Performance Evaluation of the Flow-Aware Networking (FAN) architecture under Grid environment

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***Abstract*—Grid networks have captured a lot of attention in recent years because of their potential to generate new applications thanks to network, computing and storage resources virtualization. Quality of Service (QoS) is a key issue for Grid services provisioning. Current Grid services are provided on multi service networks such as the Internet. Thus, QoS architectures originally developed for the Internet such as DiffServ (DS) have been tested in Grid environment. Since Grid network services based on Internet networks will be developed in the next years, we propose in this paper to investigate the potentialities of an innovative Internet QoS architecture known as Flow-Aware Networking (FAN). FAN appears as a promising alternative to DS for QoS provisioning in IP networks. DS proceeds to traffic differentiation and QoS provisioning through IP packet marking whereas FAN consists in implicit IP flow differentiation and a flow-based admission control. A Grid session may be seen as a succession of parallel TCP flows with voluminous data transfers. In this paper, we compare by means of computer simulations the performance of FAN and DS architectures under Grid environment. Two metrics are adopted for that purpose: the average transit delay and the average goodput of a Grid session in an IP access router.**

***Index Terms*—Quality of Service; Flow-Aware Networking; Grid Networks.**

I. Introduction

Grid networks consist in large-scale distributed hardware and software resources (computing, storage, information, network components, equipment, sensors, etc.) that provide flexible, pervasive, and cost-effective services to the users. The ”Grid” term has been adopted in analogy with the power Grid. Furthermore, by sharing distributed resources on-demand, Grid networks enable the creation of virtual organizations (utility computing, utility storage, etc.) [1]. Grid networks are progressively deployed over IP networks. Several IP access router architectures have been proposed for QoS provisioning in IP-based Grid networks. Some of them are inspired from the DS architecture: GARA [2], NRSE [3], G-QoSM [4], and GNRB [5]. Nevertheless, none of these proposals has been widely adopted. QoS provisioning for IP-based Grid networks remains today a big challenge because of the distributed nature of physical components and network resources. To solve this problem, several investigations referring to DS have been carried out: [6], [7], [8], [9]. Moreover, new QoS concepts and architectures have been tested in experimental platforms: Equivalent Differentiated Services (EDS) [10], programmable networks [11], active networks [12], DiffServ-IntServ [13].

This work proposes the evaluation of a new promising approach for QoS provisioning in Grid networks called Flow-Aware Networking (FAN) [14]. Whereas DS-based approaches proceed to per-packet traffic control, FAN relies of per-flow traffic control mechanisms. Compared with packet-based router, the FAN architecture offers enhanced performance in terms of packet processing [15]. Our previous work [16] has shown that the second generation of FAN (2G-FAN) confirms this superiority of FAN over DS under Grid traffic, even if flow parallelization of Grid sessions tends to reduce this benefit. In this work we extend our

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previous analysis by introducing cross-traffic and by increasing the average job size. The DS architecture must be configured in order to facilitate a fair comparison with FAN architecture.

This paper is organized as follows. In Section 2, we briefly recall the basic characteristics and objectives the DS architecture. We then describe the GARA architecture [2] that aims to extend the DS functionalities for the Grid environment. Section 3 is dedicated to the description of the second generation FAN (2GFAN) architecture. Initially designed for traditional IP networks, we show how the 2GFAN architecture may be adapted to the Grid environment. In Section 4, we compare by means of computer simulations the performance of DS and 2GFAN architectures applied to IP access routers in the context of Grid networks. We conclude this paper in Section 5.

II. Quality of Service in IP networks and under Grid environment

Native IP technology is connectionless and only offers Best Effort (BE) services. Two paradigms have been proposed to improve QoS in IP networks: Integrated Services (IntServ) [17] and Differentiated Services (DiffServ) [18]. IntServ (IS) is based on the concept of flow defined as a packet stream that requires a specified QoS level and it is identified by the vector “IP source address, IP destination address, Protocol, TCP/UDP source port, TCP/UDP destination port”. QoS is reached by the appropriate tuning of different mechanisms: resource reservation, admission control, packet scheduling and buffer management. Both packet scheduling and buffer management act on per-flow basis. The state of the flows must be maintained in the routers and periodically updated by means of a resource reservation signaling system. Since it needs to detect each single flow, the cost and complexity increase with the number of flows, IS lacks of scalability.

DS has been proposed to solve the scalability problems of IS. DS classify an aggregation of the traffic in 64 different classes by means of a label in the DS Code Point (DSCP) field of the IPv4 packet header. Identification is performed at edge nodes. The DSCP specifies a forwarding behavior (Per-Hop Behavior; PHB) within the DS domain. Same DSCP may have different meanings in consecutive domains and negotiations are needed. The class selector PHB offers three forwarding priorities: Expedited Forwarding (EF), Assured Forwarding (AF) and Best Effort (BE). Packets marked with the highest drop precedence are dropped with lower probability than those characterized by the lowest drop precedence. Although DS does not suffer from scalability problems, it is not able to provide the required end-to-end QoS to IP flows [19]. To overcome the limitations of IS and DS, the Flow-Aware Networking (FAN) approach [20] described in section III has been proposed.

A. Quality of Service in Grid networks (GARA)

Currently, almost all Grid services are being supported by undifferentiated, nondeterministic, best effort IP services. Grid networks must support many large-scale data-intensive applications requiring high-volume and high-performance data communications. In Grid networks, network performance is not limited to the support for high-volume data flows. It is also measured by the capacity of the network to control fine-grained applications [21]. Early attempts to integrate Grid environments and networks services were primarily focused on Application Programming Interfaces (APIs) that linked the Grid services to Layer 3 services. Using this approach, DS-based router interfaces must ensure that applications requirements could be fulfilled by network resources and are controlled by Grid services. The combination of Grid services and DS techniques provides capabilities for governing many basic network process elements, including those related to policy-based service determination, priority setting, highly granulated (individual packet) behavior control (through DSCP marking), application classification, flow characteristic specification, service level specification, policy governance for services, resource requests (including those for router resources), dedicated allocation, use monitoring, and fault detection and recovery [21]. Moreover, experiments demonstrated that combining Grid services DS(EF), can provide Grid applications with significant control over network behavior. These initiatives showed that this control can be implemented not only at network edge point, but also within edge hosts. All these remarks are at the origin of the General-purpose Architecture for Reservation and Allocation (GARA)[1] [2] specifications that are part of the Globus Tool Kit (GTK)[2]. GARA was created to manage admission control, scheduling, and configurations for Grid resources, including network resources. GARA has been used in experimental implementations to interlink Grid applications with IS and DS-based

[1] http://www-fp.mcs.anl.gov/qos/gara.htm
[2] http://www.globus.org/

routers as well as for Layer 3 resource allocation, monitoring, and other functions on local or wide-area networks. GARA is extensible to other network layers and is not specifically oriented to services at a specific layer. GTK is currently being extended to Open Grid Services Architecture (OGSA) which also embraces Web services. Other efforts to provide network QoS in Grid networks are: NRSE [3], G-QoSM [4], and GNRB [5].

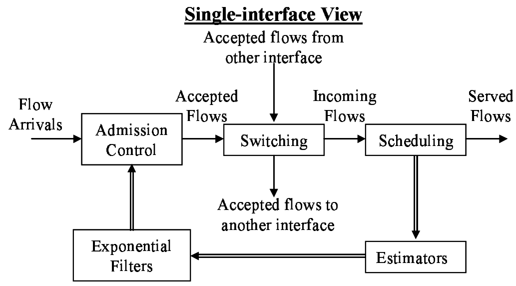

Fig. 1. Flow-Aware Networking components

III. Flow Aware Networking (FAN)

A first generation (1G) of FAN was proposed in [20] as a new approach to offer QoS at flow level. A flow can be considered a stream of packets with same header attributes and with a maximum inter-packet space and is classified explicitly (like in DS). Second generation of FAN (2GFAN) performs implicit classification (no packet marking as in DS, no resource reservation as in IS) of flows into either streaming (high-priority) or elastic (low-priority), and defines an admission control mechanism. 2GFAN seeks two objectives: on the one hand, it gives preference to streaming flows on attempts to minimize the delay and loss (signal conservation) they experience but, at the same time, it aims at assuring a minimum throughput rate to elastic flows (throughput conservation). 2GFAN simplifies network operations leading to potentially significant costs reductions in the IP backbone because it increases network efficiency. It requires no change to existing protocols and no new protocols, it can be implemented as an individual device connected to each BE router interface. 2GFAN combines two flow-based traffic control mechanisms: Per-flow Fair Queuing (pfFQ) and Per-flow Admission Control (pfAC). pfFQ ensures that link bandwidth is shared equitably between contending flows and pfAC ensures the scheduler performs correctly even in overload by keeping the rate at pfFQ above a minimum threshold. On high capacity links fair queuing is enough to guarantee low packet delay and loss for real-time flows (whose rate is less than the fair rate). An accepted flow is protected during all its transmission time if the time interval between two packets of that flow keep below a timeout value. To this aim, accepted flows are registered in a list called Protected Flow List (PFL). Figure 1 shows one interface of FAN router.

The queuing in 2GFAN architectures has one priority queue and a secondary queuing system. The admission control is proactive measurement-based and of threshold type. Packets of flows emitting at less than the current rate in pfFQ are given priority. To accomplish their tasks, 2GFAN uses two estimators: Priority Load (PL) and Fair Rate (FR). PL is the service rate of the priority queue and FR is the service rate a new TCP flow can get when using fair queuing. PL is estimated every tenths of milliseconds (packet timescale) and FR is estimated every hundredths of milliseconds (flow timescale). The fair rate measure is equivalent to the available throughput available for a new TCP connection and is estimated using the TCP phantom technique [22]. The priority load estimator represents the amount of bytes served by the priority queue during the sampling period. Figure 2 shows the structure of the admission control.

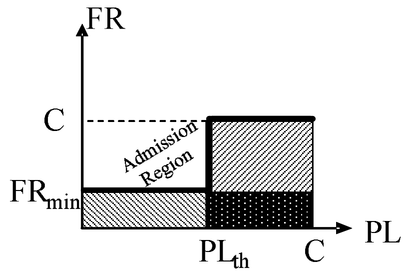

Fig. 2. Flow-based admission control mechanism

Incoming flows are denied access to the system, when the 2GFAN architecture can not guarantee a given performance level (delay and fair rate). The complete process is as follows: When a packet arrives at the system, the admission control finds the flow it belongs to, namely f_n, and evaluates whether such f_n is in its inner Protected Flow List (PFL). This list stores the ids of each flow already accepted and transmitted over the IP layer. If $f_n \in$ PFL, then the packet is served. Otherwise, the packet is part of a new flow which must pass through the admission control process. When so, it is tested whether $PL < Th_{PL}$ and $FR > Th_{FR}$, that is, whether a given QoS guarantees defined by the Th_{PL} and Th_{FR} thresholds are maintained or not. If this is the case, the new flow is accepted; otherwise, it is rejected. Although flows already accepted are somehow protected, only those flows which transmit at a lower rate than Th_{FR} are treated as streaming flows (high-priority). All the others are considered as elastic flows and receive less preference. This is done in order to avoid flows which abuse from the system resources. Finally, a Priority Fair Queuing (PFQ) policy, as defined in [23] (which is based on the Start-time Fair Queuing algorithm [24]), is used to give preference to streaming over elastic flows.

Basically, PFQ is a PIFO (Push In First Out) queue, which stores packet information (flow identifier, size and memory location) and time stamp, the latter determined by the SFQ algorithm. The PFQ queue is split into two areas delimited by a priority pointer (see fig. 3), whereby streaming flows are temporally stored at the priority queue area (at the head of the queue), and the elastic flows are stored at the tail of the queue. Preference is given to the priority area since it is served before the non-priority area. Finally, the queue stores elastic and streaming packet count statistics, which are further used to compute the values of PL and FR.

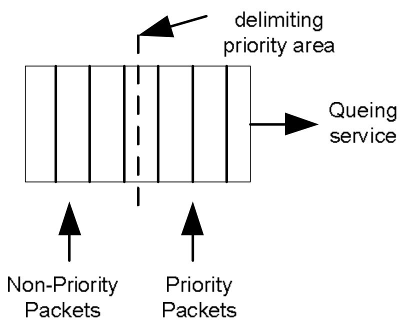

Fig. 3. Priority Fair Queue architecture

In addition, an Active Flow List (AFL) is maintained by the PFQ. This list is similar to the PFL defined above, but it also saves the amount of packets transmitted per flow in the recent past. The flows with the greatest amount of transmitted packets (also known as greatest "backlog") may be discarded under severe congestion conditions. This list may be thought to pose scalability problems. However, as shown in [25], this is not the case, and 2GFAN scales well. Some FAN architectures have been tested [26], [15], patented [27], [28], standardized [29] and commercialized [30]. In addition, in [15] authors compared flow-based and packet-based routers; flow-based approach offers enhanced performance in terms of packet processing. Also, to our knowledge, the only research work on QoS at flow level and related to Grid networks but applied to cluster networks is [31]. Their results show that flow level bandwidth guarantees are achievable with two of their proposed admission control schemes; they achieved an order of magnitude in jitter and latency in individual flows. All the above show that FAN is a promising approach for provisioning QoS.

A. IP traffic over FAN (IPoFAN) characterization

Internet traffic at packet level granularity can be approximated by a self-similar process [32]. Nevertheless, designing traffic control mechanisms for this traffic is very complex (e.g. Token Bucket configuration) [14]. By looking the Internet traffic at the granularity of flows is easy to see that the traffic is mostly concentrated on the TCP (elastic) and UDP (streaming). It was shown that traffic control at flow level is appropriate because users perceive QoS at this time-scale [33]. IP traffic may be represented by sessions mutually independent arriving as a stationary Poisson process [34] in case of a large number of independent demands [35]. An Internet session is a set of flows whose initial times are separated by random times called "think times" [36]. This can be modeled as a Kelly network with a processor sharing queue and a infinite server feedback [37]. It has been shown that the output process for this network is Poisson if the input is also a stationary Poisson process. This property is known as Poisson-In-Poisson-Out [38] and justify that flows, as conceived by FAN architectures, arrive following a Poisson Process.

B. Grid Traffic over FAN (GoFAN)

To the best of our knowledge, no Grid traffic modeling has been published at the date of this study [39]. In this work, we assume that Grid traffic arrivals follow a stationary Poisson process. Also, our model is based in the fact that the most used software platform in Grid community is Globus Tool Kit (GTK)[3] and offers a transport service called GridFTP [40]. GridFTP has the option of parallel channels where several TCP connections are sent at the same time. GridFTP has reached near to 90% of use over a 30Gbps link in a memory-to-memory transfer. When used to a disc-to-disc transfer, the throughput reached was 58.3% in the same link [21]. We assume that our Grid

[3] http://www.globus.org/

traffic is composed of GridFTP sessions that arrive following a stationary Poisson process with several intensities according to the average arrival rates limits [41]. We assume that job sizes follow an exponential distribution with means 100MB or 500MB, the average packet size being 1000 Bytes.

C. Motivations for FAN versus DiffServ comparison under Grid environment

Our first motivation is to test if the flow-based approach is an alternative architecture of DS for provisioning QoS in Grid networks. Second, we want to evaluate the advantages of flow-based admission control against DS under Grid environment. Moreover, with FAN, admissions decisions become network-aware or bring the network as first-class resource [21]. Also, flow admission decisions in FAN are based on real-time measurements of the network performance. Network resources are then allocated according to the current network state. Additionally, the fact that FAN ensures a minimum throughput to elastic flows allows throughout guarantees to accepted GridFTP sessions. Third, In GARA advance reservation is one of the requirements and FAN can use its PFL to facilitate the reservation process. Our last motivation is due to the originality of our approach which has not yet been considered in the literature.

IV. Performance comparison between GoFAN versus GoDS

A. Network configuration

1) Network topology: Figure 4 shows our simulation topology (single domain). A GridFTP source is connected to an ingress router; a similar GridFTP source is used as cross traffic. In the bottleneck link, outbound queue is based either on FAN or on DS. Inbound queue is drop tail (DT). Access queues are DT in both directions.

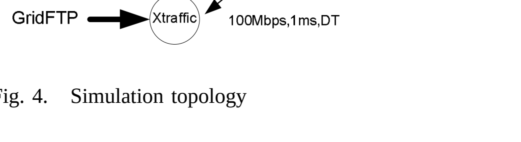

Fig. 4. Simulation topology

2) Mimicking FAN with DS: DS in Grid environments has been traditionally configured as EF [21]. In making a fair comparison we try to mimic FAN as much as possible with DS. Therefore, we choose two physical queues and two virtual queues. When no cross-traffic is applied, we use just one queue in DS. Scheduling is configured as strict priority (like in FAN). The policer (smoother) consists in a Time Slide Window with 2 Color Marking (TSW2CM). The Committed Information Rate (CIR) is equal to FR estimator of FAN and updated at the same time-period. The packet rejection probability is estimated with the size of every virtual queue (RIO-D). RED parameters are fixed at 0.6 and 0.8 of each virtual queue size [42] and the maximal probability is 0.5. The default queue weight is 0.002. In this DS configuration, packets that do not meet CIR are deprecated to the second virtual queue (they lose priority). In FAN, an accepted flow sending more than FR is deprecated to second priority.

3) Operation and management policies: GridFTP configuration is end-host specific, authors in [42] shown that throughput between 90% and 95% can be reached using between 4 and 6 parallel TCP connections, independently of the loss policy [43]. In our case we decided to keep per-flow loss policy. In operational networks, every time a GridFTP session arrives the number of parallel TCP connections is different. To evaluate the impact of the number of parallel TCPs, we assume its number is equal for all GridFTP sessions during simulation. TCP Reno has been adopted in our simulator since it is the most used by the Grid community for parallel connections [44]. In this work, GridFTP sessions are made of 3 or 9 parallel TCP/Reno connections. We assume that job sizes are divisible. We decide to apply a policy of equal quantity per-flow within a GridFTP session. Also, we applied a total GridFTP session admission policy instead of partial admission. Moreover, a single per-flow scheduling policy was applied. In FAN, FR was configured with the value of 0.25 and PL with the value of 0.8. To simplify the configuration of FAN, we considered both estimation periods of identical value of 100 ms [23]. Maximum TCP window size is set to 5000 packets.

B. Metrics

In [45], author suggest that the main QoS metrics for Grid networks are: availability (rejection rate), delay and throughput (goodput). Since we do not apply admission control to DS, only the delay and goodput metrics are considered.

C. Simulation experiments

Simulations were run using *NS-2*[4]. Grid networks use resource reservation mechanisms at different time-scales. We run discrete time simulations for one hour (3600 seconds). We checked that the first 5 minutes of each simulation run correspond to the transient period for reaching the equilibrium regime. Arrival intensities were taken from [41] and ranges from [0,20] arrivals per minute of GridFTP sessions. For each scenario, thirty replications are carried out. We use the inverse method based on time discretization to generate the Poisson process. Also, we use proper selection and configuration of random number generators [46]. Simulation experiments were executed in ns-2.31 under a multiprocessor (SMP) computer with four Intel Xeon at 3.00 GHz and OS Debian 2.6.15.

D. Simulation results

1) Average delay of GridFTP sessions: Figure 5 shows the average transit delay of GridFTP sessions from source to destination expressed in seconds versus the average arrival rate of GridFTP sessions. The average job size is set to 100MB. DS appears more sensitive than 2GFAN to the increase of the offered load. When the number or parallel TCP flows increases from 3 to 9, transit delays increase for both DS and 2GFAN. Meanwhile, for a given offered load, the relative increase of transit delays is negative significant under DS than under 2GFAN. The negative impact of cross-traffic on transit delays is also significant under DS while it is negligible under 2GFAN.

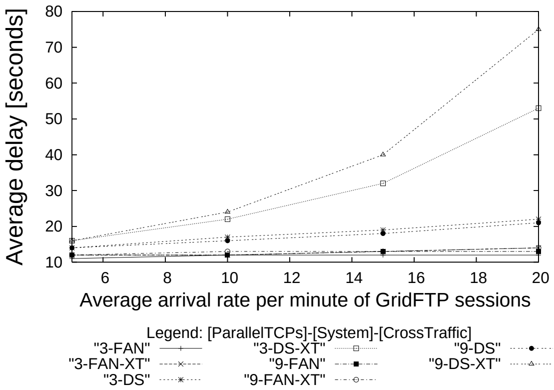

Fig. 5. Average delay of GridFTP sessions with job size of 100MB

Figure 6 shows the average delay of GridFTP sessions in seconds with average job size of 500MB. Again, for a given offered load, transit delays are higher under DS than under 2GFAN. One notices that for a same offered load, the impact of an increased average job size strongly degrades QoS under DS whereas it remains of the same order of magnitude under 2GFAN. This degradation is even more noticeable in presence of cross-traffic than without cross-traffic.

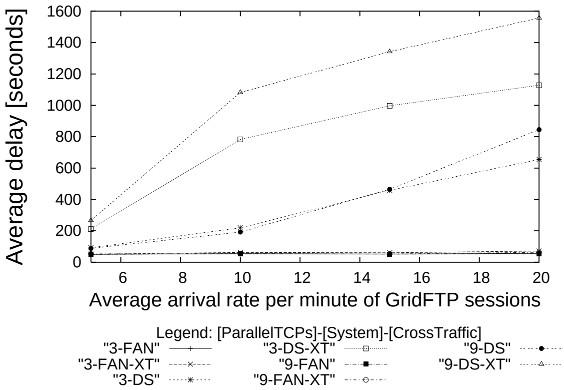

Fig. 6. Average delay of GridFTP sessions with job size of 500MB

2) Average goodput of GridFTP sessions: Figure 7 shows the average goodput of GridFTP sessions with average job size of 100MB. Whatever the number of parallel TCP flows per Grid session and in presence or the absence of cross-traffic, DS evolves better goodput than 2GFAN. For both, DS and 2GFAN, and increasing the number of parallel TCP flows the Grid session as well as cross-traffic degrades the achievable goodput.

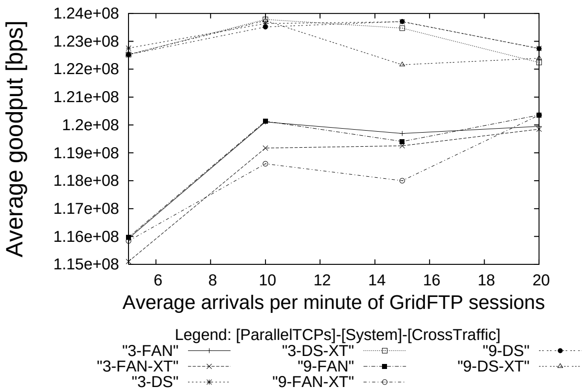

Fig. 7. Average goodput of GridFTP sessions with job size of 100MB

Figure 8 shows the average goodput of GridFTP sessions with 500MB. The superiority of DS over 2GFAN in terms of goodput is reversed, the goodput provided by DS totally collapsing whereas it

[4]http://www.isi.edu/nsnam/ns/

remains stable under 2GFAN. We can conclude from figures 7 and 8 that in the case of cross-traffic, the better stability of 2GFAN over DS in terms of goodput and transit delay makes this technique better suited for Grid environment.

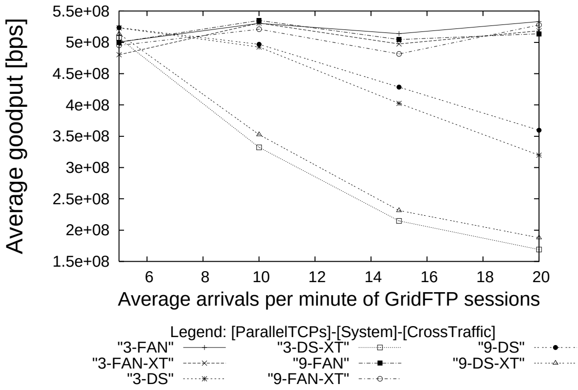

Fig. 8. Average goodput of GridFTP sessions with job size of 500MB

V. Conclusions and future work

In this work, we have compared via computer simulations the suitability of the DS and 2GFAN architectures applied at IP access routers for Grid environment. Our numerical results show that for a given average job size, 2GFAN enables lower average access delays of GridFTP sessions than DS. The higher the GridFTP load, the higher this benefit. We have also observed that for a given offered load, the benefit of 2GFAN over DS in terms of average access delay per Grid session is even more noticeable in presence of cross traffic. We have also investigated the impact of the average job size on DS and 2GFAN efficiency. We have observed a strong degradation of the average access delays of GridFTP sessions with DS, which is not the case with 2GFAN. At the opposite, for a given offered load and a given average job size, the achievable average goodput per Grid session is lower for 2GFAN than for DS. This gap in terms of goodput decreases as the offered load increases. It has been observed that for high job size (over 500 MB), this superiority of DS over 2GFAN disappears, the achievable goodput remaining stable under 2GFAN while it collapses under DS. This degradation of DS performance in terms of goodput is accentuated in the presence of cross-traffic. For all these reasons, we can state that 2GFAN is a very good candidate for Grid services provisioning in IP networks. Our coming investigations will consist in comparing different scheduling algorithms applied to the 2GFAN architecture.

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