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Large-Scale Broadband Measurement Use Cases

Abstract

Measuring broadband performance on a large scale is important for network diagnostics by providers and users, as well as for public policy. Understanding the various scenarios and users of measuring broadband performance is essential to development of the Large-scale Measurement of Broadband Performance (LMAP) framework, information model, and protocol. This document details two use cases that can assist in developing that framework. The details of the measurement metrics themselves are beyond the scope of this document.

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1. Introduction

This document describes two use cases for the Large-scale Measurement of Broadband Performance (LMAP). The use cases contained in this document are (1) the Internet Service Provider Use Case and (2) the Regulator Use Case. In the first, a network operator wants to understand the performance of the network and the quality experienced by customers, while in the second, a regulator wants to provide information on the performance of the ISPs in their jurisdiction. There are other use cases that are not the focus of the initial LMAP work (for example, end users would like to use measurements to help identify problems in their home network and to monitor the performance of their broadband provider); it is expected that the same mechanisms are applicable.

Large-scale measurements raise several security concerns, including privacy issues. These are summarized in [Section 7](#) and considered in further detail in [\[Framework\]](#).

2. Use Cases

From the LMAP perspective, there is no difference between fixed service and mobile (cellular) service used for Internet access. Hence, like measurements will take place on both fixed and mobile networks. Fixed services include technologies like Digital Subscriber Line (DSL), Cable, and Carrier Ethernet. Mobile services include all those advertised as 2G, 3G, 4G, and Long Term Evolution (LTE). A metric defined to measure end-to-end services will execute similarly on all access technologies. Other metrics may be access technology specific. The LMAP architecture covers both IPv4 and IPv6 networks.

2.1. Internet Service Provider (ISP) Use Case

A network operator needs to understand the performance of their networks, the performance of the suppliers (downstream and upstream networks), the performance of Internet access services, and the impact that such performance has on the experience of their customers. Largely, the processes that ISPs operate (which are based on network measurement) include:

- o Identifying, isolating, and fixing problems, which may be in the network, with the service provider, or in the end-user equipment. Such problems may be common to a point in the network topology (e.g., a single exchange), common to a vendor or equipment type (e.g., line card or home gateway), or unique to a single user line (e.g., copper access). Part of this process may also be helping

users understand whether the problem exists in their home network or with a third-party application service instead of with their broadband (BB) product.

- o Design and planning. Through monitoring the end-user experience, the ISP can design and plan their network to ensure specified levels of user experience. Services may be moved closer to end users, services upgraded, the impact of QoS assessed, or more capacity deployed at certain locations. Service Level Agreements (SLAs) may be defined at network or product boundaries.
- o Understanding the quality experienced by customers. The network operator would like to gain better insight into the end-to-end performance experienced by its customers. "End-to-end" could, for instance, incorporate home and enterprise networks, and the impact of peering, caching, and Content Delivery Networks (CDNs).
- o Understanding the impact and operation of new devices and technology. As a new product is deployed, or a new technology introduced into the network, it is essential that its operation and its impact are measured. This also helps to quantify the advantage that the new technology is bringing and support the business case for larger roll-out.

2.2. Regulator Use Case

A regulator may want to evaluate the performance of the Internet access services offered by operators.

While each jurisdiction responds to distinct consumer, industry, and regulatory concerns, much commonality exists in the need to produce datasets that can be used to compare multiple Internet access service providers, diverse technical solutions, geographic and regional distributions, and marketed and provisioned levels and combinations of broadband Internet access services.

Regulators may want to publish performance measures of different ISPs as background information for end users. They may also want to track the growth of high-speed broadband deployment, or to monitor the traffic management practices of Internet providers.

A regulator's role in the development and enforcement of broadband Internet access service policies requires that the measurement approaches meet a high level of verifiability, accuracy, and provider-independence to support valid and meaningful comparisons of Internet access service performance. Standards can help regulators'

shared needs for scalable, cost-effective, scientifically robust solutions to the measurement and collection of broadband Internet access service performance information.

3. Details of ISP Use Case

3.1. Understanding the Quality Experienced by Customers

Operators want to understand the quality of experience (QoE) of their broadband customers. The understanding can be gained through a "panel", i.e., measurement probes deployed to several customers. A probe is a device or piece of software that makes measurements and reports the results, under the control of the measurement system. Implementation options are discussed in [Section 5](#). The panel needs to include a representative sample of the operator's technologies and broadband speeds. For instance, it might encompass speeds ranging from below 8 Mbps to over 100 Mbps. The operator would like the end-to-end view of the service, rather than just the access portion. This involves relating the pure network parameters to something like a 'mean opinion score' [MOS], which will be service dependent (for instance, web-browsing QoE is largely determined by latency above a few Mbps).

An operator will also want compound metrics such as "reliability", which might involve packet loss, DNS failures, retraining of the line, video streaming under-runs, etc.

The operator really wants to understand the end-to-end service experience. However, the home network (Ethernet, Wi-Fi, powerline) is highly variable and outside its control. To date, operators (and regulators) have instead measured performance from the home gateway. However, mobile operators clearly must include the wireless link in the measurement.

Active measurements are the most obvious approach, i.e., special measurement traffic is sent by -- and to -- the probe. In order not to degrade the service of the customer, the measurement data should only be sent when the user is silent, and it shouldn't reduce the customer's data allowance. The other approach is passive measurements on the customer's ordinary traffic; the advantage is that it measures what the customer actually does, but it creates extra variability (different traffic mixes give different results) and, in particular, it raises privacy concerns. [\[RFC6973\]](#) discusses privacy considerations for Internet protocols in general, while [\[Framework\]](#) discusses them specifically for large-scale measurement systems.

From an operator's viewpoint, understanding customer experience enables it to offer better services. Also, simple metrics can be more easily understood by senior managers who make investment decisions and by sales and marketing.

3.2. Understanding the Impact and Operation of New Devices and Technology

Another type of measurement is to test new capabilities before they are rolled out. For example, the operator may want to:

- o Check whether a customer can be upgraded to a new broadband option.
- o Understand the impact of IPv6 before it is made available to customers. Questions such as these could be assessed: Will v6 packets get through? What will the latency be to major websites? What transition mechanisms will be most appropriate?
- o Check whether a new capability can be signaled using TCP options (how often it will be blocked by a middlebox -- along the lines of the experiments described in [[Extend-TCP](#)]).
- o Investigate a QoS mechanism (e.g., checking whether Diffserv markings are respected on some path).

3.3. Design and Planning

Operators can use large-scale measurements to help with their network planning -- proactive activities to improve the network.

For example, by probing from several different vantage points the operator can see that a particular group of customers has performance below that expected during peak hours, which should help with capacity planning. Naturally, operators already have tools to help with this -- a network element reports its individual utilization (and perhaps other parameters). However, making measurements across a path rather than at a point may make it easier to understand the network. There may also be parameters like bufferbloat that aren't currently reported by equipment and/or that are intrinsically path metrics.

With information gained from measurement results, capacity planning and network design can be more effective. Such planning typically uses simulations to emulate the measured performance of the current network and understand the likely impact of new capacity and potential changes to the topology. Simulations, informed by data

from a limited panel of probes, can help quantify the advantage that a new technology brings and support the business case for larger roll-out.

It may also be possible to use probes to run stress tests for risk analysis. For example, an operator could run a carefully controlled and limited experiment in which probing is used to assess the potential impact if some new application becomes popular.

3.4. Monitoring Service Level Agreements

Another example is that the operator may want to monitor performance where there is a Service Level Agreement (SLA). This could be with its own customers; in particular, enterprises may have an SLA. The operator can proactively spot when the service is degrading near the point of the SLA limit and get information that will enable more informed conversations with the customer at contract renewal.

An operator may also want to monitor the performance of its suppliers, to check whether they meet their SLA or to compare two suppliers if it is dual-sourcing. This could include its transit operator, CDNs, peering, video source, or local network provider for a global operator in countries where it doesn't have its own network. A virtual operator may monitor the whole underlying network.

Through a better understanding of its own network and its suppliers, the operator should be able to focus investment more effectively -- in the right place at the right time with the right technology.

3.5. Identifying, Isolating, and Fixing Network Problems

Operators can use large-scale measurements to help identify a fault more rapidly and decide how to solve it.

Operators already have Test and Diagnostic tools, where a network element reports some problem or failure to a management system. However, many issues are not caused by a point failure but something wider and so will trigger too many alarms, while other issues will cause degradation rather than failure and so not trigger any alarm. Large-scale measurements can help provide a more nuanced view that helps network management to identify and fix problems more rapidly and accurately. The network management tools may use simulations to emulate the network and so help identify a fault and assess possible solutions.

An operator can obtain useful information without measuring the performance on every broadband line. By measuring a subset, the operator can identify problems that affect a group of customers. For example, the issue could be at a shared point in the network topology (such as an exchange), or common to a vendor, or equipment type; for instance, [IETF85-Plenary] describes a case where a particular home gateway upgrade had caused a (mistaken!) drop in line rate.

A more extensive deployment of the measurement capability to every broadband line would enable an operator to identify issues unique to a single customer. Overall, large-scale measurements can help an operator fix the fault more rapidly and/or allow the affected customers to be informed of what's happening. More accurate information enables the operator to reassure customers and take more rapid and effective action to cure the problem.

Often, customers experience poor broadband due to problems in the home network -- the ISP's network is fine. For example, they may have moved too far away from their wireless access point. Anecdotally, a large fraction of customer calls about fixed BB problems are due to in-home wireless issues. These issues are expensive and frustrating for an operator, as they are extremely hard to diagnose and solve. The operator would like to narrow down whether the problem is in the home (a problem with the home network, edge device, or home gateway), in the operator's network, or with an application service. The operator would like two capabilities: firstly, self-help tools that customers use to improve their own service or understand its performance better -- for example, to reposition their devices for better Wi-Fi coverage; and secondly, on-demand tests that the operator can run instantly, so that the call center person answering the phone (or e-chat) could trigger a test and get the result while the customer is still in an online session.

4. Details of Regulator Use Case

4.1. Providing Transparent Performance Information

Some regulators publish information about the quality of the various Internet access services provided in their national market. Quality information about service offers could include speed, delay, and jitter. Such information can be published to facilitate end users' choice of service provider and offer. Regulators may check the accuracy of the marketing claims of Internet service providers and may also encourage ISPs to all use the same metrics in their service level contracts. The goal of these transparency mechanisms is to promote competition for end users and potentially also help content, application, service, and device providers develop their Internet offerings.

The published information needs to be:

- o Accurate - the measurement results must be correct and not influenced by errors or side effects. The results should be reproducible and consistent over time.
- o Comparable - common metrics should be used across different ISPs and service offerings, and over time, so that measurement results can be compared.
- o Meaningful - the metrics used for measurements need to reflect what end users value about their broadband Internet access service.
- o Reliable - the number and distribution of measurement agents, and the statistical processing of the raw measurement data, need to be appropriate.

In practical terms, the regulators may measure network performance from users towards multiple content and application providers, including dedicated test measurement servers. Measurement probes are distributed to a 'panel' of selected end users. The panel covers all the operators and packages in the market, spread over urban, suburban, and rural areas, and often includes both fixed and mobile Internet access. Periodic tests running on the probes can, for example, measure actual speed at peak and off-peak hours, but can also measure other detailed quality metrics like delay and jitter. Collected data goes afterwards through statistical analysis, deriving estimates for the whole population. Summary information, such as a service quality index, is published regularly, perhaps alongside more detailed information.

The regulator can also facilitate end users to monitor the performance of their own broadband Internet access service. They might use this information to check that the performance meets that specified in their contract or to understand whether their current subscription is the most appropriate.

4.2. Measuring Broadband Deployment

Regulators may also want to monitor the improvement over time of actual broadband Internet access performance in a specific country or a region. The motivation is often to evaluate the effect of the stimulated growth over time, when government has set a strategic goal for high-speed broadband deployment, whether in absolute terms or benchmarked against other countries. An example of such an initiative is [DAE]. The actual measurements can be made in the same way as described in [Section 4.1](#).

4.3. Monitoring Traffic Management Practices

A regulator may want to monitor traffic management practices or compare the performance of Internet access service with specialized services offered in parallel to, but separate from, Internet access service (for example, IPTV). A regulator could monitor for departures from application agnosticism such as blocking or throttling of traffic from specific applications, or preferential treatment of specific applications. A measurement system could send, or passively monitor, application-specific traffic and then measure in detail the transfer of the different packets. While it is relatively easy to measure port blocking, how to detect other types of differentiated treatment is a research topic in itself. The "Glasnost: Enabling End Users to Detect Traffic Differentiation" paper [M-Labs_NSDI-2010] and follow-on tool "Glasnost" [Glasnost] provide an example of work in this area.

A regulator could also monitor the performance of the broadband service over time, to try and detect if the specialized service is provided at the expense of the Internet access service. Comparison between ISPs or between different countries may also be relevant for this kind of evaluation.

The motivation for a regulator monitoring such traffic management practices is that regulatory approaches related to net neutrality and the open Internet have been introduced in some jurisdictions. Examples of such efforts are the Internet policy as outlined by the Body of European Regulators for Electronic Communications guidelines for quality of service [BEREC-Guidelines] and the US FCC's "Preserving the Open Internet" Report and Order [FCC-R&O]. Although legal challenges can change the status of policy, the take-away for LMAP purposes is that policy-makers are looking for measurement solutions to assist them in discovering biased treatment of traffic flows. The exact definitions and requirements vary from one jurisdiction to another.

5. Implementation Options

There are several ways of implementing a measurement system. The choice may be influenced by the details of the particular use case and what the most important criteria are for the regulator, ISP, or third party operating the measurement system.

One type of probe is a special hardware device that is connected directly to the home gateway. The devices are deployed to a carefully selected panel of end users, and they perform measurements according to a defined schedule. The schedule can run throughout the day, to allow continuous assessment of the network. Careful design

ensures that measurements do not detrimentally impact the home user experience or corrupt the results by testing when the user is also using the broadband line. The system is therefore tightly controlled by the operator of the measurement system. One advantage of this approach is that it is possible to get reliable benchmarks for the performance of a network with only a few devices. One disadvantage is that it would be expensive to deploy hardware devices on a mass scale sufficient to understand the performance of the network at the granularity of a single broadband user.

Another type of probe involves implementing the measurement capability as a webpage or an "app" that end users are encouraged to download onto their mobile phone or computing device. Measurements are triggered by the end user; for example, the user interface may have a button to "test my broadband now." One advantage of this approach is that the performance is measured to the end user, rather than to the home gateway, and so includes the home network. Another difference is that the system is much more loosely controlled, as the panel of end users and the schedule of tests are determined by the end users themselves rather than the measurement system. While this approach makes it easier to make measurements on a large scale, it is harder to get comparable benchmarks, as the measurements are affected by the home network; also, the population is self-selecting and so potentially biased towards those who think they have a problem. This could be alleviated by encouraging widespread downloading of the app and careful post-processing of the results to reduce biases.

There are several other possibilities. For example, as a variant on the first approach, the measurement capability could be implemented as software embedded in the home gateway, which would make it more viable to have the capability on every user line. As a variant on the second approach, the end user could initiate measurements in response to a request from the measurement system.

The operator of the measurement system should be careful to ensure that measurements do not detrimentally impact users. Potential issues include the following:

- * Measurement traffic generated on a particular user's line may impact that end user's quality of experience. The danger is greater for measurements that generate a lot of traffic over a lengthy period.
- * The measurement traffic may impact that particular user's bill or traffic cap.

- * The measurement traffic from several end users may, in combination, congest a shared link.
- * The traffic associated with the control and reporting of measurements may overload the network. The danger is greater where the traffic associated with many end users is synchronized.

6. Conclusions

Large-scale measurements of broadband performance are useful for both network operators and regulators. Network operators would like to use measurements to help them better understand the quality experienced by their customers, identify problems in the network, and design network improvements. Regulators would like to use measurements to help promote competition between network operators, stimulate the growth of broadband access, and monitor 'net neutrality'. There are other use cases that are not the focus of the initial LMAP charter (although it is expected that the mechanisms developed would be readily applied); for example, end users would like to use measurements to help identify problems in their home network and to monitor the performance of their broadband provider.

From consideration of the various use cases, several common themes emerge, while there are also some detailed differences. These characteristics guide the development of LMAP's framework, information model, and protocol.

A measurement capability is needed across a wide number of heterogeneous environments. Tests may be needed in the home network, in the ISP's network, or beyond; they may be measuring a fixed or wireless network; they may measure just the access network or across several networks.

There is a role for both standardized and non-standardized measurements. For example, a regulator would like to publish standardized performance metrics for all network operators, while an ISP may need their own tests to understand some feature special to their network. Most use cases need active measurements, which create and measure specific test traffic, but some need passive measurements of the end user's traffic.

Regardless of the tests being operated, there needs to be a way to demand or schedule the tests. Most use cases need a regular schedule of measurements, but sometimes ad hoc testing is needed -- for example, for troubleshooting. It needs to be ensured that measurements do not affect the user experience and are not affected by user traffic (unless desired). In addition, there needs to be a

common way to collect the results. Standardization of this control and reporting functionality allows the operator of a measurement system to buy the various components from different vendors.

After the measurement results are collected, they need to be understood and analyzed. Often, it is sufficient to measure only a small subset of end users, but per-line fault diagnosis requires the ability to test every individual line. Analysis requires accurate definition and understanding of where the test points are, as well as contextual information about the topology, line, product, and the subscriber's contract. The actual analysis of results is beyond the scope of LMAP, as is the key challenge of how to integrate the measurement system into a network operator's existing tools for diagnostics and network planning.

Finally, the test data, along with any associated network, product, or subscriber contract data, is commercial or private information and needs to be protected.

7. Security Considerations

Large-scale measurements raise several potential security, privacy (data protection) [RFC6973], and business sensitivity issues:

1. A malicious party may try to gain control of probes to launch DoS (Denial of Service) attacks at a target. A DoS attack could be targeted at a particular end user or set of end users, a certain network, or a specific service provider.
 2. A malicious party may try to gain control of probes to create a platform for pervasive monitoring [RFC7258] or for more targeted monitoring. [RFC7258] summarizes the threats as follows: "An attack may change the content of the communication, record the content or external characteristics of the communication, or through correlation with other communication events, reveal information the parties did not intend to be revealed." For example, a malicious party could distribute to the probes a new measurement test that recorded (and later reported) information of maleficent interest. Similar concerns also arise if the measurement results are intercepted or corrupted.
- * From the end user's perspective, the concerns include a malicious party monitoring the traffic they send and receive, who they communicate with, the websites they visit, and such information about their behavior as when they are at home and the location of their devices. Some of the concerns may be greater when the probe is on the end user's device rather than on their home gateway.

- * From the network operator's perspective, the concerns include the leakage of commercially sensitive information about the design and operation of their network, their customers, and suppliers. Some threats are indirect; for example, the attacker could reconnoiter potential weaknesses, such as open ports and paths through the network, which enabled it to launch an attack later.
 - * From the regulator's perspective, the concerns include distortion of the measurement tests or alteration of the measurement results. Also, a malicious network operator could try to identify the broadband lines that the regulator was measuring and prioritize that traffic ("game the system").
3. Another potential issue is a measurement system that does not obtain the end user's informed consent, fails to specify a specific purpose in the consent, or uses the collected information for secondary uses beyond those specified.
 4. Another potential issue is a measurement system that does not indicate who is responsible for the collection and processing of personal data and who is responsible for fulfilling the rights of users. The responsible party (often termed the "data controller") should, as good practice, consider such issues as defining:
 - o the purpose for which the data is collected and used,
 - o how the data is stored, accessed, and processed,
 - o how long the data is retained, and
 - o how the end user can view, update, and even delete their personal data.

If anonymized personal data is shared with a third party, the data controller should consider the possibility that the third party can de-anonymize it by combining it with other information.

These security and privacy issues will need to be considered carefully by any measurement system. In the context of LMAP, [Framework] considers them further, along with some potential mitigations. Other LMAP documents will specify one or more protocols that enable the measurement system to instruct a probe about what measurements to make and that enable the probe to report the measurement results. Those documents will need to discuss solutions to the security and privacy issues. However, the protocol documents

will not consider the actual usage of the measurement information. Many use cases can be envisaged, and earlier in this document we described some likely ones for the network operator and regulator.

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