic in this study. This means that all the bandwidth is assigned to priority traffic.

In all the simulations, we used the following traffic model. The inter-arrival time is exponentially distributed with a mean of 0.5 seconds. The flow holding time is also exponential with a mean of 100 seconds. In a flow, the length of ON and OFF periods were both following the Pareto distribution with a mean of 5 seconds and parameter α of 1.1. Unless otherwise stated, during ON periods a 40 bytes packet was sent in every 20 ms for each flow generating 16 kb/s peak load. Hence, the sources represent the behaviour of voice flows with heavy tailed ON and OFF periods.

The parameter settings of the TSD algorithm are: $p_{loss\ target}$ = 10^{-4}, K = 10, and T_s = 20 ms, as suggested in [17].

All the simulations have duration of 5000 seconds and were repeated using different random number generators. We consider one performance measure in evaluating the TSD algorithm, which is link utilisation. This measure represents how much of the link's or network's maximum data rate is used.

B. One-link Scenario

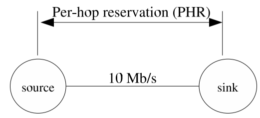

Figure 3: one-link scenario

In the first scenario, our goal is to investigate the maximum achievable link utilisation of the TSD algorithm. We used a single bottleneck link of 10 Mb/s with a link delay of 1 ms and a queue size of 25 packets. As shown in Fig. 3, RIMA PHR operates between the source and the sink. The source initiate flow requests and the RIMA PHR protocol performs admission control for this single link. Furthermore, during this experiment we varied the mean flow active time from 20 to 160 seconds. Note that for this scenario we have used only homogeneous voice flows.

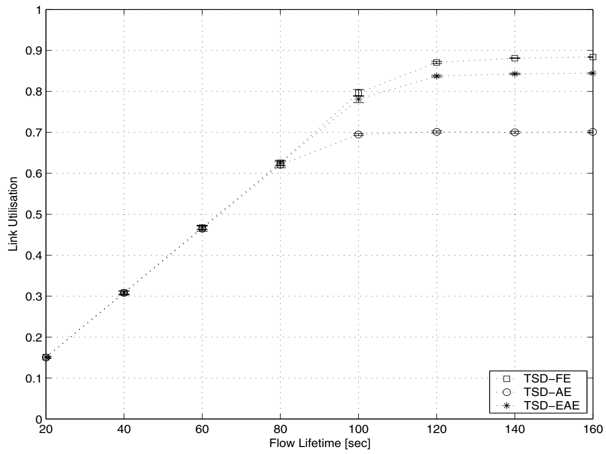

Figure 4: Link Utilisation for a one-link scenario

Fig. 4 shows the utilisation performance of TSD-FE, TSD-AE, and TSD-EAE for a single bottleneck link. A number of observations can be made. The link can only be fully utilised at flow active times higher than 100 seconds because the offered load is then 100 percent of the link capacity. As expected, TSD-FE provides the highest link utilisation, approximately 0.89, and it allocates 11 percent of the link bandwidth to capture the traffic variance. TSD-AE, in turn, has the lowest link utilisation of 0.7. This is caused by three variance components, traffic variance, variance due to flow dynamics, and the variance contribution due to the correction in (Eq. 7). Our proposal, TSD-EAE achieves link utilisation of 0.84. Its utilisation is only limited by the traffic variance and the variance due to flow dynamics.

C. Network Scenario

In this subsection we investigate the link utilisation for a typical RAN network.

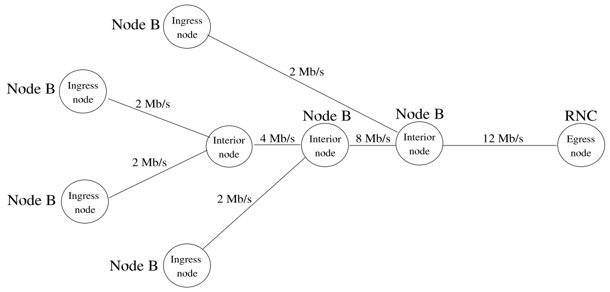

Figure 5: Tree network topology

As shown in Fig. 5, the simulated IP-based RAN has six Node Bs, and one RNC. Each link between these nodes is labelled with its bandwidth. The delay of each link within the network is assumed to be 1 ms. The PDR protocol operates between the Node Bs and the RNC and the RIMA PHR protocol operates in each interior node. Flows are initiated at each Node B and request connection establishment with the RNC. The flows requested bandwidths are: 16 kbps, 32 kbps, 48 kbps, and 64 kbps, which are uniformly distributed.

In this scenario, the link capacity (C) in (Eq. 5, Eq. 6, and Eq. 8) is replaced with vC, where v is the utilisation target parameter. The utilisation target parameter (v) is used in the criteria to bound the maximum link utilisation in order to limit the packet delay in the network.

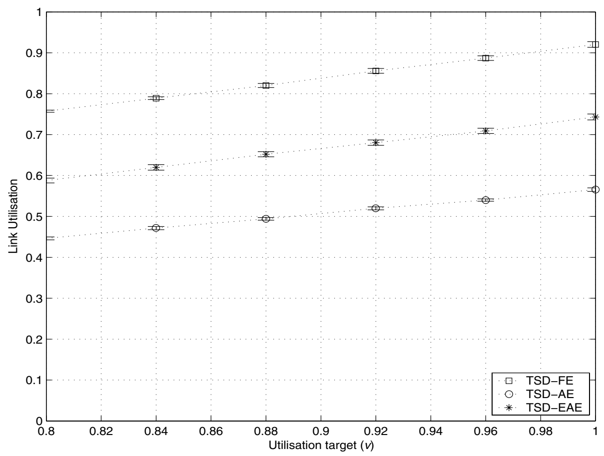

Figure 6: Utilisation for the network scenario

Fig. 6 shows the utilisation performance of TSD-FE, TSD-AE, and TSD-EAE for a network scenario with various utilisation targets. The figure clearly shows a significant performance difference between the various TSD criteria. TSD-FE provides the highest utilisation performance as expected. Whereas, TSD-EAE achieve much better network utilisation than TSD-AE.

As we are focusing on a TSD algorithm that is based on aggregate measurement statistics due to scalability reasons. Our results indicate that for both scenario's TSD-EAE outperforms TSD-AE.

VII. Conclusion

In this paper, we first quantitatively evaluated several MBAC algorithms for the IP-based RAN. We then selected the TSD algorithm as the most suitable MBAC algorithm for IP-based RANs based on the evaluation. We have studied the performance of two variants of TSD algorithm and compared with our enhanced TSD algorithm. In order to perform this study, a UMTS network simulator that is based on RIMA protocol was built in the ns2 framework.

The simulation results show that TSD-FE gives the highest network link utilisation. However, due to its scalability problem this algorithm is not suitable for the IP-based RAN. Furthermore, we have also shown that our enhanced TSD-EAE outperforms TSD-AE and is able to provide satisfactory network utilisation.

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