Computer Communication & Collaboration (Vol. 2, Issue 4, 2014)
ISSN 2292-1028(Print) 2292-1036(Online)
Submitted on Sep. 3, 2014
DOIC: 2292-1036-2014-04-003-40

Estimating Available Bandwidth in Wired IPv6 Networks

Mahamat Hassan Borgou
Institute of Science and Technology of Abeche
Abeche (Tchad)
mahamatborgou@yahoo.fr

Cheikh SARR (Correspondence author)
Faculty of Science and Technology, University of Thies
BP 967, Thies Senegal
csarr1979@hotmail.com

Abstract: In this article, we propose a new technique to estimate the available bandwidth of routers and by extension of one-hop links in wired IPv6 networks. Our technique exploits the fact that a router can estimate the link occupancy by monitoring its environment. It also provides a non intrusive estimation meaning that it does not generate additional traffic to perform the evaluation. This estimation process is based on IPv6 extensions. We show by simulations that our technique provides an accurate estimation of available bandwidth on wired links in IPv6 environment compared to other approaches.

Keywords: Available Bandwidth Estimation, Quality of Service, IPv6 networks, IPv6 extensions, Coaxial links

1. Introduction

Internet Protocol version 6 (IPv6) [4] is the next generation Internet Protocol designed to be the successor to version 4 (IPv4). Full deployment of IPv6 can be expected to complete within the next years. IPv6 provides new features like for instance expanded addressing, simplified header format, improved extension and option support [6]. These new features also integrate Quality of Service (QoS) mechanism to offer applications better performance. The term QoS is vague and gathers several concepts. Some protocols intend on offering strong guarantees to the applications regarding given parameters, for instance bandwidth, delay, packet loss, or network load. Some others, which seem more suited to a wired environment, only intend on selecting the best route among all possible regarding similar criteria. In both cases, an accurate evaluation of the capabilities of the routes is required. Most of the current QoS proposals leave this problem aside by relying on the assumption that layer-2 protocols are able to perform this evaluation. The resource evaluation problem is far from being trivial, as it must consider several phenomena related to a wired IPv6 environment. Some frameworks like for instance DiffServ [10] try to provide QoS to network but don't specify how to evaluate available resources.

In this article, we will focus on one of the fundamental resources, ***the available bandwidth***. Estimating the remaining bandwidth at a given time an in a given part of the network is a difficult task. We present a new method to evaluate the available bandwidth in wired IPv6 networks.

Hereafter, we define the **available bandwidth** between two neighbor IPv6 routers as the maximum throughput that can be transmitted between these two peers without disrupting any ongoing flow in the network. This term should not be confused with the **link capacity** (also called **base band- width**) that designates the maximum throughput a flow can achieve between two neighbor routers, even at the cost of other flows' level of service degradation. For performance evaluation, our proposal uses IPv6 extension header to design a efficient QoS protocol.

The rest of the paper is organized as follows: Section 2 presents our motivation. Section 3 introduces the links available bandwidth estimation mechanism we propose, first from a single router's point of view and then from a link's perspective. Section 4 describes the ABv6 protocol design and finally and NS-2 simulation results are presented in Section 5.

2. Motivation

Available bandwidth evaluation has generated several contributions in the wired networks communities. They can be classified into two major categories:

- The **active approaches** [3, 7, 2, 9] techniques rely on the emission of dedicated end-to-end probe packets to estimate the available bandwidth along a path. Generally, two or more packets are sent together in varying configurations and use the relationship between the packets to determine the network bandwidth. These packets can be sent in pairs of equal or varying sizes or as a train of packets.

- The **passive approaches** techniques use only local information on bandwidth utilization. The typical example of such approaches is a router monitoring the link utilization These mechanisms may exchange information via one-hop broadcasts. This exchange can be done through Hello messages used by many routing protocols to discover the local topology. As long as these exchanges are not too bandwidth consuming and integrated into the routing process, such measurement could be considered as passive technique.

All the active techniques present two major drawbacks. First, when many routers need to perform such an evaluation for several destinations, the number of probe packets introduced in the network can be important and interact with the existing traffic and with other probes. Secondly, a wired network can contain links of heterogeneous quality. An end-to-end evaluation technique may not be as reactive as a local technique when it comes to local reconstruction of routes. Any local technique should, however, be complemented with an appropriate measurements combination technique.

The active techniques do not yield to accurate results in a wired context. They do not consider the need for preserving existing flows service level when computing a path's capacity. They also introduce additional traffic in the network that may disturb the network operation and simultaneous measurements may interfere.

According to our previous remarks, passive techniques seem to be the best scheme for available bandwidth measurement. Even though ensuring that the link capacity is not overloaded anywhere in the network may be realized by only considering both the emission volumes and could be improved by considering the synchronization between emitters and receivers.

3. Link available bandwidth estimation

Based on the previous literature study and considering how the IPv6 protocol operates, we can point out three mechanisms that should be carried out to perform available bandwidth evaluation.

- Before transmitting data packets, a router needs to estimates locally the amount of available bandwidth, regarding to other close flows. This issue can be done by monitoring the link utilization around the router to estimate the local available bandwidth.

- For a transmission to take place, both emitter and receiver need that no jamming occurs during the whole transmission. Therefore, the value of the available bandwidth on a link depends on both routers' respective link utilization ratios but also on the idle periods synchronization. This synchronization needs to be evaluated.

- From an operational point of view, we need to integrate our available bandwidth computation into a protocol which uses IPv6 extensions.

In section 3 and 4, we examine in turn all three points listed above and describe how we consider these phenomena. Each point could, in theory, be evaluated by measuring some local metrics and exchanging information with close and farther neighbors. However, in this article, we are looking for a lightweight and local mechanism to avoid consuming too much resources for network management. We also consider coaxial links [8] adapted to multimedia traffic which are half duplex. It's mean that a router cannot send and receive simultaneously on the same link.

3.1 Estimating a router's available bandwidth

Whenever a router tries to send a packet, it first needs to contend for link access and it cannot emit its packet until the link is free. Therefore a potential sender needs to evaluate the load of the link, i.e. the proportion of time the link is idle to determine the chance he has to successfully gain access.

Let us consider a router s in the network during an observation interval of Δ seconds on the link i. We use the following notations:

- $\mathcal{T}_s^i$ is the total idle time during which router *s* neither emits any packet nor senses the link *i* busy.

- $\mathcal{B}_s^i$ the available bandwidth of router *s* at link *i*, i.e. the maximum throughput it can emit without degrading close flow's rate.

- $\mathcal{C}_i$ is the capacity of link *i*.

During an observation interval Δ, each router may monitor for every link, the utilization in its surroundings and measure the total amount of time that is idle for emitting packets.

As this monitoring neither takes into account the reception side of the transmission, the available bandwidth we can compute this way at router's on link i is imprecise. Above this threshold, collision probability can increase quickly. Some packets may still be correctly transferred, though, due to a favorable scheduling of transmissions or to capture effects. Under this threshold, a scheduling between different contending emitters that prevents two simultaneous emissions exists.

We therefore consider that this value is an upper bound of the available bandwidth we are seeking:

$$\mathcal{B}_s^i \leq \frac{\mathcal{T}_s^i}{\Delta} . \mathcal{C}i(1)$$

3.2 Estimating a link's available bandwidth

In the previous section, we have evaluated an upper bound of the available bandwidth a router could use to emit packets. The reception part of the transmission also requires that the link is free during the transmission, thus the previous bound should also be considered at the receiver's side.

Let us simply consider again a link *i* or link (*s*,*r*) composed of two neighbor routers *s* and *r*. To be able to use combinatorial tools, we consider that time is discrete. We introduce the following additional notations:

- δ is the time discretization step.
- $\tau_m = \Delta/\delta$ is the number of time units in a measurement period.
- τ_S (resp. τ_r) is the number of time units during which the link *i* is available for router *s*(resp. r) in a measurement period, computed according to the constraints described above.
- $\mathcal{B}_s^i$ (resp. $\mathcal{B}_r^i$) is the available bandwidth bound for router *s* (resp. r), measured with the method described previous section.
- $\mathcal{B}_{(s,r)}$ is the true available bandwidth on the link (*s*,*r*), i.e. the real bandwidth that can be used without degrading close flows.
- $b_{(s,r)}$is the estimated available bandwidth on the link *(s, r)*.

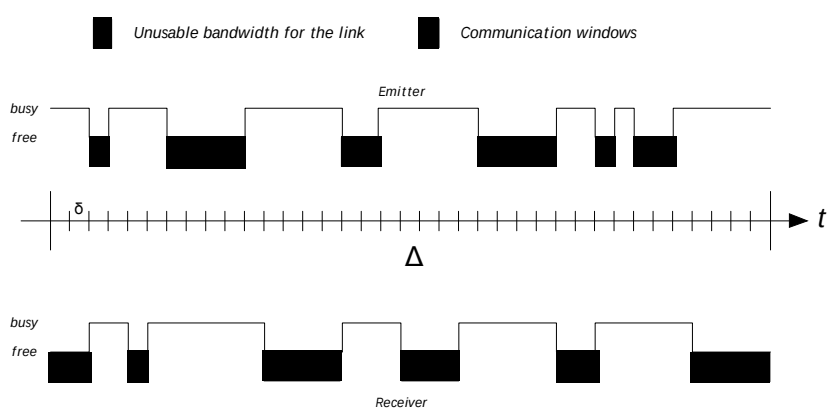


Figure 1. Worst case: link idle periods of sender and receiver never overlap

If $\mathcal{B}_s^i$ is null or close to zero, *s* either never gains access to the link or already emits packets at a rate that saturates the link. Similarly, if the link is always busy on the receiver's side, s's emissions systematically collide and the communication never succeeds. Trivially, we can state that $\mathcal{B}_{(s,r)}^i \leq \min(\mathcal{B}_s^i, \mathcal{B}_r^i)$. However, simply considering that the available bandwidth on a link is the minimum of both values is not sufficient. In fact, sending a flow with a throughput higher than min ($\mathcal{B}_s$, $\mathcal{B}_r$) necessarily provokes a link saturation around *s* and/or *r*.

Figures 1, 2 and *3* represent the link availability during time at the emitter and a receiver of a given transmission. On Figure 1, the periods of link availability of both peers never overlap and the available bandwidth on the link is null. In opposite, the equality holds in the situation depicted on Figure 2 where the periods of link availability fully match. Finally, the general case where the periods of link availability partially match is depicted on Figure 3.

In wired IPv6 network, the routers are unlikely to be synchronized. However, precisely evaluating this impact of this asynchronism requires the communication of the exact transmission patterns of both peers and a fine clock synchronization mechanism, which represents a huge overhead. Therefore, we proposed to use a probabilistic mechanism to estimate the effect of this phenomenon. Let us examine the requirements for a successful packet transmission.

Once emission of the sender's router *s* starts on link *i*, the link at the receiver's side has to be free during the time required to transmit the whole data packet, otherwise a collision would happen.

Let us consider a uniform random distribution of the link occupancy over the observation period, it is then possible to compute the expected delay $d(l_{(s,r)})$ before routers *s* and *r* sense the link idle simultaneously. We denote by $p(i, j, k)$ the probability that:

• the first occurrence of such synchronization in a measurement interval occurs at time slot *i*

• the sender has been idle for j time units before synchronization.

• the receiver has been idle for *k* time units before synchronization.

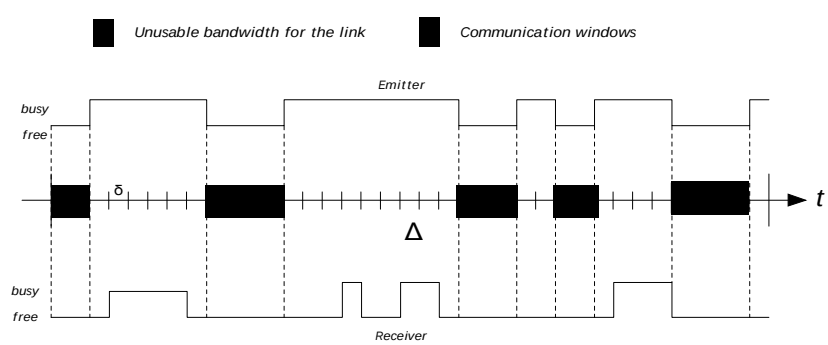


Figure 2. Best case: link idle periods of sender and receiver always overlap

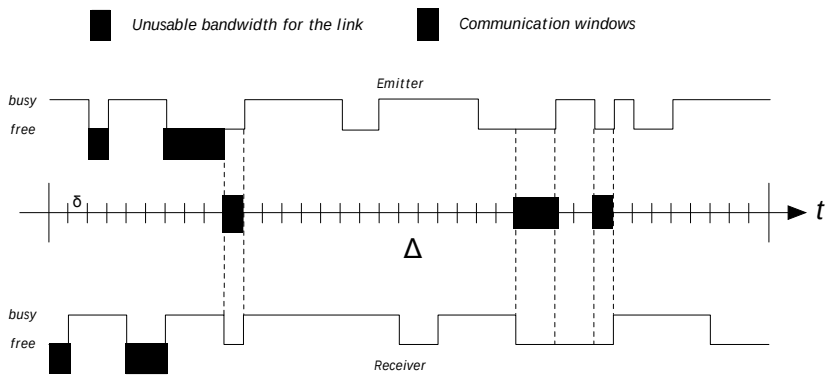


Figure 3. General case: link idle periods of sender and receiver partially overlap

$$Then, p(i,j,k) = \frac{\binom{i}{j}.\binom{i-j}{k}.\binom{\tau_m - i - 1}{\tau_s - j - 1}.\binom{\tau_m - i - 1}{\tau_r - k - 1}}{\binom{\tau_m}{\tau_s}.\binom{\tau_m}{\tau_r}}$$

From this expression we can compute the probability $p(l_{(s,r)}) = i$ that the first synchronization occurs at a given time unit and the expected delay $d(l_{(s,r)})$ before synchronization:

$$p(l_{(s,r)} = i) = \sum_{j=\max(0,\tau_s-(\tau_m-i))}^{min(\tau_s-1,i-1)} \left(\sum_{k=\max(0,\tau_s-(\tau_m-i))}^{min(\tau_r-1,i-1-j)} p(i,j,k) \right) (2)$$

$$d(l_{(s,r)}) = \sum_{i=0}^{\min(\tau_m,2.\tau_m-(\tau_s+\tau_r))} i.p(l_{(s,r)}) = i \qquad (3)$$

Still considering a uniform random distribution of the link occupancy, the available expected bandwidth $E(b_{(s,r)})$can be evaluated by expressing the probability that the link is free simultaneously at the emitter's and receiver's side:

$$p(b_{(s,r)} = i) = \frac{\binom{\tau_s}{i}\binom{\tau_m-\tau_s}{\tau_r - i}}{\binom{\tau_m}{\tau_r}} (4)$$

$$E(b_{(s,r)}) = \sum_{i=0}^{\min(\tau_s,\tau_r)} i.P(b_{(s,r)} = i) = \tau_s \times \tau_r (5)$$

The different points mentioned above can be combined to estimate the available bandwidth on a wired IPv6 link, i.e. between an emitter and a receiver. The whole mechanism rather relies on

perceptions the routers have of their environment.

To summarize, the available bandwidth between two neighbor routers s and r can be estimated by the following formula:

$$E_{final}\left(b_{(s,r)}\right) = E\left(b_{(s,r)}\right).C_{s,r} \quad (6)$$

where $E\left(b_{(s,r)}\right)$ is the available bandwidth on the link (s,r) as evaluated in equation 5 and $C_{s,r}$ the capacity of link (s,r).

4. ABv6 protocol design

From an operational point of view, it is very difficult to evaluate the accuracy of the sole available bandwidth estimation. Therefore, we integrate the previously described available bandwidth evaluation into the OSPF protocol for IPv6 [1] (called OSPFv6). Therefore we call our new protocol ABv6 (Available bandwidth for IPv6). We introduce in ABv6 some modifications on the usual Hello packets to take into account our bandwidth measurement. With such a protocol, we can study the impact of our estimation technique on the bandwidth management in the network and compare it with other similar approaches.

In ABv6, neighboring routers exchange their information using Hello messages every Δ seconds. During a measurement period Δ, each router locally estimates its link occupancy ratio (from 0 to 100%) and includes this information in the IPv6 ***"hop by hop"*** extensions of Hello packets. Then, these Hello messages are sent to all ABv6's neighbors routers at the multicast destination FF02::5. Each router receiving this message, can exploit the information stored in the Hello extension header and can compute his available bandwidth with the sender as calculated in equation 6.

In fact, since RFC 2460, IPv6 proposes a new extension called "hop by hop" [5]. This extension is placed just behind classical IPv6 header and is examined by all neighbors routers.

The modified IPv6 hop by hop extension in ABv6 contains the fields described as follows:

- ***Next header*** : 8-bit field identifies the next header that follows this extension header.

- ***Header extension length*** : 8-bit field identifies the length of this extension header in units of 8 bytes.

- ***Header sequence*** : 16-bit field identifies the sequence number of this extension.

- ***Header occupancy*** : 8-bit fields identifies the percentage of the link occupancy. This value varies from 0 to 100

The accuracy of the bandwidth evaluation obviously depends on the value of Δ, which is equivalent to a sampling period. The larger Δ is, the more stable the measurements will be, hiding fast variations in the link load. However, Δ should also be small enough to allow fast reactions to long-term load variation.

We keep a proactive approach for the link available bandwidth measurement to maintain a constantly updated and distributed bandwidth information on the whole network. At any time, the available bandwidth of whole links in the network should be known. This total knowledge of the state of the links, will help a reactive protocol to make more quickly the decision to forward data or not.

A simple admission control process is also set up. The aim of the this admission control procedure is to find a route between the sender and the receiver that meets the constraints specified by the application level in term of bandwidth. Therefore, two flows with the same source and destination can follow different routes depending on the network state.

Each router that receives a bandwidth request for a specific traffic performs an admission control by simply comparing the bandwidth requirement and the estimated available bandwidth presented above. If this check is positive, the router forwards the traffic; otherwise it discards the flow.

5. Simulations

In this section, we compare the accuracy of our estimator by simulation, using network simulator 2 (NS-2.35). We compare the performances of our estimation technique through the ABv6 protocol described previously in section 4 with the TIPv6 protocol presented in [2] which uses an active approach to compute available bandwidth estimation. We also compare to the basic OSPFv6 protocol which does not include a bandwidth estimation scheme.

To evaluate the different protocols and illustrate the effectiveness of ABv6, we generate random topologies with random constant bit-rate flows (random source, random destination and random throughput with fixed 1500 bytes frames). For each of these protocols, similar scenarios (same number of nodes and same number of flows) lead to similar behaviors. Hereafter we only analyze two specific scenarios. For each scenario, the results presented here were obtained over 30 simulations runs with different random seeds.

5.1 Experimental setup

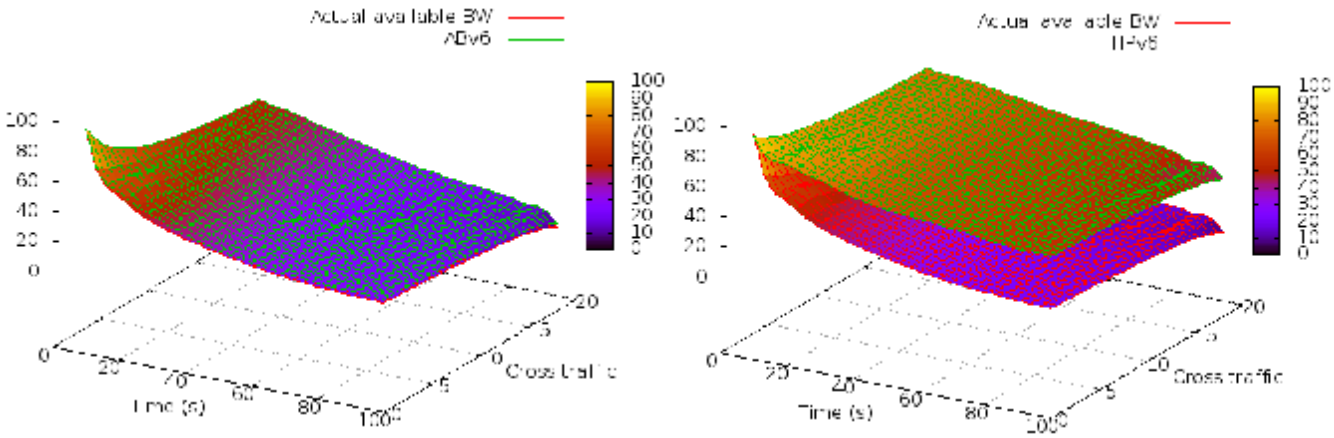
First of all, we create a network composed by a single 20-hop path connecting two hosts A and B. Cross traffic at each hop is modeled using a Poisson process with packet size determined by an exponential random distribution with a mean packet size of 1000 bytes. The mean rate of the cross traffic flows ranged from 2 Mbps to 4 Mbps at each hop. The number of cross traffic flows ranging from 0 to 20 at each hop. The link capacity at each hop is also set to 100 Mb/s and each simulation lasts 100 seconds.

The purpose of this experimental setup is to compare the available bandwidth performed by ABv6 and TIPv6 to the actual available bandwidth to show the accuracy of measurement along the path, when cross traffic increases.

Figure 4(a) represents the evolution of the available bandwidth computed with ABv6 in function of the simulation time and the number of cross traffic, while figure 4(b) shows the same result for TIPv6.

Figure 4(b) clearly shows that TIPv6 overestimates the available bandwidth during the measurement process. In fact, probe packets sent back to back to compute the available bandwidth in TIPv6 don’t preserve existing flows service level, consume bandwidth and reduce the capacity of the network. They can introduce additional traffic that may disturb the network operation and

simultaneous measurements may interfere. Moreover, collision can happen on these probe packets involving in false available bandwidth measurement. However, figure 4(a) show that ABv6 involves estimations that were from 90% up to almost 100% accurate compared to the actual bandwidth capacity, whereas TIPv6 method produced estimations that were as low as 30% accurate.



a) ABv6 *b) TIPv6*

Figure 4. Actual available bandwidth versus ABv6 and TIPv6 evaluation

5.2 Accuracy of the bandwidth management

Let us now investigate the general case. To reflect the accuracy of the available bandwidth estimation, we define a metric accounting for the number of right admissions. A right admission happens when the admission control process allows the routing of a flow and this flow's throughput is not degraded by more than 5 % when it gets transferred. The metric we represent hereafter is defined by the following expression:

$$\varphi = \frac{Number\ of\ right\ admission}{Total\ number\ of\ flows}$$

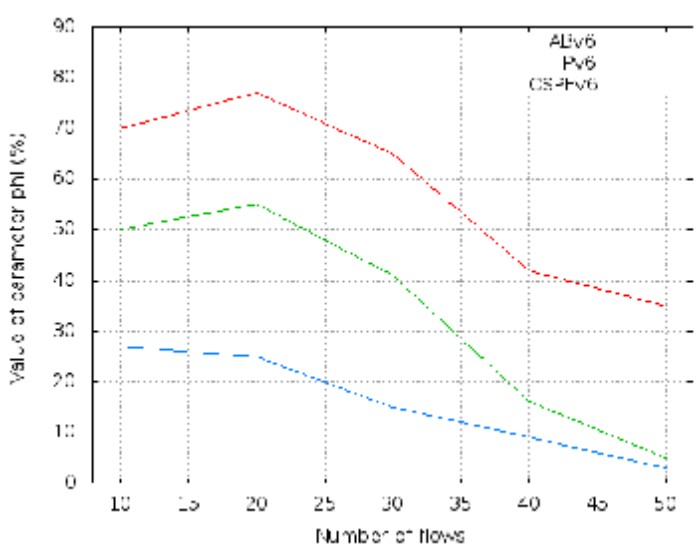


Figure 5. Acceptance rate of flows with ABv6, TIPv6 and OSPFv6

A falsely admitted flow either degrades the throughput of cross traffic or is not able to achieve its desired throughput. Hence, the value of φ decreases. We measured the value of φ by simulation on a networks composed of 100 routers. The routers are randomly placed. The medium capacity is set to 100 Mb/s. The number of flows ranging from 10 to 50. The throughput of each flow is uniformly drawn between 256 Kb/s to 2 Mb/s. Each simulation lasts 100 seconds and randomly chosen pairs of routers try to establish connections towards random destinations.

Figure 5 represents the value of φ for ABv6, TIPv6 and OSPFv6. As the number of flows of the network increases, φ decreases, which is expected as the available bandwidth per link decreases and lower quality routes can be established.

When the network is not too loaded (between 10 and 20 flows), the acceptance rate φ is almost 70% for ABv6 whereas TIPv6 achieves 56% and almost 30% for OSPFv6.

However, the main improvement can be seen when the network density increases. For example, when the network becomes loaded (between 20 and 30 flows), TIPv6 acceptance rate decreases more fastly. The main explication is that TIPv6 upper-estimates the available bandwidth, and therefore the network tends to accept more flows than it is able to convey, without degrading existing traffic. ABv6 exhibits good performance in every situation.

Finally, when the network becomes very loaded (between 40 and 50 flows), also achieves 35% for acceptance rate while TIPv6 and OSPFv6 raises very bad performance (5% of acceptance rate).

6. Conclusion and future works

In this paper, we have presented a new technique to compute the available bandwidth between two neighbor routers and by extension along a path. We combine channel monitoring to estimate each router's medium occupancy and by extension to links. This evaluation uses IPv6 extensions to provide accurate measurements. This technique has been integrated in a new routing protocol called ABv6 for comparison purposes. We show the accuracy of the available bandwidth measurement through NS-2 simulations. The different scenarios prove that the most difficult point when designing a QoS protocol is not the routing process, but the estimation of available resources through the network.

As future works, we plan to carry out more complete and exhaustive simulation models in more diverse topologies and compare it with other available bandwidth technique in order to refine the available bandwidth measurement.

References

[1]. Rob Coltun, Dennis Ferguson, John Moy, and A Lindem (2008), *Ospf for ipv6*. IETF RFC2740, 2: 839–841, 2008.

[2]. Marshall Crocker, GY Lazarou, Julie Baca, and Joe Picone (2009), *A bandwidth determination method for ipv6-based networks*. International Journal of Computers & Applications, 31(2), 2009.

[3]. Priyanka Dhiman and Arvind Kalia (2013), *Available bandwidth measurement of campus wide optical fiber network using packet pair technique*. International Journal of Computer Applications, 65(9): 17-22, 2013

[4]. Christian Huitema (1996), *IPv6: the new Internet protocol*, Volume 2. Prentice Hall Englewood Cliffs, New Jersey, 1996.

[5]. Sheng Jiang and Brian Carpenter (2013), *Transmission of IPv6 extension headers*. RFC 7045, 2013.

[6]. Peter Loshin(2004), *IPv6: Theory, protocol, and practice*. Morgan Kaufmann, 2004.

[7]. Liu Min, Li Zhongcheng, Shi Jinglin, and Guo Xiaobing (2003), *Estimating available bandwidth in ipv6 networks*. In Communications of APCC 2003. The 9th Asia-Pacific Conference, volume 3, pages 939–944. IEEE, 2003.

[8]. Gopalaswamy Soora and Vernon Lawton Tice (1998), *Multimedia distribution network including video switch*, May 26 1998. US Patent 5,756,280.

[9]. Li Xing-feng, Wang Yi-zhi, and Luo Wan-ming (2007), *A novel IPv6 networks measuring algorithm for locating available bandwidth bottleneck*. In Advanced Communication Technology, The 9th International Conference, volume 2, pages 1195–1200. IEEE, 2007.

[10]. Juan Zhou, Yi Wang, and Gang Hu (2010), End-to-end performance measurement model on diffserv domain in ipv6 network. In Networked Computing and Advanced Information Management (NCM), 2010 Sixth International Conference on, pages 203–206. IEEE, 2010.