discard-analysis-2018

September 7, 2018

1 Switch Discard Technical Report

MeasurementLab

2 Abstract

On February 1st, 2018, during a regular data quality review, we identified an increase in switch discards at sites with 10Gbps equipment connected to 1Gbps uplinks. We have collected high-resolution, switch telemetry (DISCO) since June 2016 to monitor traffic microbursts. To assess the impact of switch discards at 10Gbps sites, we deployed a new ETL parser for the DISCO data set. By February 15th, we found that affected sites had up to 30% of timebins with discard counts greater than zero. Immediately, we began trials to test remediation strategies. After identifying Ethernet flow control as an option, we began live trials the week of the 26th. And, by March 8th, all affected sites were enabled with Ethernet flow control. The rate of switch discards at sites with 10Gbps equipment is now zero. Since April 13th, the DISCO dataset includes pause frame counts to observe Ethernet flow-control activity.

The rate of switch discards was approximately 10x less than the rate of retransmissions found in NDT download tests. In other words, the Internet has a 10x higher discard rate than the M-Lab switch in the worst case. When we compare download performance before and after enabling Ethernet flow-control, we find no measurable performance impact of switch discards on the NDT data set.

This report:

- describes the cause of switch discards.
- describes the switch configuration changes made to prevent switch discards.
- describes the analysis used to conclude that the configuration change was positive.
- describes how to determine whether experiment data was affected by switch discards.

3 Timeline

2018-02-01:

- During data-quality review, we identify high levels of discards in SNMP monitoring.
- We prioritize parsing high-resolution switch data for detailed investigation.

2018-02-15:

- The DISCO data confirms excessive packet discard rates at many sites.
- We recognize that this is due to 10g hardware with 1g uplinks.
- We begin investigating options for remediation.

2018-02-22 - 27:

- Test & Live trials exploring software solutions: DPDK and qdisc

2018-03-01:

- We recognize that Ethernet flow-control is a better solution than qdisc.
- Live trials using Ethernet flow-control begin.

2018-03-06 - 08:

- We enable flow-control at all 10g sites.

2018-04-13:

- DISCO data set includes pause-frame counts globally.

4 Cause: 10Gbps Hardware to 1Gbps Uplink

M-Lab is upgrading sites to be 10Gbps capable. These upgrades are incremental – first we upgrade to 10Gbps equipment and preserve the 1Gbps uplink (e.g. "10Gbps-to-1Gbps"). Later, we upgrade the uplink to 10Gbps (e.g. "10Gbps-to-10Gbps"). Because these upgrades are independent, there is a period after hardware upgrade and before uplink upgrade where the machines can send at 10Gbps while the uplink can only send at 1Gbps. Because of this difference, a single server could send data faster than the switch could forward it. Once the switch buffers are full the switch may discard additional packets until the buffers drain.

5 Remediation: Enable Ethernet Flow-Control

By design, network devices may discard packets as a signal to senders that the network is under congestion. In fact, some technologies seeking to reduce packet discards turn out to negatively affect individual or aggregate network performance, i.e. head-of-line blocking, buffer-bloat. As a measurement platform, M-Lab seeks to balance measurement fidelity of actual network conditions with test performance under those conditions.

To prevent packet discards in M-Lab switches, we have enabled Ethernet flow-control on all 10Gbps machine-to-switch ports. Ethernet flow-control prevents switch discards due to tail drop in the single-machine, 10Gbps-to-1Gbps configuration. As well, Ethernet flow-control prevents switch discards due to fan-in congestion in the multi-machine, 10Gbps-to-10Gbps configuration. Both scenarios introduce no more contention between machines than already exists from the uplink capacity.

While Ethernet flow-control is known to cause "head of line blocking" in certain circumstances, these do not apply to M-Lab sites. In particular, M-Lab sites are optimized for sending "north-south" traffic (e.g. upload / download through the switch) and never "east-west" traffic (e.g. between machines). This eliminates all sources of "external head of line blocking" from machine-to-machine traffic. As well, our configuration enables flow-control only between the machine-to-switch link, so cannot contribute to "congestion spreading" beyond the switch. Because Ethernet flow-control can contribute to problems in more complex configurations, “everybody knows” that it should not be turned on. However, M-Lab’s unique setup makes Ethernet flow-control helpful.

Since 2016-06, the DISCO data set has recorded switch telemetry at 10 second intervals, including packet discards. Since enabling Ethernet flow-control the occurrence of packet discards has reduced to zero. In 2018-04, we added pause-frame counters to the DISCO data set. The pause-frame counters allow us to observe flow-control in action, and we have not observed bad NDT performance correlated with Ethernet flow-control.

6 Analysis

As M-Lab client integrations have grown over time, so has the percentage of site uplink capacity. Figure 1 shows the increase of median uplink utilization over a two year period using unicast transfer rates. Between late 2016 and late 2018, the daily median transfer rates have increased roughly 10x, more in some sites. Figure 2 shows the corresponding change in the median NDT download rates over the same period.

```
In [1]: # To load figures outside browser, use "%matplotlib" with no argument.
        %matplotlib inline

        import os
        import math
        import pandas as pd
        import numpy as np
        import matplotlib
        import matplotlib.dates as dates
        import matplotlib.pyplot as plt
        import matplotlib.ticker
        import datetime
        import collections
        import itertools

        from scipy import stats

        # Depends on: pip install sklearn
        from sklearn.model_selection import train_test_split

        # Some matplotlib features are version dependent.
        assert(matplotlib.__version__ >= '2.1.2')

        # Depends on: pip install --upgrade google-cloud-bigquery
        from google.cloud import bigquery


        def run_query(query, project='measurement-lab'):
            client = bigquery.Client(project=project)
            job = client.query(query)
            results = collections.defaultdict(list)
            for row in job.result(timeout=3000):
                for key in row.keys():
                    results[key].append(row.get(key))

            return pd.DataFrame(results)


        def unlog(x, pos):
            """Formats the x axis for histograms taken on the log of values."""
            v = math.pow(10, x)
            frac, whole = math.modf(v)
            if frac > 0:
                return '%.1f' % v
            else:
                return '%d' % whole


        def hist(vals, bin_count, log=True, cdf=False):
            """Produces hist or cdf values for smooth plots."""
            if log:
                r = [math.log10(x) for x in vals]
            else:
                r = vals

            m, bins = np.histogram(r, bin_count, normed=True)
            m = m.astype(float)

            tops = m
            if cdf:
                tops = np.cumsum(m)
                total = sum(m)
                tops = [float(t) / total for t in tops]

            return tops, bins


        matplotlib.rcParams['figure.dpi']= 150
        logFormatter = matplotlib.ticker.FuncFormatter(unlog)

In [2]: def plot_df(
            df, xname='', yname='',
            cname='', bins=None, cdf=False,
            xlog=None, ylog=False,
            fig_by='', axes_by='', group_by='',
            figsize=(6,8), axes=(1,1),
            label='{group}',
            xlabel='', ylabel='',
            xlim=(), ylim=(),
            fx=list, fy=list,
            suptitle='',
            title='',
            legend={},
            figmap=None,
            fxn=None,
            info=False):
            """Creates a scatter or histogram plot from df, split on mulitple dimen

            plot_df helps plot structured data frames as simple scatter or histogra
            slicing the dataframe along distinct values of some column names. For
            example, a df that includes a "state" column could be used to create a
            figure for every state with the `fig_by="state"` parameter. Within a si
            figure, it's possible to slice the data into multiple axes using anothe
            column, for example one named "city" using `axes_by="city"`.

            Args:
              df: pandas.DataFrame, structured data to plot.
              xname: str, name of df column to use as x-axis. Use only with yname.
              yname: str, name of df column to use as y-axis. Use only with xname.
              cname: str, name of df column to calculate the histogram. Use only wi
                  cdf, and bins.
              cdf: bool, whether to plot histogram as a CDF. Default is as a PDF. U
                  only with cname and bins.
              bins: int or callable, the number of histogram bins. May be a functio
              xlog: bool, whether to take the log of histogram. Use only with cname
              ylog: bool, whether to plot the y axis using semilog scale.
              fig_by: str, name of column where distinct values split data into mul
                  figures.
              axes_by: str, name of column where distinct values split data into
                  multiple axis panels on a single figure.
              group_by: str, name of column where distinct values are all plotted o
                  same axis.
              figsize: (int, int), dimensions of figure. Default (6, 8).
              axes: (int, int), arrangement of axes within figure. Default (1, 1).
              label: str, the legend format per data series. Used as a format strin
                  Other parameters available are {figure}, {axis}, {size}.
                  Default {group}.
              xlabel: str, the xlabel value. Used as a format string. Other paramet
                  available are {figure}, {axis}, {size}.
              ylabel: str, the ylabel value. Used as a format string like xlabel.
              xlim: (xmin, xmax), explicitly set minimum and maximum values of x ax
              ylim: (ymin, ymax), explicitly set minimum and maximum values of y ax
              fx: func, if set, operate on x axis series data before plotting.
              fy: func, if set, operate on y axis series data before plotting.
              suptitle: str, figure title.
              title: str, axis title.
              legend: **legend_args,
              figmap: the figmap value returned by an earlier cal of plot_df. May b
                  used to overlay values from multiple data frames. Must use the sa
                  fig_by, axes_by, and group_by values.
              fxn: callable that accepts parameters (r, **kwargs). Kwargs will incl
                  figure, axis, group, names and data set size. Only called for
                  histogram plots.
              info: bool, whether to log additional info messages.
            Returns:
              dict of str to (figures, axes) tuples
            """
            def log_info(f):
                if info:
                    print f

            def get_label_color(ax, label):
                """Returns the color of the collection with given label."""
                color = None
                for c in ax.collections:
                    if c.get_label() == label:
                        color = c.get_facecolors()[0]
                return color

            check_colors = figmap is not None
            if figmap is None:
                log_info('new figmap')
                figmap = {}

            scatter = None
            if (xname and yname):
                scatter = True
            if cname:
                scatter = False
            if scatter is None:
                raise Exception('Provide xname and yname or cname')

            default_names = set(['default'])

            figure_names = set(df[fig_by]) if fig_by else default_names
            for f in sorted(figure_names):
                if f in figmap:
                    log_info('loading figmap for %s' % f)
                    fig, ax, ax_index = figmap[f]
                else:
                    fig = plt.figure(figsize=figsize)
                    ax = fig.subplots(axes[0], axes[1], squeeze=False)
                    ax_index = list(itertools.product(range(axes[0]), range(axes[1]
                    log_info('saving figmap for %s' % f)
                    figmap[f] = (fig, ax, ax_index)

                df_fig = df if f == 'default' else df[df[fig_by] == f]

                axes_names = set(df_fig[axes_by]) if axes_by else default_names
                for p, a in enumerate(sorted(axes_names)):
                    if p >= len(ax_index):
                        print 'SKIPPING', p, f, a, 'too few axes positions'
                        continue

                    if a == 'default':
                        df_axes = df_fig
                    else:
                        df_axes = df_fig[df_fig[axes_by] == a]

                    i, j = ax_index[p]
                    group_names = set(df_axes[group_by]) if group_by else default_
                    for g in sorted(group_names):
                        if g == 'default':
                            df_g = df_axes
                        else:
                            df_g = df_axes[df_axes[group_by] == g]

                        if scatter:
                            x = fx(df_g[xname])
                            y = fy(df_g[yname])
                            l = label.format(figure=f, axis=a, group=g)
                            kw = {}
                            found_color = None
                            if check_colors:
                                # When a figmap is given, and the current label mat
                                # an existing label, re-use the original color.
                                found_color = get_label_color(ax[i][j], l)

                            if found_color is not None:
                                kw['color'] = found_color
                            else:
                                kw['label'] = l

                            ax[i][j].scatter(x, y, s=1, **kw)

                        else:
                            r = df_g[cname]
                            if bins is None:
                                size = int(math.sqrt(len(r)))
                            else:
                                size = bins(r)
                            if fxn:
```

```
                        result = fxn(r, figure=f, axis=a, group=g, size=siz
                    log_info("%s %s %s %s %s" % (f, a, g, size, len(r)))
                    h_tops, h_bins = hist(r, size, log=xlog , cdf=cdf)
                    l = label.format(figure=f, axis=a, group=g, size=size,
                                     result=result)
                    ax[i][j].plot(h_bins[:-1], h_tops, label=l)

            if i != len(ax)-1:
                ax[i][j].set_xticklabels([])

            if title:
                ax[i][j].set_title(title.format(figure=f, axis=a, group=g))
            if ylabel:
                ax[i][j].set_ylabel(ylabel.format(figure=f, axis=a, group=g
            if xlabel:
                ax[i][j].set_xlabel(xlabel.format(figure=f, axis=a, group=g

            if xlim:
                ax[i][j].set_xlim(xlim)
            if ylim:
                ax[i][j].set_ylim(ylim)

            ax[i][j].grid(color='#dddddd')
            ax[i][j].legend(fontsize='x-small', **legend)
            if scatter:
                ax[i][j].tick_params(axis='x', labelrotation=-90)
            if xlog:
                ax[i][j].xaxis.set_major_formatter(logFormatter)
            if ylog:
                ax[i][j].semilogy()

        if suptitle:
            fig.suptitle(suptitle.format(figure=f))
        fig.tight_layout(rect=[0, 0.03, 1, 0.95])

    return figmap


def plot_scatter(df, xname, yname, **kwargs):
    return plot_df(df, xname=xname, yname=yname, **kwargs)


def plot_hist(df, cname, bins=None, **kwargs):
    return plot_df(df, cname=cname, bins=bins, **kwargs)
```

7 Daily Median Uplink Utilization

```
In [3]: df_disco_pct = run_query("""
        #standardSQL

        WITH measurementlab_switch_dedup AS (
          SELECT
            metric,
            REGEXP_EXTRACT(hostname, r'(mlab[1-4].[a-z]{3}[0-9]{2}).*') AS hostname
            sample.timestamp AS ts,
            sample.value AS value
          FROM
            `measurement-lab.base_tables.switch*`,
            UNNEST(sample) AS sample
          WHERE
                metric = 'switch.octets.uplink.tx'
            AND REGEXP_CONTAINS(hostname, r"mlab1.(dfw|lga|nuq)\d\d")
          GROUP BY
            hostname, metric, ts, value
        )


        SELECT
          UPPER(REGEXP_EXTRACT(hostname, r'mlab1.([a-z]{3})[0-9]{2}.*')) AS metro,
          REGEXP_EXTRACT(hostname, r'mlab1.([a-z]{3}[0-9]{2}).*') AS site,
          UNIX_SECONDS(TIMESTAMP_TRUNC(ts, DAY)) AS ts,
          0.8 * APPROX_QUANTILES(value, 101)[ORDINAL(50)] as bytes_50th

        FROM
          measurementlab_switch_dedup

        WHERE
          hostname IS NOT NULL

        GROUP BY
          hostname, ts

        ORDER BY
          hostname, ts
        """)
```

```
/usr/local/google/home/soltesz/.local/lib/python2.7/site-packages/google/auth/_defa
  warnings.warn(_CLOUD_SDK_CREDENTIALS_WARNING)
```

```
In [4]: _ = plot_scatter(
            df_disco_pct, 'ts', 'bytes_50th',
            axes_by='metro', group_by='site',
            axes=(3, 1), figsize=(7, 9),
            suptitle='Daily Median Uplink Utilization',
            ylabel="Mbps",
            title='{axis}',
            xlim=(pd.to_datetime("2016-05-31"), pd.to_datetime("2018-08-01")),
            ylim=(1e4, 1e9),
            fx=lambda l: [pd.to_datetime(t, unit='s') for t in l],
            legend={'loc':3, 'ncol':7, 'columnspacing':1},
            ylog=True)
```

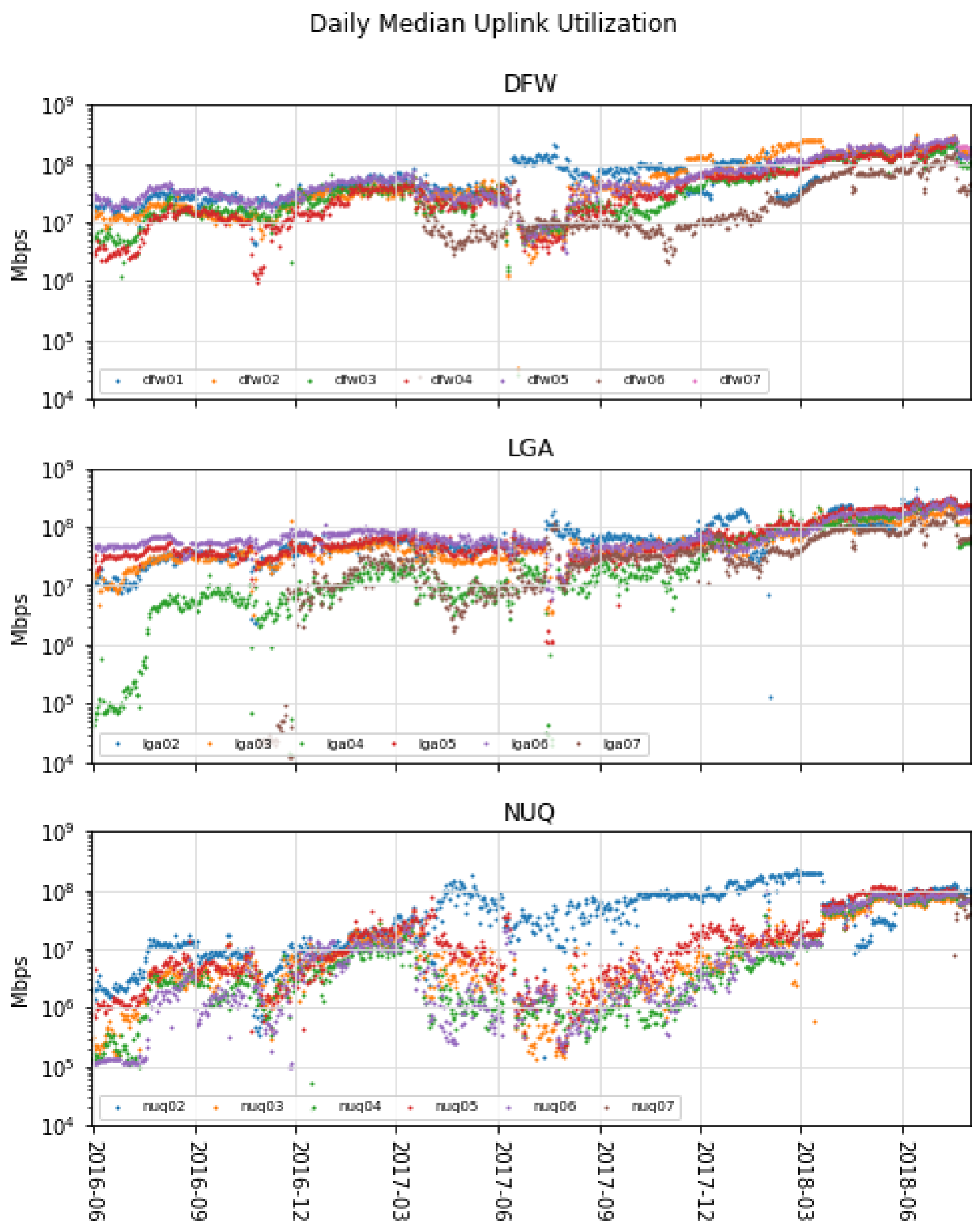


Figure 1: Daily Median Uplink Utilization. Rates from select US sites from 2016-06 to 2018-08. Rates include all unicast packets (UDP & TCP) according to the DISCO data set.

8 Median NDT Download Rates

```
In [5]: df_ndt_all = run_query("""
        WITH measurementlab_ndt_dedup AS (
          SELECT
            connection_spec.server_hostname as server_hostname,
            web100_log_entry.connection_spec.remote_ip as remote_ip,
            log_time,
            (8 * (web100_log_entry.snap.HCThruOctetsAcked / (
                  web100_log_entry.snap.SndLimTimeRwin +
                  web100_log_entry.snap.SndLimTimeCwnd +
                  web100_log_entry.snap.SndLimTimeSnd))) AS download_mbps

          FROM
            `measurement-lab.release.ndt_all`

          WHERE
                REGEXP_CONTAINS(connection_spec.server_hostname, r"(lga|dfw|nuq)\d
            AND web100_log_entry.snap.HCThruOctetsAcked >= 1000000
            AND (web100_log_entry.snap.SndLimTimeRwin +
                 web100_log_entry.snap.SndLimTimeCwnd +
                 web100_log_entry.snap.SndLimTimeSnd) >= 9000000
            AND (web100_log_entry.snap.SndLimTimeRwin +
                 web100_log_entry.snap.SndLimTimeCwnd +
                 web100_log_entry.snap.SndLimTimeSnd) < 600000000
            AND connection_spec.data_direction = 1
            AND web100_log_entry.connection_spec.remote_ip != "45.56.98.222"
            AND web100_log_entry.connection_spec.remote_ip != "2600:3c03::f03c:91ff
            AND web100_log_entry.connection_spec.remote_ip != "35.225.75.192"
            AND web100_log_entry.connection_spec.remote_ip != "35.192.37.249"
            AND web100_log_entry.connection_spec.remote_ip != "35.193.254.117"
            AND log_time >= TIMESTAMP("2016-06-01")

          GROUP BY
            connection_spec.server_hostname,
            log_time,
            web100_log_entry.connection_spec.remote_ip,
            web100_log_entry.connection_spec.local_ip,
            web100_log_entry.connection_spec.remote_port,
            web100_log_entry.connection_spec.local_port,
            download_mbps
        )

        SELECT
          metro,
          site,
          day,
          APPROX_QUANTILES(download_mbps, 101)[ORDINAL(50)] as download_mbps,
          count(*) as count

        FROM
        (
          SELECT
            UPPER(REGEXP_EXTRACT(server_hostname, r"([a-z]{3})[0-9]{2}")) as metro,
            REGEXP_EXTRACT(server_hostname, r"([a-z]{3}[0-9]{2})") as site,
            TIMESTAMP_TRUNC(log_time, DAY) as day,
            MAX(download_mbps) as download_mbps

          FROM
            measurementlab_ndt_dedup

          GROUP BY
            metro, site, day, remote_ip
        )

        GROUP BY
          metro, site, day

        ORDER BY
          day
        """)
```

```
In [6]: _ = plot_scatter(
            df_ndt_all, 'day', 'download_mbps',
            axes_by='metro', group_by='site',
            axes=(3, 1), figsize=(8, 10),
            suptitle='Median NDT Download Rates',
            ylabel="Mbps",
            title='{axis}',
            xlim=(pd.to_datetime("2016-05-31"), pd.to_datetime("2018-08-01")),
            ylim=(0, 50),
            fx=lambda l: [pd.to_datetime(t) for t in l],
            legend={'loc':3, 'ncol':7, 'columnspacing':1})
```

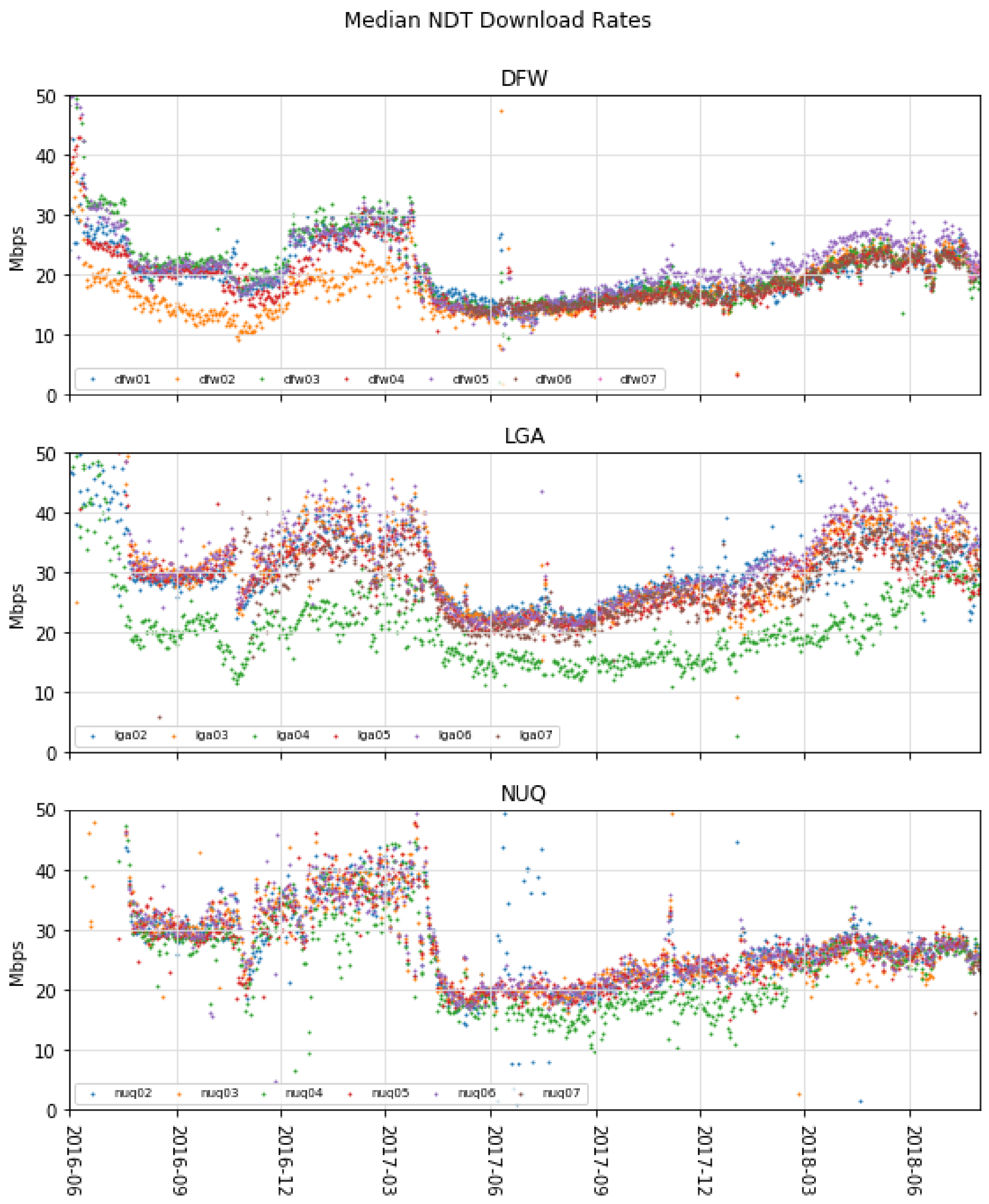


Figure 2: Daily median NDT download rates from select US sites from 2017-05 to 2018-08. Multiple tests from the same remote_ip are counted only once. Figure 2 shows median client behavior changing over time. These client behavior changes started before the hardware upgrades (so are unaffected by the switch discards).

9 Daily Packet Loss Ratio

```
In [7]: df_disco_ratio = run_query("""
        #standardSQL

        WITH measurementlab_switch_dedup AS (
          SELECT
            metric,
            REGEXP_EXTRACT(hostname, r'(mlab[1-4].[a-z]{3}[0-9]{2}).*') AS hostname
            sample.timestamp AS ts,
            sample.value AS value

          FROM
            `measurement-lab.base_tables.switch*`,
            UNNEST(sample) AS sample

          WHERE
                (metric LIKE 'switch.discards.uplink.tx'
              OR metric LIKE 'switch.unicast.uplink.tx')
            AND REGEXP_CONTAINS(hostname, r"mlab1.(dfw|lga|nuq)\d\d")

          GROUP BY
            hostname, metric, ts, value
        )

        SELECT
          UPPER(REGEXP_EXTRACT(hostname, r'mlab1.([a-z]{3})[0-9]{2}.*')) AS metro,
          REGEXP_EXTRACT(hostname, r'mlab1.([a-z]{3}[0-9]{2}).*') AS site,
          hostname,
          ts,
          IF(total > 0, discards / total, 0) as ratio

        FROM (
          SELECT
            hostname,
            UNIX_SECONDS(TIMESTAMP_TRUNC(ts, DAY)) AS ts,
            SUM(IF(metric = "switch.discards.uplink.tx", value, 0)) AS discards,
            SUM(IF(metric = "switch.unicast.uplink.tx", value, 0)) AS total
          FROM
            measurementlab_switch_dedup
          WHERE
            hostname IS NOT NULL
          GROUP BY
            hostname, ts
          HAVING
            discards < total
          ORDER BY
            hostname, ts
        )
        GROUP BY
          hostname, ts, ratio
        HAVING
          ratio < 0.01
        ORDER BY
          hostname, ts
        """)
```

```
In [8]: _ = plot_scatter(
            df_disco_ratio, 'ts', 'ratio',
            axes_by='metro', group_by='site',
            axes=(3, 1), figsize=(8, 10),
            suptitle='Daily Packet Loss Ratio (discards / unicast)',
            ylabel="Ratio",
            title='{axis}',
            xlim=(pd.to_datetime("2016-05-31"), pd.to_datetime("2018-08-01")),
            ylim=(1e-6, 1e-1),
            fx=lambda l: [pd.to_datetime(t, unit='s') for t in l],
            legend={'loc':2},
            ylog=True)
```

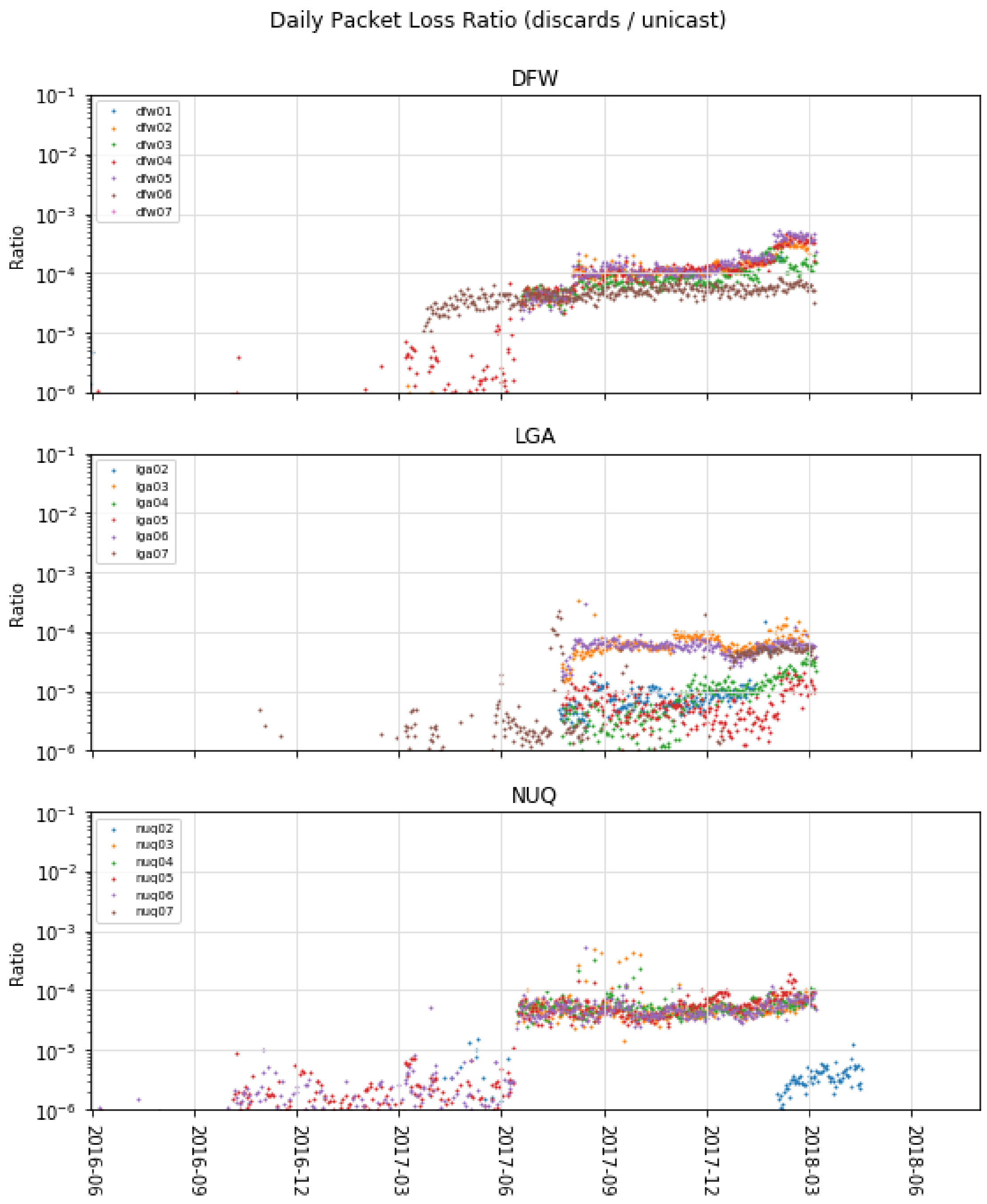


Figure 3: Switch Discard Ratio calculated using the daily switch uplink discard count divided by the total uplink packet count. DFW had the globally highest rate of discards. Typically other sites were less than 0.01% (1 packet per 10,000 packets).

10 Median NDT Retransmission Ratio

```
In [9]: df_ndt_retrans = run_query("""
        WITH measurementlab_ndt_dedup AS (
          SELECT
            connection_spec.server_hostname as hostname,
            web100_log_entry.connection_spec.remote_ip as remote_ip,
            log_time,
            web100_log_entry.snap.SegsRetrans as SegsRetrans,
            web100_log_entry.snap.SegsOut as SegsOut

          FROM
            `measurement-lab.release.ndt_all`

          WHERE
                REGEXP_CONTAINS(connection_spec.server_hostname, r"(lga|dfw|nuq)\d
            AND web100_log_entry.snap.HCThruOctetsAcked >= 1000000
            AND (web100_log_entry.snap.SndLimTimeRwin +
                 web100_log_entry.snap.SndLimTimeCwnd +
                 web100_log_entry.snap.SndLimTimeSnd) >= 9000000
            AND (web100_log_entry.snap.SndLimTimeRwin +
                 web100_log_entry.snap.SndLimTimeCwnd +
                 web100_log_entry.snap.SndLimTimeSnd) < 600000000
            AND connection_spec.data_direction = 1
            AND web100_log_entry.connection_spec.remote_ip != "45.56.98.222"
            AND web100_log_entry.connection_spec.remote_ip != "2600:3c03::f03c:91f
            AND web100_log_entry.connection_spec.remote_ip != "35.225.75.192"
            AND web100_log_entry.connection_spec.remote_ip != "35.192.37.249"
            AND web100_log_entry.connection_spec.remote_ip != "35.193.254.117"
            AND log_time >= TIMESTAMP("2016-06-01")

          GROUP BY
            connection_spec.server_hostname,
            log_time,
            web100_log_entry.connection_spec.remote_ip,
            web100_log_entry.connection_spec.local_ip,
            web100_log_entry.connection_spec.remote_port,
            web100_log_entry.connection_spec.local_port,
            SegsRetrans,
            SegsOut
        )

        SELECT
          UPPER(REGEXP_EXTRACT(hostname, r"([a-z]{3})[0-9]{2}")) as metro,
          REGEXP_EXTRACT(hostname, r"([a-z]{3}[0-9]{2})") as site,
          day,
          APPROX_QUANTILES(ratio, 101)[ORDINAL(50)] AS median_ratio,
          count(*) as count
        FROM
        (
          SELECT
            hostname,
            TIMESTAMP_TRUNC(log_time, DAY) as day,
            MAX(SAFE_DIVIDE(SegsRetrans, SegsOut)) as ratio

          FROM
            measurementlab_ndt_dedup

          GROUP BY
            hostname,
            day,
            remote_ip
        )

        GROUP BY
          hostname, day

        ORDER BY
          day
        """)
```

```
In [10]: _ = plot_scatter(
             df_ndt_retrans, 'day', 'median_ratio',
             axes_by='metro', group_by='site',
             axes=(3, 1), figsize=(8, 10),
             suptitle='Median NDT Retransmission Ratio - (SegsRetran / SegsOut)',
             ylabel="Ratio",
             title='{axis}',
             xlim=(pd.to_datetime("2016-05-31"), pd.to_datetime("2018-08-01")),
             ylim=(1e-6, 1e-1),
             fx=lambda l: [pd.to_datetime(t) for t in l],
             legend={'loc':2},
             ylog=True)
```

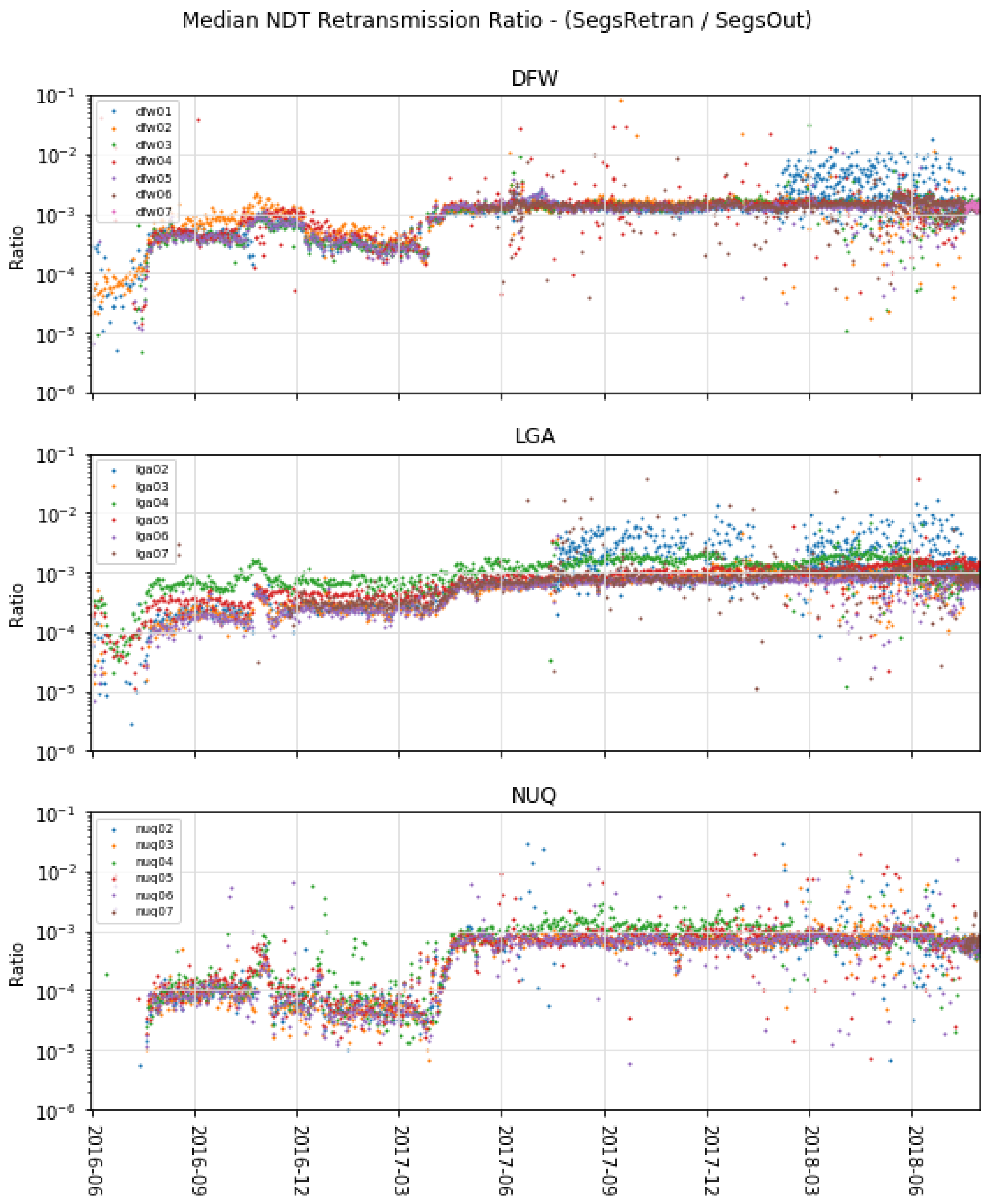


Figure 4: NDT Segment Retransmission Ratio calculated using the web100 metrics for SegsRetrans and SegsOut. Multiple tests from the same remote_ip are counted only once. Notice that the packet discard rates for the Internet are more than 10x the switch discard rates.

11 Combined Chart

```
In [11]: f = plot_scatter(
             df_disco_ratio, 'ts', 'ratio',
             axes_by='metro', group_by='site',
             axes=(3, 1), figsize=(8, 10),
             suptitle='Combination - Daily Packet Discard Ratio & NDT Retransmissio
             ylabel="Ratio",
             title='{axis}',
             xlim=(pd.to_datetime("2016-05-31"), pd.to_datetime("2018-08-01")),
             ylim=(1e-6, 1e-1),
             fx=lambda l: [pd.to_datetime(t, unit='s') for t in l],
             legend={'loc':2},
             ylog=True)

         _ = plot_scatter(
             df_ndt_retrans, 'day', 'median_ratio',
             axes_by='metro', group_by='site',
             axes=(3, 1), figsize=(8, 10),
             ylabel="Ratio",
             title='{axis}',
             xlim=(pd.to_datetime("2016-05-31"), pd.to_datetime("2018-08-01")),
             ylim=(1e-6, 1e-1),
             fx=lambda l: [pd.to_datetime(t) for t in l],
             legend={'loc':2},
             ylog=True, figmap=f)
```

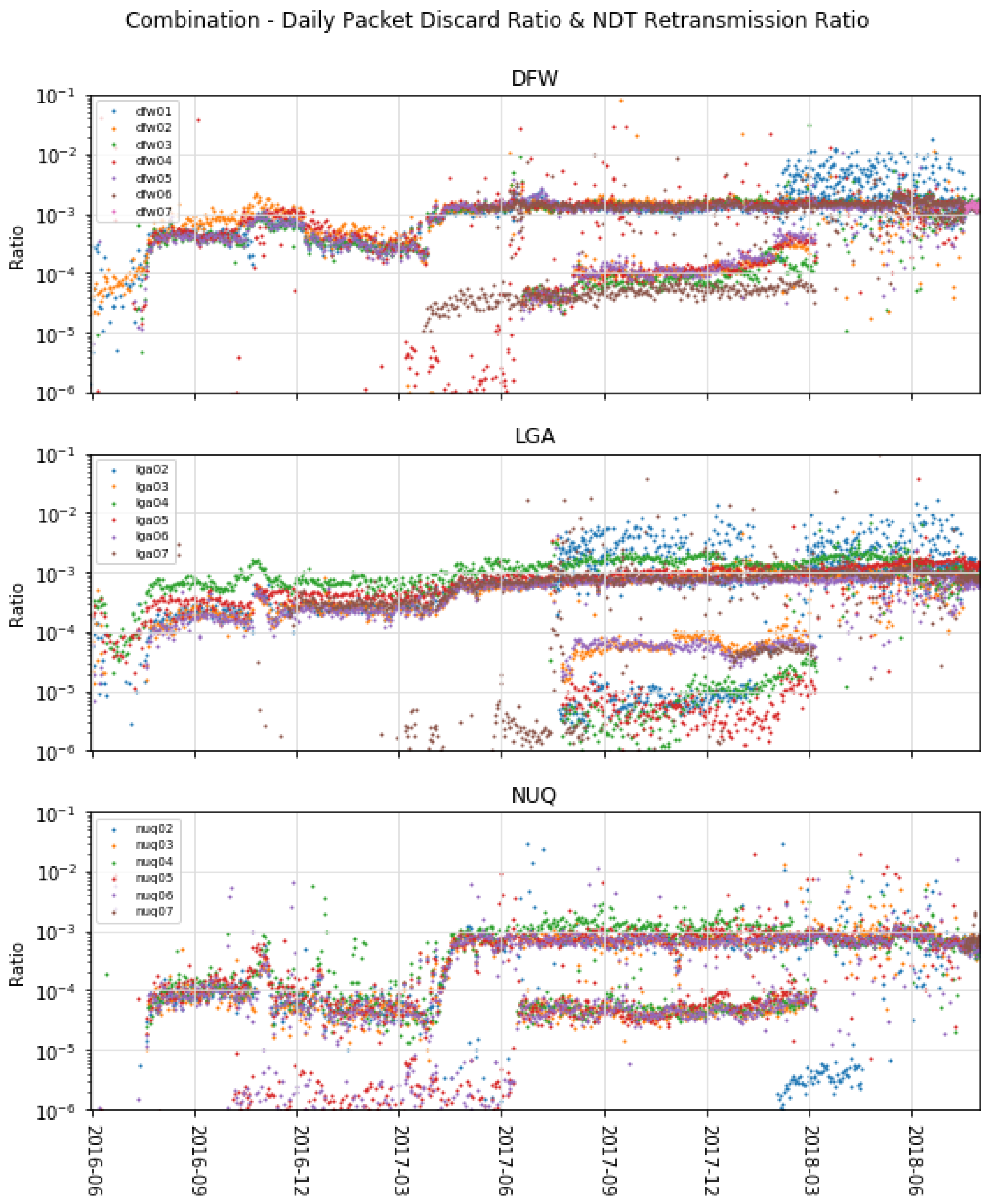


Figure 5: Combination of Switch Discard Ratio and NDT Retransmission Ratios. When comparing figures 3 and 4, we see that NDT retransmissions are consistently 4x to 10x higher than the switch loss ratio, with no changes once flow control was enabled.

11.1 Compare NDT Download Distributions

To assess whether the switch discards measurably affected NDT tests, we compare performance before and after the Ethernet flow-control configuration change. To reduce the effect of dynamic client populations, we selected a cohort that ran tests in both periods.

For tests used in this analysis, all of the following must be true: * the client ran more than 10 download tests between 2018-02-11 and 2018-02-25 * the client ran more than 10 download tests between 2018-03-11 and 2018-03-25 * the client ran these tests to machines in the same metro area

We assume that clients from this cohort have the same connectivity in both periods and that the number of tests reduce variation caused by external factors.

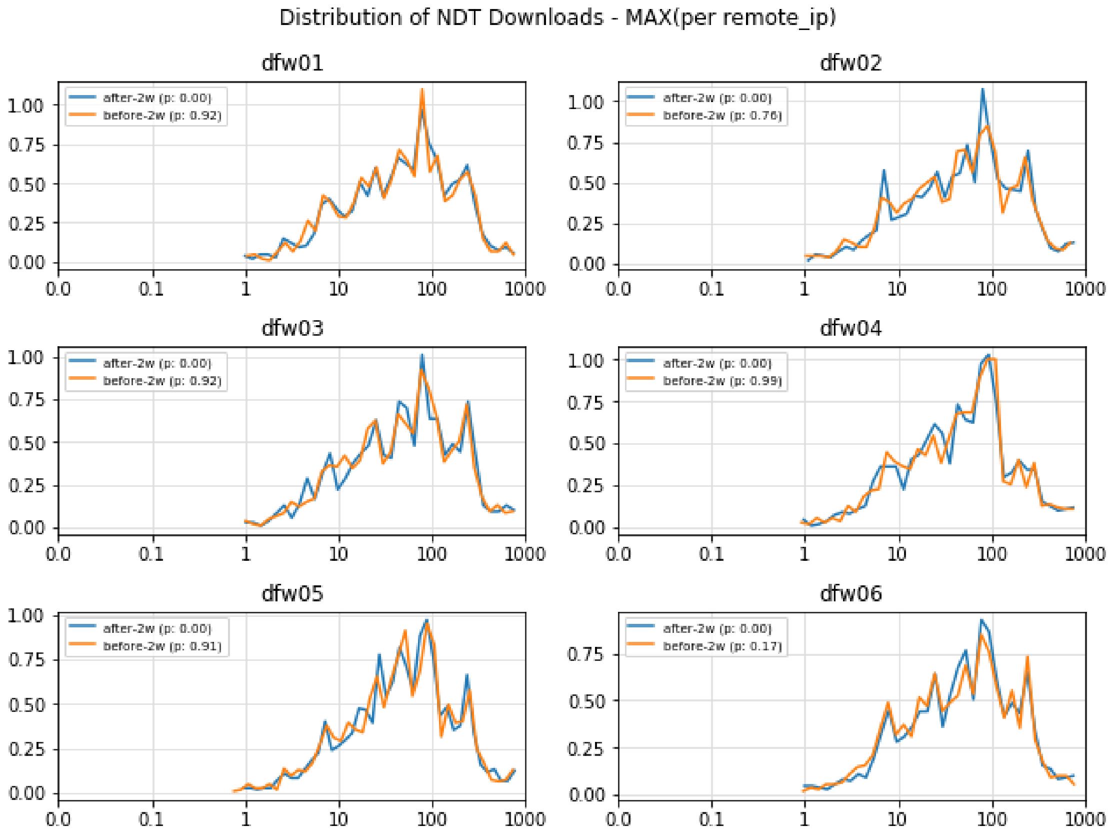
We take the maximum download rate per client and then operate on the distribution of all maximum client rates per site.

Figure 6 shows the distribution of test rates before and after the configuration change as a PDF. We compare the maximum download rates per remote_ip, as well as the average download rates per remote_ip. Both distributions emphasize the similarity. We quantify the similarity using the ks-test. The null hypothesis is that the measurements are from the same distribution. And, we would reject the null hypothesis if the p-value is below 1%. In all cases, we accept the null hypothesis – these distributions are not measurably different.

```
In [12]: df_ndt_variance = run_query("""
         WITH measurementlab_ndt_dedup AS (

           SELECT
             UPPER(REGEXP_EXTRACT(connection_spec.server_hostname,
                 r'mlab[1-4].([a-z]{3})[0-9]{2}.*')) AS metro,
             REGEXP_EXTRACT(connection_spec.server_hostname,
                 r'mlab[1-4].([a-z]{3}[0-9]{2}).*') AS site,
             REGEXP_EXTRACT(connection_spec.server_hostname,
                 r'(mlab[1-4].[a-z]{3}[0-9]{2}).*') AS hostname,
             web100_log_entry.connection_spec.remote_ip as remote_ip,
             log_time,
             (8 * (web100_log_entry.snap.HCThruOctetsAcked / (
                   web100_log_entry.snap.SndLimTimeRwin +
                   web100_log_entry.snap.SndLimTimeCwnd +
                   web100_log_entry.snap.SndLimTimeSnd))) AS download_mbps

           FROM
             `measurement-lab.release.ndt_all`

           WHERE
               (TIMESTAMP_TRUNC(log_time, DAY) BETWEEN
                   TIMESTAMP("2018-02-11") AND TIMESTAMP("2018-02-25")
             OR TIMESTAMP_TRUNC(log_time, DAY) BETWEEN
                   TIMESTAMP("2018-03-11") AND TIMESTAMP("2018-03-25"))
             AND REGEXP_CONTAINS(connection_spec.server_hostname, r"(dfw)\d\d")
             AND web100_log_entry.snap.HCThruOctetsAcked >= 1000000
             AND (web100_log_entry.snap.SndLimTimeRwin +
                  web100_log_entry.snap.SndLimTimeCwnd +
                  web100_log_entry.snap.SndLimTimeSnd) >= 9000000
             AND (web100_log_entry.snap.SndLimTimeRwin +
                  web100_log_entry.snap.SndLimTimeCwnd +
                  web100_log_entry.snap.SndLimTimeSnd) < 600000000
```

```
    AND connection_spec.data_direction = 1
    AND web100_log_entry.connection_spec.remote_ip != "45.56.98.222"
    AND web100_log_entry.connection_spec.remote_ip != "2600:3c03::f03c:91f
    AND web100_log_entry.connection_spec.remote_ip != "35.225.75.192"
    AND web100_log_entry.connection_spec.remote_ip != "35.192.37.249"
    AND web100_log_entry.connection_spec.remote_ip != "35.193.254.117"
    AND log_time >= TIMESTAMP("2016-06-01")

  GROUP BY
    connection_spec.server_hostname,
    log_time,
    web100_log_entry.connection_spec.remote_ip,
    web100_log_entry.connection_spec.local_ip,
    web100_log_entry.connection_spec.remote_port,
    web100_log_entry.connection_spec.local_port,
    download_mbps
)


SELECT
  metro,
  site,
  hostname,
  CASE
    WHEN TIMESTAMP_TRUNC(log_time, DAY) BETWEEN
        TIMESTAMP("2018-02-11") AND TIMESTAMP("2018-02-25") THEN 'before-2
    WHEN TIMESTAMP_TRUNC(log_time, DAY) BETWEEN
        TIMESTAMP("2018-03-11") AND TIMESTAMP("2018-03-25") THEN 'after-2w
    ELSE 'what'
  END AS period,
  remote_ip,
  STDDEV(download_mbps) AS download_stddev,
  (STDDEV(download_mbps) / AVG(download_mbps)) AS download_cv,
  MAX(download_mbps) AS download_max,
  MIN(download_mbps) AS download_min,
  AVG(download_mbps) AS download_avg

FROM
  measurementlab_ndt_dedup

WHERE
  remote_ip IN(
    SELECT remote_ip
    FROM (
      SELECT   remote_ip, count(*) as c1
      FROM     measurementlab_ndt_dedup
      WHERE    TIMESTAMP_TRUNC(log_time, DAY) BETWEEN
          TIMESTAMP("2018-02-11") AND TIMESTAMP("2018-02-25")
      GROUP BY remote_ip
      HAVING   c1 > 10
    ) INNER JOIN (
      SELECT   remote_ip AS remote_ip, count(*) as c2
      FROM     measurementlab_ndt_dedup
      WHERE    TIMESTAMP_TRUNC(log_time, DAY) BETWEEN
          TIMESTAMP("2018-03-11") AND TIMESTAMP("2018-03-25")
      GROUP BY remote_ip
      HAVING   c2 > 10
    ) USING (remote_ip))

GROUP BY
  metro, site, hostname, period, remote_ip

HAVING
  download_stddev is not NULL
""")
```

```
In [13]: values = {}
         def ks_compare(r, figure='', axis='', group='', size=''):
             values["%s-%s-%s" % (figure, axis, group)] = r
             if group == 'before-2w':
                 after = values["%s-%s-%s" % (figure, axis, 'after-2w')]
                 result = stats.ks_2samp(r, after)
                 if result.pvalue < 0.01:
                     print 'diff', figure, axis, result
                 return result.pvalue
             return 0

         _ = plot_hist(
             df_ndt_variance, 'download_max', lambda r: int(math.sqrt(len(r))),
             fig_by='metro', axes_by='site', group_by='period',
             suptitle='Distribution of NDT Downloads - MAX(per remote_ip)',
             label='{group} (p: {result:.2f})',
             title='{axis}', axes=(3, 2),
             xlim=(math.log10(.01), math.log10(1000)),
             cdf=False, xlog=True, figsize=(9, 7),
             fxn=ks_compare)

         values = {}
         _ = plot_hist(
             df_ndt_variance, 'download_avg', lambda r: int(math.sqrt(len(r))),
             fig_by='metro', axes_by='site', group_by='period',
             suptitle='Distribution of NDT Downloads - AVERAGE(per remote_ip)',
             label='{group} (p: {result:.2f})',
             title='{axis}', axes=(3, 2),
             xlim=(math.log10(.01), math.log10(1000)),
             cdf=False, xlog=True, figsize=(9, 7),
        fxn=ks_compare)
```



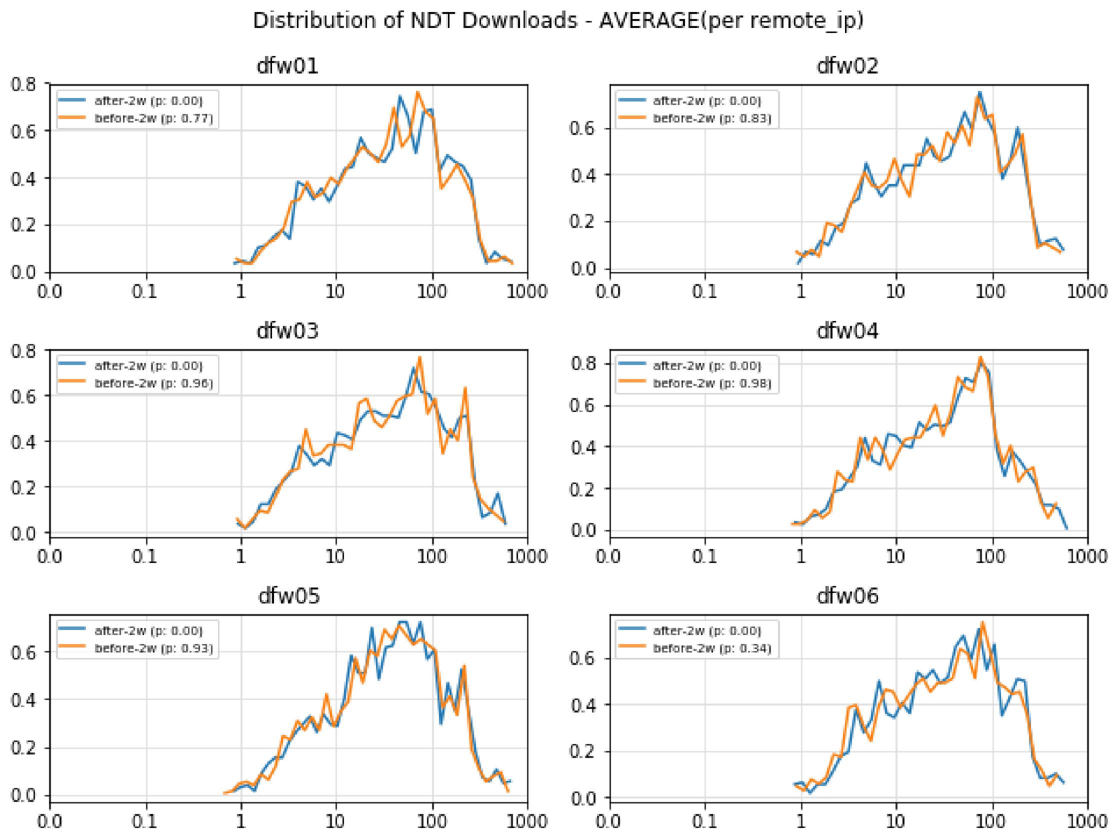


Figure 6: NDT Download Distribution. For every client in the cohort, we take the maximum and average download rate per period. Then plot the distribution of performances before and after the configuration change. Ethernet flow-control does not change the performance distributions.

11.2 NDT Test Counts

NDT is a single-stream TCP test and more sensitive to network disturbances than multi-stream tests. By design, a packet loss in any single flow of a multi-stream test is less significant because the remaining flows may compensate. Using the Sidestream data set we found similar results for multi-stream tests on M-Lab.

Finally, the number of NDT tests potentially affected by switch discards is relatively small. The globally worst case was at DFW02, where approximately 50% of tests ran during periods with nonzero switch discards. If analysts would like to identify these tests as part of their analysis, see the query in the next section.

```
In [14]: import time
         def query(site):
             print 'running query', site, time.ctime()
             return """
         CREATE TEMPORARY FUNCTION
           timeBin(ts_usec INT64,
             size INT64) AS ( CAST(TRUNC(ts_usec / 1e6 / 10) * 10 AS INT64) );
```

```
WITH ndt_test_ids_with_discards AS (
  SELECT
    ndt.test_id as test_id,
    SUM(disco.discards) AS discards
  FROM (
    SELECT
      hostname,
      UNIX_SECONDS(sample.timestamp) - 10 AS tstart,
      UNIX_SECONDS(sample.timestamp) AS tend,
      sample.value AS discards
    FROM
      `measurement-lab.base_tables.switch*`,
      UNNEST(sample) AS sample
    WHERE
      metric = 'switch.discards.uplink.tx'
      AND sample.timestamp BETWEEN
          TIMESTAMP("2016-06-01") AND TIMESTAMP("2018-08-01")
      AND hostname = "mlab1."""+site+""".measurement-lab.org"
    GROUP BY
      hostname,
      tstart,
      tend,
      discards
    HAVING
      discards > 0
  ) AS disco
  JOIN (
    SELECT
      REGEXP_EXTRACT(connection_spec.server_hostname,
          r"(mlab1."""+site+""".measurement-lab.org)") as hostname,
      timeBin(web100_log_entry.snap.StartTimeStamp, 10) AS tstart,
      timeBin(web100_log_entry.snap.StartTimeStamp, 10) + 20 AS tend,
      test_id

    FROM
      `measurement-lab.release.ndt_all`

    WHERE
          log_time BETWEEN TIMESTAMP("2016-06-01") AND TIMESTAMP("2018-08-
      AND connection_spec.data_direction = 1
      AND (connection_spec.server_hostname =
              "mlab1."""+site+""".measurement-lab.org"
         OR connection_spec.server_hostname =
              "ndt.iupui.mlab1."""+site+""".measurement-lab.org")
      AND (web100_log_entry.snap.SndLimTimeRwin +
           web100_log_entry.snap.SndLimTimeCwnd +
           web100_log_entry.snap.SndLimTimeSnd) >= 9000000
      AND (web100_log_entry.snap.SndLimTimeRwin +
           web100_log_entry.snap.SndLimTimeCwnd +
           web100_log_entry.snap.SndLimTimeSnd) < 600000000
      AND web100_log_entry.snap.HCThruOctetsAcked >= 1000000

    GROUP BY
      test_id,
      hostname,
      tstart,
      tend ) AS ndt
  ON (disco.hostname = ndt.hostname
      AND (disco.tstart = ndt.tstart OR disco.tend = ndt.tend))
  GROUP BY
    test_id
  )


SELECT
  day, metro, site, hostname, discards, COUNT(*) as count

FROM
(
  SELECT
    TIMESTAMP_TRUNC(log_time, DAY) as day,
    UPPER(REGEXP_EXTRACT(connection_spec.server_hostname,
        r'mlab[1-4].([a-z]{3})[0-9]{2}.*')) AS metro,
    REGEXP_EXTRACT(connection_spec.server_hostname,
        r'mlab[1-4].([a-z]{3}[0-9]{2}).*') AS site,
    REGEXP_EXTRACT(connection_spec.server_hostname,
        r'(mlab[1-4].[a-z]{3}[0-9]{2}).*') AS hostname,
    CASE
      WHEN test_id IN(SELECT test_id FROM ndt_test_ids_with_discards) THEN
      ELSE 'zero'
    END as discards

  FROM
    `measurement-lab.release.ndt_all`

  WHERE
        log_time BETWEEN TIMESTAMP("2016-06-01") AND TIMESTAMP("2018-08-01
    AND connection_spec.data_direction = 1
    AND (connection_spec.server_hostname =
            "mlab1."""+site+""".measurement-lab.org"
         OR connection_spec.server_hostname =
            "ndt.iupui.mlab1."""+site+""".measurement-lab.org")
    AND (web100_log_entry.snap.SndLimTimeRwin +
         web100_log_entry.snap.SndLimTimeCwnd +
         web100_log_entry.snap.SndLimTimeSnd) >= 9000000
```

```
            AND (web100_log_entry.snap.SndLimTimeRwin +
                 web100_log_entry.snap.SndLimTimeCwnd +
                 web100_log_entry.snap.SndLimTimeSnd) < 600000000
            AND web100_log_entry.snap.HCThruOctetsAcked >= 1000000
          )
        GROUP BY
          day, metro, site, hostname, discards
        """


        df_test_counts = pd.concat([
            run_query(query("dfw01")),
            run_query(query("dfw02")),
            run_query(query("dfw03")),
            run_query(query("dfw04")),
            run_query(query("dfw05")),
            run_query(query("dfw06")),
        ])
```

```
running query dfw01 Fri Sep  7 12:06:27 2018
running query dfw02 Fri Sep  7 12:07:04 2018
running query dfw03 Fri Sep  7 12:11:29 2018
running query dfw04 Fri Sep  7 12:13:41 2018
running query dfw05 Fri Sep  7 12:16:32 2018
running query dfw06 Fri Sep  7 12:19:54 2018
```

```
In [15]: _ = plot_scatter(
             df_test_counts, 'day', 'count',
             fig_by='metro', axes_by='site', group_by='discards',
             suptitle='NDT Test Counts (with or without discards)',
             label='{group}',
             title='{axis}',
             axes=(3, 2), figsize=(12, 10),
             ylim=(-200, 30000),
             xlim=(pd.to_datetime("2016-05-31"), pd.to_datetime("2018-08-01")),
             fx=lambda l: [pd.to_datetime(t) for t in l])
```

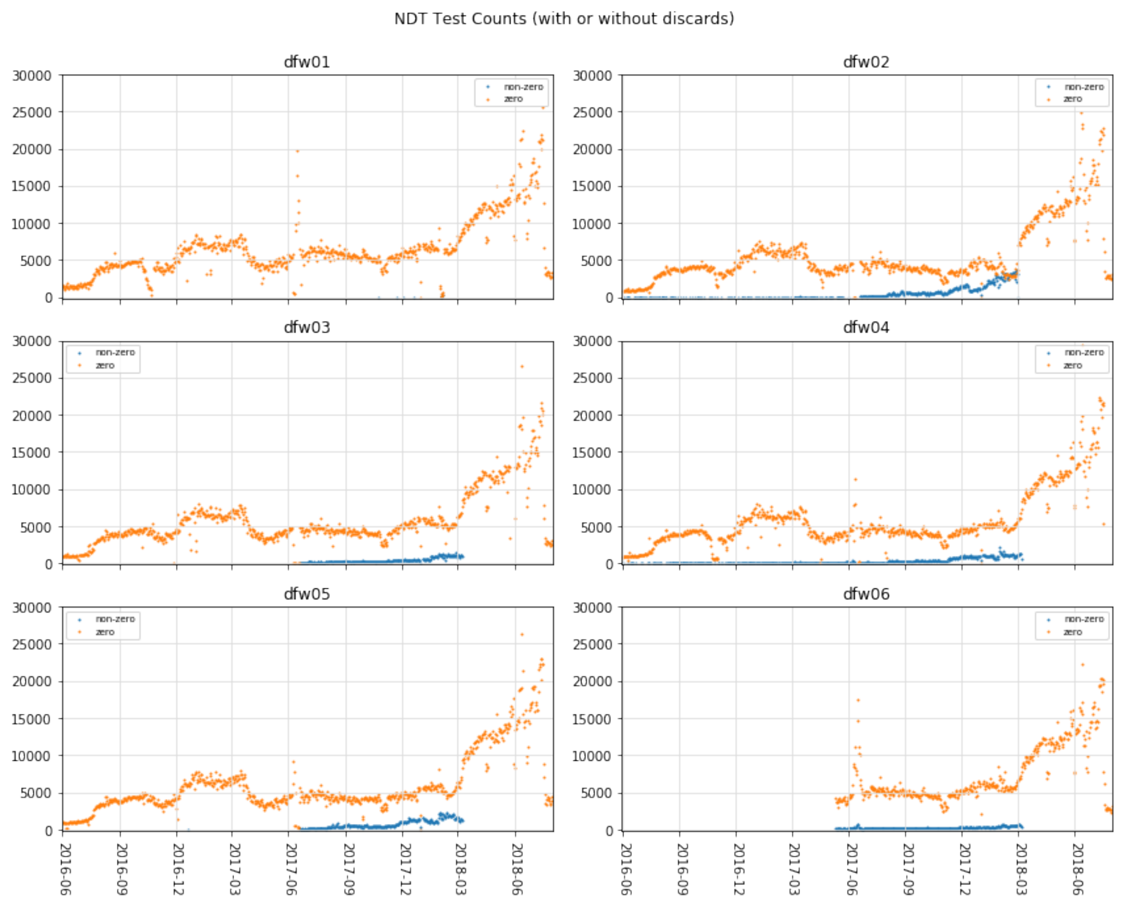


Figure 7: NDT Test Counts. Counts are separated into those with discards (any non-zero amount) and those without discards (strictly zero). The worst site globally was dfw02 where tests run with discards about half the time. All other sites see significantly less.

12 Identifying Discard Events During Tests

M-Lab switches have separate buffers for inbound and outbound traffic. We have observed no discards from inbound traffic. This means that only "download" tests may be affected.

The "NDT Test Counts" query above identifies all NDT test_ids with nonzero discards for the given site name. Adjust the dates or machine names to meet your needs.

13 Alternatives Considered

Before deploying the Ethernet flow-control configuration changes we considered and rejected several alternative strategies.

13.1 No Changes

There was anecdotal evidence that a switch discard might increase performance of high throughput clients without congestion signals from other sources in the network. As well, this provides a data set to investigate the question: is download performance impacted by switch discards. Ultimately, however, we believe that the M-Lab platform as a measurement instrument should minimize loss.

13.2 Hardware

Some NICs support multiple performance modes depending on the link layer or software configuration. In our case, the Mellanox ConnectX-3 NICs are single-mode, supporting only 10Gbps operation. So, configuring them to run at 1Gbps natively was not an option.

13.3 Linux Queuing Disciplines

Linux Queuing Disciplines (a.k.a. “qdisc”) is a software based throttle that still resulted in discards. However, because these discards were deep in the Linux kernel, we had no way to monitor them. So, this would be worse than doing nothing because “doing nothing” would still allow us to monitor the switch discards in the DISCO data set.

13.4 Data Plane Development Kit (DPDK)

The 2.6.32 kernel is incompatible with supported versions of the DPDK.

14 References

http://www.dell.com/downloads/global/products/pwcnt/en/Flow-Control-and-Network-performance-with-PowerConnect.pdf