Report of AT&T Independent Measurement Expert
Background and supporting arguments for measurement and reporting requirements

UC, San Diego's Center for Applied Internet Data Analysis
KC Claffy, Amogh Dhamdhere
in collaboration with independent contractors:
David Clark, Steven Bauer
Submit any feedback/concerns to att-ime-feedback@caida.org

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1 Introduction

This document is a companion to the document titled "Report of AT&T Independent Measurement Expert: Reporting requirements and measurement methods", which is the set of requirements specified by the Independent Measurement Expert in the matter of the Memorandum Opinion and Order for the merger of AT&T and DirecTV. In this document, we elaborate on the reasoning and motivation behind the measurement methodology we have specified. A paragraph from the merger order provides context for our task:

> *217. Discussion. As stated in the 2015 Open Internet Order, "consumers bear the harm when they experience degraded access to the applications and services of their choosing due to a dispute between a large broadband provider and an interconnecting party." Also, because OVD subscribers expect high-quality video, OVDs are vulnerable to degradation at the interconnection point with a broadband Internet access service provider's last mile network. Thus, as stated in the 2015 Open Internet Order, we find that "broadband Internet access providers have the ability to use terms of interconnection to disadvantage edge providers and that consumers' ability to respond to unjust or unreasonable broadband provider practices are limited by switching costs." We appreciate commenters' concerns in this area.*

2 The complex character of link loading

Links that are heavily loaded often show a plateau (flat top) of utilization at or near the actual link capacity. Such a plateau is a possible signal of congestion. However, content providers can often deliver traffic from different sources, and load links to near capacity without triggering symptoms of actual congestion, e.g., packet loss. This reality of modern traffic engineering is why utilization metrics alone cannot reveal an accurate picture of congestion; one must also examine sufficiently accurate metrics of loss and latency distributions. In the context of the AT&T measurement and reporting requirements, one drawback of a failure to negotiate the use of TWAMP/IPSLA may be that the less accurate fall-back probing method may incorrectly report higher levels of packet loss and variation in latency, thus signaling congestion where none is actually present.

3 Limitations of our measurement methods

3.1 Inaccuracies in active measurements of loss and latency

The use of our fall-back method is subject to several limitations:

- Some routers may not respond reliably to pings or fail to send TTL-expired responses, leading to an over-estimate of the loss rate.
- Some routers respond to TTL-expired events with highly variable delay, leading to distortion of the latency measure.[1]
- In some cases, a router may drop probe packets with higher probability than typical packets carrying data. This scenario will inflate estimates of packet loss.

[1] In practice, we have seen delays of a quarter of a second in the response to a test probe, while the typical queuing delays encountered due to congestion are around 30-50 ms, and almost never over 100 ms.

- It may be possible to mitigate these problems by probing to a machine one hop beyond the router on the far side of the connecting link. This method requires a topology discovery process to identify destinations behind each far-side router, or cooperation of the connecting party to identify a suitable target IP address for the probe.
- In some cases, the return route from the far-side router may not be the LAG under measure, but a path by some other LAG.

There are circumstances in which a combination of events will lead to the outcome that there are no useful measures of loss and latency with a specific interconnecting party. In particular, if the party is not willing to cooperate by sharing loss counters and/or implementing TWAMP/IPSLA, then AT&T must use a less accurate fall-back method based on ICMP. In our own research, we have seen situations where ICMP gives a stable and plausible characterization of the link performance, and other cases where the results are meaningless, apparently because the border router on the far side of the link discards probe packets or injects such high delays in processing packets that there is no useful information in the probing. This risk of such useless probing creates the need for cooperation with the interconnecting party to achieve the most precise and accurate possible measurements of loss and latency, a critical component of deriving value from this reporting obligation. We have crafted our requirements so as to encourage that cooperation, including accommodating alternative schemes, such as probing to a network element beyond the far-side router but closely co-located.

3.2 Application adaptation that hides congestion

Many applications adapt their sending rate to match the available capacity of a LAG. In particular, content providers may change the way they encode content, reducing the data rate, which generally reduces the quality of the transmitted content. The result may be a LAG running near capacity but not overloaded, with little jitter and packet loss, but a degradation of (e.g., video) quality.

Network measurement cannot easily detect this sort of rate adaptation. One could attempt to correlate data about rate adaptation with LAG performance metrics, but we know of no reliable way to demonstrate that one LAG in particular (e.g., the interconnection LAG) is the point that triggered rate adaptation.

3.3 Inaccuracies in measuring loss with router counters

Estimates of packet loss derived from router counters may understate actual losses. While we assume such estimates are generally accurate, errors can arise from a number of causes. First, identifying which counters to include for each different type of router and software version is non-trivial. Have all possible counters that could be incremented when a packet is discarded been included? Second, at least historically speaking, routers have certain exceptional code paths where a packet can be discarded but a counter is not incremented. Even router software can be buggy. Third, network engineers have told us that unrecorded losses can occur when a router is under extreme load or in a partial failure condition. These are often times when large number of losses would be occuring as well, so the failure to record such losses can have a large impact on the accuracy of the loss estimate. Finally, dropping a packet because a TTL expired (as traceroute induces) will not be recorded as a loss by a router counter. Thus, a routing loop could result in many losses unrecorded by a router's loss counter. These limitations illustrate the value of estimating loss from both active and passive probing techniques, as an active probe would properly record losses during the period of time a routing loop existed.

3.4 Limitations of TWAMP and IPSLA

There are limits to the precision and reliability of tools such as TWAMP. RFC 6673: *"Round-Trip Packet Loss Metrics"*, Section 7 emphasizes the need for caution when processing TWAMP data, and conservatively recommends discarding reverse path measurements in the case of substantial loss or delay variation on the forward path measurements. We recommend a less conservative approach of annotating the data rather than discarding it.

We require that AT&T separately report loss rate in the forward and reverse direction if the probing method permits. One reason is to detect whether the loss rate in the reverse direction is suspect. Similarly, if there is high delay variation on the forward path, then the reverse path may not be sampled according to the desired process (Poisson or periodic), and thus RFC 6673 argues that those results should be discarded. This approach is conservative, but arguably reasonable. However, to implement this conservative approach, it is necessary to separately observe the forward and reverse measures of latency, which is complex without synchronized clocks. We have not called for the separate reporting of forward and reverse latency measures.

3.5 Congestion on other parts of network path

The merger Order limits the measurements and reporting to the interconnection link between AT&T and its interconnecting parties. While historically interconnection links have been the most likely location for congestion to occur in provider provisioned links, this is not always the case even today and it may not continue in the future. In particular links could be congested somewhere in the middle mile between the interconnection links and the access links to the users. Similarly an interconnecting party might choose to shed load upstream of heavily congested interconnection link. They might reason that there was no need to build out capacity to the interconnection link if the interconnection link was not capable of carrying the aggregate traffic load. In both cases, the congestion would be missed by the measurement methodology described here. Thus congestion may be underestimated.

4 Requirements and motivation for sharing limited data with interconnecting parties

The Memorandum Opinion and Order states (Page 148):

> *This condition will enable the monitoring of the combined entity's future interconnection agreement's terms to determine whether the combined entity is using such agreements to deny or impede access to its networks in ways that limit competition from third-party online video content providers. In addition, this condition requires the combined entity to work with an independent measurement expert to report certain Internet interconnection performance metrics, and to the extent possible, make such metrics publicly available.*

This paragraph of the order signals the value of releasing some form of what is learned in this reporting exercise. We agree that there is great value in releasing overall insights and aggregated data to the public, as well as releasing specific data about a given interconnecting party to that party. The most important role of such sharing is scientific integrity: to support cross-checking and validation of the measurement methods we propose. A secondary role is process integrity: interconnecting parties need to see what is being reported about them if they are to cooperate in gathering data about their interconnection, thus we require data sharing as a component of negotiation with the parties. We provide additional details on both of these roles.

First, all measurement methodologies should include some form of cross-check or validation, in order to detect errors that may arise, whether from a flaw in the measurement method, misconfiguration of a database, or a failure in the measurement apparatus. The goal of this IME effort is to demonstrate with rigorous quantitative measurement that the performance of AT&T's points of interconnection are not the source of performance impairment for consumers. To that end, where possible, we have specified approaches that allow for comparison of different methods for measuring the same parameter, to lend confidence in interpretation of the data.

Since these measurements all relate to behavior of a point of interconnection with another party, one way to increase confidence in the measurements and their interpretation is to allow the other party to see what is reported. We therefore have described a general approach in which data being gathered concerning the interconnection with each party is shared with that party

We recognize that sharing of data (in both directions) implies the release to the interconnecting party of data that may be considered proprietary to the firm. We have tried to carefully balance the benefits of disclosure with the potential consequences of release of this data to the party. The final decision as to the merits of sharing vs. protection of reported data must lie with the FCC. However, an important outcome, and indeed the primary objective, of these measurement and reporting conditions is that all parties feel that the process has been balanced and fair to each of them. In our view, data sharing is a necessary component of this outcome, and we urge all parties to consider the balance between protection of data and insuring that this process leads to data reporting that is not in any way seen as potentially biased or reflecting the interests of one party in an unbalanced way. With these concerns in mind, we have integrated the following data sharing requirements into the measurement and reporting methodology.

We require that AT&T share with each qualifying interconnecting party the location and capacity of all LAGs to that party. Both parties already have this information, thus this sharing requirement should not raise any issues with respect to commercial sensitivity of data. The purpose of the sharing is to allow the interconnecting party to cross-check this data with their own records, should they choose.

Similarly, we require that AT&T share packet and byte counters in both directions at each router in a LAG at a 5-minute granularity. Again, both parties should equally have this information, so this requirement should not raise any issues with respect to proprietary data, and will allow the party to cross-check this data with their own records, should they choose.

We also require that AT&T share with interconnecting parties the results of probing using a cooperative method such as IPSLA or TWAMP. This measurement data is new, required as part of our method but not currently being collected by AT&T, and requires the interconnecting party to cooperatively implement a protocol responder. In this case, where both parties have cooperated to gather the data, it seems unreasonable and a material barrier to achieving this cooperation if the resulting data is made available to only one of the parties.

We believe that the benefits of holding these measurements private are not commercially significant, and are outweighed by the benefits of sharing. In particular, these measurements will not reveal whether the sender uses some sort of traffic differentiation scheme across this interconnection, but will reveal the treatment of packets in the class of traffic in which the probing is classified. Either party could develop and execute measurements of their own to observe this behavior, if they were so motivated. Because the interconnecting party could reasonably and independently obtain these measurements, we do not consider this information commercially sensitive between

AT&T and the interconnecting party.

The most valuable and readily available source of data to measure loss across the interconnection is the interconnecting party's outgoing loss counters (which reflect packet drops) at the party's sending end. Specifically, outgoing loss counters on AT&T routers at their border with another network reveal drops due to insufficient capacity in the direction toward the interconnecting party. Conversely, outgoing loss counters on the routers of the interconnecting party's borders with AT&T reveal insufficient capacity in the direction toward AT&T. Based on the merger Order and public comments, we understand that the FCC is primarily concerned with performance impairment in the direction toward AT&T, which makes the loss counters from AT&T's routers less important than the loss counters from the interconnecting party's routers. Indeed, loss counters from the interconnecting party's routers are essential to validation of our method, and we thus consider it important that AT&T is successful in negotiating this cooperation with their interconnecting parties. To that end, we have requested that AT&T copy the IME on correspondence with the interconnection parties related to this negotiation, and required that AT&T provide the IME with an opportunity to discuss any concerns with an interconnecting party interested in cooperating.

We recognize that the release of this packet loss information might signal insights about business practices of the revealing party(s) that they may not want to reveal. Specifically: (1) If the LAG is highly utilized but there are no drops, this combination of information implies that the sending party is using sophisticated traffic management techniques to control LAG loading. (2) If the LAG is highly utilized and there are reported drops during periods of high load, the drops confirm that the high load is inducing congestion. (3) If the LAG is underloaded, but the loss counter is reporting drops, the implication is that there is an operational problem, or the sending party is selectively dropping certain packets that leads to some classes of traffic being rate-limited (dropped) even though the LAG is overall underloaded. A sending party may not wish to signal that such treatment is happening.

5 Continuing role of the IME

The contract between UC, San Diego (CAIDA) and AT&T was negotiated in the context of the terms of the merger order. It describes a temporarily continuing role of the IME in this process:

> *(c) CAIDA and AT&T jointly will review the first report that AT&T must submit to the FCC on Internet interconnection performance metrics resulting from the Methodology (the "Metrics Report").*
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> *(i) AT&T acknowledges and understands that in order for CAIDA to fulfill its obligations as part of this review process, including to assert confidence as to the validity of the Methodology, CAIDA must have reasonable access to certain underlying data necessary to validate the Methodology. Any method for measurement must be tested and evaluated in practice, and CAIDA must be materially involved in this activity.*
>
> *(ii) If either CAIDA or AT&T believes that there is an issue with the performance metrics contained in the first Metrics Report, CAIDA will (A) propose reasonable adjustments to the Methodology to resolve the issues(s) that are satisfactory to the FCC, and (B) consult with AT&T on AT&T's explanation of the issue(s) and the proposed adjustments to the Methodology to the FCC and the ICO. CAIDA and AT&T will repeat this process until there has been a Metrics Report that CAIDA believes contains appropriate performance metrics.*

(d) If, after CAIDA's repeated, good faith attempts to propose reasonable adjustments to the Methodology to resolve issue(s), the FCC fails to approve the proposed Methodology, CAIDA reserves the right to terminate this Agreement upon prior written notice to AT&T and the FCC and indicating the reasons therewith. If such termination occurs: (1) This agreement shall terminate and CAIDA shall no longer have the right to access and use the Protected Information (as described in 5(b)), (2) CAIDA is relieved of any obligation or penalty under this Agreement; and (3) AT&T shall reimburse CAIDA for all services performed and reimbursable expenses incurred up to that point of terminaton.

An important methodological concern arises from the structure of the merger order, and these terms of the contract between AT&T and UC, San Diego. Some operational issues that triggered the reporting requirement, such as overloaded LAGs, may not arise during the limited period in which the IME is reviewing the measurement method and resulting reporting. Validation of a method to detect an issue is not possible until and unless the condition of interest arises. The FCC needs to understand this concern and its implications for any continuing role of the IME.