

EXPERIMENTAL ANALYSIS ON ACTIVE BANDWIDTH ESTIMATION TOOLS FOR  
CLINK, BING, STAB FOR MESH WIRELESS LOCAL AREA NETWORK

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## ABSTRACT

Available bandwidth – as well as capacity or achievable bandwidth – on a path or a link is one of the very important parameters to measure or estimate in a network: it is of high interest for many networking functions (routing, admission and congestion control, load balancing, etc). The bandwidth measurement techniques can be divided into two type which were active and passive measurement technique. Active measurement techniques provide the easiest and the more flexible approach, for estimating available bandwidth. In addition, they can be used for different network technologies or structures. Many techniques and tools for available bandwidth estimation appeared recently, but little attention has been given to the accuracy of the estimated values in the real Internet, most of previous studies focusing on validating the accuracy of these tools on local platform. WLAN offers wireless network communication over short distances using radio or infrared signals instead of using traditional network cabling. Therefore, this paper evaluates more about analysing bandwidth estimation in mesh wireless local area network (WLAN) using three selected active bandwidth estimation tools. This paper then discusses the results we got in different environments with different active tools. The results were discussed based on three aspects which were accuracy, consistency and failure pattern. They were tested in two different network environments: optimum network (network without external traffic) and network with external traffic. In order to carry out the testing, one access point, two access points with same bandwidth and two access points with different bandwidth were used in both network environments.

## ABSTRAK

Jalur lebar yang didapati - sepertimana kapasiti atau jalur lebar yang dapat dicapai - pada laluan atau sambungan adalah salah satu parameter yang terpenting untuk mengukur atau menganggar dalam rangkaian. Ia adalah penting untuk pelbagai fungsi rangkaian (jalan laluan, kebenaran masuk dan kawalan kesesakan, pengimbangan beban, sbg). Teknik pengukuran jalur lebar boleh dibahagikan kepada dua jenis iaitu teknik pengukuran aktif dan teknik pengukuran pasif. Teknik pengukuran aktif menyediakan pendekatan yang mudah dan lebih sesuai, untuk menganggar jalur lebar yang ada. Tambahan pula, ia boleh digunakan dalam teknologi rangkaian atau struktur yang berbeza. Terdapat banyak teknik dan alat untuk penganggaran jalur lebar yang ada, tetapi hanya sedikit perhatian diberi dalam ketepatan anggaran nilai dalam platform setempat. WLAN menyediakan rangkaian komunikasi tanpa wayar bagi jarak dekat dengan menggunakan radio atau signal infrared selain menggunakan rangkaian kabel secara tradisional. Oleh yang demikian, projek ini menerangkan dengan lebih terperinci mengenai penganalisan penganggaran jalur lebar dalam rangkaian tanpa wayar MESH (WLAN) dengan menggunakan tiga alat penganggaran jalur lebar aktif. Penyelidikan ini diteruskan dengan membincangkan keputusan yang diperolehi dalam persekitaran yang berbeza dengan alat aktif yang berbeza. Hasil itu dibincangkan berdasarkan tiga aspek iaitu ketepatan, keselarian dan corak kegagalan. Ia diuji dalam dua persekitaran rangkaian yang berbeza : rangkaian optimum (rangkaiannya tanpa trafik) dan rangkaian dengan trafik luar. Demi menjalankan eksperimen ini, satu pusat akses, dua pusat akses dengan kadar jalur lebar yang sama dan dua pusat akses dengan kadar jalur lebar yang berbeza digunakan dalam kedua-dua persekitaran.

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## CHAPTER 1

### INTRODUCTION

#### 1.1 Introduction

The development of new technology which is widely increases the need of using laptop computers within the enterprise, and also increase in worker mobility has encouraged the demand for wireless networks. This is because the network especially for small businesses can have the accessibility where you can access your network resources from any location within your wireless network's coverage area or from any WiFi hotspot. As it is mobility, you are no longer tied to your desk, as you were with a wired connection. Productivity is one of the benefits of wireless network. Wireless access to the Internet and to your company's key applications and resources helps your staff get the job done and encourages collaboration. It is also easy setup. You do not have to string cables, so installation can be quick and cost-effective. Another benefit is security. Advances in wireless networks provide robust security protections.

According to some authors, the Wireless Mesh Network is well-matched for providing broadband wireless access in areas that traditional WLAN systems are unable to cover and where the seamless voice and mobility capabilities of cellular systems are not required. The meshed topology provides good reliability, market coverage, and scalability. The Wireless Mesh Network extends the reach of WLAN by avoiding service outages by providing efficient routing using auto-discovery and self-healing algorithms. Besides, it using standard 802.11b/g interfaces, exploiting the immense and growing consumer base of WLAN compatible devices. This wireless mesh networks can also be implemented with various wireless technology including 802.11, 802.15, 802.16, cellular technologies or combinations of more than one type. In this research, the 802.11g specification is used. It is a standard for wireless local area networks (WLANs) that offers transmission over relatively short distances at up to 54 megabits per second (Mbps), compared with the 11 Mbps theoretical maximum with the earlier 802.11b standard.

Bandwidth can be defined as the amount of data that can be transmitted in a fixed amount of time. It describes the rate at which data can be transferred to your computer from a website or internet service within a specific time. Measuring network bandwidth is useful for many Internet applications and protocols especially those involving high volume data transfer among others. The bandwidth available to these applications directly affects their performance. Therefore the amount of bandwidth you have (the bandwidth 'strength') determines the efficiency and speed of your internet activity such as when you open web pages, download files and so on. It is usually expressed in bits per second (bps) or bytes per second.

Bandwidth estimation tool is used to provide an accurate estimation of available bandwidth such that network applications can adjust their behaviour accordingly. The bandwidth estimation tools are divided into two types which are active measurement and passive measurement. Active measurement means that the tool actively sends probing packets into the network whereas the passive measurement is the tools that monitor the passing traffic without interfering. Passive measurement is appreciated, however, less reliable than active, as it cannot extract any data pass through it. Though, bandwidth test results differ greatly, even from moment to moment, and occasionally produce improbable figures.

## 1.2 Problem Statement

The network congestion has increased tremendously due to the rapid growth of wireless application may lead to the bandwidth estimation research. On the other hand, bottlenecks are not always obvious. Therefore, the measuring bandwidth may become more essential for service providers as congestion increases. There are several available bandwidth estimation tools has been selected will be used to study and analysing the bandwidth performance in the different type of wireless mesh network scenarios

A comparative analysis will be carried out for the following attributes:

- i. Consistency.** The consistency of the measurement of the tool will be précised as whether it will fluctuate of over estimating or under estimating value.
- ii. Accuracy.** The accuracy of the tool will be measured to evaluate the available bandwidth whether it will over estimate or not under estimate.
- iii. Failure patterns.** It will monitor and measure the reliability of the tool's failure to estimate the bandwidth throughout the testing cycle.

### 1.3 Objective

- i. To measure available bandwidth with selected bandwidth estimation tools in various network.
- ii. To compare the selected tool based on their estimation preference in term of accuracy, consistency and failure pattern in various networks.
- iii. To suggest the best bandwidth estimation tools for the given estimation tools.
- iv. To improve current systems as well as diagnosis network problems.

### 1.4 Scope

In this research, there were several limitations have been decided in evaluating the active measurement bandwidth estimation tools for multiple hop wireless mesh network. The limitations are shown below:

- i. Three bandwidth estimation tools will be used. The tools were BING, CLINK and STAB.
- ii. IEEE 802.11 as the wireless network standard
- iii. The operating system used was LINUX
- iv. The wireless hardware used were two laptops with built in wireless 802.11b/g and two wireless access points.
- v. Twenty readings will be taken for each tool was recorded for each experiment analysis.
- vi. A measurement was test based on the traffic generated by the bandwidth estimation tools.

## **1.5 Thesis Organization**

The research consists of six chapters:

Chapter 1 discussed the overview of the project. In chapter 1, the problem statements are introduced.

Chapter 2 critical analysis of the bandwidth estimation is done in this chapter with reference to the previous work done across this area and introduction to the bandwidth estimation tools also given.

Chapter 3 explains more about the methodology that will be used to carry out this research. It will be elaborated in detail about the step by step process that is being used to complete the project.

Chapter 4 detailed explanation to the design procedure followed by developing the framework and model through flow work. There will be explanation on how the tools been implemented into selected algorithm.

Chapter 5 focused on analysing the results obtained from the experiment that has been done and discuss further the reading recorded from each tool for every experiment.

Chapter 6 conclusion to the complete work done and the corresponding observations are made in this chapter.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.0 WLAN

Instead of using the traditional network cabling, a WLAN offers wireless network communication over short distances using radio or infrared signals. A WLAN characteristically extends an existing wired local area network. They are manufactured by attaching a device called the access point (AP) to the edge of the wired network. Clients communicate with the AP using a wireless network adapter parallel in function to a traditional Ethernet adapter. The important issue for WLANs is network security. Random wireless clients must usually be prohibited from entering the WLAN. WEP is an example of technologies that can increase the level of security on wireless networks to rival that of traditional wired networks [1]

On the other hand, a wireless LAN (or WLAN, for wireless local area network) is one in which a mobile user can connect to a local area network (LAN) through a wireless (radio) connection. The IEEE 802.11 group of standards specify the technologies for wireless LANs. 802.11 standards use the Ethernet protocol and CSMA/CA (carrier sense multiple access with collision avoidance) for path sharing and include an encryption method, the Wired Equivalent Privacy algorithm [2]

#### 2.1 Available Bandwidth

From a previous research, the author defined available bandwidth as the unused capacity in the link independently of the transport protocol. The available bandwidth is a function resulting from the utilization and the capacity. [3] Let's consider the first path, made of N links: the available bandwidth for the  $i$ th link is defined by:

$$AvBi = Ci (1 - Ui) \quad (1)$$



The available bandwidth of a path is designed by the link which has the lowest available bandwidth:

$$AvB = \min (AvB_1, AvB_2, AvB_3 \dots, AvB_N) \quad (2)$$

The link having the minimum available bandwidth is called the tight link. In the example below, the tight link defining the available bandwidth is  $l_3$  and  $AvB$  equals to  $AvB_3$ .

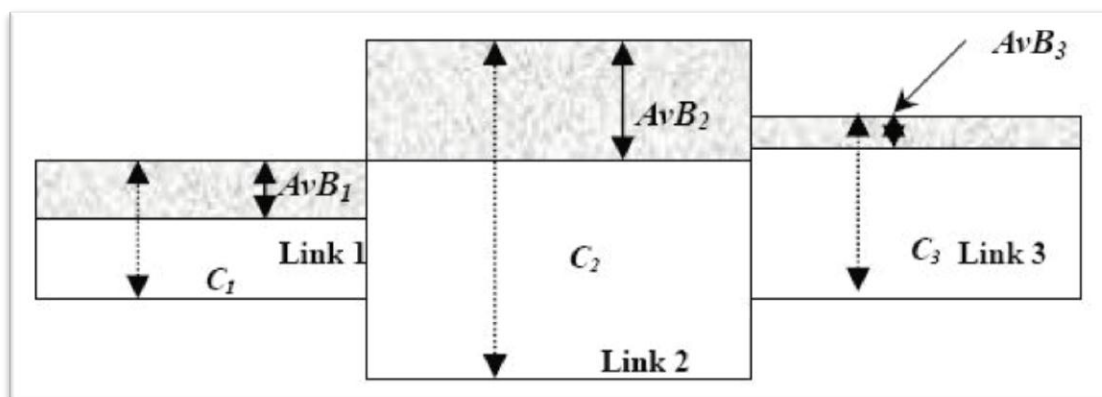


Figure 2.0 Example of Available Bandwidth: Narrow link (link 1) and tight link (link 3) on a path.

The other author states that the available bandwidth is a fundamental metric for describing the performance of a network path. This parameter is used in many applications, from routing algorithms to bottleneck control mechanisms and multimedia services. For example, the authors investigated the importance of the available bandwidth for adaptive content delivery in peer-to-peer (P2P) or video streaming systems. [4]

## 2.2 Bandwidth Estimation

According to an author, in order to categorize some basic concepts of bandwidth estimation, the network bandwidth can be evaluated based on the basis of per hop or end-to-end path. For each hop/path, we can measure its capacity or available bandwidth. The capacity is the upper limit of the transmission rate. On the other hand, the available bandwidth acted as the spare space for accommodating more traffic. The author states more, that the measurements can be done in two techniques, active measurement technique and passive measurement technique [5]

Passive measurements perform measurements of the network traffic already in the network. This means that passive measurement techniques in general have fewer networks overhead, but are limited to information that can be derived from on-going communication. Due to the fact that these techniques rely on analysing information owned by others, privacy and security issues might also arise. In addition, the passive measurement techniques can be CPU intensive, as they rely on analysing a potentially huge amount of on-going traffic. [6]

Active measurement technique is the technique where there is additional traffic inserted into the network, most commonly in the form of network probes. The measurements are then determined based on the performance of these probes experience. The active probing can be used to measure the amount of different network parameters, and requires few local resources, such as CPU and storage. However, the main consequence is that these techniques insert traffic into the network would increase the traffic load which means that an active measurement is intrusive. There are some techniques are depend on saturating the network with probes, and will thus causes non-measurement traffic attempting to use the same network. [6]

This technique does not need huge quantities of storage space and they can be used to measure things that the passive measurements cannot do. Furthermore, there is no privacy issues existed since the data used does not contain any confidential information. All active probe packets are artificial as they are generated on demand and therefore they usually contain only random bits as payload [7]

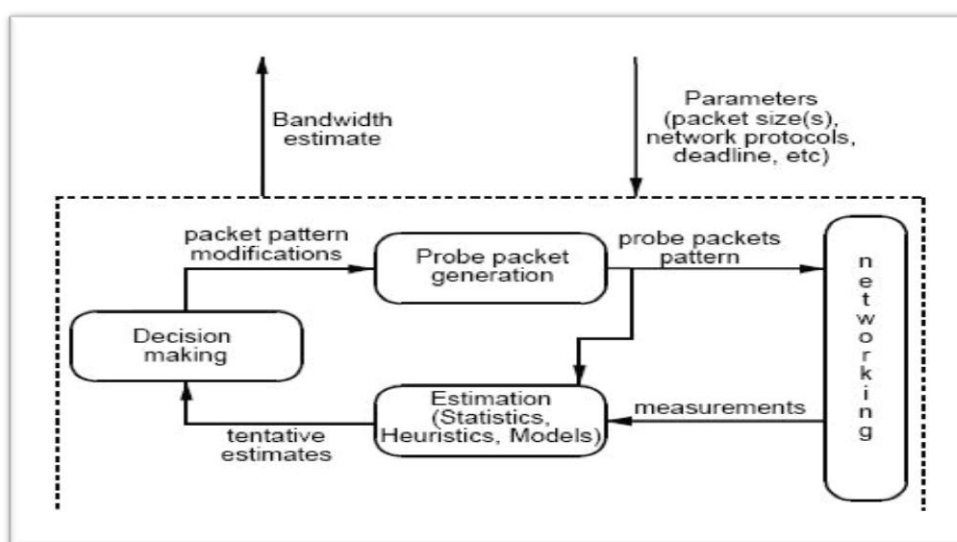


Figure 2.1 Simplified scheme of an active bandwidth estimation tool.

In the aim to measure or determine the available bandwidth actively, some bandwidth estimation tools are needed in order to perform the task effectively. In spite of this, there are multiple of bandwidth estimation tools that are available that could be used. But the subject is which bandwidth estimation tool will be the best to perform the task.

### 2.3 Impact of External Traffic

The author from earlier research agreed that among the different parameters characterizing traffic and networks, one of the most significant is the available bandwidth of network paths. This is due to the important role of available bandwidth in traffic engineering algorithms as well as in other scenarios like file sharing, server selection, and in general network aware applications [8]

From this earlier paper, the researcher presents a comparative analysis with two types of cross traffic. As for this paper, the first cross traffic type (type1) has been created with constant PS and exponentially distributed IDT. The second one (type2) has been constructed by using constant PS and Poisson profiled IDT. Additionally, for every cross traffic profile three different bit rates are used: 10, 50 and 90Mbps. Besides, 10 test repetitions are performed for every experiment and the gained results are averaged in order to minimize the influence of random error on measured values. Table below shows the results obtained.

CT (Mbps)	PS	IDT	Parameter	BET	Path Load	Path Chirp
90	CONST	EXP	AB (Mbps)	3.8	0.08	9.40
			RE (%)	62.00	99.20	6.02
			TMT (s)	58	87.89	10
50	CONST	EXP	AB (Mbps)	53.81	26.40	45.62
			RE (%)	7.62	47.21	8.76
			TMT (s)	25.17	7.2	60
10	CONST	EXP	AB (Mbps)	91.18	89.33	81.14
			RE (%)	1.31	0.75	9.84
			TMT (s)	25	9.08	30
90	CONST	POIS	AB (Mbps)	5.27	3.71	9.37
			RE (%)	47.35	62.93	6.27
			TMT (s)	51	34.83	10
50	CONST	POIS	AB (Mbps)	52.1	51.66	51.52
			RE (%)	4.20	3.32	3.04
			TMT (s)	22.12	4.93	30
10	CONST	POIS	AB (Mbps)	101.2	102.37	88.66
			RE (%)	12.44	13.74	29.4
			TMT (s)	21.3	5.47	30

Table 2.0 Example of results of the comparative analysis with different traffic profiles

Specifically, with type1 cross traffic and bit rate equal to 10Mbps both BET and Pathchirp achieved the best performance in terms of measure accuracy. Instead, when cross traffic rate was equal to 90Mbps, only Pathchirp achieved the best performance in terms of accuracy. When cross traffic are generated according to type2, and bit rate equal to 50Mbps, the three applications collected the same performance in terms of accuracy. With cross traffic rate equal to 10Mbps BET and Pathload achieved the best performance in terms of measure accuracy. Finally, when the cross traffic rate was 90Mbps the best performance in terms of accuracy was achieved by Pathchirp.

As the conclusion, it is recognizable the behaviour of the widely used tools with different traffic patterns. It shows that the present of higher cross traffic rate affect the performance of accuracy for each tool. Besides, it is proved that BET represents a good compromise among all variables in a fitness function that considers accuracy and total estimation time.

## **2.4 Measurement criteria**

Based on some previous research, they have decided to focus on three criteria such as accuracy, consistency and failure pattern in both optimum network and network with traffic environments. The results obtained from the testing using the selected bandwidth estimation tools are determined based on these three criteria.

### **2.4.1 Accuracy**

The main target of a routing is either to give the best routes in function of some parameters (like bandwidth, delay, packet loss, etc.) or to find routes that will provide guarantees on some of these parameters. Many QoS routing protocols have been suggested and bandwidth parameter is considered. It is very significant to get very accurate information on the used and available bandwidth in designing a well-organized QoS routing. Such estimation is not so easy to process in multihop wireless networks. The nodes share the medium and their perception of the used bandwidth or the available bandwidth can be very different from one mobile to another. As a result, before introducing a new flow in the network, each mobile need to be accurately clarify the available bandwidth that is offered to it, but it also needs to recognize the available bandwidth available to the nodes with which it may share the medium in order to not penalize them [9]. In this paper, the accuracy of the network can be

determined by using the bandwidth estimation tools and the accuracy are evaluated based on the percentage of the readings which are in between the benchmark range. The benchmark range decided for this testing are between 6Mbps to 54Mbps.

#### **2.4.2 Consistency**

The key to success of an Internet connection is a combination of a good speed with a good consistency of service. In fact, it is preferable to have a slower 3 Mbps (Megabits per second) connection with a 99% consistency of service rather than a 6 Mbps connection with a 50% consistency of service. Both will achieve about the same throughput overall, however the delays inherent in the packet flow that result in a lower consistency of service will adversely impact time-dependant applications such as VoIP, video or MP3.

#### **2.4.3 Failure Pattern**

It is important to identify the failure pattern of the network. The failure pattern can be observed based on the error of several tools in running their experiment. On the other hand, the environment itself can bring to the failure pattern whether in optimum network or network with traffic environment. This is because some tools may not perform well in certain conditions. There are also some of the readings recorded are not sense and not match with the desired results. Therefore, they are considered as failure. Besides, the readings obtained are totally underestimate and overestimate the benchmark range is one of the causes why the failure pattern existed.

### **2.5 Active Bandwidth Estimation Tools**

Researchers have selected three active bandwidth estimation tools in order to measure the available bandwidth. These tools were selected based on their availability, performance and specification requirement. They were tested under two environments which were network with optimum traffic and network without external traffic. Those tools were the following:

#### **2.5.1 Clink**

Clink is a utility that estimates the latency and bandwidth of Internet links by sending UDP packets from a single source and measuring round-trip times. The basic mechanism is similar to ping and traceroute, except that clink generally has to send many more packets. The

interface of clink is based on the interface of pathchar, and the underlying mechanism is based on Jacobson's description of pathchar. No pathchar source code is included in clink [10]

```

If clink succeeds, the output will look something like:

clink to host-06.colby.edu (137.146.210.39)
  8 probes at each of 93 sizes (28 to 1500 by 16)
0 localhost
|      n= 744  lat= 0.234 ms  bw= (8.493, 8.506, 8.506) Mb/s
1 cb3500-02.switches.network.colby.edu (137.146.194.17)
|      n= 744  lat= 0.182 ms  bw= (9.034, 9.134, 9.552) Mb/s
2 port-0.router-1.network.colby.edu (137.146.238.209)
|      n= 744  lat= 1.020 ms  bw= (4.325, 4.389, 4.458) Mb/s
3 host-06.colby.edu (137.146.210.39)

```

Figure 2.2 The Example Output of the Clink.

**n** is the number of probes that were used to characterize each link. In this testing, clink makes 8 measurements at each of 93 sizes, for a total of 744 links. If clink encounters a routing instability, it may have to send more probes before it gets a complete set of probes at each size. If you encounter an alternating link, you might want to use the **-D** option to generate a dump file, and then explore the dump file for more information about the instability. **lat** indicates latency, in milliseconds. **bw** indicates bandwidth, in megabits per second. Three values are given for bandwidth: a low estimate, a high estimate, and (in the middle) a best estimate. The distance between the high and low estimates gives some indication of how reliable the estimate is. SIGCOMM paper explained the reasons why the "best" estimate does not necessarily fall between the high and low values.

### 2.5.2 Bing

Bing is a network utility, written by Pierre Beyssac. It enables the measurement of bandwidth between two computers on the network. Unlike other tools, Bing measures the real throughput between two computers that are remote to each other. Essentially, if a link is saturated and shared among multiple users, and one user is getting few Kbps out of link, Bing

will be able determine if it is a 56 kbps link or 1 MB connection. It generates some traffic on the network by sending ICMP requests. As such, this tool is intended for use only during network analysis and management. Because of the additional overhead put on the network, it is not advised to use Bing during normal operations [11]

```

bsd1# ping -e10 -c1 205.153.60.2 165.166.36.17
PING    205.153.60.2 (205.153.60.2) and 165.166.36.17 (165.166.36.17)
        44 and 108 data bytes
1024 bits in 0.835ms: 1226347bps, 0.000815ms per bit
1024 bits in 0.671ms: 1526080bps, 0.000655ms per bit
1024 bits in 0.664ms: 1542169bps, 0.000648ms per bit
1024 bits in 0.658ms: 1556231bps, 0.000643ms per bit
1024 bits in 0.627ms: 1633174bps, 0.000612ms per bit
1024 bits in 0.682ms: 1501466bps, 0.000666ms per bit
1024 bits in 0.685ms: 1494891bps, 0.000669ms per bit
1024 bits in 0.605ms: 1692562bps, 0.000591ms per bit
1024 bits in 0.618ms: 1656958bps, 0.000604ms per bit

--- 205.153.60.2 statistics ---
bytes  out  in  dup  loss  rtt (ms):  min      avg      max
   44   10   10      0    0%      3.385    3.421    3.551
   108  10   10      0    0%      3.638    3.684    3.762

--- 165.166.36.17 statistics ---
bytes  out  in  dup  loss  rtt (ms):  min      avg      max
   44   10   10      0    0%      3.926    3.986    4.050
   108  10   10      0    0%      4.797    4.918    4.986

--- estimated link characteristics ---
estimated throughput 1656958bps
minimum delay per packet 0.116ms (192 bits)

average statistics (experimental) :
packet loss: small 0%, big 0%, total 0%
average throughput 1528358bps
average delay per packet 0.140ms (232 bits)
weighted average throughput 1528358bps

```

Figure 2.3 The Example Output of the Bing.

The output begins with the addresses and packet sizes followed by lines for each pair of probes. Next, ping returns round-trip times and packet loss data. Finally, it returns several estimates of throughput. The observant reader will notice that ping reported throughput, not bandwidth. Unfortunately, there is a lot of ambiguity and inconsistency surrounding these terms.

In this particular example, we have specified the options `-e10` and `-c1`, which limit the probe to one cycle using 10 pairs of packets. Alternatively, you can omit these options and watch the output. When the process seems to have stabilized, enter a `Ctrl-C` to terminate the program. The summary results will then be printed. Interpretation of these results should be self-explanatory. Ping allows for a number of fairly standard options. These options allow controlling the number of packet sizes, suppressing name resolution, controlling routing, and obtaining verbose output.

### 2.5.3 STAB (Spatio-Temporal Available Bandwidth)

**STAB** is a new active probing tool for locating **thin links** on a network path. A thin link is a link with less available bandwidth than all links preceding it on the path. The last thin link on the path is the link with the minimum available bandwidth or **tight link**. STAB combines the concept of "self-induced congestion", the probing technique of "packet tailgating", and special probing trains called "chirps" to efficiently locate the thin links [12]

**Self-induced congestion:** The principle of self-induced congestion allows a straightforward technique for estimating  $A$ . It relies on the following heuristic: if the probing bit-rate  $R$  exceeds  $A$  then the probe packets become queued at some router, resulting in an increased transfer time. On the other hand, if  $R < A$ , then the packets face no extra delay. We thus estimate  $A$  simply as the probing rate at the onset of congestion.

**Packet Tailgating:** Packet-tailgating is a powerful technique that provides local information about segments of network paths. It uses special probe trains consisting of large packets interleaved with small tailgating packets (see Figure 1). The large packets exit the path midway due to limited TTLs<sup>1</sup> but the small packets travel to the destination while capturing important timing information.

**Chirp trains:** In a chirp probing train the interarrival time between successive packets decreases exponentially (see Figure 2). As a result, chirps rapidly sweep through a wide range of probing bit-rates using few packets. This allows an efficient available bandwidth estimation scheme based on the self-induced congestion principle [13].

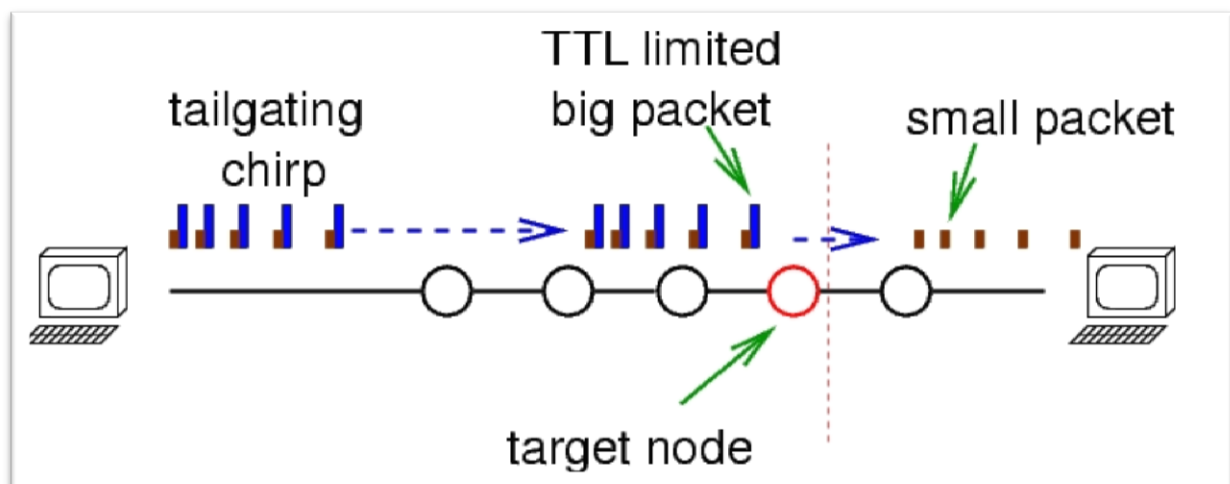


Figure 2.4 The Architecture of STAB process