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On The Existence Of Optimal LEDBAT Parameters

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Abstract—The Low Extra Delay Background Transport (LEDBAT) protocol is a recently standardized protocol that aims to offer a scavenger service (i.e. the goal is to exploit the remaining and unused capacity of a link). LEDBAT is a delay-based protocol mainly defined by two parameters: a target queuing delay and a gain. The RFC 6817 provides guidelines to configure both parameters that strongly impact on the LEDBAT behavior in terms of fairness with other protocols. However, these guidelines are questioned by several studies as they might lead to the generation of a non-LBE (Less-than-Best-Effort) traffic. This paper explores the set of optimal parameters allowing LEDBAT protocol to effectively perform as an LBE traffic. We conclude that the optimal couple of target and decrease gain is (5 ms; 10). However, we observe that the aggregated use of optimized LEDBAT sources still disturb the overall traffic performance and that the exponential backoff is not an answer to this issue. As a result, we believe that additional strategies to limit the number of LEDBAT flows are required for integrating this protocol at a large scale.

I. INTRODUCTION

Internet Engineering Task Force (IETF) has recently standardized the RFC of Low Extra Delay Background Transport (LEDBAT) [1] which is a delay-based congestion control mechanism providing a Less-than-Best-Effort (LBE) service, also known as a “scavenger” service. LEDBAT is designed for background applications like automatic backup, software updates, or bulk data transfer. As an example, since december 2008, the official BitTorrent client is using LEDBAT for data transfer [2]. It is also worth noting that LEDBAT is a potential solution to provide free Internet access [3].

LEDBAT aims to exploit the remaining capacity while limiting the queuing delay around a predefined target τ , which may be set up to $\tau = 100$ ms according to the RFC [1]. Consequently, LEDBAT flows lower their impact on Best-Effort flows like TCP. Despite being a promising protocol, LEDBAT has been revealed to be difficult to configure. In particular, its tuning highly depends on the network condition and LEDBAT may become more aggressive than TCP in case of misconfiguration [4]. As an illustration, in a recent study, the authors of [5] conclude that the LEDBAT target parameter should not be higher than 5 ms in a large bandwidth-delay product (BDP) network. Furthermore, the authors of [6] show that LEDBAT can greatly increase the network latency making its impact on the network not transparent anymore.

Considering that:

- 1) LEDBAT is currently deployed over BitTorrent network;

- 2) the misconfiguration of LEDBAT can significantly increase the network latency;
- 3) LEDBAT might exacerbate the bufferbloat issue [7];
- 4) several projects attempt to reduce Internet latency, such as *RITE*¹ or the *Workshop on Reducing Internet Latency*²;
- 5) the congestion cannot be clearly localized [8] (i.e. this recent study shows that the bottleneck is not always on the access router);

we believe that a deep study on the impact of LEDBAT internal parameters would allow to find sets of parameters to reduce its potential negative effect on the network. In particular, we question the optimal setting of two LEDBAT key parameters, the target and the gain, considering various buffer sizes. We also study the impact of LEDBAT on TCP in a highly loaded network. The main objective of such study is to close to the discussion about the feasibility to integrate LEDBAT at a large scale, before diving into possible improvements of its algorithm as proposed in [9].

We first gives in Section II an overview of LEDBAT algorithm. Then using *ns-2*, we evaluate in Section III the impact of different buffer sizes on the behavior of LEDBAT in the presence of TCP New Reno. In Section IV, we assess whether there exists a couple of target and decrease gain that let LEDBAT have an LBE behavior in different network configurations. Section V tests the optimal couple of target and decrease gain of LEDBAT in a highly loaded network. We propose a discussion in Section VI.

II. LEDBAT ALGORITHM AND RELATED WORK

In this section, we detail the algorithm of LEDBAT congestion control.

LEDBAT is characterized by the following parameters: target queuing delay (τ), gain (i.e. impact of the delay variation) (γ), minimum One-Way Delay (D_{min}) and current One-Way Delay (D_{ack}). For each ACK received, the new congestion window (*cwnd*) value is updated according to:

$$cwnd = cwnd + \frac{\gamma(\tau - (D_{ack} - D_{min}))}{cwnd} \quad (1)$$

LEDBAT congestion control is based on queuing delay variations (i.e., the queuing delay is used as a primary congestion

¹See <http://riteproject.eu>

²See <http://www.internetsociety.org/latency2013>

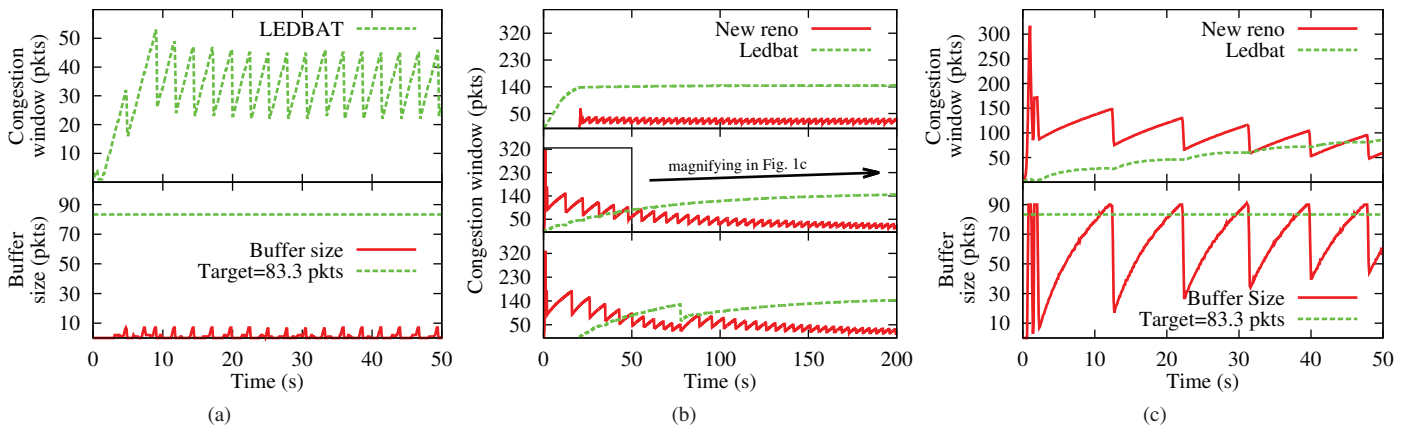


Fig. 1: Time evolution of LEDBAT and TCP congestion windows and the queue length

notification), estimated by $(D_{ack} - D_{min})$. The target queuing delay τ embodies the maximum queuing time that LEDBAT is allowed to introduce.

The impact of delay variation, γ , is the reactivity of LEDBAT to queuing delay variations. The bigger γ is, the faster LEDBAT congestion control increases or decreases its congestion window. In order to prevent LEDBAT from being too aggressive, the RFC states that γ must be lower than 1. However in the RFC [1], in the LEDBAT implementation in *ns-2* [10] and in one study on the solutions to reduce the aggressivity of LEDBAT [9], it has been implemented or discussed that the gain can be set to different values depending on the sign of $D = \tau - (D_{ack} - D_{min})$: if $D > 0$, $\gamma = \gamma_{incr}$ (increase gain) and we define an upper bound for $\gamma_{incr} \times D$ (so that LEDBAT does not increase its congestion window faster than TCP); if < 0 , $\gamma = \gamma_{dec}$ (decrease gain) which may not be limited, to let LEDBAT raise the pace at which it decreases its congestion window when the queuing delay increases. To sum up, increasing γ_{dec} let LEDBAT be more sensitive to increases of queuing delay and defining an upperbound for $\gamma_{incr} \times D$ prevent LEDBAT from increasing its congestion window faster than TCP.

These considerations suggest that, in order to conclude on the possibility to integrate LEDBAT, it is primordial to assess the reduction of LEDBAT aggressivity by increasing γ_{dec} . Our idea is thus to study the impact of buffer sizes, target value and decrease gain on the capability of LEDBAT to enable a Less-than-Best-Effort service.

III. LEDBAT BEHAVIOR

In this section, we evaluate by simulation the impact of different buffer sizes on the behavior of LEDBAT in the presence of TCP New Reno (hereinafter simply denoted TCP).

A. Simulation setup

Simulations have been performed using the network simulator *ns-2*. We use the LEDBAT module developed by Valenti et al. [10], based on the IETF RFC 6817 [1].

As reference network topology, we use a dumbbell topology where a TCP flow and a LEDBAT flow share a single bottleneck link. Both LEDBAT and TCP sources send packets size of $P = 1500$ B. The bottleneck link has a capacity set to $C = 10$ Mb/s and a one-way propagation delay $d = 50$ ms. The bottleneck router uses a FIFO drop-tail queue with a size of B packets. For convenience, we express the bottleneck buffer B as the ratio to the bandwidth-delay product BDP in terms of packets. Hence, we have $B = \lceil n * BDP \rceil = \lceil n * C * 2 * d / (8 * P) \rceil$, where the ratio $n \in [0.1, 0.2, \dots, 1.9, 2.0]$ and $\lceil x \rceil$ is the ceiling function. Since the value of B must be an integer, we use the ceiling function to get the smallest integer not less than B . We explore the set of target queuing delays $\tau \in [25, 50, 100]$ ms and the set of decrease gains $\gamma_{dec} \in [1, 10]$. We also express B as the ratio to the target τ in the same way as with the BDP .

To analyze the behavior of LEDBAT with respect to different buffer sizes, we consider the LEDBAT congestion window, the queue length of the bottleneck buffer, and the link utilization η of LEDBAT and TCP flows.

We consider only long-lived TCP and LEDBAT flows. Every simulation lasts 200 seconds, and the link utilization is computed over the last 150 seconds of the simulation. We denote by t_X the time at which the flow using protocol X starts to transmit data. The following scenarios are simulated:

- Scenario A: $t_{LEDBAT} = t_{TCP} = 0$ s;
- Scenario B: $t_{LEDBAT} = 0$ s, $t_{TCP} = 20$ s;
- Scenario C: $t_{LEDBAT} = 20$ s, $t_{TCP} = 0$ s.

B. Endangered TCP – LEDBAT misconfiguration

This section presents misconfiguration leading to a full utilization of the capacity by LEDBAT flows whatever the TCP load. Similar situations are also reported by other authors [4], [9]. In this work, we take a closer look at this problem and its relationship with the buffer sizing. Fig. 1 shows the time evolution of LEDBAT and TCP congestion windows as well as the queue length, in cases where LEDBAT does not fulfill its primary objectives. The target is $\tau = 100$ ms ($\simeq 83.3$ packets), and the decrease gain is $\gamma_{dec} = 1$.

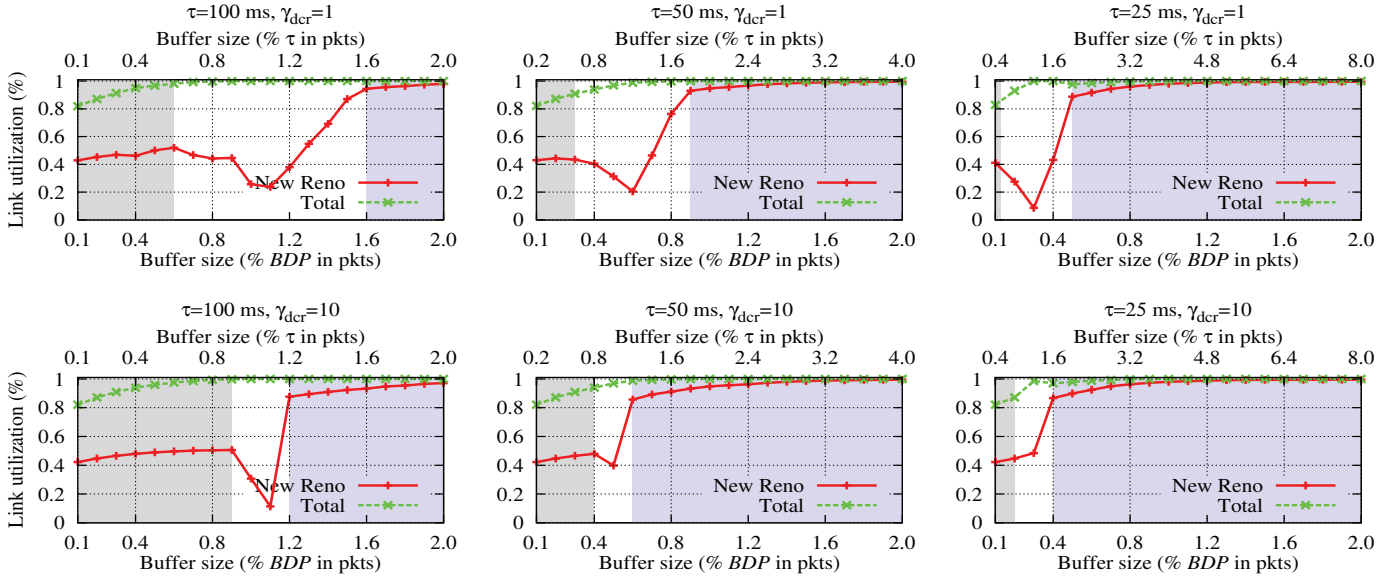


Fig. 2: Link utilization in terms of buffer size

RFC 6817 [1] states that, if a compromised target is set to infinity, “the algorithm is fundamentally limited in the worst case to be as aggressive as standard TCP”. Actually, it corresponds to the case where the buffer size is too small in comparison to the target, as shown in Fig. 1a. In this case, the buffer size is 9 packets, so the ratio of the buffer size to the target is 0.1. Thus, the queuing delay sensed by LEDBAT never reaches the target. Therefore, LEDBAT always increases its sending rate until a loss event is reported.

However, there are circumstances “worse than RFC worst case” in which hostile LEDBAT makes TCP back off. Fig. 1b illustrates three hostile scenarios with a same network configuration but with a buffer size of 92 packets. Even in an unfavorable situation for LEDBAT, when it starts after TCP, LEDBAT succeeds to increase its congestion window more than TCP. Whatever the scenario presented in this section, TCP cannot compete against LEDBAT.

To understand this hostile behavior of LEDBAT, we inspect the scenario where two flows TCP and LEDBAT start at the same time (middle plot in Fig. 1b). In Fig. 1c, we magnify the results of the first 50 seconds of the simulation. In the slow-start phase, TCP increases exponentially its congestion window. As a consequence, the buffer fills up immediately and then blocks the LEDBAT congestion window to one packet. After the slow-start phase, from $t = 3$ s to $t = 5$ s, as the queuing delay is small compared to the target, LEDBAT and TCP congestion windows conjointly grow at the same speed. As the queue continues to increase, LEDBAT reduces the increasing speed of its congestion window. Meanwhile, TCP continues to increase linearly its congestion window. After $t = 11$ s, when the queuing delay is higher than the target, LEDBAT decreases slowly and slightly its congestion window. Although the buffer size is bigger, it remains relatively small to the target. The ratio of the target to the buffer size is 1.1

in this case. Thus, LEDBAT does not have enough time to react to queuing delay before TCP causes a buffer overflow at $t = 15$ s. After that, TCP halves its congestion window, resulting in a reduction of the queuing delay. Since the queuing delay is now below the target, LEDBAT raises again its congestion window conjointly with TCP. Consequently, after several cycles, LEDBAT exploits more capacity than TCP.

C. LEDBAT working regions

The previous section illustrates cases where LEDBAT is too aggressive. In this section, we identify different working regions of LEDBAT. We denote as “working regions” areas where LEDBAT behaves correctly as a LBE protocol. For each couple of target and decrease gain, we plot the link utilization of TCP flow and the total link utilization of two flows against the buffer size.

Fig. 2 presents only the simulation results from the scenario where two TCP and LEDBAT flows start at the same time (i.e., Scenario A). We do not present the results of Scenario B and C as similar behavior is observed. Each plot corresponds to a couple of target and decrease gain. From left to right, the target slides from 100 ms to 25 ms. The decrease gain is set to 1 in the first row and 10 in the second row. The first (bottom) x-axis is the ratio of the buffer size to the BDP. The second (top) x-axis represents the same buffer size but as the ratio to the target. The y-axis is the link utilization.

1) *Impact of the target:* Fixing the decrease gain to 1, we study the impact of the target setting on the behavior of LEDBAT. As shown in Fig. 2, we distinguish three operating regions of LEDBAT. First, in the leftmost region, LEDBAT behaves like TCP. In other words, as previously explained in Section III-B, LEDBAT always increases its sending rate until a loss event is reported. In this case, the buffer size is small in comparison to the target. Hence, TCP and LEDBAT fairly share the link capacity ($\eta_{TCP} \simeq \eta_{LEDBAT}$). Then, in the

middle region, LEDBAT starts to become hostile to TCP. In consequence, the link utilization of TCP reduces progressively to a certain point ($\eta_{TCP} \ll \eta_{LEDBAT}$). As the buffer size still increases, the aggressiveness of LEDBAT decreases. Finally, in the rightmost region, LEDBAT works correctly as a LBE protocol ($\eta_{TCP} \gg \eta_{LEDBAT}$). To have enough time to react to queuing delay variations, we measure that LEDBAT needs a large buffer size in comparison to its target (more than 1.5 times).

Considering now the buffer size in terms of the ratio to the BDP , we see that a target of 100ms requires a buffer size as large as 1.6 times the BDP in order to perform in low-priority mode. This excess need of buffer introduces an excessive queuing delay known as bufferbloat phenomenon [7]. A smaller target mitigates this issue. As seen in Fig. 2, the smaller is the target, the smaller is the size of the buffer.

2) *Impact of the decrease gain*: We now study the impact of the decrease gain setting on LEDBAT behavior. Fig. 2 shows that, for each target, increasing the decrease gain shrinks the hostile region from both sides. As a consequence, the LBE region expands to the left, meaning a reduction in the need for buffer size of LEDBAT for low-priority mode. However, a higher decrease gain also amplifies the loss-based region.

As a conclusion, to increase the LBE working region of LEDBAT, we can reduce the target or raise the decrease gain separately or in the same time. We also highlight that setting LEDBAT parameters is a trade-off as a target too small could make LEDBAT sensible to network conditions and a decrease gain too high could reduce significantly its performance.

IV. OPTIMAL COUPLE OF TARGET AND DECREASE GAIN

In this section, we assess if there exists a couple of target and decrease gain allowing LEDBAT to behave as LBE protocol whatever the network configuration is.

A. Network configuration

We use the same dumbbell topology as in Section III. We consider different capacities $C \in [1, 5, 10, 20, 50]$ Mb/s and different one-way propagation delays $d \in [10, 50, 100, 150, 200, 250]$ ms of the bottleneck link. As in Section III, we express the bottleneck buffer B as the ratio to the bandwidth-delay product BDP . For each network setting C , d , and B , we explore the set of target queuing delays $\tau \in [5, 25, 50, 75, 100]$ ms and the set of decrease gains $\gamma_{dcr} \in [1, 10]$. Therefore, we run about 60 simulations for each setting of target and decrease gain. We drove only fewer simulations for small BDP networks as we exclude all cases with duplicate values of B caused by the ceiling function and where B is equal to 1.

In each simulation, a LEDBAT flow starts at $t = 0$ s and then a TCP flow starts at $t = 200$ s later. The simulation lasts 1000 seconds. We calculate the link utilization η of each flow over the last 500 seconds.

We use the following clustering method to classify our data and represent the set of working couples. The classification method is defined as follows: for each couple of target and

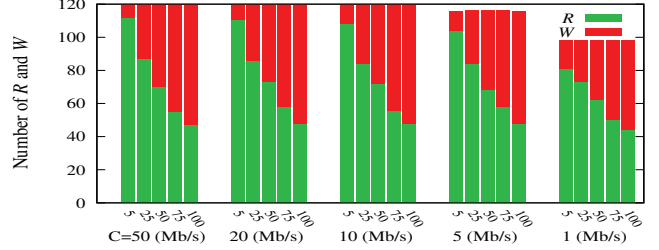


Fig. 3: Number of R and W cases for each target setting

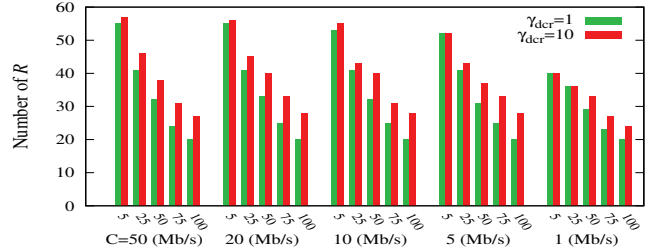


Fig. 4: Number of R cases when $\gamma_{dcr} = 1$ and $\gamma_{dcr} = 10$ for each target setting

decrease gain, when $B = BDP$, if the link utilization of TCP flow η_{TCP} is greater than or equal to 0.8, then we choose the link utilization of LEDBAT flow as reference $\eta_{ref} = \eta_{LEDBAT}$. Then, for every other value of B , we calculate $\Delta = |\eta_{LEDBAT} - \eta_{ref}|$. If Δ is less than or equal to a certain value of ε and $\eta_{TCP} \geq 0.8$, then we classify B in the cluster “Right” (denoted R), otherwise, in the cluster “Wrong” (denoted W). In our study, we use $\varepsilon = 0.15$. So, for different buffer sizes, if η_{TCP} is always greater than or equal to 0.8 and the difference between η_{LEDBAT} and η_{ref} is in a limit of 15%, then we say that the couple of target and decrease gain works well for these buffer sizes.

Finally, we use statistical analysis to find which couple of target and decrease gain works well in most network configurations.

B. Choosing the target

We begin our analysis by finding the optimal target value. In Fig. 3, using histogram, we group the simulation results into different categories of network capacities and then, into subclass of target values. For every target value, the stacked column represents the number of R and W cases. The column height corresponds to the total simulations including all decrease gain setting for a target value. For each setting of target, we have 120 simulations for high capacity networks and fewer simulations in case of small capacity networks.

In Fig. 3, we observe that the number of R cases of a target decreases as the network capacity decreases. Actually, the buffer size, expressed in ratio to the BDP , reduces when the network capacity is smaller. Therefore, the ratio of the buffer size to the target also becomes smaller. In consequence, LEDBAT behavior falls back into either hostile region or loss-based region.

As expected, Fig. 3 shows that a target value of 5 ms works in most cases. These experiments allow us to conclude that setting the target to 5 ms is optimal.

C. Choosing the decrease gain and the optimal couple of LEDBAT parameters

Having the optimal target value, we still use the histogram representation to find the optimal decrease gain. For each target setting, we present the number of R cases for each corresponding decrease gain value. As shown in Fig. 4, setting the decrease gain to 10 is better as it increases the number of R cases.

D. Testing the optimal couple

We now evaluate the optimal couple of target and decrease gain using the network configuration in Section III. Moreover, for reference purpose, we also simulate the scenario where TCP is the only protocol in the network. Table I reports results of two cases where $B = BDP = 84$ packets and $B = \frac{BDP}{2} = 42$ packets. For comparison, we are only interested in couples of parameters that work in low-priority mode with either buffer sizes, i.e., $(25\text{ ms}; 1)$ and $(25\text{ ms}; 10)$ (see Fig. 2 in Section III). Beside, we report also the performance of the runner-up couple $(5\text{ ms}; 1)$.

TABLE I: Optimal LEDBAT sharing bandwidth with Reno

Buffer (pkts)	Reno+LEDBAT ($\tau; \gamma_{dcr}$)	η Reno (% C)	η LEDBAT (% C)	η Total (% C)
84 (BDP)	$(25\text{ ms}; 1)$	98.04	1.95	99.99
	$(25\text{ ms}; 10)$	98.02	1.97	99.99
	$(5\text{ ms}; 1)$	99.15	0.84	99.99
	$(5\text{ ms}; 10)$	99.13	0.86	99.99
	Only Reno	99.99	X	99.99
42 ($\frac{BDP}{2}$)	$(25\text{ ms}; 1)$	88.77	8.82	97.59
	$(25\text{ ms}; 10)$	89.87	8.02	97.89
	$(5\text{ ms}; 1)$	93.93	3.35	97.28
	$(5\text{ ms}; 10)$	94.21	3.53	97.74
	Only Reno	96.04	X	96.04

When the buffer size equals to BDP , TCP alone exploits almost full capacity of the network (99.99%). Introducing LEDBAT using the optimal couple of parameters reduces TCP performance by 0.86% while keeping the total throughput same as in the case of TCP alone. In this case, the performance of the runner-up couple $(5\text{ ms}; 1)$ is a little better than the optimal couple and could be neglected.

When the buffer size equals to $\frac{BDP}{2}$, TCP alone obtains less network capacity (96.04%). But in this case, introducing LEDBAT using the optimal couple of parameters increases the total network capacity exploited by 1.7% while causing least impact on TCP performance. The couple $(25\text{ ms}; 10)$ allows to obtain a better network capacity, but also makes more impact on TCP in the same time.

Finally, we conclude that the optimal couple of target and decrease gain is $(5\text{ ms}; 10)$. This result is consistent with our discussion in Section III.

V. LEDBAT IN HIGHLY LOADED NETWORKS

In this section, we test the optimal couple of target and gain of LEDBAT found in Section IV in a highly loaded network. We also take this opportunity to evaluate other LBE protocols like TCP Nice [11] and TCP-LP [12]. TCP-LP implementation is available in *ns-2* TCP-Linux. For TCP Nice, we use the module proposed in [4].

As in Section III, we use a dumbbell topology with a bottleneck capacity $C = 10\text{ Mb/s}$ and a one-way propagation delay $d = 50\text{ ms}$. The buffer size is set to 84 packets and equals to the BDP , according to the classical “rule-of-thumb”. In each simulation, we consider N LBE sources and N TCP sources, where $N \in [1, 10, 20, 40, 60, 80, 100]$. The starting time of a TCP flow is uniformly distributed between 0 and 200 seconds. To assess on the impact of LBE protocols on TCP, LBE flows begin to transfer data in an unfavorable situation, i.e., only after all TCP flows have started. Therefore, the starting time of a LBE flow is uniformly distributed between 300 and 500 seconds. It should be noticed that the late-comers problem of LEDBAT is negligible when there is interaction between LEDBAT and TCP [10]. Thus, in our study, we introduce LEDBAT at random time neglecting any effects on our results. We also simulate only N TCP flows without other competing LBE flows as reference.

As performance metrics, apart from the aggregate average throughput, we also define the TCP bandwidth released ($TCP_{released}$) as the link utilization of TCP when it shares the bottleneck link with the tested LBE protocol over the link utilization of TCP when it is the only protocol on the same link, i.e., $TCP_{released} = \eta TCP_{Reno+LEDBAT} / \eta TCP_{only\ Reno}$.

Every simulation lasts 1200 seconds, and all metrics are measured over the last 600 seconds.

A. Results and discussions

Fig. 5a presents the aggregate average throughput of N TCP flows and N LBE flows sharing the bottleneck link. To weight up the impact of LBE flows, we plot in Fig. 5b the $TCP_{released}$ depending on the network load, i.e., the direct impact of the introduction of LBE flows on TCP performance. As seen in Fig. 5, when the number of TCP and LBE flows is small, LBE protocols fulfill their role. However, increasing the number of LBE flows also increases their impact on TCP traffic, even though an equivalent amount of TCP flows is also introduced into the network. The more we introduce LBE flows, the less capacity is left for TCP traffic. For instance, 100 LEDBAT flows compete as aggressive as 100 TCP flows for the full capacity. In this case, TCP flows must yield to LEDBAT flows 47% of the bandwidth obtained when they are alone in the network.

When the number of flows is above 100 (Fig. 5a), LEDBAT is even more aggressive. This is explained by the misestimation of the OWD. Indeed, LEDBAT keeps track of the minimum One-Way Delay D_{min} in order to estimate the queuing delay variation. Thus, if LEDBAT runs long enough and the queue is never empty, D_{min} is always nearly equal to D_{ack} and to the maximum queuing delay allowed by the

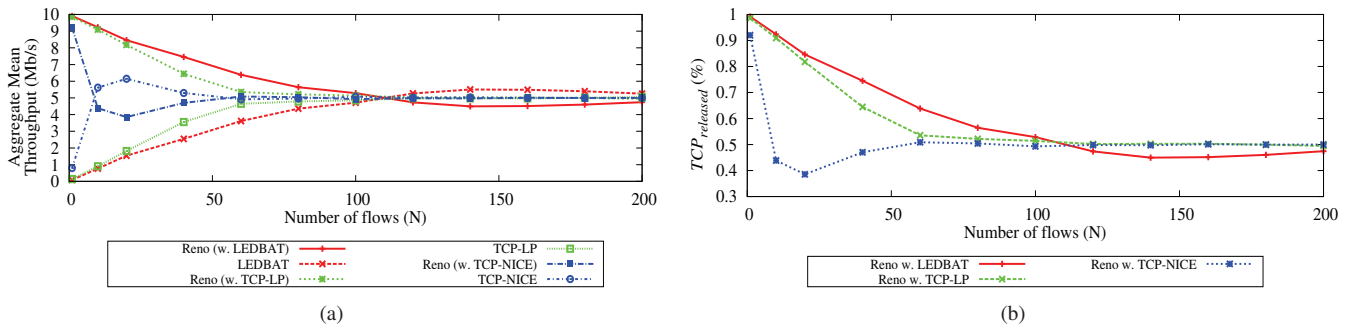


Fig. 5: Impact of N LBE flows on N TCP flows

bottleneck buffer. As a result, the queuing delay sensed by LEDBAT always approximates to zero ($D_{ack} - D_{min} \simeq 0$). In consequence, LEDBAT tends to raise its congestion window to reach the target queuing delay. This limitation of LEDBAT algorithm is studied in detail in [6]. As shown in Fig. 5, if we do not limit the number of LBE flows, an aggregate of LBE flows do not behave as a LBE traffic anymore.

To better understand this problem, we measure the average congestion window of a LEDBAT flow, in the case where the number of flows of each protocol TCP and LEDBAT is 100. As a result, the average congestion window of a LEDBAT flow is 1.3 packet. Thus, a LEDBAT flow sends data at an average rate of 1.3 packet per RTT. For 100 LEDBAT flows, the router always receives on average a burst of 130 packets. An exponential backoff mechanism, as proposed in RFC 6817 [1], could help to reduce the burst size at a given time. Note that this mechanism is already implemented in the LEDBAT module used in our simulations. Unfortunately, exponential backoff does not resolve this issue on the long term as we must impose a maximum backoff time. Although the RFC 6817 states that a maximum value MAY be placed on backoff time, we argue that this maximum value MUST be always set. If LEDBAT flows can backoff in unlimited time, their impact on long-lived TCP traffic will then reduce significantly. This could lead to case where long-lived TCP flows cut off LEDBAT traffic in long periods of time. Moreover, unlimited backoff time could raise a potential intra-unfairness of LEDBAT flows as a side effect.

Our results in this section indicate that when LEDBAT is deployed at large scales, we must use additional strategies to limit the number of LEDBAT flows.

VI. CONCLUSION

Recent studies pointed out cases in which the capacity of LEDBAT to carry out Less-than-Best-Effort is questioned. The misconfiguration of this protocol may result in a significant delay in the network. This motivated us to lead a deep analysis on the impact of its internal parameters on its performance.

We propose an optimal parametrization for the internal parameters of LEDBAT. We found that a target of 5 ms and a decrease gain of 10 are optimal. The optimal target is far from

the guideline in the RFC, which says that the target must be lower than 100 ms. However, it is worth pointing out that in all simulation cases, LEDBAT is not fully LBE and borrows some capacity of the primary flows. We also measure the impact of the increasing number of LEDBAT flows which is alarming.

We conclude that the congestion control of LEDBAT must be adapted before large scale implementation.

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