Internet Tomography in Support of Internet and Network Simulation and Emulation modelling

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Abstract

Internet performance measurement data extracted through Internet Tomography techniques and metrics and how it may be used to enhance the capacity of network simulation and emulation modelling is addressed in this paper. The advantages of network simulation and emulation as a means to aid design and develop the component networks, which make up the Internet and are fundamental to its ongoing evolution, are highlighted. The Internet's rapid growth has spurred development of new protocols and algorithms to meet changing operational requirements such as security, multicast delivery, mobile networking, policy management, and quality of service (QoS) support. Both the development and evaluation of these operational tools requires the answering of many design and operational questions. Creating the technical support required by network engineers and managers in their efforts to seek answers to these questions is in itself a major challenge. Within the Internet the number and range of services supported continues to grow exponentially, from legacy and client/server applications to VoIP, multimedia streaming services and interactive multimedia services. Services have their own distinctive requirements and idiosyncrasies. They respond differently to bandwidth limitations, latency and jitter problems. They generate different types of "conversations" between end-user terminals, back-end resources and middle-tier servers. To add to the complexity, each new or enhanced service introduced onto the network contends for available bandwidth with every other service. In an effort to ensure networking products and resources being designed and developed handling diverse conditions encountered in real Internet environments, network simulation and emulation modelling is a valuable tool, and becoming a critical element, in networking product and application design and development. The better these laboratory tools reflect real-world environment and conditions the more helpful to designers they will be.

This paper describes how measurement of empirical Internet data, obtained through Internet Tomography Measurement Systems (ITMS), can serve an important role in providing these laboratory simulation and emulation modelling tools with Internet parameterization data. The data being extracted from up-to-date real-world Internet can be used to re-create such conditions within the modelling experiments. This paper sets out how such data may be captured over extended and targeted periods of time and used in the laboratory modelling and experiments to define best-, average-, and worst-case Internet scenarios likely to be encountered by the applications or network upgrades being designed. An example of real-time one-to-many global-based Internet QoS measurement data sets obtained within a collaboration in the Réseaux IP Européens (RIPE) project for this purpose is presented.

Keywords: TCP/IP QoS metrics, Service Level Agreement (SLA), Internet Tomography Measurement System (ITMS), Network Simulation, Network Emulation, Empirical Network Modelling.

I. Introduction

The popular and pervasive Internet continues to grow exponentially. Made up of an ever expanding range of networks, autonomous systems, meshed backbones, server farms and so forth, the effect of the Internet is characterized as a social revolution with the immense changes it has brought to every facet of daily living for all people, businesses, and economic and political communities. However while vast engineering effort is invested in developing the Internet and Internet services in all their parts, albeit in a disjointed fragmented way consonant with the nature of the Internet itself, these same "Internet engineers" face a constant technological challenge of handling, predicting, reacting to and resolving from network delays, bottlenecks and outages and so forth which compromise the Quality of Service (QoS) in various ways with varying, more or less, significant consequences, [1,2,3,4,5]. New service introductions may encounter and add to QoS problems compromising their performance as experienced or perceived by the targeted consumers resulting in significant economic consequences such as damaging or undermining business plans. Performance bottlenecks may be created where none existed before, impacting network's ability to support services that were previously running smoothly, [6]. On the other hand the Internet, particularly the core infrastructure resources are constantly changing, growing and expanding. New locations, sub-networks, autonomous systems continue to be added, backbone networks and links, and equipment, are constantly being upgraded and/ or re-configured. Agreements with service providers thus also are dynamic, being modified or even switched. In some cases, new management and security tools, introduced to enhance the network operations, may have a negative QoS impact on networking environment. All this adds to the high level of dynamism and complexity for everyone today, especially "on-the-inside", associates with the Internet environment. One result is that even subtle changes can have a major, unforeseen impact on application performance and availability.

Network managers and engineers will always have particular responsibility for QoS performance to their network users. An ability to do capacity planning to make sure their networks can accommodate future growth, has to be accompanied by means to assess and validate new technologies, the value added by their implementation in terms of QoS improvements and business competitive advantages wrought. In the Internet market customers have high Internet QoS expectations when dealing with Internet vendors. Thus in turn network managers, service providers and such players will be demanding in terms of products' quality, i.e. products to be comprehensively tested and come with strong reliability guarantees. On the other hand there is constant pressure to decrease "time-to-market" to match shrinking business opportunity windows, resulting in shorter development cycles and limited testing time, cf. e.g. [7].

Service providers and network providers are in much tighter budget regimes than the telecommunication network operators of a generation ago. Managers have finite budgets. They cannot today so simply over-provision network infrastructure to make generous provision for unexpected growth, resource demands and unforeseen capacity expansion needs, e.g. increased global demand and unforeseen success of a service; or growth in new services. Basically network managers would like to be able to have readily available spare link and node bandwidth capacity to cater satisfactorily for all QoS demands of their service-provider clients and service end-users. Thus QoS performance, reliability, change and growth have to be achieved in ways, which are as cost-efficiently as directed and as measurable as possible. Network modelling and simulation and emulation tools have a growing in importance role in this. Through these, network engineering teams are better enabled to manage strategically and pro-actively the resource investments and growth of networking environments [6, 7, 8, 13].

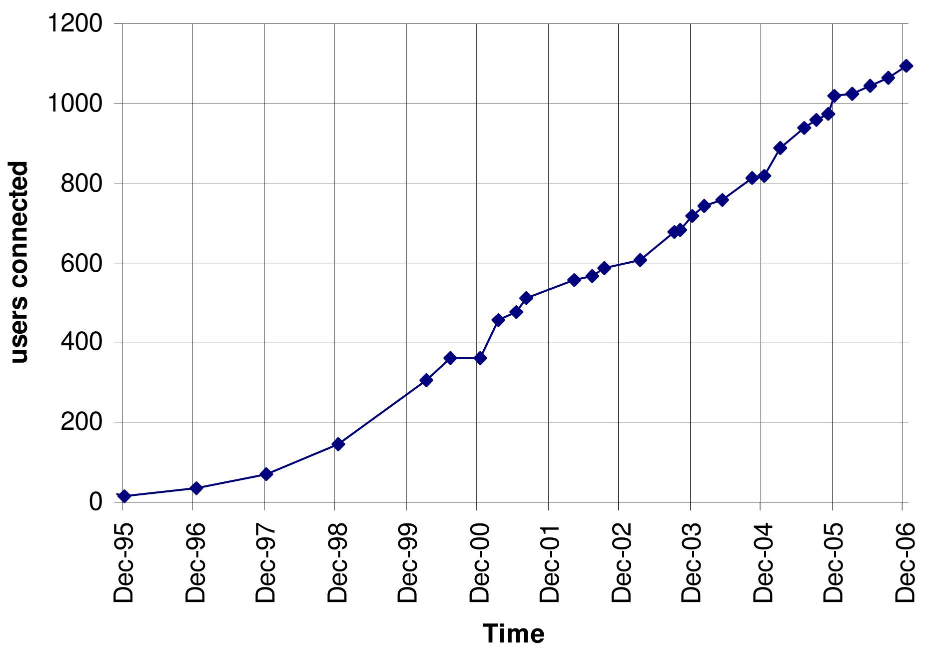
The capabilities of these network modelling and simulation and emulation tools to provide network engineers with adequate support are related to how closely they are connected to the real-world Internet situations. As will be seen in this paper, an Internet Tomography Measurement System, ITMS, can play a vital role of being a source of empirical Internet statistical performance. ITMS measurement results and metrics are periodically updated and made available on the web for consumption by variety of Internet players such as ISPs, network operators, and of course their network engineering and service application development teams. These latter as mentioned, will require the data in formats appropriate to addressing network emulating/simulating tools requirements e.g. [10].

The rest of the paper is organised as follows. Section II introduces the need for non-invasive Internet Tomography measurement with associated benefits. Section III presents the ITMS configuration, methodology and metrics used. Section IV covers network simulation and emulation modelling for design and analysis with relevance to Internet tomography measurement datasets. Section V presents an example of empirical network modelling and integrated network experimentation. Section VI concludes this work.

II. Non-invasive Internet Tomography Measurement and Associated Benefits

As regional and global Internet user populations grows –in 2007 the global Internet user population is estimated at c.17% of world population; cf. Figure 1 and Table 1–, QoS expectations of users in respect of all services accessible by them monotonically grows in line with the general quality of their experience of well established services. This is evidenced by the very slow general move to IP

Fig 1 Millions of users on the internet



telephony by the network providers as the risks of poorer quality with the status of today's Internet infrastructure is too great. Users are ready to pay for better QoS (even if this is perhaps not a readiness to pay at the level network and service provider owners would like). This is not so much the problem. Rather the problem is the access provider's inability to guarantee QoS levels with reasonable confidence in an Internet environment.

Performance requirements among different Internet user populations vary widely. For example, the scientific research community includes high-end Internet users whose tasks often involve substantial bandwidth requirements. Users in the financial markets and online businesses sectors require secure, reliable connectivity for high-volume, high-rate, low-capacity transactions, synchronised with distributed database operations. Gaming, entertainment, peer-to-peer services and applications markets, requiring, for example, support of new real-time interactions with streaming multi-media and virtual reality, stretch the limits of existing network technologies and resources, [17,18]. Actually measuring and quantifying user/customer requirements and expectations is a significant challenge itself, cf. [11].

Regions	**Population (2007 Est.) millions**	**Internet Usage, Millions Jan 2007**	**% Population (Penetration)**	**Usage % of World**	**Usage Growth 2000-2007**
Africa	933	**33**	3.5 %	3.0 %	625.8 %
Asia	3,712	**389**	10.5 %	35.6 %	240.7 %
Europe	810	**313**	38.6 %	28.6 %	197.6 %
Middle East	193	**19**	10.0 %	1.8 %	490.1 %
North America	335	**232**	69.4 %	21.2 %	114.7 %
Latin America/Caribbean	557	**89**	16.0 %	8.1 %	391.3 %
Oceania / Australia	34	**18**	53.5 %	1.7 %	141.9 %
WORLD TOTAL	6,575	**1,094**	16.6 %	100.0 %	202.9 %

Table 1 World Internet usage and population statistics as of 11 Jan 2007;
Compliments of www.Internetworldstats.com . Miniwatts Marketing Group

Nonetheless, the responsibility falls on service providers to manage infrastructures and provide dedicated, secure connections in a way that ensures that performance expectations of their customers are met to a satisfactory level. Consequently a need arises to provide services based on Service Level Agreements, SLAs, [12]. These will be mostly intra-network agreements, service-provider to network-provider agreements, and users/customers to access-networks agreements. These in turn raise a major challenge, namely to develop and implement a set of robust QoS measurement standards and end-to-end IP-based Service Level Verification (IP-SLV) solutions that can measure the user experience, completely or to a large extent, on critical paths through to end-to-end paths on an on-going basis, [6,31]. The kind of measurement process this requires is one which avoids causing possible performance degradation of normal user Internet traffic or at least has minimal impact on it, and does not in any way threaten, undermine or put in danger of compromising the network security, data integrity and privacy – concerns arising from among all stakeholders in the Internet. This has led to the development of Internet-wide non-invasive Internet tomography measurement concepts and techniques, and has become today the preferred way for capturing of performance data, [1,19,23, 24, 29]. Here we refer to it as an Internet tomography measurement system, ITMS.

Both passive and active performance measurements can be invasive, as described in some of the literature sources referenced in the paragraphs above and in their bibliographies. A brief summary of this aspect is present here. Passive measurements, while by nature do not impact the user traffic, does use it for its QoS measurements. Thus user packet payloads have to be (or should be) desensitised for data privacy reasons. Intra-network QoS measurements use this approach as a norm relying on their own internal professionalism to maintain integrity on privacy and security issues. There are many tools on the market for network engineers and managers in support of such QoS measurement philosophy. However access at this level for extra-network entities no matter what the goals or who the entities are, would normally be very unusual for many reasons. For instance, the simple fact of involvement of third parties in actions like this on user traffic can be a sufficiently reasonably source of concern in a security and privacy sense to deny it.

Active measurements is where test traffic is generated, thus overcoming privacy concerns. While it may provide greater control over measurement, it does intrinsically impact on overall network and Internet traffic, even though this may be kept at an acceptably insignificant level by control of test traffic characteristics, e.g. ensuring it is composed of small bursts of precisely controlled small sized packets.

ITMS goal: A non-invasive ITMS has the goal of delivering short-term and long-term (even continuous), comprehensive QoS assessment/measurement of IP performance in the core, across the edge, end-to-end and even extending into customer sites without impacting negatively on normal user traffic nor especially violating security and privacy concerns in the process. Systems may be implemented in a wide variety of organised and 'unorganised' ways. Typically a system is designed to monitor what the end-user QoS experience is at different locations and has to construct a comprehensive network statistical performance picture relevant to the interested parties [15, 16]. This is the Internet QoS measurement technique used in the work being described here, i.e. an active non-invasive Internet tomography measurement. It allows control of test traffic as the Internet tomography probing stations (ITPS) generate their own traffic. QoS measuring test traffic may easily be passed through targeted links and networks with minimal cooperation from their owners just like any other Internet traffic. A major advantage of this approach is of course the absence of any need to get access to the internal QoS statistics the Internets component networks, valuable all as these may be.

The Telecommunications Research Centre at University of Limerick entered the Réseaux IP Européens, RIPE, collaboration partnership. Through this we collaborated with other groups spread throughout the globe in extracting QoS performance data. We brought to RIPE the important contribution of adding an ITMS probe test station at University of Limerick in the west of Ireland. This extended the global range of Internet Tomography measurements to the western edge of Europe.

Garnering support to create a successful widely distributed ITMS test stations greatly helps the establishment of an open dynamic and distributed database of broad statistical metrics of IP QoS over a wide spatial (geographic) and temporal range.

This is well under way. From this database, it is possible to extract QoS data which serves to, e.g. cf [11, 13, 22]:

- Catalogue critical needs of the Internet networking infrastructure;
- Understand real geographic- and temporal-based performance behaviour;
- Provide real-world input data for network parameterisation in emulation and simulation modelling and experimentation;
- Set realistic geographic- and temporal-based expectations for customers,
- Identify problem areas – networks, sub-networks, autonomous systems, edge-edge links, and so forth; and
- Provide information for troubleshooting and assisting in the rationalisation of allocated resources to improve QoS and performances.

III. ITMS configuration and methodology

Here we describe aspects of the non-invasive probing applications and algorithms used to carry out the measurements and gather the raw data.

ITMS configuration is shown in Figure 1. The system consists of probing stations positioned in the local area networks (LANs) of participating network sites over the Internet. Each probing station generates a pre-defined pattern of test messages. The test messages are sent through the border gateway/router of each participating network. IP QoS parameters measured are:

- latency/delay (one-way);
- delay jitter (one-way);
- packet loss rate (one-way);
- derived metrics {loss distance, loss period}). Loss distance and loss period describe loss distribution. The loss period metric captures frequency and length (burstiness) of loss once it starts whilst loss distance captures the spacing between loss periods.

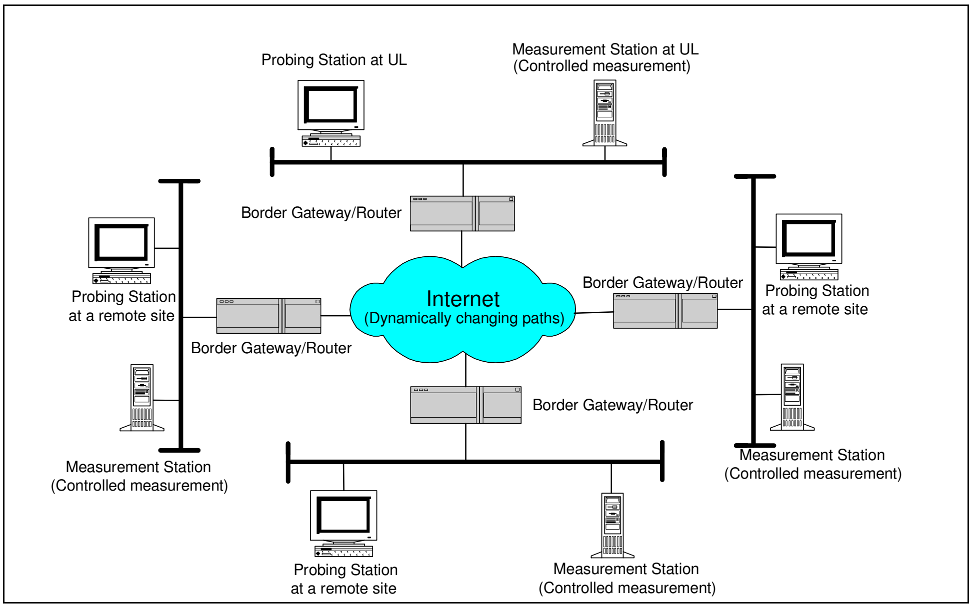


Fig. 2. ITMS configuration

For each routing vector, a measurement record is created and stored for post-processing of parameters under investigation.

This ITMS test station configuration and operation pose no security breach to corporate information systems, including when test stations are located within the network. In fact, as may be inferred from fig. 2, probe test stations may be installed on the outer side (de-militarized zone, DMZ) of the firewall of the participating sites' LANs, and this is normally the case. At each, site e.g. the one at University of Limerick (UL in fig. 1), the probing station generates probing traffic, which is sent to chosen remote measurement station(s). Receiving ITMS probing test packets is done with a filter/sniffer. Packets do receive timestamp accurately usually using a calibrated integrated GPS timing system. “Kernel level” timestamps are used as they are more accurate than “application level” timestamps. Where stations are ITMS receive-only stations, the action may be described as a non-invasive passive one.

The RIPE ITMS algorithms, measurement methodology and metrics comply with RFC 2330, RFC 2678, etc. as outlined by the IETF IPPM working group which was set up in order to maintain standardized ITMS framework [19, 20, 21]. Developments in the IP QoS performance metrics are ongoing and thus RIPE measurement strategies are updated accordingly.

IV. Network Simulation and Emulation, and Analysis of IP QoS Performance Data

The competitive e-business environment is best served by high QoS performing networks. Thus for network engineers and managers maximising network performance is key [22, 31, 32]. As mentioned, there are lots of tools for intra-network performance measurement which enables the engineers and managers to know their own network and thus to maximise its performance as best they can. However that is only half the picture, as they are only ‘one more network’ in the Internet. On behalf of their customers they need also to try to manage the overall Internet performance as experience or perceived by their customers. This they do through a variety of means, e.g. entering SLAs, [12], with collaborating networks those Internet links are most frequently and intensely used by their customers; buying other networks; installing their own backbone networks to bypass Internet problem areas; etc. In all cases squeezing the highest performance from the current network infrastructure, including those networks bound by SLAs, is critical. When enterprises seek the implementation of new or upgraded enterprise applications, assessing the impact of these applications on the network prior to implementation allows not only the network to be engineered for the application but the application to be modified to improve performance across the existing network. Service providers and IT organizations that seek to deliver high service levels in a cost-efficient manner, must be able to accurately model the production network environment. Accuracy in network modelling is, of course, key to effective testing, capacity planning, diagnostics and service-level assurance, [6, 7, 26, 31, 32].

Techniques used in design and validation of new and existing networking ideas include simulation, emulation and live network testing [9, 26, 27, 28, 32]. Each has its own benefits and tradeoffs. However, the different techniques need not be viewed as competing rather as complementing each other's limitations in order to better validate ideas, new concepts or verify operations. How they are used will vary from case to case; some situations they run in sequence and in others, as is more often the case, in an iterative methodology. General comparisons of these techniques are presented in table 2 under a brief description of features, benefits and limitations.

Network Modelling	Description	Benefits	Limitations
Network Simulation	• An absolutely repeatable and controlled environment for network experimentation for predicting behaviour of network and applications under different situations/scenarios. • Involves creating of a model for the proposed system and sees its proper working. • Two simulation methods: 1. Discrete event simulators: create an extremely detailed, packet-by-packet model of predicted network activity; it requires extensive calculations to simulate a very brief period. Analytical simulators: use mathematical equations, especially statistical models, to predict network and application performance.	• Economically feasible. • Saves time, in the sense of debugging faulty or inefficient algorithms or protocols before their installation on real networks; or discovering poor application design, i.e. which makes poor or inefficient use of network resources • Very efficient for medium to very large networks.	• Cannot give real-time view of how a user would experience some services using a new application or network. • Testing is usually constrained, e.g. without the presence of actual protocols implementations and applications unless implementations are ported to the simulation package. • Not feasible to port each version to the simulation environment for testing.
Network Emulation	• A technique that is usually applied to testing experimental network protocols, especially in networks that use IP as the network layer.	• Network Emulation environment is well controlled and reproducible. • Economical. • Saves time (relatively as for network simulation). Actual performance implementations of protocols and applications can be examined.	• Problem with accuracy of model, e.g. due to lack of parameters drawn from the real-world performance. • Properties are always estimates. • Time consuming - duration of an experimental session is determined by speed of the modelled network.
Live-network testing with Network Tomography	• Discipline that borrows techniques from signal processing and medical imaging. • Uses active and passive probing methods to generate real-time performance data. • Internet tomography has ability to extend beyond one's network.	• More accurate and realistic testing of new applications & protocols especially if they are already debugged. • Readily provides testing platform of new protocols and applications. • Provides most conclusive verification of network simulation and emulation results.	• Fully statistical by nature with Internet statistical processes, and thus lacking in a level of experimental controllability and reproducibility. • More costly and time consuming. • Security and privacy concerns when invasive measurements are used. • Risks due to unforeseen bugs or flaws.

Table 2: Network simulation, emulation and live–network analysis and design tools compared.

V. Empirical Network Modelling and Integrated Network Experimentation

Empirical network modelling and integrated network experimentation combines real elements, through real Internet data extracted using an ITMS or such like real QoS data capture means, with simulated elements in one or more instances of an existing simulation engine to model different portions of a network topology in the same experimental run [25, 26, 30]. This experimental approach leverages the advantages of using both real world and simulated elements to achieve goals such as:

- Validation of experimental simulation models in real traffic conditions;
- Exposing experimental real traffic conditions, and thus extracting likely network performance impact, to cross traffic conditions (be they congestive and/or reactive) derived from a variety of existing, validated simulation models;
- Scaling to larger network topologies and user activities by the multiplexing of simulated elements on physical resources other than would be the case with just real elements.

Simulation scenarios require network topologies that define links, and their characteristics and traffic models that specify sender and receiver QoS experiences and perceptions, [6]. Some parameters are selected and associated data extracted, e.g. through non-invasive Internet tomography in the case of simulation of Internet scenarios, to be used as input data suitable for simulation and emulation experimentation. This approach creates a high confidence for achieving realistic results in simulation or emulation test-beds. The combination of parameters, including number of hops with corresponding delay, jitter and packet loss rate for given routes and periods, are so chosen as to allow any simulation or emulation analysis to be performed making use of certain bounds based on the real parameter values. That is these real parameter values are based on the extracted measurement data, which is representative of realistic scenarios. The benefit of going to these lengths in modelling and simulation may eventually be seen, for instance, in successfully planned cost-efficient application or service deployment, or guaranteed secure service level assurance for services to be deployed in real networks.

A demonstrative example of a parameterisation framework for input data for evaluating an application or networking product performance in respect of robustness reliability, throughput, etc. is presented in Table 3. Possible approaches that may be followed for instance are: a point-to-many evaluation scenario, or inter-regional evaluation scenario or such like. Only the former approach is presented here. The idea is to evaluate the would-be best-, average-, worst-case IP QoS performance (one-way) between a chosen measurement point (University of Limerick – Limerick tt128) and a number of selected measurements points scattered around the globe using performance data extracted through the RIPE ITMS over a three-month 24-hour period. The structured parameter-based dataset presented in the table is comprised of delay percentiles, jitter, packet loss, number of hops, and number of routing vectors for parameterisation. The Internet link-network performances presented here would be an immense help in pre-deployment simulation or emulation studies focused on resource planning, network impact analysis, and expected performance analysis for an inter-regional IP network product or application deployment venture. The networking application scenario could be envisaged here as having a specific central point of operations, which would be typical of a company with global Internet business impact. In the example, Limerick is used as such as a specific central point of operations. The global Internet measurement points used are representative of regions around the globe, from USA west and USA east, Europe (U.K. – London), Middle East (Israel), Australia (Melbourne) and New Zealand (Waikato).

In order to test against various IP-network/Internet configurations and impairments, delay percentiles (2.5, 50, 97.5) are used to define best-, average-, worst-case performance scenarios respectively for each given route. Other corresponding parameters such as packet loss and jitter are used to further define each scenario or to check against consequent behaviour when the delay percentiles in combination with other input parameters, e.g. hop count range [minimum to maximum] and routing vectors, are applied or used. Some IP-network/Internet configurations, such as planned bandwidth, queuing and/or QoS schemes, are also used in the scenario generation. This process for instance, enables "What if …" scenario analysis by adjusting parameters on the basis of real-time QoS time performance data.

Route TO and FROM Limerick tt128		**Delay Percentiles**[1] (Delay in *msec*)			**Packet Loss %**	**Jitter (ms)**	**Hop count Range** (Min – Max)	**Number of Routing Vectors**
		2.5	**50.0**	**97.5**				
USAtt87	To	77.73	77.80	78.60	0.00	0.58	4 – 30	32
	From	75.92	76.30	77.64	0.00	0.73	9 – 30	18
USAtt84	To	48.13	48.42	48.99	0.07	2.70	4 – 30	28
	From	48.97	49.24	50.10	0.00	2.40	13 – 30	13
Londontt26	To	10.84	10.92	11.60	0.00	1.21	10 – 30	11
	From	12.02	14.29	15.38	0.10	2.75	10 – 30	21
CERNtt31	To	17.66	17.90	19.09	0.07	1.06	2 – 30	12
	From	17.66	17.80	19.09	0.00	0.82	9 - 30	8
Israeltt88	To	46.84	50.44	64.35	0.47	7.70	5 – 30	38
	From	48.48	49.76	94.84	0.30	13.53	4 – 30	34
Melbournett74	To	154.08	154.52	156.63	0.47	4.80	3 – 30	37
	From	154.08	154.86	158.35	0.10	2.92	6 – 30	42
Waikatott47	To	152.58	153.52	167.14	0.47	5.73	2 – 30	49
	From	142.59	143.95	154.02	1.00	4.92	19 – 30	26

Notes: For all the queuing scheme is Weighted Fair Queuing/ Random Early Detection (WFQ/RED) and planned bandwidth upgrades for the period after these measurements were taken were 128, 256, and 512Mbs.

Legend	
Limerick tt128	University of Limerick ITPS, Ireland
USAtt87	West of USA ITPS, USA
USAtt84	East of USA ITPS, USA
Londtt26	London ITPS, UK
CERN tt31	CERN ITPS, Switzerland
Israel tt88	Israel ITPS, Middle East
Melbournett74	Melbourne ITPS, Australia
Waikatott47	Waikato University ITPS, New Zealand

Table 3: Demonstrative example of parameterisation in a one-to-many global Internet scenario. Parameter values are extracted from empirically measured data gathered through the collaborative RIPE ITMS.

Using the data in simulation and/or emulation will help enable realistic modelling and thus facilitate network engineers and managers in their planning, analysis, and product deployment activities. Benefits and outcomes of such testing exercises can

[1] The **percentile** is a way of providing estimation of proportions of the data that should fall above and below a given value. The *p*th percentile is a value such that at most (100*p*)% of the observations are less than this value and that at most 100(1 - *p*)% are greater. Thus for example, the data for "from Israel" 48.48 would mean that 2.5% had delay 48.48ms or less.

eventually lead to building customer confidence in products, foreseeing and eliminating performance bottlenecks, avoiding cost and embarrassing mistakes in sizing and provisioning an intended/designed solution prior to deployment venture, [32].

VI. Conclusion

Internet Tomography measurement featured in Traffic-Engineering-solution space is an effort to address Internet performance shortfalls by providing QoS visibility into networks and providing raw performance data for capacity network planning, simulation and emulation modelling and experimentation. Development aspects of a pilot non-invasive Internet Tomography Measurement System (ITMS) intended to address Internet performance issues have been outlined.

Simulation, emulation, and network tomography in terms of features, benefits and limitations have been described and compared. The advantages of empirical network modelling and integrated network experimentation were highlighted, especially focusing on an experimental approach which involves usage of real-time network parameters and elements, provided by a network tomographic measurement system, being integrated into simulated elements in an existing simulation engine. This enables realistic "What if…?" scenarios to be created by making incremental adjustments to an accurate baseline network model instead of speculating about future changes in environment behavioural parameters. A demonstrative example was used to illustrate the concept of empirical network modelling and integrated network experimentation using real-time Internet performance data between measurement point at University of Limerick and various measurement points across the globe.

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