RED-based admission control algorithm for Flow-Aware Networks

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***Abstract*—Measurement-based admission control mechanism in Flow-Aware Networks (FAN) may lead to performance issues related to over-admitting, especially when traffic sources generate large number of flows. When too many new transmissions arrive close in time to each other, all of them may be accepted even though there is no room in the outgoing link. The source lies, unfortunately, in the very basic principles of the mechanism. In this paper, we show that there is a simple, yet very efficient remedy to the problem. The proposed solution utilizes the Random Early Detection algorithm. As a result we can steer the number of accepted flows taking into consideration current load in a link. The proposed solution has significant advantages over currently available algorithms for admission control in FAN. Moreover it provides better performance which is confirmed by the simulation results.**

***Index Terms*—Flow-Aware Networks, FAN, QoS, RED.**

I. Introduction

It is very difficult to build a measurement-based admission control block which operates smoothly in the networks where traffic characteristics are unknown a priori. The problem is as follows: how can a device know whether to accept or reject a new transmission when it does not know how much resources is needed for this transmission. There are some approaches to this issue. Flow-Aware Networking (FAN) employs a reactive stance, i.e., new transmissions are blocked only after the congestion in the outgoing link is detected. This is a straightforward approach, yet not without drawbacks. One of the most important is the problem of over-admitting: the device accepts all transmission up to the point when the congestion is detected, which is usually too late. As a consequence too many flows are accepted and the promised service level cannot be guaranteed.

In this paper we show that it is possible to employ a RED-based admission criteria for FAN in order to improve the measurement-based admission control block performance. We compare this solution with the original FAN routine showing clear advantage of the proposed scheme. We also explain why it is better to use RED-based approach rather than other solutions presented in the literature.

The remainder of the paper is organized as follows. Section II introduces the reader to the general concept of Flow-Aware Networking with special attention devoted to those aspects that are crucial to understanding the paper. Section III presents the roots of the so called fair rate degradation phenomenon which exists in FAN. The problem is described with the use of performance metrics. Also, some existing solutions are shown. In Section IV, a new method to solve the fair rate degradation problem is described, while in the following section, the solution is evaluated through simulations. Finally, Section VI concludes the paper.

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II. Flow-Aware Networking

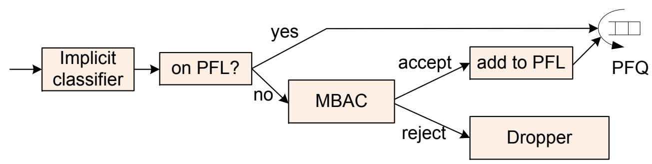

Fig. 1. The principle of FAN operations

Flow-Aware networking is an approach to provide Quality of Service (QoS) assurance in IP networks. The idea is not to provide strict QoS guarantees but to assure that each flow transferred in the network receive a certain minimum guaranteed bandwidth. The concept of FAN was first introduced by Roberts and Ouselati in [1]. The goal was to achieve efficient packet transmission in a simple way, without any signalling protocol and having only minimal knowledge of the network. In various flow-based architectures, the concept of a flow can be understood differently. Also, architectures usually define their set of flow types [2]. In FAN, only two types of flows are distinguished: *elastic* — usually used for data transmissions and served as best effort and, *streaming* — used for low throughput services like VoIP. *Streaming* flows are served with a priority over *elastic* traffic. Since there is no signalling the type of traffic cannot be advertised by the source. Flows are classified as *elastic* or *streaming* based on their current bandwidth consumption only.

As mentioned, FAN strives to guarantee some minimum level of resources for each flow transmitted in a link. It is achieved by the following two main traffic management mechanisms: measurement-based admission control (MBAC) [3] and fair scheduling with priorities [4], [5]. Those mechanisms are implemented in a so-called cross-protect (XP) router. The MBAC is implemented at incoming router interface while scheduler is placed at the outgoing interface. The principle of XP router operations are presented in Fig. 1. All incoming packets are implicitly classified into flows based on the so called 5-tuple, i.e., source and destination addresses, source and destination port numbers and the transport protocol that

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is used. All packets having the same combination of these are identified as belonging to a single flow. Identifiers of flows being served are stored in the Protected Flow List (PFL). If an incoming packet is recognized as belonging to an active flow (stored in PFL) it is forwarded unconditionally. The flow is removed from PFL when it has been inactive (has not sent any packet) for a predefined period. If the first packet of a new flow arrives, the MBAC takes a decision whether to accept the packet, and thereby a new flow, or not. If it is accepted, the flow identifier is added to PFL. Otherwise, the packet is dropped and the flow is blocked. In a not congested network every flow is accepted. When congestion occurs, new flows are blocked to protect the active flows and provide them with a minimum level of service.

The basic MBAC algorithm takes an admission decision based on the information obtained from scheduler placed at the outgoing interface to which the packets of a new flow should be forwarded. There are two indicators measured periodically: priority load (PL) and fair rate (FR). The former informs about the amount of traffic that is treated as prioritized. The latter represents the link's bandwidth that is available for each flow at a given moment. MBAC checks current values of those indicators against predefined thresholds. New flows are not admitted (link is congested) if either PL exceeds threshold $maxPL$ or FR falls below $minFR$ level which determines the minimum transmission rate that is guaranteed to each flow in a FAN network.

Three fair queuing algorithms have been proposed for realizing scheduling block: Priority Fair Queuing (PFQ), Priority Deficit Round Robin (PDRR) and Approximate Fair Dropping (AFD). All the algorithms have, logically, one priority queue for serving *streaming* flows and a secondary queuing system to realize fair sharing of link's bandwidth to elastic flows. More detailed descriptions of application of those queuing algorithms to FAN can be found in [4], [5] and [6], respectively. It has been shown that all the scheduling algorithms have similar performance [7], [8]. In this paper we assume that the PFQ is used. The proposed MBAC algorithm does not require any modifications in the packet scheduler.

Current estimation of priority load in PFQ is calculated using the following formula:

$$PL = \frac{(pb\,(t_2) - pb\,(t_1)) \times 8}{C\,(t_2 - t_1)} \tag{1}$$

where variable $pb\,(t)$ represents values of a counter incremented on the arrival of each priority packet by its size in bytes, while (t_1, t_2) is an interval over which the measurement is done and C is the link capacity. To estimate a fair rate in PFQ, a fictitious flow sending single byte packets is assumed. Such a flow can potentially transmit packets at the link rate if the link is idle. Otherwise, the number of bytes that could be transmitted by such flow is given by the evolution of a so-called virtual time. A fair rate is given by the formula:

$$FR = \frac{\max\left\{S \times C, (vt\,(t_2) - vt\,(t_1)) \times 8\right\}}{t_2 - t_1} \tag{2}$$

where $vt\,(t_2)$ is the value of the virtual time at time t, S is the total idle time during time interval (t_1, t_2), and C is the link capacity. More details on PL and FR calculations can be found in [4].

III. Fair rate degradation

If a FAN link is not congested, the throughput of active flows is not limited by the router. The measured fair rate is above the $minFR$. When congestion occurs, FR decreases to the $minFR$ level and should be maintained at this level to ensure that the available bandwidth is fairly shared by all the active flows, giving each the guaranteed minimum bitrate of $minFR$. In practice, it is difficult to stabilize FR [9], [10], [11]. That problem stems from the algorithm's operation. New flows are accepted if current value of FR is greater than $minFR$ threshold. If a measured value of FR drops below $minFR$ all new flows are rejected. Fair rate measurements are performed periodically. It may happen that in the interval between two consecutive measurements of FR too many new flows get accepted resulting in a significant drop of FR below $minFR$. This problem is called over-admission. Once FR exceeds $minFR$ the MBAC algorithm again starts to accept new flows. It was shown in [9] that using such an algorithm results in high oscillations of FR around $minFR$ threshold. Moreover, FR may drop significantly below $minFR$. If FR deviates too much from $minFR$ than some flows may suffer from unfair sharing of link capacity and may not achieve a minimum transfer speed.

A. Performance metrics

The stability of FR, i.e., its low deviations from $minFR$ and the assurance that it does not fall too much below $minFR$ are the main performance indicators. Therefore, the following two metrics are used to evaluate the admission control algorithm used by MBAC:

- mean deviation δ of a measured FR from the $minFR$ threshold. It is defined as

$$\delta = \frac{1}{n}\sum_{i=1}^{n}\frac{|minFR - FR_i|}{minFR} \cdot 100\% \tag{3}$$

  where FR_i are the measured values of FR over time. The performance of the system is higher if the deviation of FR from $minFR$ is low, that is, FR does not significantly oscillate around $minFR$. In other words, the FR is quite stable during the congestion period. As a result, all active flows share the available bandwidth fairly.
- the percentage of time τ_β in which FR drops below certain tolerance margin of $minFR$ threshold. The margin is defined as $\beta \cdot minFR$ where $0 < \beta \leq 1$. For example, if the factor β is equal to 0.95 the measured value of $\tau_{0.95}$ gives information on the percentage of time (over the some observation period) in which the measured FR is below 95% of $minFR$. This performance metric is very important for streaming applications which require some minimum bandwidth to ensure playback continuity and low video distortions at a user device.

B. Existing solutions

FR oscillations and the over-admission problem can be mitigated by increasing the frequency of measurements of FR, that is, by reducing of interval between consecutive measurements of FR. Since the number of new flows accepted between measurements is statistically lower the system may react faster to a degradation of FR resulting from too large number of accepted new flows. However, as shown in [9] the effectiveness of increasing the FR measurement frequency strongly depends on the number of active flows. The deviation δ increases with the increased traffic. Similarly, FR drops below $minFR$ get deeper if the number of active flows increases. Concluding, the links with high offered load may require more frequent FR measurements to keep values of performance metrics at a reasonably low level. It is a real problem, since frequent FR measurements require high computational power at XP routers. Moreover, FR cannot be measured too often, as the product of such measurement is susceptible to short bursts of traffic which can falsify the outcome.

Another proposed solution is a limitation mechanism (LM). The LM mechanism limits the number of flows that can be admitted between two consecutive measurements of FR to a fixed number. The authors of [9] proved that the algorithm offers better performance than classical FAN admission control with respect to aforementioned performance metrics, δ and τ_β, while keeping low measurement frequency (good results are achievable if FR is measure every second). LM offers low mean deviation of FR independently of the number of active flows. Also the second metric, τ_β, is low and does not increase with the number of active flows and new flows' arrival rate. The main disadvantage of this method is the dependence on the traffic pattern, e.g. the size of flows. It was shown that the limit should be carefully chosen and has different optimal value for different traffic patterns. If it is not selected properly, the performance of the mechanism decreases significantly. Additionally, LM may easily lead to under-admission when the network is not congested. Therefore, the mechanism provides good results, but only when it is configured properly, which is a serious drawback.

LM can be enhanced to provide better performance. For example, in [12], [13], it is shown that the limit can be estimated, instead of being strictly set. Those solutions offer better adaptability to the current network congestion status, usually with the cost of slightly worse performance compared to the properly configured static LM.

IV. RED-based flow blocking algorithm

In this paper, we propose a new MBAC algorithm which derives from a concept of random early detection (RED) used for active queue management to avoid congestions. In RED, if queue length exceeds a predefined threshold, packets are dropped with a probability proportional to the current estimation of the average queue length. The measurements are preformed on each packet arrival. Similar concept is adopted in the RED-based flow blocking algorithm (RFB). In RFB, the admission decision depends on the current measurement of a fair rate. There are two thresholds: $minFR$ and $\alpha \cdot minFR$, where $\alpha > 1$. New flows are accepted with respect to the following rule:

- if measured fair rate is below $minFR$ all new flows are rejected,
- if fair rate is greater than $\alpha \cdot minFR$ than all flows are accepted,
- if fair rate is between $minFR$ and $\alpha \cdot minFR$ new flows are accepted with a probability related to the current value of the fair rate.

Numerically, the probability P_a of new flow admission is defined as follows:

$$P_a\left(i\right) = \begin{cases} 0 & \text{if } FR_i < minFR \\ \frac{(FR_i - minFR)}{(\alpha-1)minFR}\frac{p_{th}}{m+1} & \text{if } minFR \le FR_i \le \alpha \cdot minFR \\ 1 & \text{if } FR_i > \alpha \cdot minFR \end{cases} \tag{4}$$

where $0 < p_{th} \le 1$. Algorithm parameters α and p_{th} are configurable. Parameter α determines the threshold below which the probability of flow admission starts to decrease. The higher the value of α the earlier MBAC starts to react to the increase of a link's load. If the measured FR drops below the threshold $\alpha \cdot minFR$ the link is considered to enter into a congestion state. New flows still can be admitted but the number of accepted flows must be controlled. In turn, the parameter p_{th} decides how strong the reaction to the congestion will be. If p_{th} is low, the admission probability P_a falls immediately when the measured fair rate drops below $\alpha \cdot minFR$ threshold. Additionally, the factor m appears in the formula (4). It is a counter introduced to assure that the number of flows accepted during the measurement period (between two consecutive measurements of FR) will not be proportional to the number of new requests, i.e., the offered traffic. It is crucial for the stability of the algorithm. m counts the number of flows accepted since the last measurement of FR. As a result, the probability of accepting consecutive flows within a single FR measurement period decreases. Otherwise, all new flows within a single measurement period would be admitted with the same probability P_a and the number of admitted flows would be proportional to new flows' arrival rate. After a new measurement of fair rate, the counter is reset to 0. Proper selection of the configuration parameters is crucial for the performance of RFB. The aim is to maintain FR between $minFR$ and $\alpha \cdot minFR$ during the congestion period. It is acceptable that FR occasionally falls below $minFR$ but it should be rare and not severe (refer to τ_β performance metric). This issue is discussed in the paper.

V. Performance evaluation

The performance of the proposed MBAC algorithm was evaluated by a set of experiments implemented in `ns-2` simulator. The network with a bottleneck link of 100 Mbit/s capacity was considered. The traffic on that link was managed with an XP router, i.e., it was a FAN link. The $minFR$ parameter was set to 5 Mbit/s (5% of the link capacity), which is the value usually used in analyses of FAN links. The FR measurement interval was 1 second, which is a reasonable value for this variable. The number of flows L generated differed between simulation experiments and it was set to 1000, 2000, 3000 or 4000. New flows were generated given the exponential distribution. The average time between consecutive flow arrivals was set to $^{100}/_{L}$ [s]. The volume to be sent by each flow was generated following the Pareto distribution with the shape factor 1.5 and the average (mean flow size) set to 15 MB, 35 MB or 50 MB, depending on the experiment. Each time, we simulated 400 s of the working congested link.

To ensure the experiment credibility we disregarded the results obtained in the simulation warm-up period, i.e., the time needed for a link to achieve a stable congestion state. The simulations were repeated until the confidence intervals were sufficiently small. Confidence intervals were calculated from Student t-distribution on 95% confidence level.

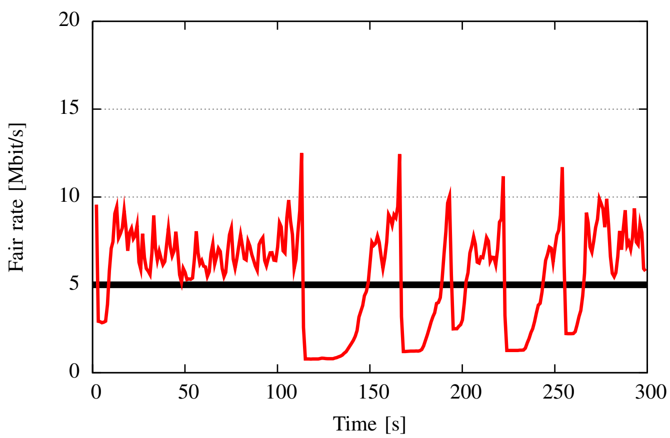

Fig. 2. FR measurements over time.

We evaluated the RFB algorithm under several settings of parameters and traffic patterns. We considered two versions of the algorithm: with and without dividing the admission probability by the factor $(m + 1)$. The aim was to show the effect of this factor.

The first set of experiments was devoted to evaluate the performance under different settings of the algorithm's parameters. The aim was to find the best configuration. In this set of experiments, various traffic patterns were generated. Due to space limitations, we present the configuration which yielded best results: 4000 flows, and average flow size 50 MB. Parameter p_{th} was changed from 0.1 to 1 with a step of 0.1, while parameter α was set to 2, 4 or 6. Resulting values of the RED threshold, $\alpha \cdot minFR$, are equal to 10, 20 and 30 Mbit/s, respectively.

Obtained results are presented in Figures 3 and 4. If the decreasing admission probability is not used, the optimal setting of p_{th} is between 0.2 — 0.4 (Fig. 3 (a)). For higher values of p_{th} the value of $\tau_{0.9}$ increases. Moreover, the results depend on the selection of α. With decreasing probability, the

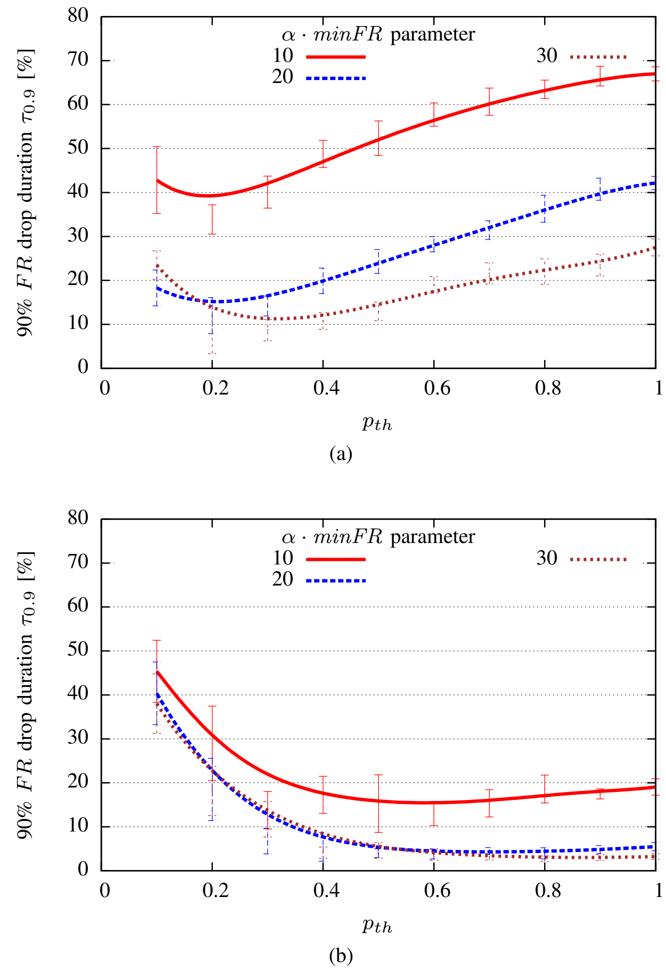

Fig. 3. FR drop duration in FAN with standard RED (a) and RED with decreasing probability (b) with respect to various traffic patterns.

performance of the algorithm is significantly better. Values of $\tau_{0.9} \approx 4.5$ are achievable (not possible without decreasing probability). Additionally, it is observed that the best results are for $p_{th} = 1$ and they are similar for α equal to 4 and 6. Setting higher values of α does not improve the results. The second metric, average deviation δ, decreases for higher values of p_{th} and also achieves a minimum for $p_{th} = 1$. Algorithm without decreasing probability gives slightly better results for lower values of p_{th}. However, for $p_{th} = 1$ the values of δ are almost the same. By focusing on the algorithm with decreasing probability, we can notice that the best results are for $\alpha = 2$. The value of δ increases slightly for greater values of α. Thus, taking into account both metrics, $\tau_{0.9}$ and δ we have a trade-off. However, the former metric is more important since preventing a minimum level of a fair rate is the main goal of FAN. Summarizing, RFB offers the best performance for $p_{th} = 1$ and $\alpha = 4$ (threshold $\alpha \cdot minFR = 20$). Such a setting was used in the next set of experiments.

For a completeness of our considerations we present a possible negative result of improper setting of RFB configuration parameters. Figure 2 shows the evolution of a measured

TABLE I

THE PERCENTAGE OF TIME IN WHICH FR DROPS BELOW 90% OF THE $minFR$ THRESHOLD $\tau_{0.9}$ (A) AND MEAN DEVIATION δ (B)

Measurement interval	Number of flows			
	1000	2000	3000	4000
$\tau_{0.9}$ (a)				
Classical FAN	52.94 ± 2.38	82.34 ± 1.35	88.87 ± 0.45	91.73 ± 0.60
FAN with limitation	3.46 ± 1.11	5.51 ± 0.95	5.61 ± 1.89	4.55 ± 1.26
RFB w/o decreasing P_a	7.16 ± 1.74	22.84 ± 2.07	35.28 ± 3.05	44.16 ± 4.37
RFB with decreasing P_a	**4.31 ± 1.88**	**5.13 ± 1.81**	**5.09 ± 1.49**	**3.74 ± 1.02**
δ (b)				
Classical FAN	156.69 ± 25.44	47.52 ± 1.21	54.97 ± 0.71	61.04 ± 0.65
FAN with limitation	215.17 ± 40.65	17.10 ± 1.38	17.23 ± 2.54	16.62 ± 2.55
RFB w/o decreasing P_a	228.29 ± 47.57	46.62 ± 5.38	34.56 ± 2.34	31.49 ± 2.92
RFB with decreasing P_a	**319.97 ± 30.76**	**94.44 ± 7.80**	**58.62 ± 5.98**	**45.09 ± 3.22**

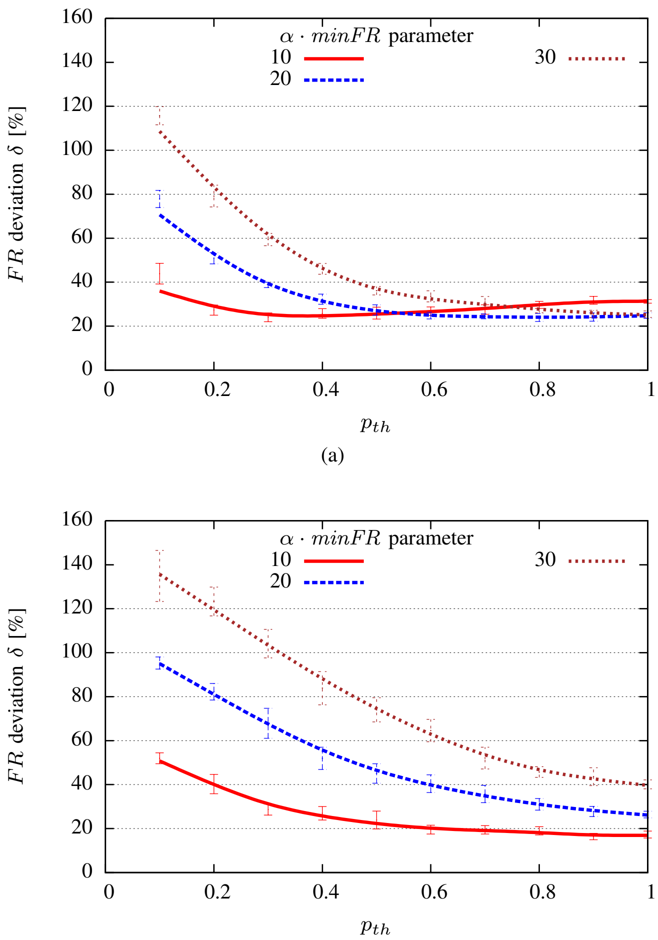

Fig. 4. FR deviation in FAN with standard RED (a) and RED with decreasing probability (b) with respect to various traffic patterns.

FR over time. In this experiment α was set to 2 and p_{th} to 0.1. The interval between $minFR$ and $\alpha \cdot minFR$ was short. In such settings the algorithm reacted too aggressively to congestion. The admission probability was too low. Too few flows were accepted, therefore FR remained between $minFR$ and $\alpha \cdot minFR$ for some time. After that, when some flows finished their transmission FR exceeded $\alpha \cdot minFR$ threshold. Then, in a given measurement interval all new flows were accepted. Since the arrival rate of new flows was high, large number of flows got accepted. In turn, it resulted in over-admission and, soon after, a significant decrease of FR. Finally, we observed high oscillations of FR and long periods when FR was significantly below $minFR$. The conclusion is that α should not be too low and the reaction to congestion should not be too aggressive.

In the second phase we focused on the comparison between the RFB algorithm (with and without decreasing probability), the classical FAN admission control and FAN with the LM mechanism. RFB parameters were set to $p_{th} = 1$ and $\alpha = 4$ (the selection of these parameters was described in the previous set of experiments). The average volume size was set to 35 MB. The number of flows varied from 1000 to 4000. The results are presented in Table I. One can see that RFB offers a superior performance to classical FAN in terms of $\tau_{0.9}$ metric. Average deviation δ is also improved with RFB. The only exception is for lower number of flows but it is not a significant drawback. The link was only lightly congested and using the RFB caused under-admission.

Table I compares also RFB to LM mechanism. It must be noted that LM *limit* parameter was tuned to the traffic pattern and set to 5 flows. With such a setting, both RFB with decreasing P_a and LM mechanism provide high performance in terms of $\tau_{0.9}$ metric. Looking at the mean deviation δ metric one can argue that the LM mechanism outperforms RFB. It is true that LM offers lower values of δ but it must be remembered that this mechanism requires meticulous selection of the *limit* value, according to traffic characteristics. We will show in the fourth set of experiments that the main benefit of using RFB is higher independence of the traffic pattern.

In the third set of experiments, we evaluated the influence of the traffic pattern on the performance of RFB. The parameters of the algorithm were again set as follows: $p_{th} = 1$ and $\alpha = 4$. The traffic pattern was changed with two settings of respective distributions: an average flow size and the number of generated flows. Figure 5 presents the dependence of $\tau_{0.9}$ performance metric on the traffic type. For RFB with decreasing probability (Fig. 5 (b)) we observe that $\tau_{0.9}$ remains on the same level for

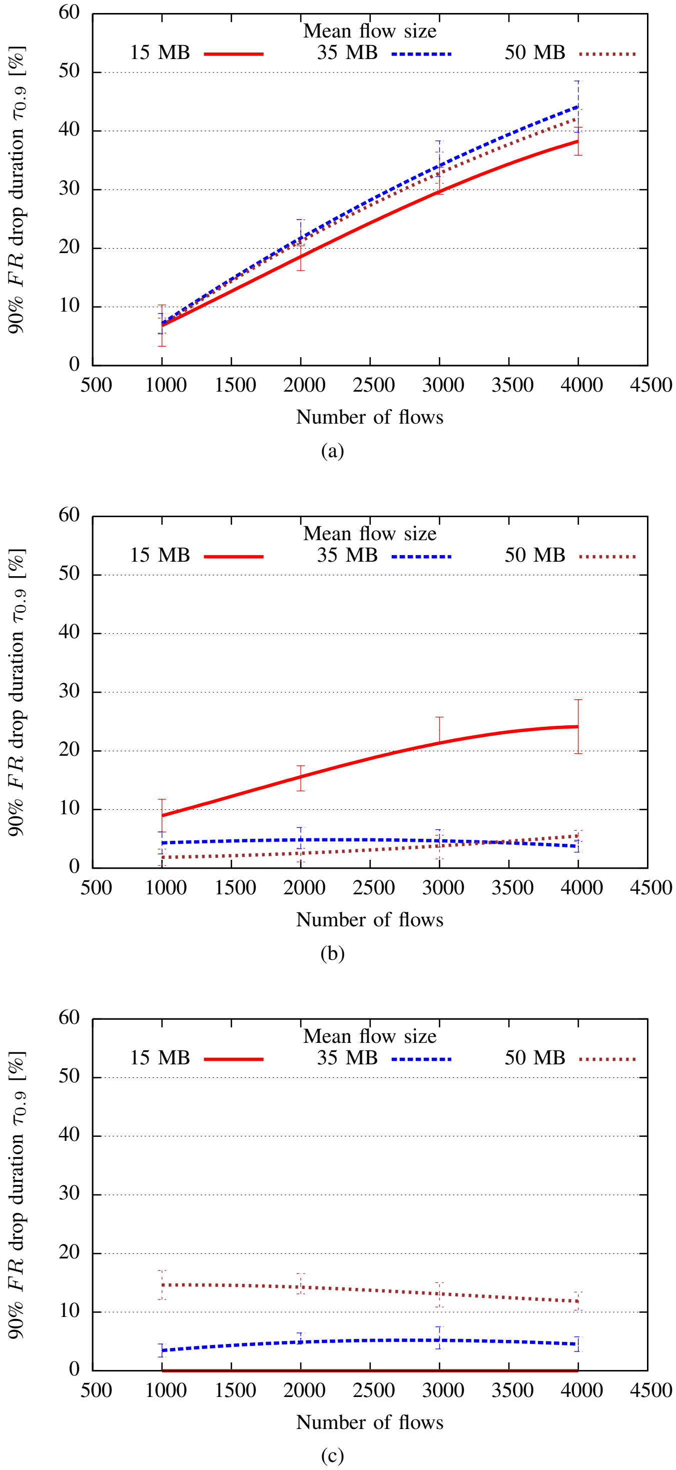

Fig. 5. FR drop duration in FAN with standard RED (a), RED with decreasing probability (b), and FAN with limitation mechanism (c) with respect to various traffic patterns.

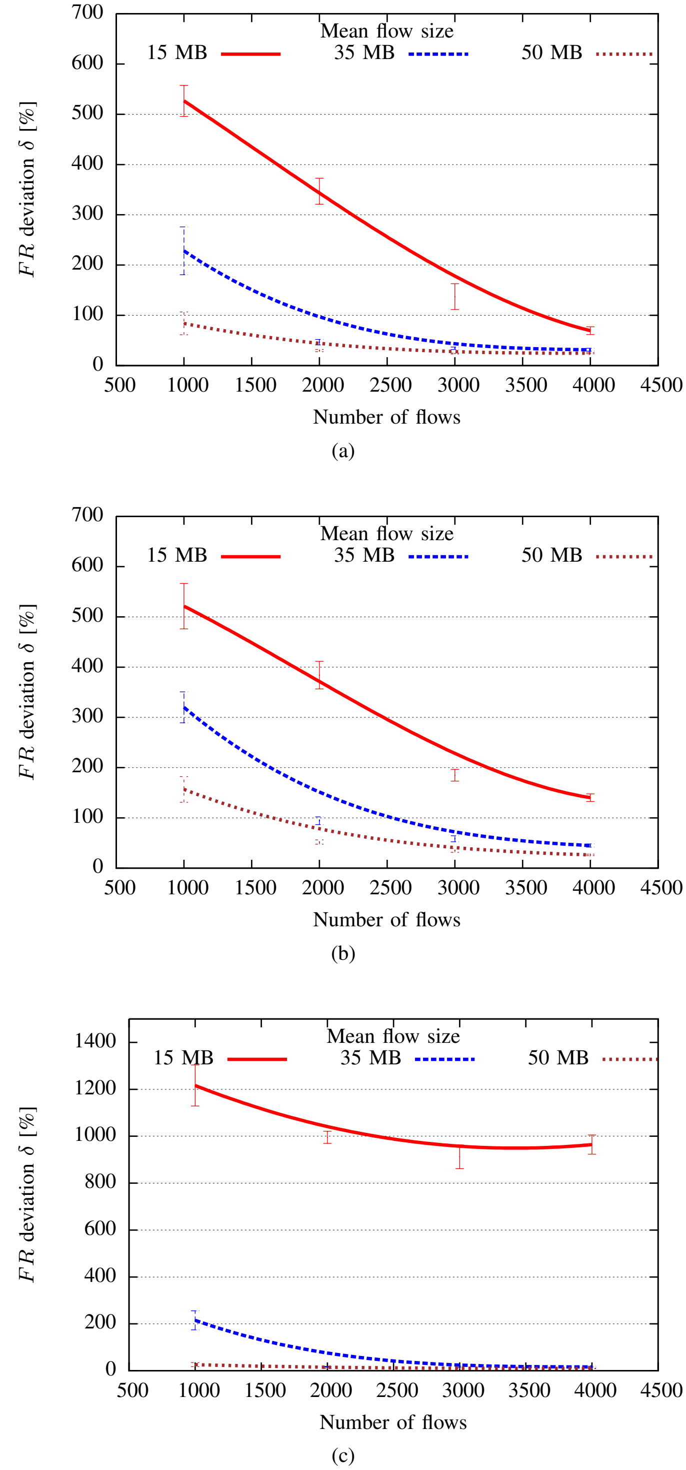

Fig. 6. FR deviation in FAN with standard RED (a), RED with decreasing probability (b), and FAN with limitation mechanism (c) with respect to various traffic patterns.

flows of a mean size of 35 MB and 50 MB and any number of flows. For shorter flows, $\tau_{0.9}$ increases starting from 9% for 1000 flows and tends to stabilize for higher number of flows at a level of ≈25%. Thus, $\tau_{0.9}$ is quite independent of the traffic type, unlike in classical FAN (see Tab. I). Also, Fig. 5 (a) shows that in RFB without decreasing probability $\tau_{0.9}$ depends on the number of flows. Figure 6 presents the impact of traffic pattern on δ. This metric appears to depend on the traffic type. However, with the increasing traffic load its value decreases, similarly to classical FAN (compare Tab. I). Additionally, it should be noted that greater oscillations of FR for a lightly congested link (lower number of flows in our experiments) is natural and occurs for any FAN admission control mechanism, including classic and LM (discussed below). Such oscillations are acceptable if $\tau_{0.9}$ is kept low meaning that FR rarely drops below $minFR$. The dependence of δ on the number of flows is natural and it is unnecessary to eliminate this feature if the main goal – the assurance of $minFR$ – is satisfied. Having $\tau_{0.9}$ values reasonably low and independent of the traffic characteristics, we can accept δ being dependent on the number of flows and having higher values for lower number of flows.

The fourth set of experiments was devoted to comparison of the performance of RFB and LM mechanisms. The $limit$ parameter was set to 5 flows, which is the value tuned for average flow size of 35 MB. The results for LM are presented in figures 5 (c) and 6 (c). Qualitatively, the results are similar to those for RFB with decreasing probability: low and stable values of $\tau_{0.9}$ and δ decreasing with increasing number of flows. For mean flow size of 35 MB quantitative results are similar to RFB with decreasing probability but looking at δ metric LM performs even better. However, this experiments clearly reveals the main weakness of LM — the necessity to configure the $limit$ properly. For mean flow size of 15 MB $\tau_{0.9} \approx 0$ but it does not mean a good performance. Since too few flows are accepted FR almost never drops to $minFR$ and we observe very high oscillations of FR (Fig. 6 (c)). In turn, for mean flow size of 50 MB $\tau_{0.9}$ is significantly higher than for RFB.

VI. Conclusion

We have shown that a simple RED-like mechanism can be implemented in FAN networks for the benefit of performance. The problem of FR degradation is significantly diminished. RFB provides much better performance than classic FAN and similar to what can be achieved by LM. The results show that LM can provide a bit better performance, however only when it is tuned to the current traffic patterns. Whenever those change, the LM needs to be readjusted. Unlike LM, RFB does not suffer so much from misconfiguration. Simulation results show that even when RFB is not perfectly configured, it can still produce acceptable results. Moreover, RFB does not depend so much on traffic characteristics changes and can quickly adapt. Even though we present the results for two versions of RFB, i.e., with and without decaying of the admission probability, the former yields better results and should be considered superior.

One of the most important benefits of using the RFB is that the RED algorithm is generally a well-known solution and already proved useful in queue management. Therefore, implementing RFB in FAN is much easier process, as one can use the available experience. Finally, RED is a very simple mechanism and such simple mechanisms are required so that they would not degrade the operation performance of the device.

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