Service Stability

A Data Analytics Approach

A Technical Paper prepared for SCTE by

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1. Introduction

Technologies such as wearables, smart homes, smart cities, and smart industries are changing customer expectations for internet services. These new technologies prioritize consistency and responsiveness over sheer volume. Customers expect their smart devices to be responsive and always on. Customers want their wearables and smart home devices such as thermostats, windows, doors, smoke & fire detectors, and security systems to respond to them in near real time. Similarly, smart city and smart industries also have business requirements for low latency and internet service consistency. Customers and businesses are less tolerant of issues regarding network connectivity and latency variability as the demand for "connectedness" is ever increasing amongst internet users and machines.

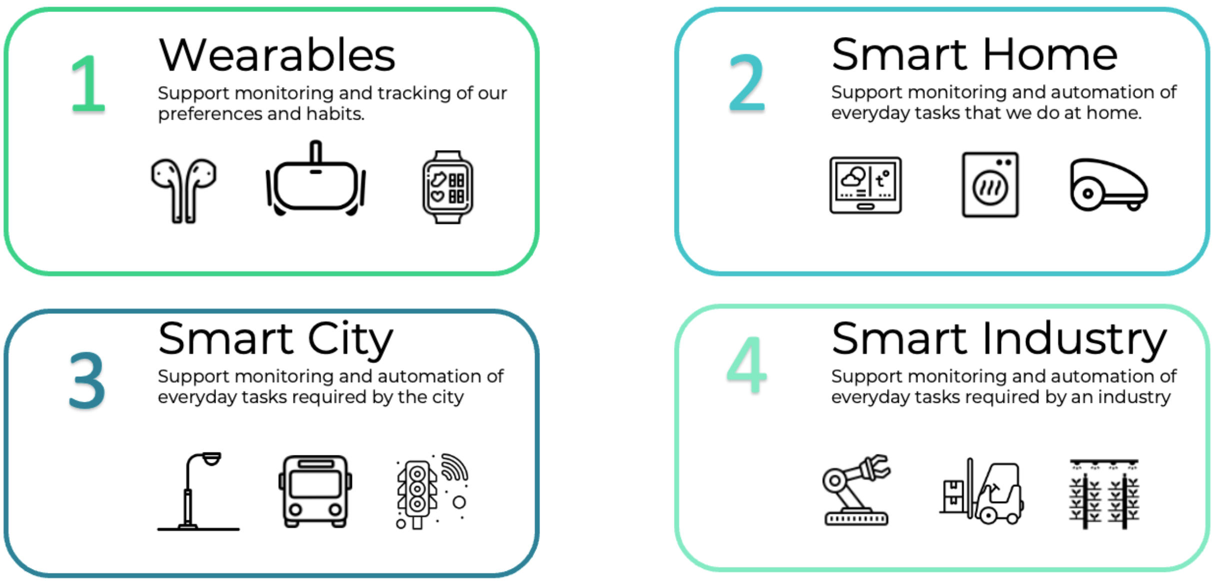

Figure 1 - Future of Connectivity

Operators are developing new methods to better understand their customers' service experiences. Operators will need to measure variability of service in addition to threshold performance.

Traditional radio frequency (RF) diagnostic tools measure current and historical values based on manufacturer thresholds and are effective at fault detection. This means assessing if a CM has exceeded a performance threshold that may cause performance degradation. We need a different method for determining the stability of service or degree of variation in service. The lower the variability means the more reliable the service. High variability would indicate that additional measures are required to stabilize the service.

Statistical Process Control (SPC) is a cornerstone of heavily adopted process improvement methodologies such as Six Sigma. SPC can provide operators with the tools to measure and monitor service stability, which can result in improved service quality and reliability to meet the needs of advancing technologies.

2. Statistical Process Control

SPC is a statistics methodology for measuring and monitoring the variability of a desired process and can be implemented as a tool. SPC can provide us with insights about variability based on changes of averages, upper control limits, and lower control limits calculated using conventional statistics methodology. Control charts in SPC are an effective way to visually communicate variability in a concise and easily understandable graph.

In the 1920s, American physicist, engineer, and statistician Walter A. Shewhart developed the control chart used in statistical process control. The application of his detection methodology at Bell allowed engineers to observe and measure the stability of their system and thereby improve quality and reliability of Bell's transmission systems.

Today Shewhart's control charts are still in use in process improvement methodologies such as Six Sigma. In Six Sigma control charts are used to determine quality characteristics.

The primary rule or Shewhart's rule identifies assignable cause whenever a single point falls outside the three-sigma limits. Shewhart—and later Lloyd S. Nelson and Western Electric—developed additional rules that can be used to further increase detection sensitivity to variance at the cost of a higher false positive rate.

Using SPC we can improve process quality and reliability by measuring and monitoring the effectiveness of applied controls to our processes.

2.1. Control Charts

Control charts are graphs that can help us visualize the state of control for a given process. There are various types of control charts used to depict different aspects of SPC.

The center line denoted as $\overline{x}$ is the average of individual values of the samples collected and is calculated using:

$$\overline{x} = \frac{\sum_{i=1}^{n} x_i}{n-1}$$

$$x_i = Each\ of\ the\ values\ of\ the\ data$$

$$n = The\ number\ of\ data\ points$$

The upper control limit (UCL) or 3σ and the lower control limit (LCL) or -3σ are calculated using the standard deviation of a sample formula:

$$\sigma\ (sample\ rather\ than\ population) = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

$$n = The\ number\ of\ data\ points\ in\ sample$$

$x_i = Each\ of\ the\ values\ of\ the\ data$

$$\bar{x} = The\ mean\ of\ x_i$$

Common-cause variation (or noise) is the natural or expected variation in a process. Generally, noise is found between the upper and lower control limits. There are exceptions where distinct patterns within the upper and lower control limits have been identified by Shewhart, Nelson, and Western Electric as special cause variation; however, those rules will not be covered in this paper.

Special-cause variation (or signal) is the unexpected variation that results from unusual occurrences. Generally, signal is found above the UCL or below the LCL; however, there are exceptions where this would not be the case.

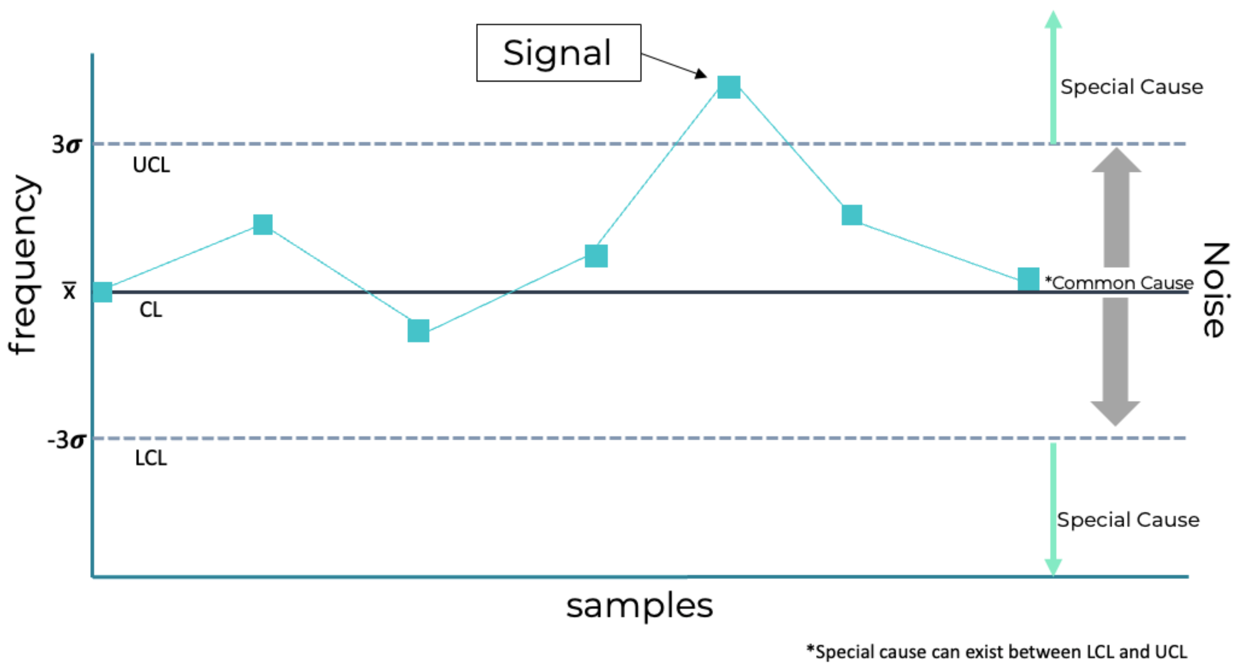

Figure 2 - Anatomy of a Control Chart

3. CM RF vs Service Metrics

CM RF metrics describe RF signal quality and performance. These metrics can be collected from CMs via simple network management protocol (SNMP). Regular collection of RF metric data has a negligible effect on the service performance of a cable modem. Hence, it is possible to collect this data at a higher frequency than internet service metrics which results in a higher resolution analysis of RF signal quality. It is important to understand that RF signal quality is strongly correlated with internet service quality but cannot be used directly quantify the internet service experience.

Consider the following:

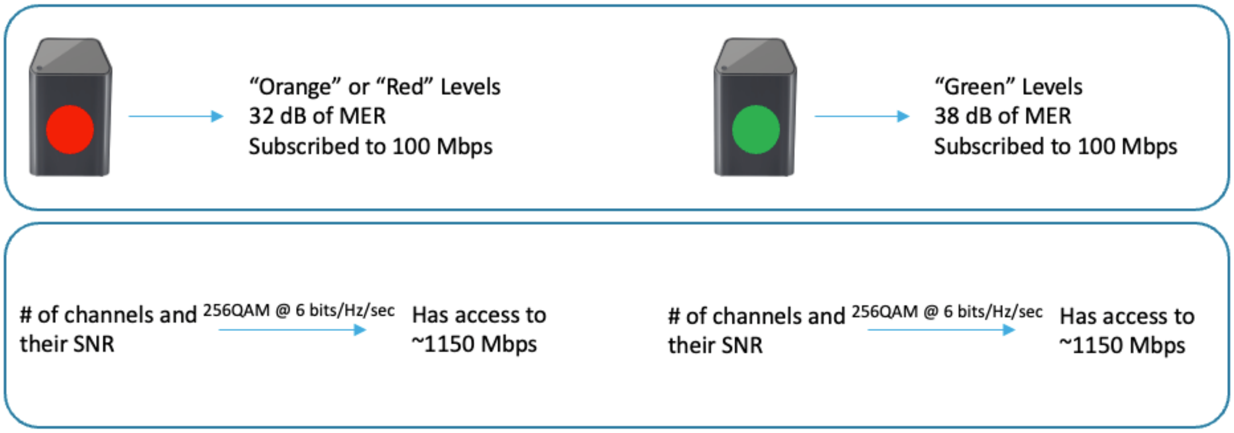

Figure 3 – CM RF Signal Quality vs Internet Speed

When CM RF metrics degrade, they do not correlate to an equivalent degradation of internet service metrics. For example, the CM RF signal to noise ratio (SNR) degrading a few dB does not equate to a consistent drop in upload or download speeds. There are thresholds, such that once exceeded, there is an observable impact to internet service metrics as seen below in Figure 4 and Figure 5.

Internet service metrics such as upload speed, download speed, latency, and jitter which are a true representation of the internet service experience is more challenging to collect. The collection of this data can be customer impacting during the collection process and thus, would be scheduled less often and during non-peak hours which may not be representative of internet service under stress.

The scatter plots below depict a correlation between SNR and uncorrectable codewords (denoted as Error %). We observe an increase in the presence of uncorrectable codewords as the SNR degrades below ~32dB for the downstream orthogonal frequency-division multiplexing (OFDM) channel in Figure 4, and below ~35dB for downstream single carrier quadrature amplitude modulation (SC-QAM) in Figure 5.

The figures below depict variability in the correlation strength of data points, which suggests that individual CMs may be impacted differently by degraded SNRs, leading to varying amounts of Error%.

SPC would allow an operator to measure each CM against itself to determine variance of a given metric. CMs that have a high degree of variability in RF or internet service metrics would require further diagnostics.

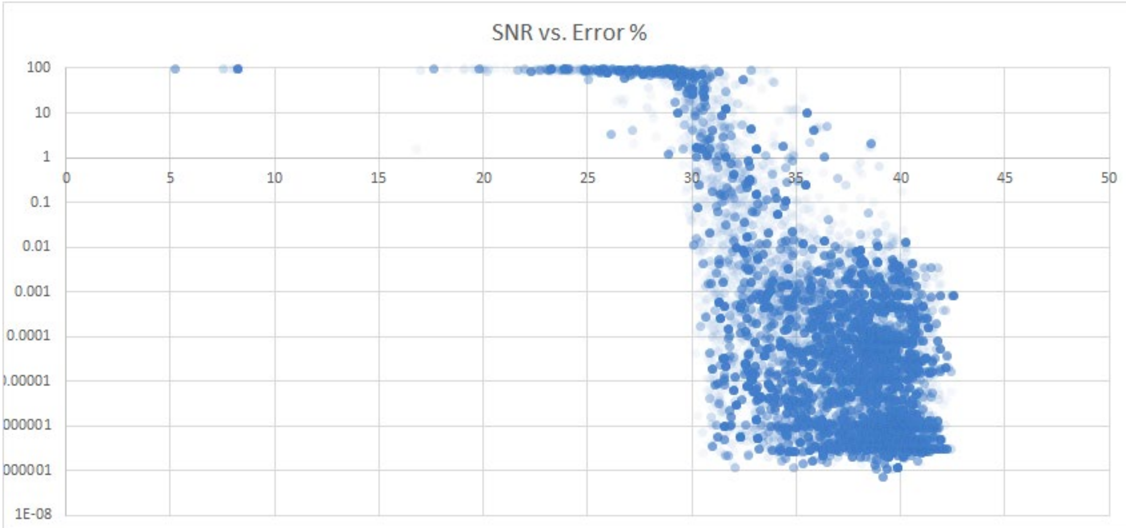

Figure 4 - CM DS OFDM Channel SNR vs Error Percentage

Figure 5 depicts more variability in correlation strength between SNR and Error %, hence the addition of a regression line (in red) to better represent this relationship.

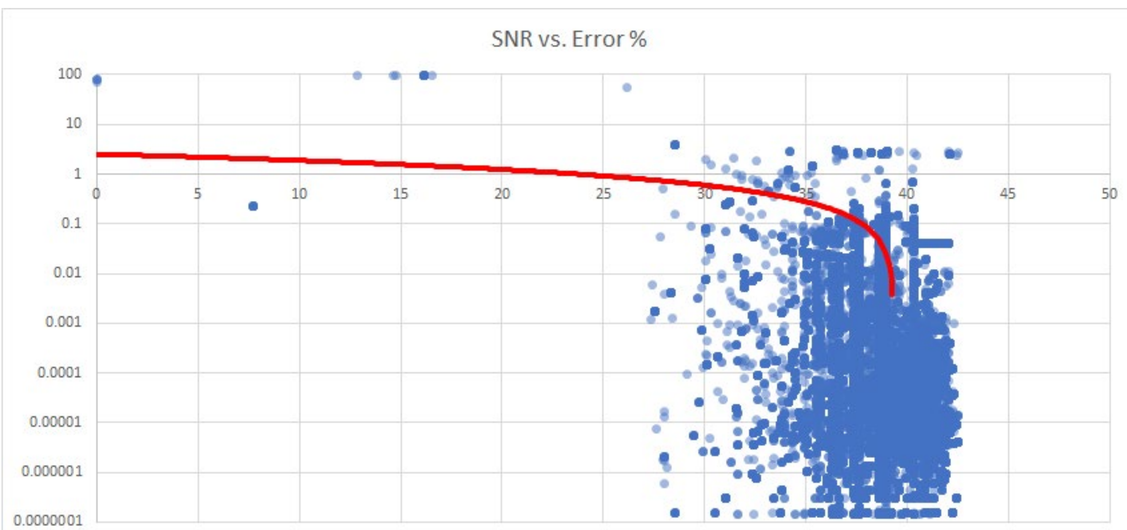

Figure 5 - CM DS SC-QAM SNR vs Error percentage

4. CM RF Control Charts

CM RF metrics such as modem flaps, SNR, receive power level, and % of errors are captured in the control charts below. CM RF metrics are sampled at regular intervals, except for codewords, which are calculated as a percentage from a cumulative counter residing on the modem. An increase or decrease in variation in one metric does not reflect consistently in other metrics.

CM flap or CM de-registration occurs when a CM loses connection to the cable modem termination system (CMTS). This metric can also be considered an internet service metric as it is an important indicator of the customer service experience. An increase in the average count or range between the UCL and LCL of this metric would likely impact the customer experience and should be prioritized over other RF metrics.

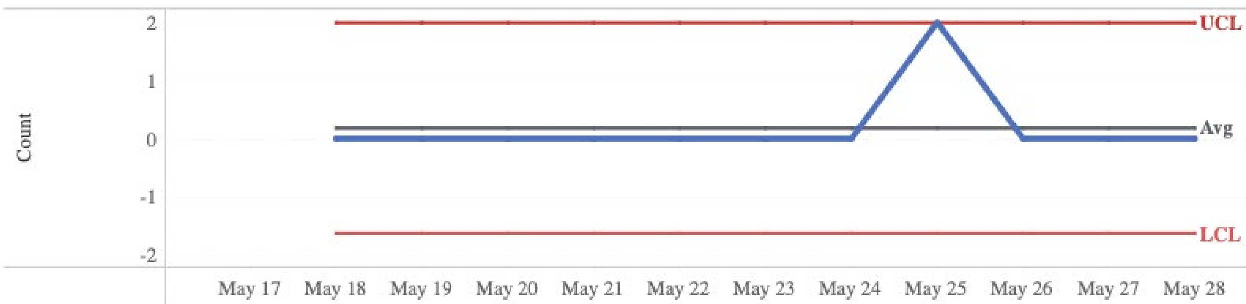

Figure 6 - Control Chart of CM Flap

SNR, transmit, and receive power levels can fluctuate based on many external variables. The tolerance of these metrics can be vendor, model, and device specific. Variability in these metrics below or above the manufacturer specification can result in intermittent service but would be a lower priority than CM flaps and error %.

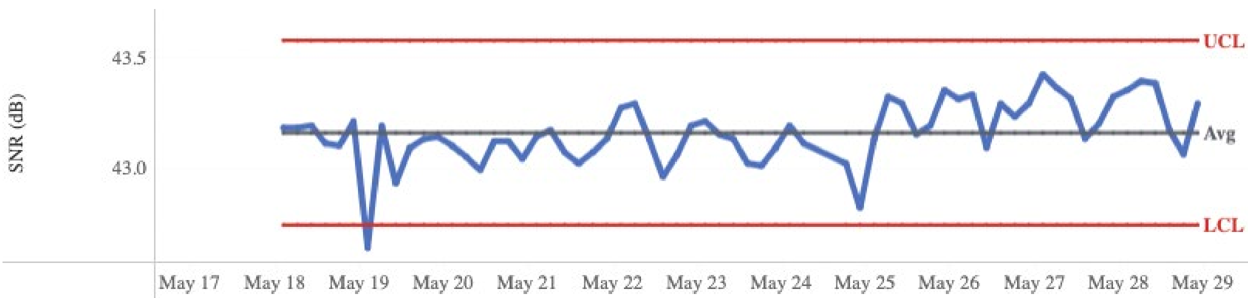

Figure 7 - Control Chart of CM DS OFDM Channel SNR

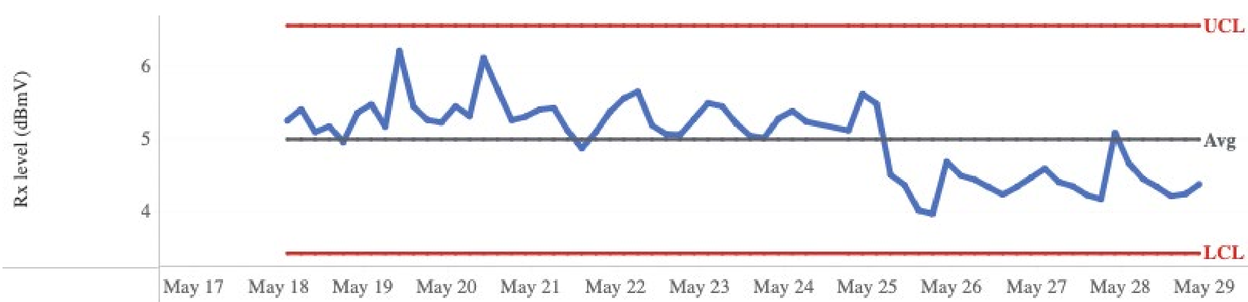

Figure 8 - Control Chart of CM DS OFDM Channel Receive Level

Uncorrectable error % is an important RF metric that can impact internet service experience. Even a small increase in this metric can be impacting to customers (between 0 and 1% of total codewords).

Figure 9 - Control Chart of CM DS OFDM Channel Error%

CM RF control charts depict variation of RF signal quality over time. The upper and lower control limits help us to quickly visualize the range of variation and if metric values can be classified as special cause. Many operators may find it difficult to determine if the overall effect of a device firmware change was positive or negative for a given device. Using this methodology, an operator can quickly visualize and quantify if a network change has improved or degraded service stability for devices in its network.

We would expect that a good change will narrow the range of variation in RF metrics meaning the UCL and LCL will be closer together and align the center line closer to the mean of the manufacturer specifications. Conversely a bad change would increase variability and move the center line closer to the threshold limits.

In either case, the control charts will continue to be effective as the UCL and LCL are calculated using the third standard deviation of the metrics. Hence, as the variation decreases then the sensitivity will increase and vice versa.

5. Internet Service Control Charts

The following control charts depict internet service stability using data from upstream speed test, downstream speed test, jitter, and latency. CM RF metrics are normally sampled at regular intervals on CMs in the field. However, at the time these control charts were created, CM RF metrics were not being collected from CM devices at regular intervals and as such we are unable to correlate insights between the CM RF and CM internet service metrics directly.

Upstream (US) and downstream (DS) speed tests have a direct relationship to the customer service experience. US and DS speed tests are affected by many external variables and tend to vary over time. A control chart is an ideal method for evaluating US and DS speed test performance over time. The control chart centerline should meet or exceed the advertised speed. The UCL and LCL should not exceed the degree of variation that the internet service provider (ISP) has specified and would allow ISP to quantify and proactively address service experience issues before a customer may notice.

Figure 10 and Figure 11 depict a control chart for a 15 Mbps US service package. The centerline for Figure 10 is at 16 Mbps while the centerline for Figure 11 is at 14 Mbps. Since Figure 11 has achieve an US speed tier (16 Mbps) higher than the advertised US speed (15 Mbps), it is possible that this CM may not have registered as a priority for service maintenance compared to other services which may have achieved a lower speed tier. However, the UCL and LCL clearly depict a different story. The service shown in Figure 11 is clearly unstable and shows a large degree of variation which would be impacting the customer’s service experience.

Figure 10 – Control Chart of CM US Speed Test of Higher Stability Service

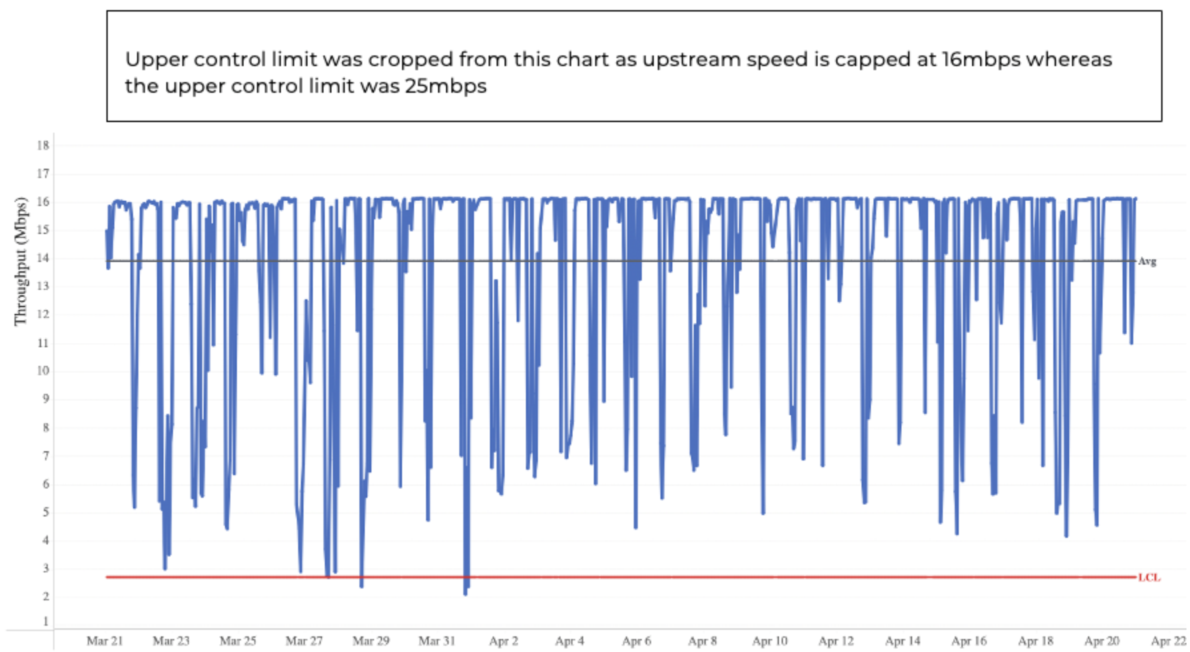

Figure 11 - Control Chart of CM US Speed Test of Lower Stability Service

The control charts shown below for DS speed tests tell a similar story to the US speed tests seen above. Both Figure 12 and Figure 13 show services that have met and exceed the advertised DS speed tier (150 Mbps) however, the amount variation seen in Figure 13 and the frequency of tests crossing the LCL is concerning.

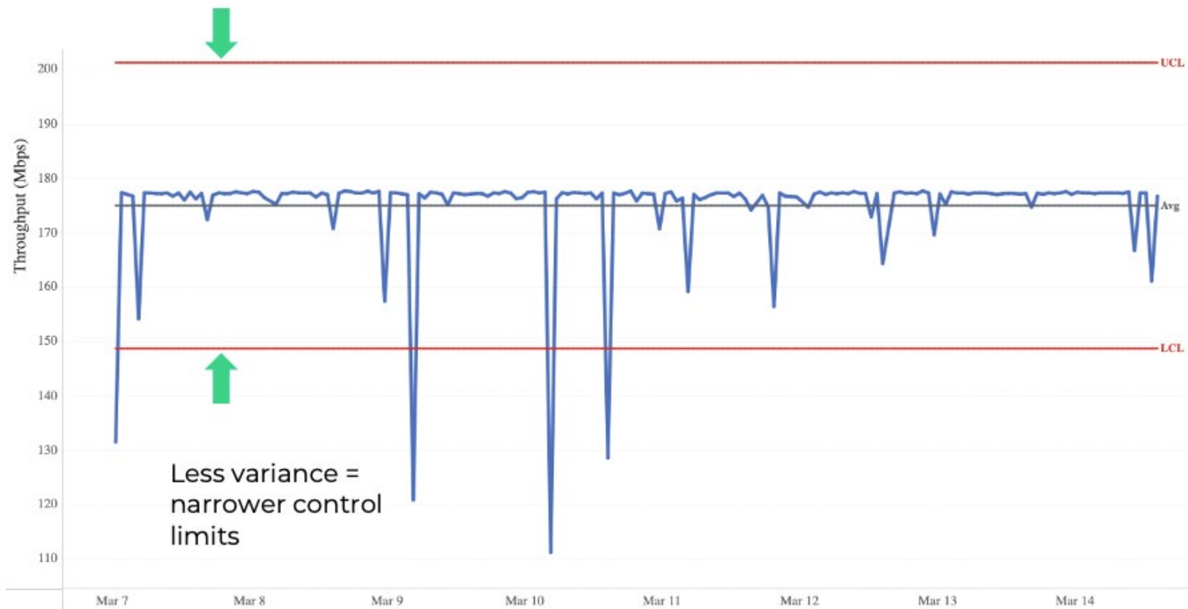

Figure 12 - Control Chart of CM DS Speed Test of Higher Stability Service

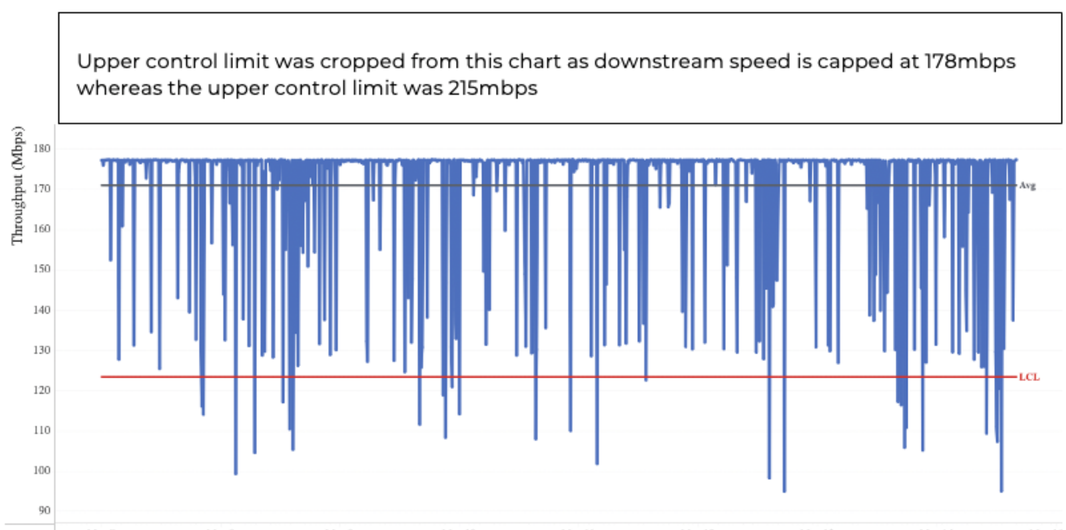

Figure 13 - Control Chart of CM DS Speed Test of Lower Stability Service

Latency and jitter are increasingly important metrics for driving positive customer experiences. The control charts below clearly depict the level of variation as well as the centerline target. Figure 14 and Figure 16 are highly stable services with a satisfactory UCL and LCL whereas Figure 15 and Figure 17 are unstable and poorly performing services.

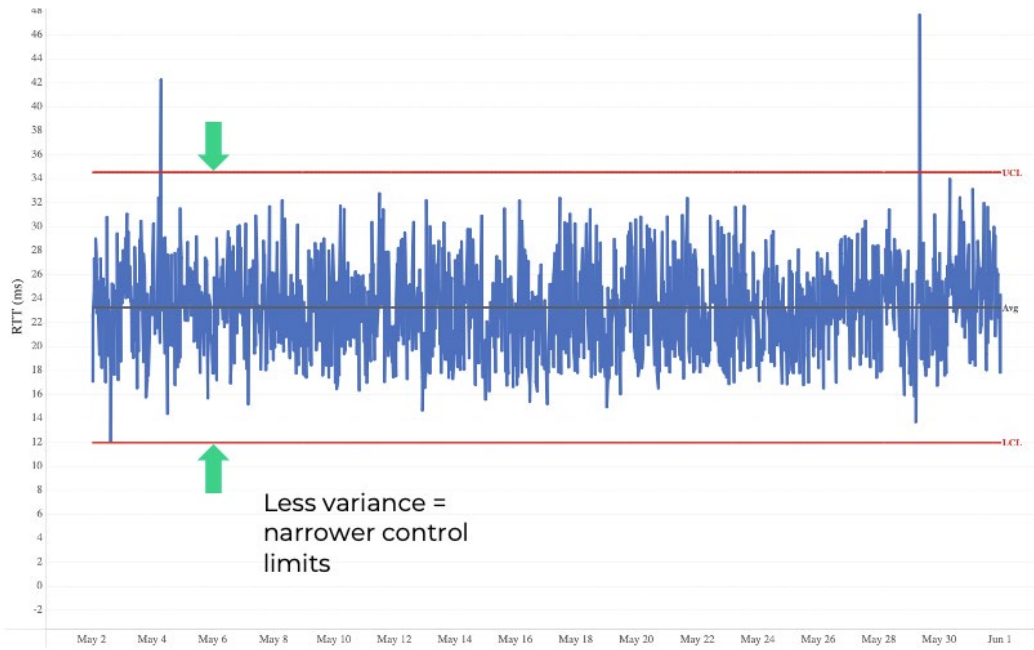

Figure 14 - Control Chart of CM DS Latency of Higher Stability Service

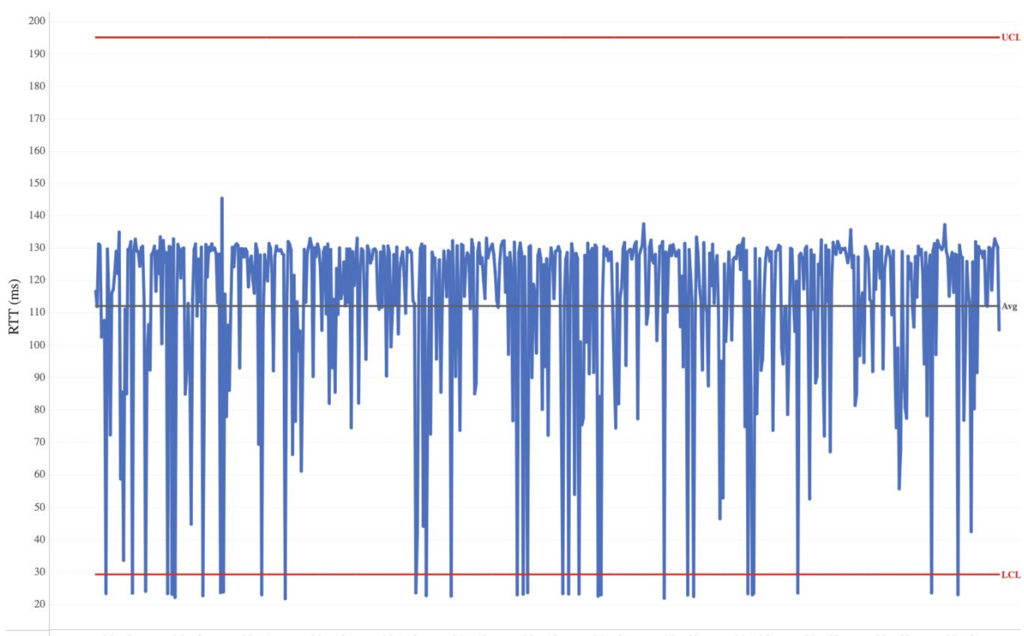

Figure 15 - Control Chart of CM DS Latency of Lower Stability Service

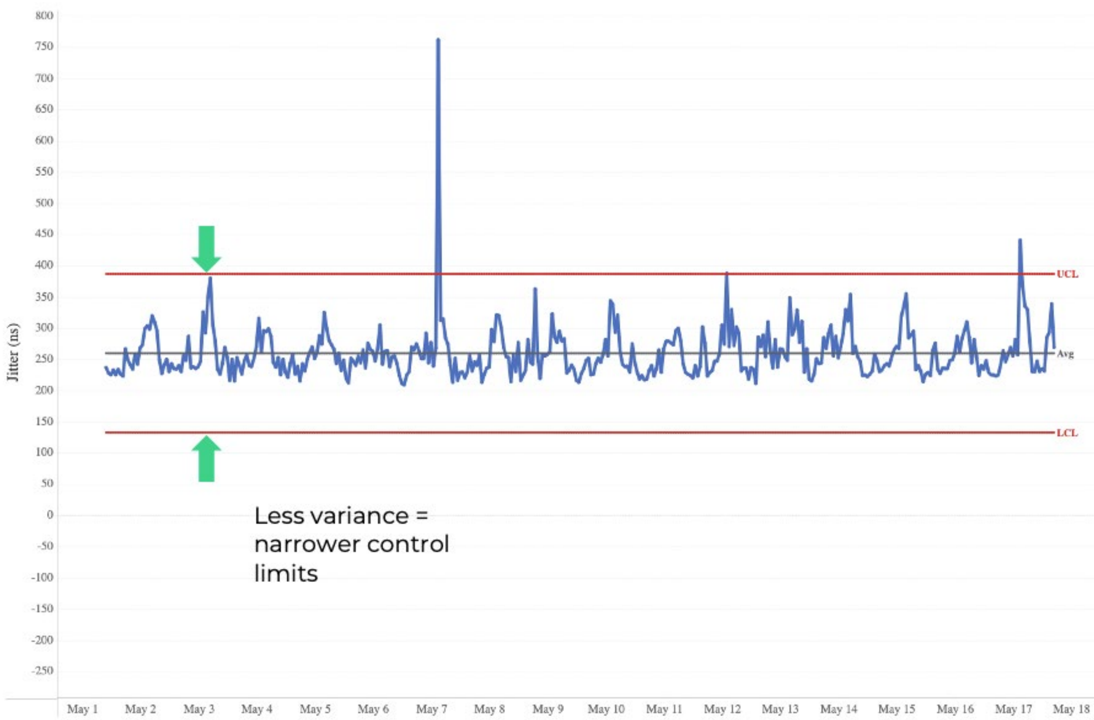

Figure 16 - Control Chart of CM DS Jitter of Higher Stability Service

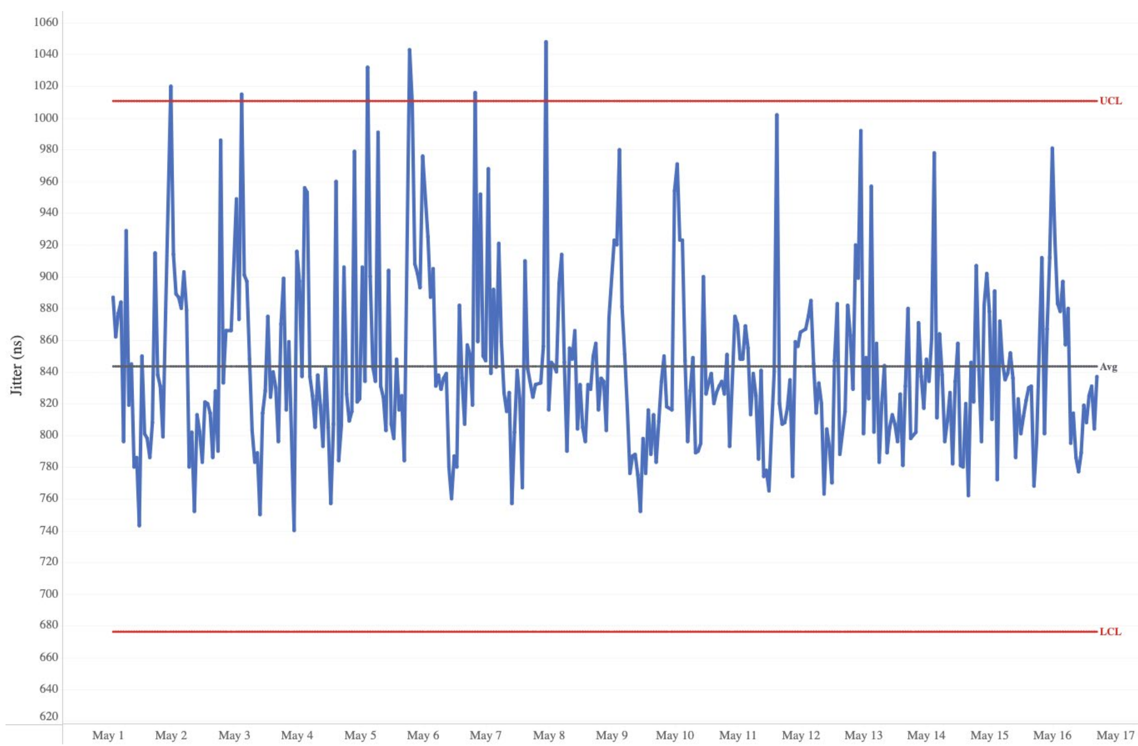

Figure 17 - Control Chart of CM DS Jitter of Lower Stability Service

Control charts provide an intuitive way of measuring variance of internet service metrics. Using control charts, we can immediately observe the mean and range of the internet service metrics delivered to a customer. Improving internet service metrics average and tightening CLs will lead to improved reliability and overall customer experience by minimizing bandwidth margins. More importantly, operators that leverage SPC will be able to deliver services ready for the next generation of "always on" users and compete to win and retain customers.

6. Operationalization

The effort to operationalize these techniques at Shaw are in progress. The control charts shown in the previous sections are rendered from historical samples of Shaw production CM data and visualized using Tableau. The post processing engine is written in python and the logic can be incorporated into current RF and service metric performance indicators. Control charts can be rendered on the current data to evaluate the service stability of Shaw's internet services using current data.

An effort is in place to develop the ability to initiate and collect CM US and DS speed test data on a regular scheduled interval so that we may directly measure customer experience using a more statistically relevant data set. Shaw also believes that increasing the data acquisition interval of CM RF data will improve the visibility of stability fluctuations in RF metrics further helping to improve CM reliability and performance.

These insights will drive new processes to improve service stability.

7. Future Work

The results from the operationalization of these techniques will be covered in a future paper. Prioritization and resolution of service issues will differ when we start to leverage SPC as seen in section 5.

8. Conclusion

Advancements in technologies like wearables, smart home, smart city, and smart industry are increasing the extent to which customers rely on connectivity for their livelihoods and well-being. It is expected that these customers will prioritize service quality and reliability over upload and download speeds, and as such, operators will be differentiated by their abilities to provide quality connectivity experiences. Detecting and controlling special-cause variances in networks and network devices are important steps in improving service stability and reliability.

Figure 18 - Speed to Service Stability Readiness

Control charts are well suited to observing and monitoring service stability, and control charts capturing internet service metrics are particularly interesting. While RF control charts can be useful in identifying problem areas for CMs, Internet service capabilities such as upload speed, download speed, latency, jitter, and bandwidth determine the competitiveness of the product offered. As seen in Section 5 of this paper, each of these internet service metrics can be captured within a control chart to be measured and validated to determine quality of service.

Operators that choose to leverage SPC will gain access to immediate eye-opening insights on how to truly measure and validate the quality of the services provided to their customers, thereby improving the overall customer experience, and preparing their networks for technologies of the future.

Abbreviations

CL	control limit
CM	cable modem
CPE	customer premises equipment
DS	downstream
LCL	lower control limit
OFDM	orthogonal frequency-division multiplexing
RF	radio frequency
SC-QAM	single carrier quadrature amplitude modulation
SNMP	simple network management protocol
SNR	signal to noise
SPC	statistical process control
UCL	upper control limit
US	upstream

Bibliography & References

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