`tracerate`: a non-intrusive method for measuring the hop-by-hop capacity of a path

Bandwidth Estimation Workshop

Mathieu Goutelle and Pascale Primet
INRIA RESO team, LIP laboratory (ENS Lyon, France)

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- Our proposition: `tracerate` ;
  - Method principles ;
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- **Simplicity** of IP networks: no control channel, few informations provided by equipments ;
- Need of an external mean to evaluate the end-to-end performances:
  - delay, loss rate: classical and easy (`ping`, `traceroute`);
  - **Capacity**: Maximal available rate between two nodes ;
  - **Available rate**: Accessible rate between two machines given an utilization on the followed path ;

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- Use of the delay between two machines $\rightarrow$ not enough to evaluate the duration of a data transfer.

Bandwidth measurement in IP networks

- A “rate” knowledge gives a more realistic view ;
  - to estimate a transfer duration estimation ;
  - to schedule transfer in grid computing ;
  - to choose a data source or a data mirror ;
  - ...

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	Method	Type of measure	Measure	Protocol	Receiver
`pathchar` [Jac97]	*Variable Packet Size*	hop-by-hop	slow	UDP, ICMP	no
`tailgater` [LB00]	*Packet Tailgating*	end-to-end	fast	TCP, ICMP	no
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- **Issues**: high-performance network, bottleneck localization, low intrusivity.

The Packet Pair method (1)

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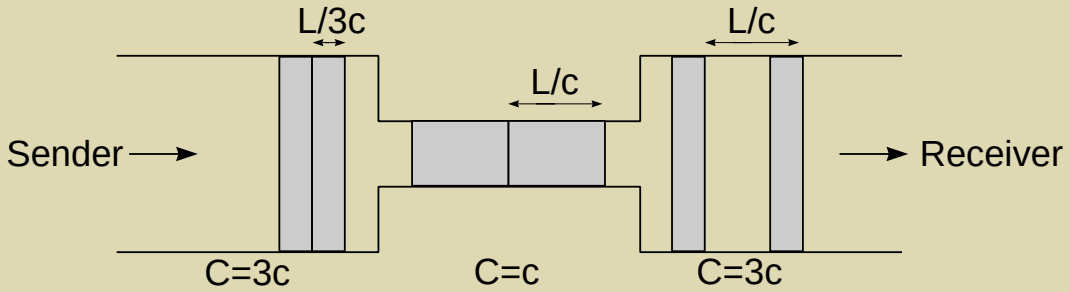
- Quite old principle (Van Jacobson, 1988 [Jac88]) ;
- A path is considered as a succession of delays (queue waiting time, transmission time, *etc.*) ;
- Capacity evaluation through the dispersion (inter-packet delay) measurement of two packets sent back-to-back ;
- This delay is the consequence of the smallest link on the path:



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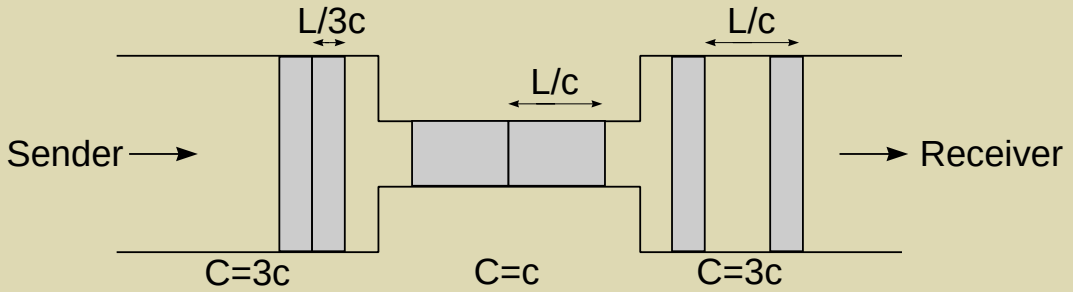

- **Hypothesis**: No concurrent traffic!
- Otherwise, concurrent traffic may cause the measure to under- or overestimate the real path capacity.

The Packet Pair method (2)

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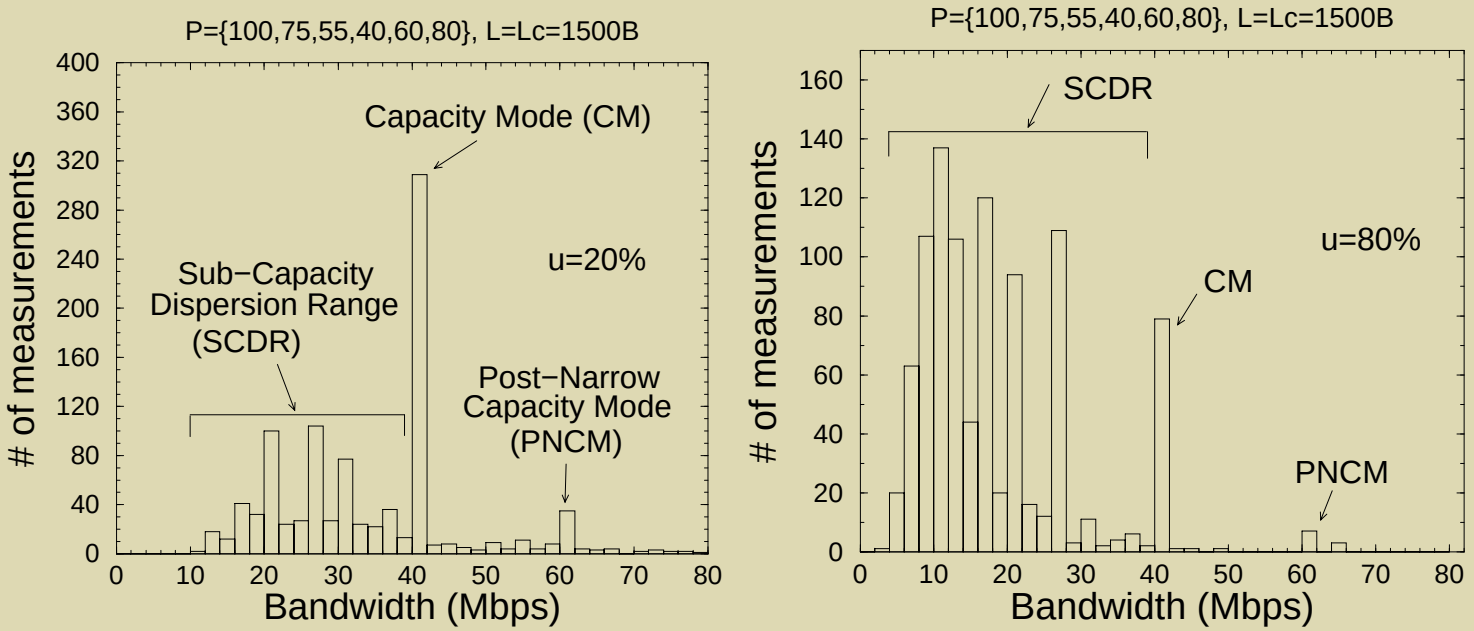
- Due to concurrent traffic, the measurement distribution is multimodal [DRM01]:



  - **under-estimation** (SCDR): A packet has spaced the two probe packets ;
  - **over-estimation** (PNCM): The first probe has waited for the second in an non-empty queue.

Our proposition: `tracerate`

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- **Objectives**: to propose a method little intrusive to measure and to localize the bottleneck of a path. It must work in a high-performance environment and without cooperation of the destination ;

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- **Objectives**: to propose a method little intrusive to measure and to localize the bottleneck of a path. It must work in a high-performance environment and without cooperation of the destination ;
- **Proposition**:
  - We use a Packet Pair because it is more robust regarding the presence of invisible nodes [PDM03] ;
  - We measure the hop-by-hop capacity (and delay and loss) up to the path bottleneck ;
  - We eliminate “topology” parasitic modes with a better hop-by-hop knowledge of the topology (like `traceroute`) ;
  - We will be able to evaluate the hop-by-hop utilization rate up to the path bottleneck ;

Topology discovery

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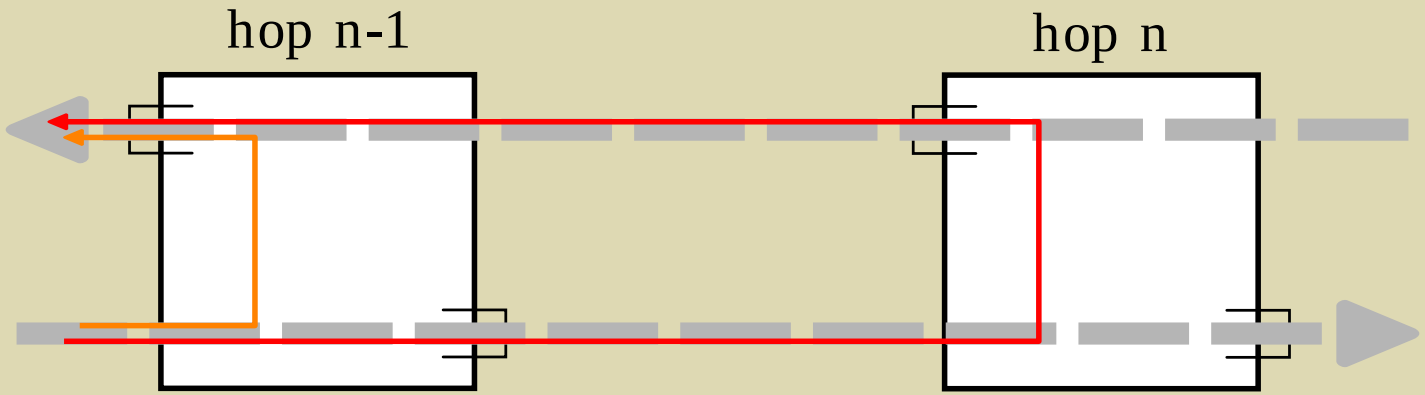
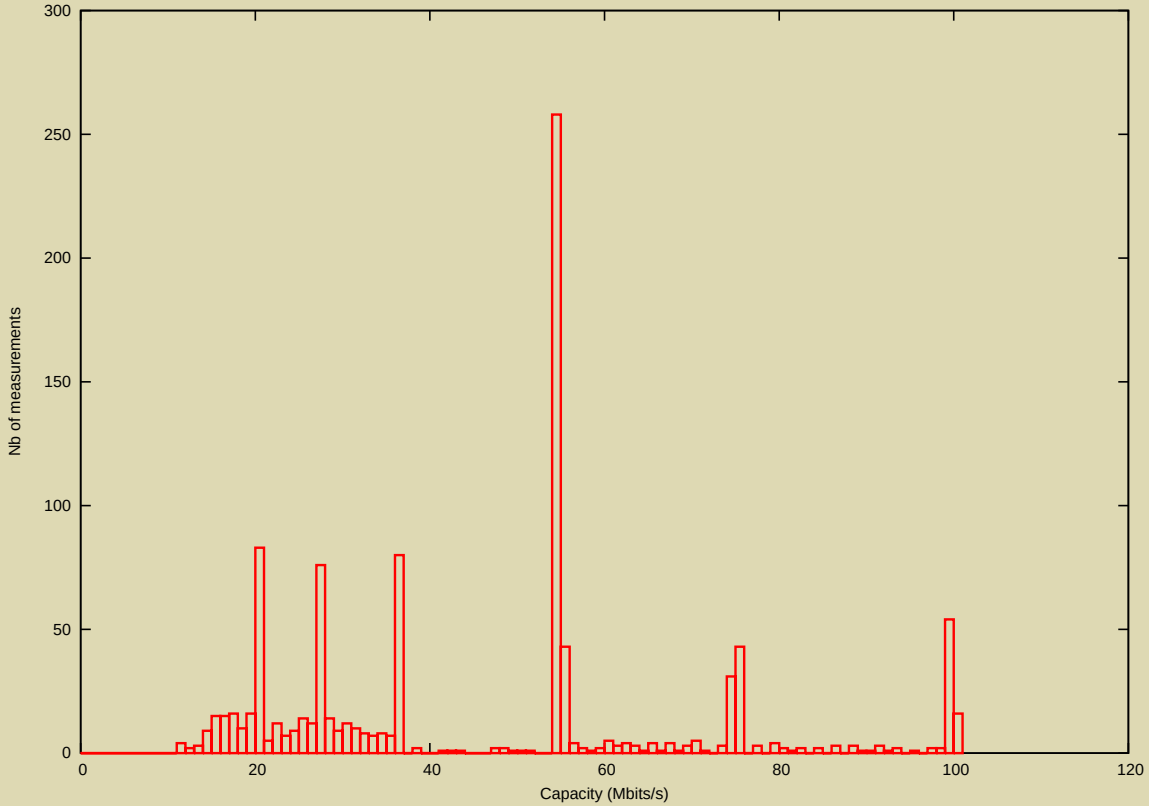
- TTL (*Time To Live*): field in the IP header. It indicates the remaining number of equipments a packet can go through:
  - If an equipment receives a packet with a zero value TTL, it sends this packet back to the sender ;
  - Otherwise, it decreases this value and sends the packet to the next hop.
- With this mechanism, you can discover the topology with increasing TTL loops.



Method principles

- Measurements gathering ;
- Distribution analysis: extraction of the capacity mode.



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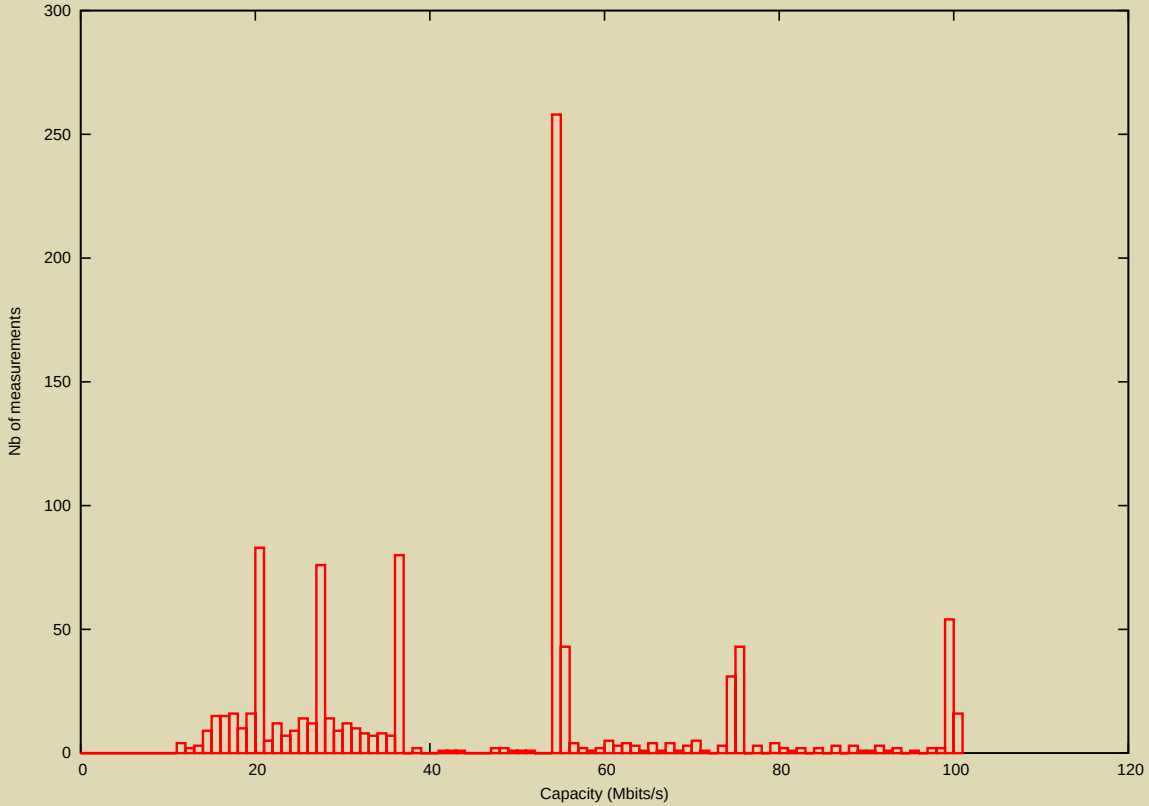

- At step $n+1$, we already have the capacity value for the loops up to n:
  - If there is no relatively acute mode below the previous capacity mode, the bottleneck (up to hop $n+1$) is in the previous loop ;
  - Otherwise, a mode below the previous capacity mode has been detected and the link between hop n and $n+1$ is the new bottleneck.

Data Analysis

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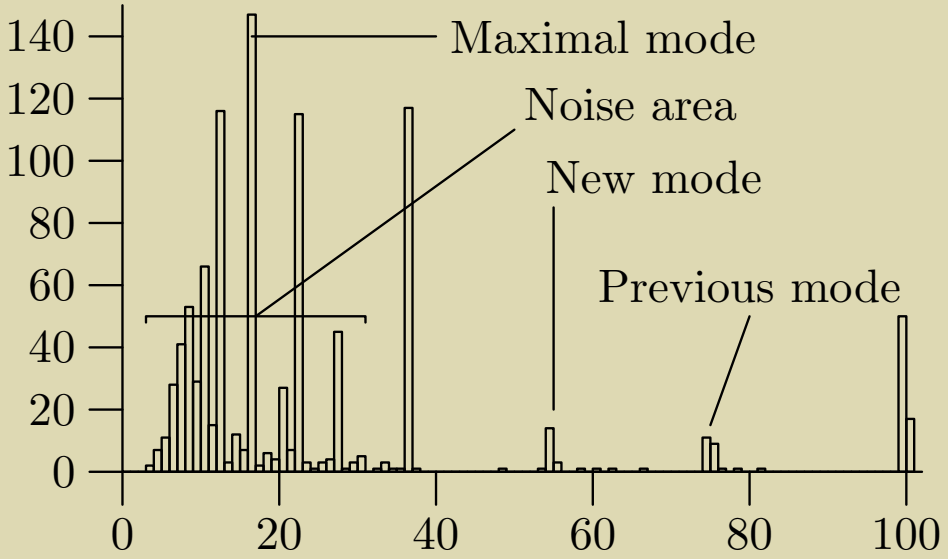
- Mode detection (increase up to a maximum and then decrease) ;
- Determination of four characteristics of the distribution:



- Capacity mode extraction depending on the position and the population of the characteristics.

Capacity mode extraction

for all hop on the path **do**
  Compute the measurements distribution
  Determine the new, previous and maximal modes and the noise area
  if max_mode = prev_mode
    or (max_mode = new_mode and new_mode not in noise_area) **then**
    capacity_mode $\leftarrow$ max_mode
  else if $1.1 \times |\text{new\_mode}| \geq |\text{prev\_mode}|$
      and new_mode not in noise_area **then**
    capacity_mode $\leftarrow$ new_mode
  else if (max_mode not in noise_area or $|\text{max\_mode}| \geq 0.6 \times$ total_pop)
      and $|\text{max\_mode}| \geq 1.25 \times |\text{prev\_mode}|$ **then**
    capacity_mode $\leftarrow$ max_mode
  else
    capacity_mode $\leftarrow$ prev_mode
  end if
end for

Validations

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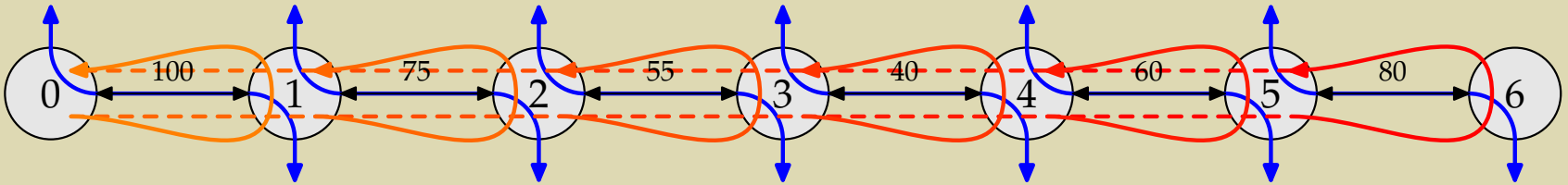
- Validations in simulations (NS-2) in a controlled environment (capacity, delay):
  - Behaviour consistent with the one expected ;
  - Accuracy validation of the analysis method ;
  - Robustness validation regarding the network conditions (path length, load).



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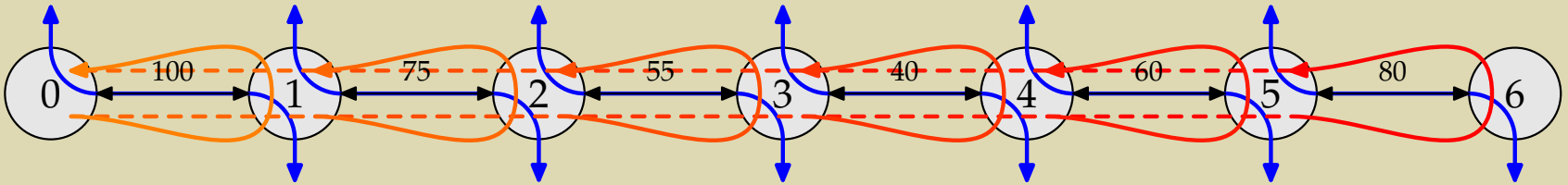

- Experimentation in a high-performance environment (DataTAG platform, `http://www.datatag.org`).

Accuracy study

- 100 simulations with a variable utilization rate from 0 up to 100% ;
- Measure of the relative error between the real capacity and the measured value for each hop:

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- Measure of the relative error between the real capacity and the measured value for each hop:

Relative error	hop 1	hop 2	hop 3	hop 4	hop 5	hop 6
$u \leq 0{,}5$	0,1%	0,1%	1,1%	2,5%	4,8%	6,9%
$u \leq 0{,}75$	0,1%	1,4%	4,6%	7,1%	5,9%	8,3%
$u \leq 1$	0,1%	12,4%	14,9%	15,3%	11,5%	13,7%

- Influence of the load and path length, but the quality degradation of the result remains low ;
- The method tries to be conservative: it can detect the bottleneck at one or two steps later.

Robustness study

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- 100 simulations with a random load and link capacities ;

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- 100 simulations with a random load and link capacities ;

	Correlation	Avg relat. err.
6 hops ($u < 0{,}5$)	0,82	0,14
6 hops ($u < 1$)	0,58	0,28
10 hops ($u < 0{,}5$)	0,88	0,16
10 hops ($u < 1$)	0,62	0,37

- The method is robust regarding the path length ;
- The network load may be a diffi culty if it becomes high.

Experimental validation

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- Implementation in Linux based on `tcptraceroute` ;
- Experimentation on a real platform (DataTAG):
  - It works!
  - Measure up to 1Gbit/s ;
  - Some problems with ICMP in routers: limitation due because the ICMP path is different from the normal path ;
  - it needs some extra tests to validate `tracerate`...

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- Non-intrusivity:

Tool	Short path (4 hops)	Long path (11 hops)
`pathchar`	11,562	31,782
`clink`	6,002	16,400
`pchar`	11,732	32,417
`nettimer`	982	6,663
`tracerate`	4,000	11,000

Utilization rate evaluation

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- When you know both the capacity and the utilization rate of a path, you can deduce almost all its characteristics ;
- Given the previous measurements (distribution for each hop), we want to find a relation between the **population in the capacity mode** and the **utilization rate**.

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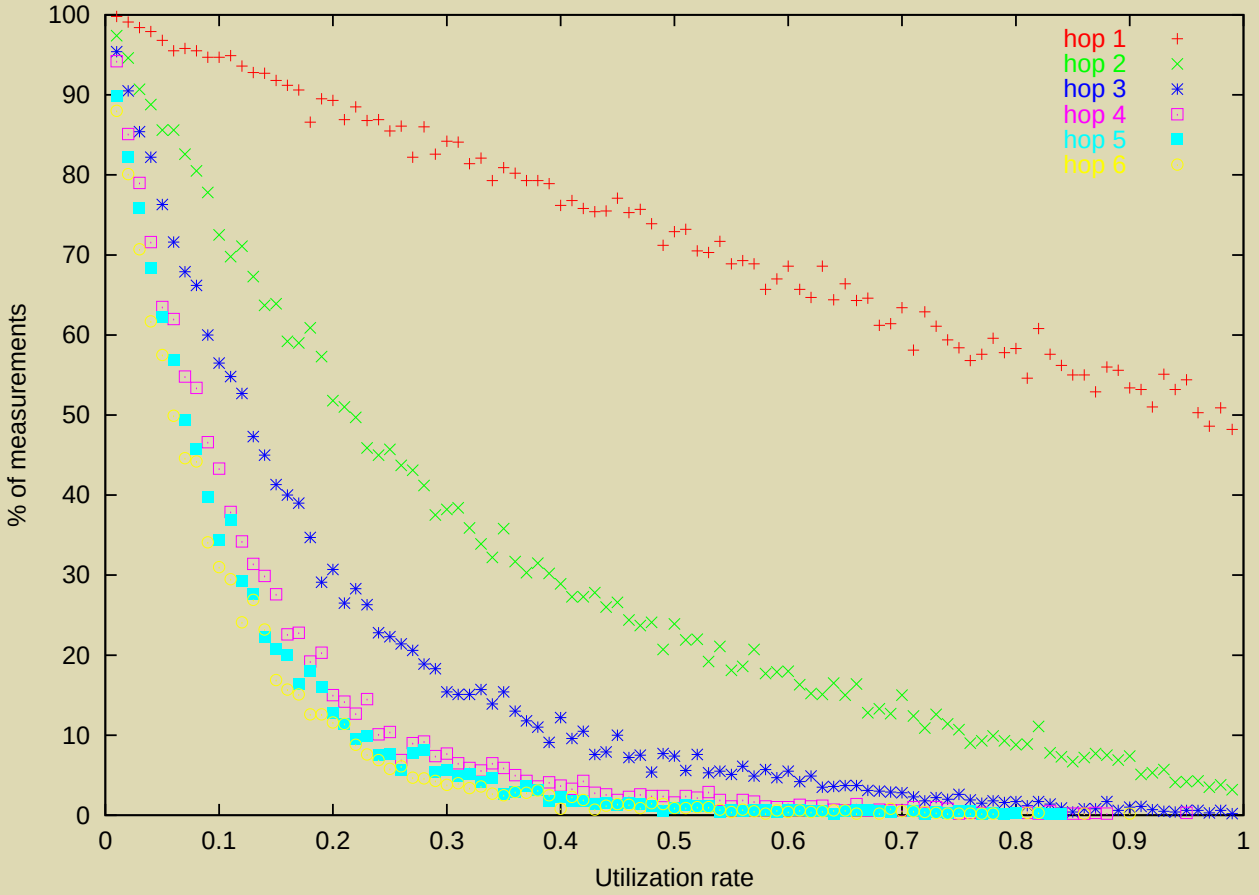

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- **Non-intrusive** method to evaluate the capacity: determination of the bottleneck and its **localization** on the path ;
- Validations in simulations ;
- Linux implementations, working in a **high-performance** environment → `tracerate` ;
- **Promising future work:** utilization rate evaluation and finalization of the implementation ;

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More details in this research report:
`http://www.inria.fr/rrrt/rr-4959.html`

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Questions?