Development of IPDV of a Real Time Micro Flow Along the Network Path of a Differentiated Services Network

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***Abstract*-- Differentiated Services (DiffServ) Architecture is based on aggregation of traffic as opposed to per flow traffic. When DiffServ is used in a real time traffic environment it is important to study the effects of traffic aggregation on quality of service parameters. Instantaneous packet delay variation (IPDV) is one of the most commonly used quality of service parameters for real time traffic. In this paper we study how IPDV of a micro flow builds up, from the source to the destination, in a DiffServ network. We define the parameters that influence IPDV of a flow at a network node through our simulations and represent them in an abstract analytical model.**

***Keywords*— Differentiated services architecture, quality of service, real time, traffic, IPDV, traffic aggregation**

I. INTRODUCTION

A scalable solution for supporting quality of service in the rapidly expanding Internet is sought through the Differentiated Services (DiffServ) framework [1]. Unlike Integrated Services (IntServ) where each traffic micro flow is treated separately, the DiffServ treats traffic in aggregation [2]. The aim is to achieve scalability and better bandwidth utilisation. However, one major problem is having to deal with different types of traffic generated from different applications.

Expedited Forwarding (EF) is defined in relation to the DiffServ framework to transmit packets with minimum delay [3]. One major parameter of concern in transmission of real time packets is instantaneous packet delay variation (IPDV), which is commonly known as jitter [4]. Jitter or IPDV is based on one-way delay of a selected pair of packets while one-way delay is based on the queue delays at the intermediate nodes.

Weighted Fair Queuing (WFQ) [5,6,7] and Priority Queue (PQ) are two contenders for packet scheduling in DiffServ framework. In PQ scheme the real time packets can be serviced with highest priority. As expected, PQ has better one-way delay and IPDV outcomes compared to WFQ for real time data [8]. The aim of this paper is, mainly, to identify a set of parameters that causes a change in IPDV of a flow at a DiffServ network node and representing them in an abstract analytical model.

Section II of this paper describes the related work carried out by Ferrari et at [9], our previous work in this area and the methodology for measuring IPDV. The basis on which the simulations were carried out was explained in section III while the observations made and the results obtained from the simulations were given in section IV. Section V contains the analytical representation of results. The summary of results is given in section VI under conclusion and we conclude the paper by giving our future direction of work in section VII.

II. RELATED WORK

Ferrari et al [9] have studied the variation of quality of service parameters in the premium service with the number of micro flows. It was found in this study that the packet-loss, one-way delay and IPDV increase with the degree of aggregation. However, in the case of IPDV, how it builds up in the network for a micro flow was not explored.

In our previous work [10,11] we studied how traffic aggregation affects quality of service parameters one-way delay and IPDV. For a single node case the IPDV of a micro flow was found to be increasing with traffic aggregation [10]. Further, in a related study, we found out that the IPDV remains constant, at a single node, as long as the Micro Flow Granularity Index (MFGI) of the flow is constant [11]. In our current study we extend the above work to a multi node DiffServ network.

The IPDV of a pair of packets of a given stream, transmitted from a given source to a given destination, is the difference between the one-way delays of the selected packets [8]. That is, the IPDV of a pair of packets is defined as ddT if the source sends the first bit of the first packet to the destination at wire-time T1 and the first bit of the second packet at wire-time T2 and the destination receives the last bit of the first packet at T1+dT1 and the last bit of the second packet at T2+dT2 where ddT = | dT2 – dT1|. This is illustrated in Fig. 1.

The IPDV between packet i and packet k is

$$IPDV_{ik} = ddT_{ik} = | dT_k - dT_i |$$

In real time packet streaming the packets that arrive relatively early at the destination are delayed in a play-out buffer so that the data is relayed uniformly to the application. This makes it more meaningful to select the 2 consecutive packets of the same stream for IPDV calculation and hence we followed this criterion for all our simulations.

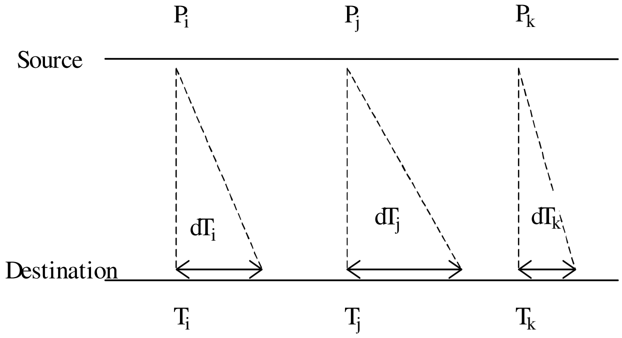

Fig. 1. Defining IPDV

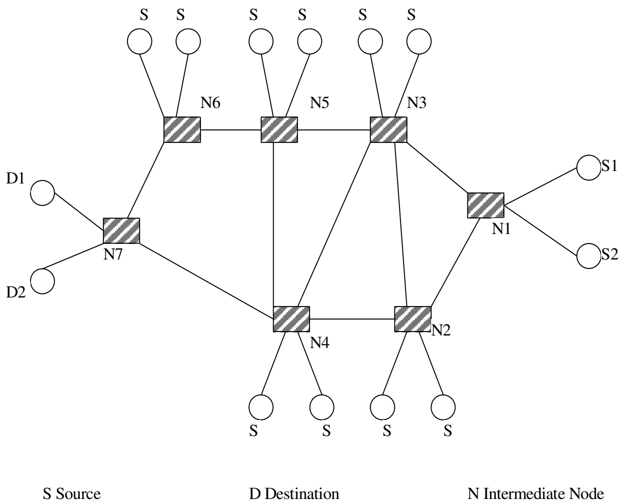

Fig. 2. Network path from source to the destination used in the simulation

III. Simulation Model

The variation of IPDV, along the network path from the source to the destination under different traffic conditions, was obtained. We confined our studies to exponential and constant inter arrival traffic streams; the former with their independent arrivals contributed the random nature of the traffic while latter represented the orderly nature.

As a measure of total aggregated real time traffic we use the term *real time fraction* (RTF); it is defined as the ratio of amount of real time traffic serviced to the total amount of traffic serviced by the queue for a given period of time [11]. That is,

$$RTF = \frac{n_R^\tau}{n_T^\tau}$$

n_R^τ is the number of real time packets serviced during the period τ and n_T^τ is the number of total packets serviced by the queue during the period τ .

The term *micro flow granularity index* (MFGI) is defined as a measure of fraction of packets of a single micro flow transmitted over a given period of time [10]. That is, if n_m^τ is the number of packets of real time micro flow m serviced during the period τ the micro flow granularity index (MFGI) with respect to the flow m is defined as,

$$MFF = \frac{n_m^\tau}{n_R^\tau} \quad .$$

For our simulations we use a DiffServ network whose routers have equal service capacities and are configured to service equal RTFs. A micro flow enters the network at an ingress node, flows through a number of intermediate nodes and exits at an egress node. The service rate of all the routers in the network was 1000 packets per second. We assume that the routers operate at maximum capacity for real time traffic always so that they have maximum effects on IPDV. The packet size for all traffic was kept constant at 512 bits for all simulations. The packet service time was proportional to the size of the packet, thus giving constant service time to each packet. OPNET Modeller 9.0 was used for the simulation. The results were obtained for 4 different MMFs of 0.5, 0.25, 0.125 and 0.083. Priority queue scheduling scheme was used at all the nodes with real time packets being serviced with the highest priority. The network topology used is shown in Fig. 2. The real time micro flow under observation was transmitted from the source S1 to the destination D1 through intermediate nodes N1, N2, N3, N4, N5, N6. When the intermediate nodes were fed with sources (S) they represented edge routers while they functioned as inner routers when all the sources were disabled.

IV. Observations and Results

A. Build up of IPDV of a micro flow at the intermediate node

Real time packets of a given micro flow are transmitted through two types of nodes in a DiffServ network – edge routers and inner routers. Edge routers usually have many incoming micro flows aggregated, thus causing the traffic be more unordered. On the other hand the inner routers are likely to get more ordered traffic and a fewer number of aggregations. These two types of traffic are represented in our simulations by exponential and constant inter-arrival traffic, respectively.

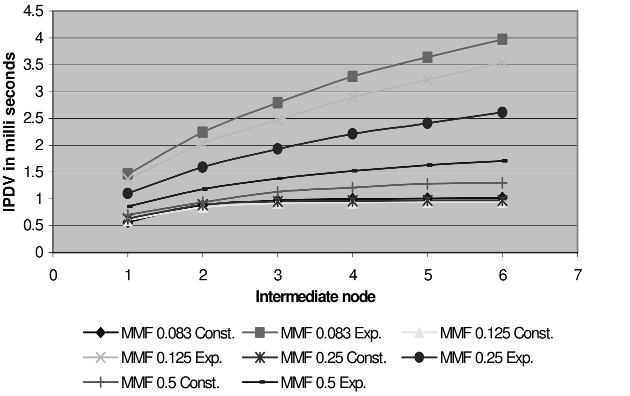

Fig. 3. Variation of IPDV of a flow generated by a source of exponential inter arrival, at intermediate nodes served with constant and exponential traffic

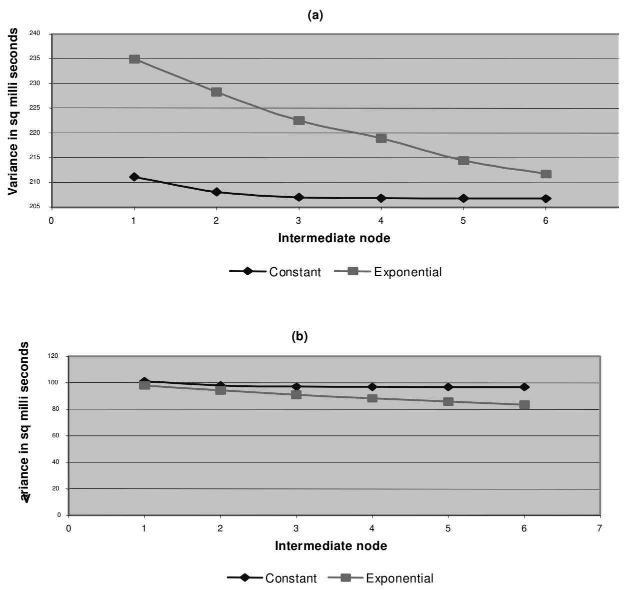

Fig. 4. Variance of packet inter arrival time for (a) MMF 0.083 (b) 0.125

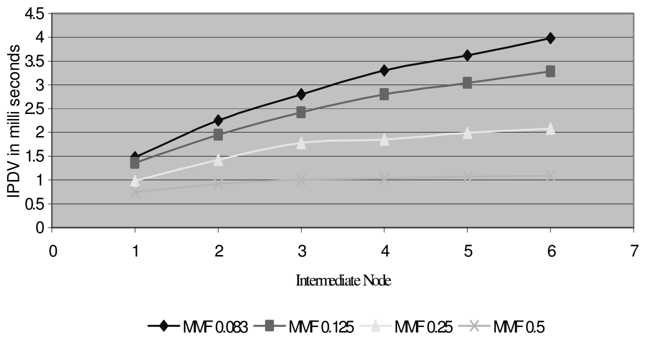

Fig. 5. Variation of IPDV of a flow generated by a constant inter arrival source, at intermediate nodes served by exponential inter arrival traffic

1) Micro flow having exponential inter-arrival initially

When a micro flow of exponential inter-arrival initially flows through the intermediate nodes, we observe that the effects on its IPDV due to other traffic at each node get lessened: that is the IPDV gets stabilised as the number of nodes increases (Fig. 3). We also observe that the variance of the packet inter arrival time, generally, is reduced at the same time (Fig. 4).

This gives the notion that the packets in the micro flow become more ordered. Further, the traffic of the micro flow clearly gets two different types of treatments when encountered with constant and exponential inter arrival traffic at the nodes it flows through till the destination. The IPDV of the flow that aggregates purely with constant inter arrival traffic at the intermediate nodes stabilises to a lower value than one aggregated with exponential inter arrival traffic.

2) Micro flow having constant inter- arrival initially

The IPDV variation for a micro flow of constant inter-arrival shows a similar pattern to the micro flow of exponential inter arrival when the MMF is low and intermediate nodes are served with exponential traffic; for high MMF value the IPDV stabilises to lower value than for a micro flow of exponential inter arrival (Fig: 4.3). This gives the notion that when the MMF is lower the effect from other traffic is larger whereas for higher MMF it is smaller. When the intermediate nodes are served with synchronised constant inter arrival traffic the IPDV values remains at bare minimum (very close to zero). However when the other traffic is not synchronised higher IPDV values are observed as in 0.5 MMF case. Higher MMFs tend to give less synchronised traffic and as a result the effects of residual time [10,11] of non real time traffic on IPDV can be considerable.

B. Effects of traffic content of intermediate nodes on destination IPDV of a micro flow

1) When intermediate nodes were fed unsymmetrically (all the nodes were not fed with same content)

When the intermediate nodes were fed with combinations of constant and exponential inter arrival streams the IPDV at the destination of a given flow showed a particular pattern: the value lie in between the IPDV range given by the two extreme scenarios of having all the intermediate nodes fed with constant inter arrival streams and all of them being fed with exponential streams (Fig. 6). More the number of intermediate nodes with exponential traffic, the higher the IPDV at the destination or in other words closer to the IPDV of having all the intermediate nodes fed with exponential traffic. This leads to the notion that the maximum IPDV a given micro flow may have accumulated at the destination would be when all the intermediate nodes were receiving exponential traffic streams. There should be, in essence, statistical variations of this highest possible IPDV value of a given micro flow travelling through a predetermined path of a given number of nodes.

2) When all the intermediate nodes were fed symmetrically (all the nodes were fed with same content)

The variation of IPDV at the destination node with equally fed fraction of exponential traffic at each intermediate node shows a similar pattern to when the same fraction of exponential traffic is fed by means of number of fully exponential traffic feeding intermediate nodes (Fig. 7). In other words, for an example, fully feeding 3 of the 5 intermediate nodes with exponential traffic and feeding each of 5 intermediate nodes, 60% of its capacity, with exponential traffic produced similar IPDV values at the destination, except for statistical variations. In both cases the other fraction of traffic was fed with constant inter arrival traffic; 2 of the other intermediate nodes were fully fed with constant traffic in the first case while 40% of the total capacity of each intermediate node was fed with similar traffic in the latter. This gives the notion that the IPDV of a given micro flow at the destination is only dependent on the fraction of exponential traffic it aggregated along the way, irrespective of how and when the aggregation took place

C. Effects on IPDV of a flow at a node by other incoming traffic

The increase of IPDV of a given flow at an intermediate node is dependant on the fraction of incoming exponential traffic from other sources. In our simulation the other portion of the incoming traffic consist of traffic with constant inter arrival. Lets define the term ETF, which gives the fraction of exponential incoming traffic against total amount of incoming traffic at a given time, for an intermediate node. That is,

$$ETF = \frac{n_e^\tau}{n_e^\tau + n_c^\tau}$$

where n_e^τ is the number of packets from exponential streams arrived at the intermediate, during the period τ and n_c^τ is the number of packets from constant streams arrived at the same node during the same period of time. The sum $n_e^\tau + n_c^\tau$ consists of the total number of packets arrived at the node other than the micro flow of our concern. We observe that the increase of IPDV of this micro flow at the node increases with the increase of ETF (Fig. 8).

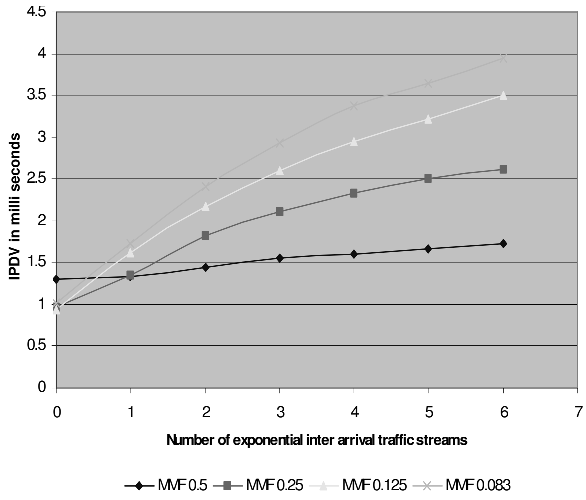

Fig. 6. Variation of IPDV with number of exponential inter arrival traffic streams at intermediate nodes for RTF 0.8

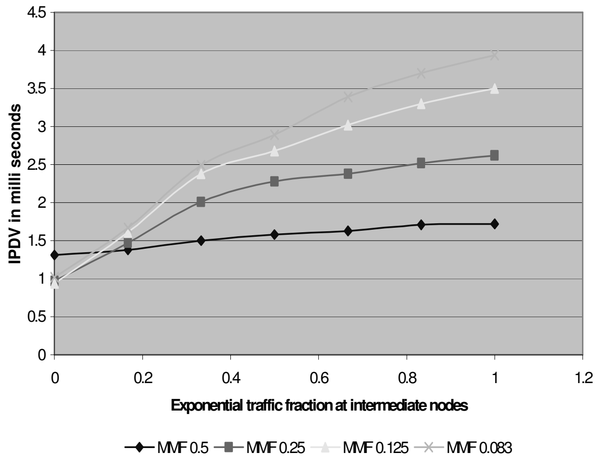

Fig. 7. Variation of IPDV at the destination with equally fed exponential traffic fraction at each intermediate node

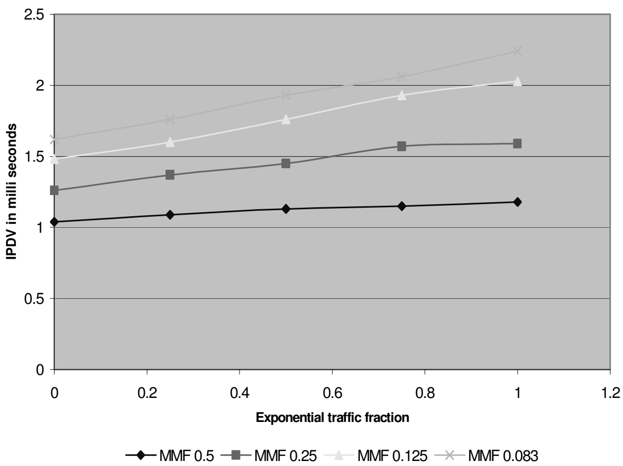

Fig. 8. Variation of IPDV with exponential traffic fraction

V. REPRESENTING THE RESULTS ANALYTICALLY

Consider a DiffServ network whose routers have equal service capacities and are configured to service equal Real Time Fractions (RTFs). Let M_f denote the function of Micro Flow Fraction (MFF) of a given flow, which enters the network at an ingress node and flows through a number of intermediate nodes before exiting at an egress node. That is,

$$M_f = M_f(a_f, s_c, r_{fr}) \qquad (1)$$

where a_f is the mean traffic arrival rate of flow f, s_c is the service capacity of each router and r_{fr} is the Real Time Fraction (RTF). Since it is assumed that s_c and RTF are equal for all the routers in the network, we have

$$M_f = M_f(a_f). \qquad (2)$$

An intermediate node could be another ingress node for some other micro flows or an internal node, which could be an aggregation point for a number of aggregated flows. The intermediate nodes are fed with other exponential and constant inter arrival traffic of varying proportions. Exponential inter arrival traffic is fed to study the effects of random arrivals on the given micro flow while constant inter arrival traffic gives an insight on the effects of more orderly traffic.

Let E_e^i denote the function of Exponential Traffic Fraction (ETF) at the intermediate node *i* (i = 1, 2, 3, ...) for the given micro flow. The subscript *e* shows the numerical value of ETF. That is,

$$E_e^i = E_e^i(a_e^i, a_c^i) = \frac{a_e^i}{a_e^i + a_c^i} \quad \forall \ i > 0 \qquad (3)$$

where a_e^i and a_c^i are the other incoming exponential and constant traffic arrival rates at node *i*.

Similarly T_e^i denote the function of Total Exponential Traffic Fraction (TETF) at the intermediate node *i* (i = 1, 2, 3, ...) of the given micro flow. The subscript *e* shows the numerical value of TETF. That is,

$$T_e^i = \begin{cases} T_e^i(t_e^i, t_c^i) = \dfrac{t_e^i}{t_e^i + t_c^i} \ldots\ldots\ldots\ldots\ldots \forall i > 1 \\ 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots i = 1 \end{cases} \qquad (4)$$

where $t_e^i = \sum_{j=1}^{i-1} a_e^j$

and $t_c^i = \sum_{j=1}^{i-1} a_c^j$.

Let initial traffic state of micro flow f be denoted by the function S_f^0. It gives an indication of how orderly the traffic stream is. That is,

$$S_f^0 = S_f^o(\sigma_f^0) \qquad (5)$$

where σ_f^0 is the initial variation of packet inter-arrival time of micro flow f.

Let IPDV increase of micro flow f at intermediate node i is denoted by I_f^i. Then as observed from the simulations we have,

$$I_f^i = I_f^i(M_f, E_e, T_e, S_f^0). \qquad (6)$$

The IPDV of micro flow at the destination, I_f^{dest}

$$I_f^{dest} = \sum_{i=1}^{N} I_f^i$$

where *N* is the number of intermediate nodes the micro flow f passes through.

The maximum IPDV a given flow f may accumulate at the destination, $I_{f,\max}^{dest}$ is given when the flow aggregates with maximum amount of exponential inter-arrival traffic along the path. That is,

$$I_{f,\max}^{dest} = \sum_{i=1}^{N} I_f^i(M_f, E_{1.0}^i, T_{1.0}^i, S_f^0) \qquad (7)$$

Similarly the minimum IPDV a given flow f may have at the destination, $I_{f,\min}^{dest}$ is given when it aggregates with the least amount of exponential inter-arrival traffic along the path. That is

$$I_{f,\min}^{dest} = \sum_{i=1}^{N} I_f^i (M_f, E_{0.0}^i, T_{0.0}^i, S_f^0) \quad (8)$$

Since all the routers are assumed to operate in full capacity from (3) for a given flow f we have

$$a_e^i + a_c^i = s_c r_{fr} - a_f \quad (9)$$

and $$E_e^i = \frac{a_e^i}{s_c r_{fr} - a_f} \quad (10)$$

From (4) and (8) we have

$$t_e^i + t_c^i = \sum_{j=1}^{i-1} s_c r_{fr} - a_f = (i-1)(s_c r_{fr} - a_f) \quad (11)$$

and $$T_e^i = \frac{t_e^i}{(i-1)(s_c r_{fr} - a_f)} \quad (12)$$

Alternatively, from (2), (5), (9) and (11) we have

$$I_f^i = I_f^i (a_f, a_e^i, t_e^i, i, \sigma_f^0) \quad (13)$$

VI. CONCLUSION

We have worked out the parameters Micro Flow Fraction (MMF), Exponential Traffic Fraction (ETF), Total Exponential Traffic Fraction (TETF) and initial traffic state (S_f^0) which cause a change in IPDV of a micro flow at an intermediate node. These parameters are obtained for a DiffServ network operating under a given set of conditions. We restricted our studies for traffic streams of exponential and synchronised constant inter arrival. The IPDV of a flow depends mainly on the difference of the number of packets in the queue to be served at the time of arrival of two consecutive packets of the micro flow [10,11]. This difference, on the whole, is more likely to be larger for more random stream of arrival than an orderly one. That is, random traffic is instrumental for maximising IPDV while the synchronised ordered traffic minimises it. This is evident in our simulation results as the micro flows that aggregated more with exponential traffic got the higher IPDV values at the destination. Under the given conditions an upper bound for the IPDV of a flow, barring the statistical variations, can be determined by aggregating it with exponential traffic to the maximum.

VII. FUTURE DIRECTIONS

An immediate objective is to develop our current analytical results to a more concrete model. That is, based on the parameters we have worked out, an expression to determine the IPDV of a flow is to be developed. Secondly we expect to generalise our current work more by removing some of the conditions under which they were obtained. For example, the condition that all the routers service in equal capacity could be removed for more generic results. The work is also to be extended for other type traffic without restricting for exponential and constant traffic only. More broadly, we plan to investigate the possibilities of deploying better packet scheduling schemes to overcome the negative effects on quality of service parameters, such as IPDV, by existing algorithms [12,13,14]. That is, scheduling algorithms will be sought, for DiffServ environment, with special focus on such parameters.

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