# Holistic Method for Evaluating Customer's Quality of Experience

*by*

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## 1.0 - Introduction

Customer Quality of Experience (QoE) is dependent on a multitude of factors. It is tightly coupled with customer satisfaction and is linked to the success of the telecommunication service provider in providing a service.

These days, with telecommunication service providers having to respond to customer's different tastes and priorities, and having to support a multitude of applications and services with very different service requirements, it is difficult to follow or come up with a simple formula that provides an answer for service providers to optimize customer service experience. Instead due to its many interdependencies, it is important to develop a framework that identifies and correlates all the elements that play a role in the Quality of Experience of a customer. These elements or factors may impact Quality of Experience differently. This paper describes the elements impact on Quality of Experience and the relationships between these different elements. Through such a process and an extensive amount of quantification of what customers' value, a service provider will be able to establish metrics to measure quality of experience.

Service QoE is dependent on many aspects. These different aspects should be weigh in order to determine a QoE Metric. One key differentiation occurs between individual QoE versus service wide QoE.

## 2.0 Service Loss or Service Downtime

First if there is an impediment on the service being provided even for a very short period of time, even if a customer has not complained or realized that the service was interrupted it's interruption duration has to be measured by the operator. In addition to measuring the duration of service loss, the number of customers impacted by that loss of service has to be quantified. Weighting can be added depending whether this is a service that is critical to customers or not. This service loss could have occurred because there has been a failure in the infrastructure that was impacted by weather or it could have been a software glitch on a server that provides the service. The duration in time of loss of service is called service downtime and is directly related to service availability by the following expression.

$$ServiceAvailability = \frac{ServiceUptime}{ServiceUptime + ServiceDowntime} \quad (1)$$

This service availability expression assumes that the entire population share the same amount of uptime and downtime. In a diverse network environment, only fractions of the total population share the same uptime and downtime. In fact, we can express this in a more granular fashion describing the fractions of the service subscriber population that share the same uptime, the same degraded uptime and the same downtime.

Let the total service subscriber population be $P_{TS}$ and let $P_{S1}$, $P_{S2}$, $P_{S3}$, …$P_{SN}$ be the N subscriber groups of the service subscriber population such that the subscribers within a group share the same performance metrics and degraded uptime, uptime and downtime.

$$P_{TS} = \sum_{i=1}^{N} P_S(i) \quad (2)$$

In addition, a proposed effective service availability for a population of $P_{TS}$ subscribers of a particular service based on the availability factor during degraded periods is given by the expression

$$EffServAvail_j = \sum_{i=1}^{N} \frac{P_{S(i)}}{P_{TS}} \cdot \frac{DegradedUptime(i,j) \cdot SAF(i,j) + Uptime(i,j)}{Measurement\_Period} \quad (3)$$

where i is the index of a specific subscriber group that shares the same performance metrics and the same degraded uptime, uptime and downtime characteristics for service j. The measurement period is equal to the sum of the degraded uptime, uptime and downtime. The availability factor (SAF(i)) is defined in the following sections as a function of a service degradation factor.

## *3.0 Sub-Optimal Service Characterized using Service Degradation Factor (SDF)*

There may be cases where the service is not lost, but it is provided in a sub-optimal fashion. In this case it is useful to assess the seriousness of the degradation and define a service degradation factor. In general, each service will have a different degradation factor for the same problem type and level. In this method, complete degradation means the service is not worth using or the service is lost for all practical purposes. In other words you are experiencing an effective service downtime. If you have the same underlying problem for 2 different types of services you will reach complete degradation at different stages. A packet loss scenario could be caused by starvation of resources, by noise or by the inability of configuration scenarios to handle impairments just to mention a few. For example for the same packet loss you will have a different service degradation level for web-browsing than for HD video service. Packet loss may be a metric that is important for certain services but not very relevant for other services. Customers will be less tolerant of video artifacts than for retransmitted packets in a web-browsing session. Latency may be important for some services like gaming and some business services but may not be as important for other. A sustainable high bit rates may be crucial to services like downloading but not for services like gaming or VoIP. A weighting function could be assigned for each of the performance metrics.

### 3.1 - Simple SDF Incorporating Performance Metrics of Applications and Services

A simple scheme that incorporates the impact of the different performance metrics used to evaluate applications and services can be used. Table 1 shows a list of services along with a set of metrics that can be used to evaluate service performance in order to come up with a service degradation indicator. The relevant metrics for a service (highlighted in red) are ranked based on their impact to the performance of the service. The example here shows high impact (H), medium (M) and low or negligible impact, which are left blank in Table 1. Each service would have specific thresholds indicating the degree of impact the different services have suffered. These thresholds determine whether the service performance for this metric is excellent (E), acceptable (A) or unacceptable (UA).

A weighting scheme could be used to determine whether the service is degraded to the point of being only partially useful or not useful at all. For example in video conferencing the relevant metrics are latency, jitter and sustainable rate (all ranked high). The suggested weights for high and medium are 1 and 0.5 respectively and the performance metrics values are 1.25 for excellent, 1 for acceptable and 0 for unacceptable.

Then a service degradation metric of less than 1 for the service according to the following formula is deemed degraded.

$$\mathrm{SDF}_{\mathrm{i,j}} = \frac{\sum_{k=1}^{K} \mathrm{Perf\_Metric\_Relevancy}_{\mathrm{k}} \cdot \mathrm{Perf\_Metric\_Value}_{\mathrm{k}} \mathrm{forSubs\_Group}_{\mathrm{i}}}{\sum_{k=1}^{K} \mathrm{Perf\_Metric\_Relevancy}_{\mathrm{k}}} \quad (4)$$

where the degradation factor for the $j^{th}$ service for a particular service group i is $SDF_{i,j}$ and K is the total number of service factors relevant for the $j^{th}$ service.

If $SDF_{i,j} \geq 1$ then $service_j$ is deemed available by 100% of the subscriber population in subscriber group i
If $0.5 < SDF_{i,j} < 1$ then $service_j$ is deemed partially available by the subscriber population in subscriber group i

If $SDF_{i,j} \leq 0.5$ then $service_j$ is not deemed not available by the subscriber population in subscriber group i

To obtain the average service degradation factor across all the subscriber groups the different service degradation factors for the individual subscriber group populations has to be added. The following equation provides the average service degradation factor for $service_j$.

$$\mathrm{SDF_j} = \frac{\sum_{i=1}^{N} Ps(i) \sum_{k=1}^{K} \mathrm{Perf\_Metric\_Relevancy_k} \cdot \mathrm{Perf\_Metric\_Value_k \, for \, Subs\_Group_i}}{P_{TS} \cdot \sum_{k=1}^{K} \mathrm{Perf\_Metric\_Relevancy_k}} \qquad (5)$$

**Table 1 – Service Performance Metrics**

| | | General Metrics | | | | | | Service Specific Metrics | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Instant Availability | Packet Loss | Latency | Jitter | Peak Rate | Sustainable Rate | Controllability | Avail. Content | Switching Speed | Capacity | Feature Richness | Drop Call % | Competence |
| Services & Applications | Channel Surfing | | | H | | | | | | H | | | | |
| | Data BE | | | | | H | | | | | | | | |
| | Video Conferencing | | | H | H | | H | | | | | | | |
| | VoD | | H | | | | H | | H | | | | | |
| | Music Services | | H | | | | H | | H | | | | | |
| | Gaming Client | | H | H | | | | | | | | | | |
| | Gaming Server | | H | H | | | | | | | | | | |
| | SuperDownloading | | | | | H | H | | | | | | | |
| | SuperUploading | | | | | H | H | | | | | | | |
| | Storage | | | | | | | | | | H | | | |
| | Tele-Medicine | H | H | H | | H | H | | | | H | | | |
| | Tele-Education | | H | H | | | H | | | | | | | |
| | Tele-Commuting | | | | | | H | | | | | | | |
| | Tele-Library | | | | | H | | | H | | H | | | |
| | Customer Support | | | | | | | | | | | | | H |
| | Home Security | H | | | | | | | | | | H | | |
| | Home Remote Ctrl | H | | | | | | H | | | | H | | |
| | Telephony | | | H | H | | | | | | | H | H | |
| | Video SD | | H | | | | H | | H | | | | | |
| | Video HD | | H | | | | H | | H | | | | | |
| | Video Low Res | | H | | | | H | | H | | | | | |
| | Business Services | H | H | H | H | H | H | | | | | | | |

## 3.2 Adding Effect of Rendering Devices to SDF of Applications & Services through Rendering Device Factor

Sometimes the same service will have a different perception of quality of experience based on what rendering device is being used. The same video service is provided to users that are experiencing it on different rendering devices, it could have a different perception on quality of experience. Customers could be more forgiving for video artifacts in their PDA than in their large screen TV or they will be more forgiving on the quality of voice over a cellular phone than over a landline phone. A factor (Rendering Device Factor) that combines variation in service expectation depending on the rendering device for the different applications is proposed here. This Rendering Device Factor which is proposed here to have high (H), medium (M) and low (L) possible granularities, modifies the service degradation factor.

**Table 2 –Rendering Device Factor for Application and Services**

| | Rendering Devices | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Services & Applications | Cell Phone | Landline Phone | TV | PC | PDA | Tablet | Stereo | Game Console w Mon |
| Channel Surfing | L | | M | H | M | H | | M |
| Data BE | L | | M | H | M | H | | M |
| Video Conferencing | | | | | | | | |
| VoD | | | H | M | | M | | |
| Music Services | | | H | H | H | | H | H |
| Gaming Client | L | | | M | M | M | | H |
| Gaming Server | L | | | M | M | M | | H |
| SuperDownloading | | | | H | | M | | |
| SuperUploading | | | | H | | M | | |
| Storage | | | | H | | | | |
| Tele-Medicine | | | | H | | | | |
| Tele-Education | | | M | H | | H | | |
| Tele-Commuting | | | | H | | | | |
| Tele-Library | | | | | | H | | |
| Customer Support | | | | | | | | |
| Home Security | | | | H | | H | | |
| Home Remote Ctrl | | | | H | | H | | |
| Telephony | | H | | | | | | |
| Video SD | | | H | M | | M | | H |
| Video HD | | | H | M | | M | | H |
| Video Low Res | | | H | H | M | H | | H |
| Business Services | | | | H | | | | |

Table 2 shows the rendering device factor (RDF) for the different applications or services when experienced through different rendering devices. The suggested values for high medium and low factors are H=1, M=1.2, L=1.4 and the modified service degradation factor that includes the rendering device impact is given by the following expression

$$\mathrm{SDF}_{\mathrm{i,j,d}} = \frac{RDF_{j,d} \cdot \sum_{k=1}^{K} \mathrm{Perf\_Metric\_Relevancy}_{\mathrm{k}} \cdot \mathrm{Perf\_Metric\_Value}_{\mathrm{k}} \mathrm{forSubs\_Group}_{\mathrm{i}}}{\sum_{k=1}^{K} \mathrm{Perf\_Metric\_Relevancy}_{\mathrm{k}}} \quad (6)$$

where the degradation factor for users within a particular subscriber group i experiencing service j through a rendering device d is $SDF_{i,j,d}$. K is the total number of service factors relevant for the $j^{th}$ service.

To obtain the average service degradation factor across all rendering devices, the different service degradation factors for the individual rendering devices within a subscriber group have to be added. The following equation provides the average service degradation factor for $group_i$ using $service_j$.

$$\mathrm{SDF}_{i,j} = \frac{1}{Ps(i)} \sum_{d=1}^{D} Ps(i,d) \cdot RDF_{j,d} \cdot \frac{\sum_{k=1}^{K} \mathrm{Perf\_Metric\_Relevancy}_k \cdot \mathrm{Perf\_Metric\_Value}_k \mathrm{forSubs\_Group}_i}{\sum_{k=1}^{K} \mathrm{Perf\_Metric\_Relevancy}_k} \quad (7)$$

To obtain the average service degradation factor across all the subscriber groups, the different service degradation factors for the individual subscriber group populations have to be added. The following equation provides the average service degradation factor for $service_j$.

$$\mathrm{SDF}_{j} = \frac{1}{P_{TS}} \sum_{i=1}^{N} \frac{1}{Ps(i)} \sum_{d=1}^{D} Ps(i,d) \cdot RDF_{j,d} \cdot \frac{\sum_{k=1}^{K} \mathrm{Perf\_Metric\_Relevancy}_k \cdot \mathrm{Perf\_Metric\_Value}_k \mathrm{forSubs\_Group}_i}{\sum_{k=1}^{K} \mathrm{Perf\_Metric\_Relevancy}_k} \quad (8)$$

where the service degradation factor for the $i^{th}$ service is $SDF_i$ and K is the total number of performance metrics relevant for the $i^{th}$ service. A medium rendering device factor is more forgiving than a high and a low RDF is more forgiving than a medium. The rendering device factors given above are just examples. A customer perception study is required to estimate the degree of forgiveness that results from experiencing services over the different rendering devices.

## 3.3 Adding Effect of Customer Importance through Customer Type Relevance Factor

The customer type relevance factor (CTR) is defined based on the type of customer and their expectation of service quality. In this case we define the types of customers based on the number of services they subscribe to and weighted by a factor which could be proportional to the revenue they generate for each type of service. For example a business customer loosing service would be more critical than a triple play customer who itself may be more critical than a single service residential customer.

$$\mathrm{CTR_n}\ \left(\text{Number of Services, Aggregate Revenue}\right) \quad (9)$$

This CTR factor is used to modify the SDF calculated earlier resulting in the following expression

$$\mathrm{SDF_{i,n}} = \mathrm{RDF_{i,n}} * \mathrm{CTR_n} * \frac{\sum_{k=1}^{K} \text{performance metric relevancy}_k * \text{performance metric value}_k \text{ for } (\text{service}_i\, \text{cust}_n)}{\sum_{k=1}^{K} \text{performance metric relevancy}_k} \quad (10)$$

The CTR factor is less than or equal one. The higher the expectations of service the lower the resulting SDF should be. Therefore for a single basic service subscriber the CTR is equal to 1. A “potentially more demanding” customer that subscribes to many services, perhaps a business customer whose business depends on the performance of the network would have a CTR less than 1.

Since the CTR and the RDF are metric linked to individual subscribers, in order to determine the actual SDF it should be calculated or average out over the population of subscribers that share the same amount of uptime, downtime and degraded uptime.

A side benefit of the Customer Type Relevance factor is that it can also be used to determine priorities regarding what problem to solve first.

$$\text{ProblemResolutionPriority} = \sum_{n=1}^{M} \text{CustomerImpactMask}_i \cdot \mathrm{CTR_n} \quad (11)$$

where M is the total number of customers affected by problem using a particular service and $\mathrm{CTR}_n$ is the CTR for the $n_{th}$ customer affected.

## *4.0 Service Availability Factor and Service Degradation Factor Relationship*

When service degradation is so severe that a significant number of customers won’t tolerate using it, it is equivalent to a service being lost or being effectively unavailable. This is an extreme scenario but service degradation can also be used to evaluate different levels of availability.

It is important to establish a correlation between the brown out conditions that are described by the service degradation factors in Table 1 and service availability in order to quantify what the condition of the services that are provided. A relationship between loss of service and service degradation is proposed to indicate the percentage of customers that tolerate a degraded service.

The proposed service degradation factor relationship to service availability factor (SAF) is as follows;

$SDF_i \geq 1$ $i^{th}$ service is deemed available by 100% of population ($SAF_j = 1$)
$0.5 < SDF_i < 1$ $i^{th}$ service is deemed available by $[4*(SDF-0.5)^2]*100\%$ of population ($SAF_j = [4*(SDF-0.5)^2]$)
$SDF_i \leq 0.5$ $i^{th}$ service is deemed not available ($SAF_j=0$)

Other relationships to reflect service availability factors could also be used

## 5.0 Quantification of Service Performance

It is important to arrive at service performance metrics through quantifiable means that can be derived from measured parameters. Some of these metrics could include packet loss/uncorrectable errors, latency, jitter, service availability, drop calls, content library size or number of items not found count, download and upload speeds etc. Some of these metrics depend directly network and plant characteristics that a cable operators has control of through network maintenance and operations such as; physical impairments, robustness configuration, capacity management, QoS strategy, etc.

## 6.0 Service Design & Configuration

A key aspect in providing a service is careful considerations of its design parameters. Parameters such as network dimensioning in conjunction with a mix of other services and the number of users for the different services, QoS parameters, robustness configuration to support maximum allowable error rates, session duration and other parameters are key technical factors impacting quality of experience.

## 7.0 Traditional Network Infrastructure Outage & Availability

Thus far we have discussed the concept of an effective network outage due to brown out conditions, mostly related to performance degradation. These are soft definitions of a network outage. These brown out conditions of network outage can be merged with the traditional network outage metrics through the concept of service availability which is now defined from both perspectives.

In the traditional network outage assessment we have that the CATV infrastructure components failure typically lead to a more clear cut picture of the number of customers affected. It is worthwhile to classify the different components that comprise the CATV network. A sample classification follows:

- Headend/Hub
  - Video & Advertisement Servers
  - Encoders, Decoders, Receivers
  - Video Multiplexers
  - CMTS
  - Call Management Servers (CMS)
  - Media Gateway Controller
  - Servers (DHCP, TFTP, RKS, OSS)
  - Optical Receiver & Transmitter
  - RF Combining/Distribution Network
- Outside plant
  - Fiber
  - Optical Node
  - Amplifiers
  - Passives (Taps, Couplers, Power Inserters)
  - Power System
  - Rigid Cable
  - Drop
- Customer Premises
  - Home Coax Network
  - Splitter
  - STB
  - CMs
  - MTAs
  - TVs
  - Home Routers
- Aggregation Network
  - Fiber Network
  - Switches & Routers
- Servers & Management
  - Application, Content & Caching Servers
- Third party connectivity & services
  - Peering
  - Servers

Failure of each component will have a different impact regarding the duration and the number of customers and services affected.

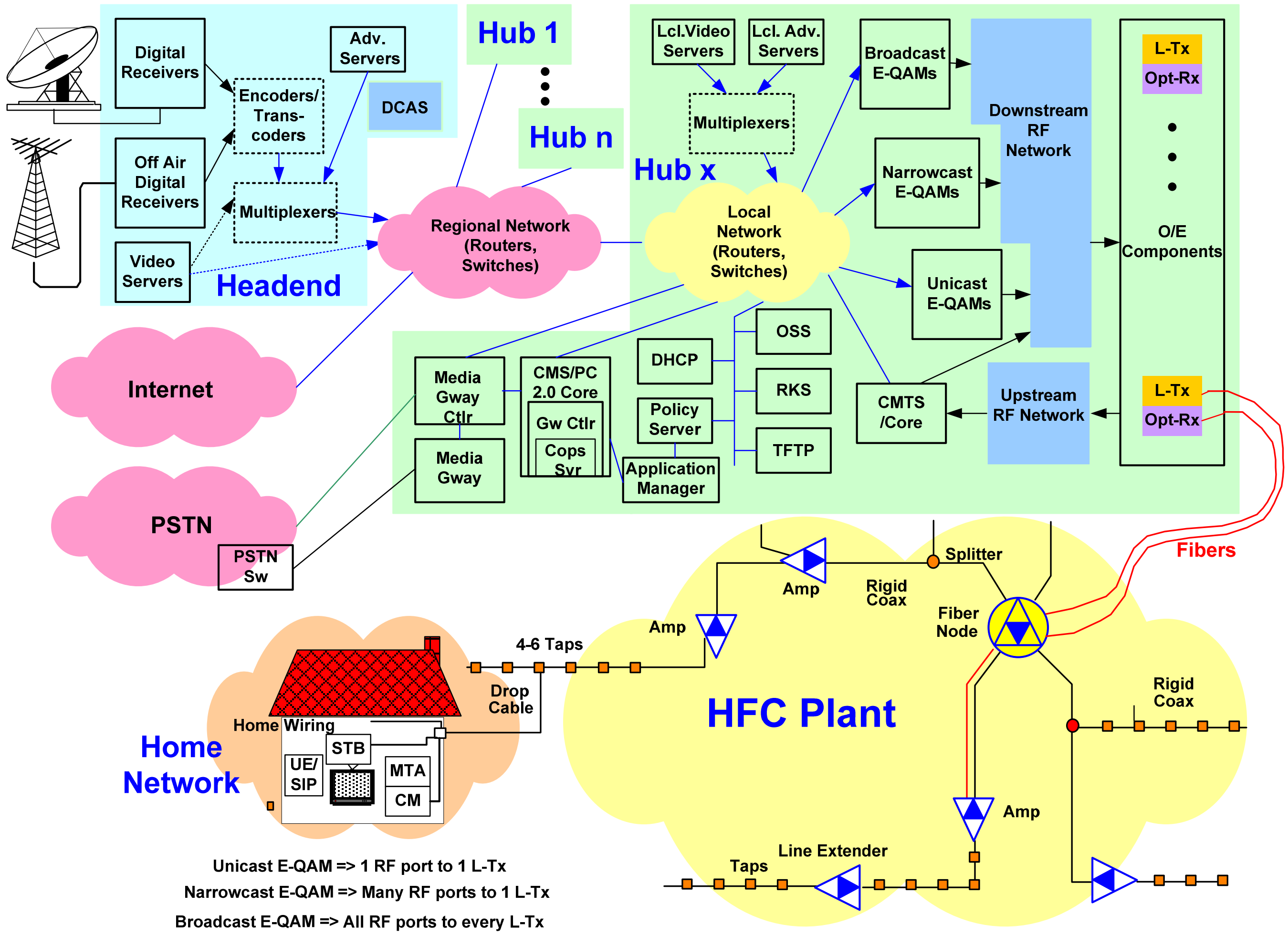


**Figure 1 Monitored CATV Network Components For Determining Service Reliability**

For a particular service provided to a particular subscriber only a subset of the components in figure 1 play a role in determining the service reliability. Figures 2, 3 & 4 show the components that play a role in determining the service reliability to a customer that subscribes respectively to video, data and telephony services. The reliability assessment impact the service degradation factor described before.

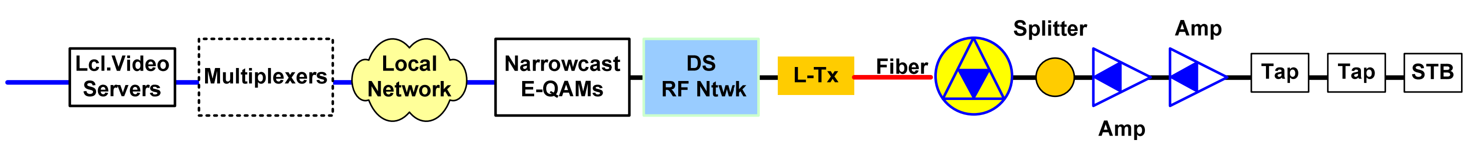


**Figure 2 Network Components Impacting Video Service Reliability**

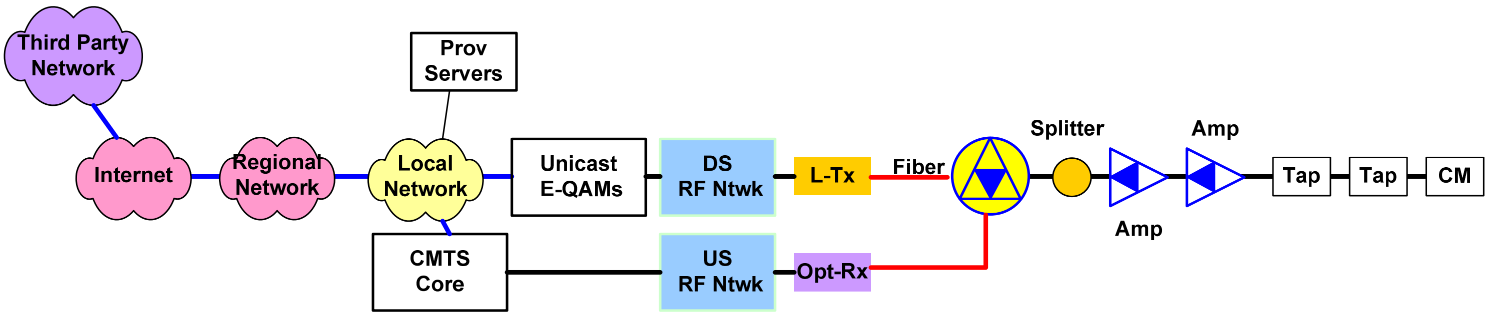


**Figure 3 Network Components Impacting Data Service Reliability**

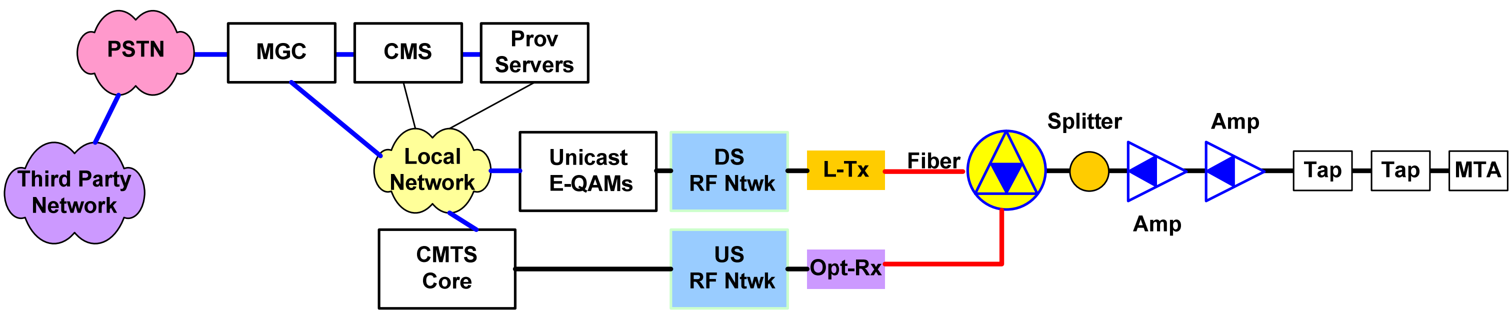


**Figure 4 Network Components Impacting Telephony Service Reliability**

The reliability assessment of these services established through the reliability of each network component and the connectivity of the different component determines the service uptime and service downtime. Adding the service degraded uptime using the concepts described in section 3 enables the determination of the overall effective service availability (Equation 3).

## 7.1 Quantifying Impact

In section 3 it is assumed that different subscriber populations will be affected differently by the brown out conditions. The same concept applies when analyzing reliability using the traditional uptime and downtime concepts. Only a portion of the network will be impacted by the failure of certain element or elements. It is important to know a priori what population of subscribers is affected when certain element or combination of elements fail.

Figure 5 shows a topological representation of a fiber node with color coded subscribers (represented by a green ellipse) based on component failure (red) and service performance metrics that result in a degraded service uptime (yellow). Figure 5 only shows the elements within a node. A complete representation would have to show the relevant components across the entire operator infrastructure.

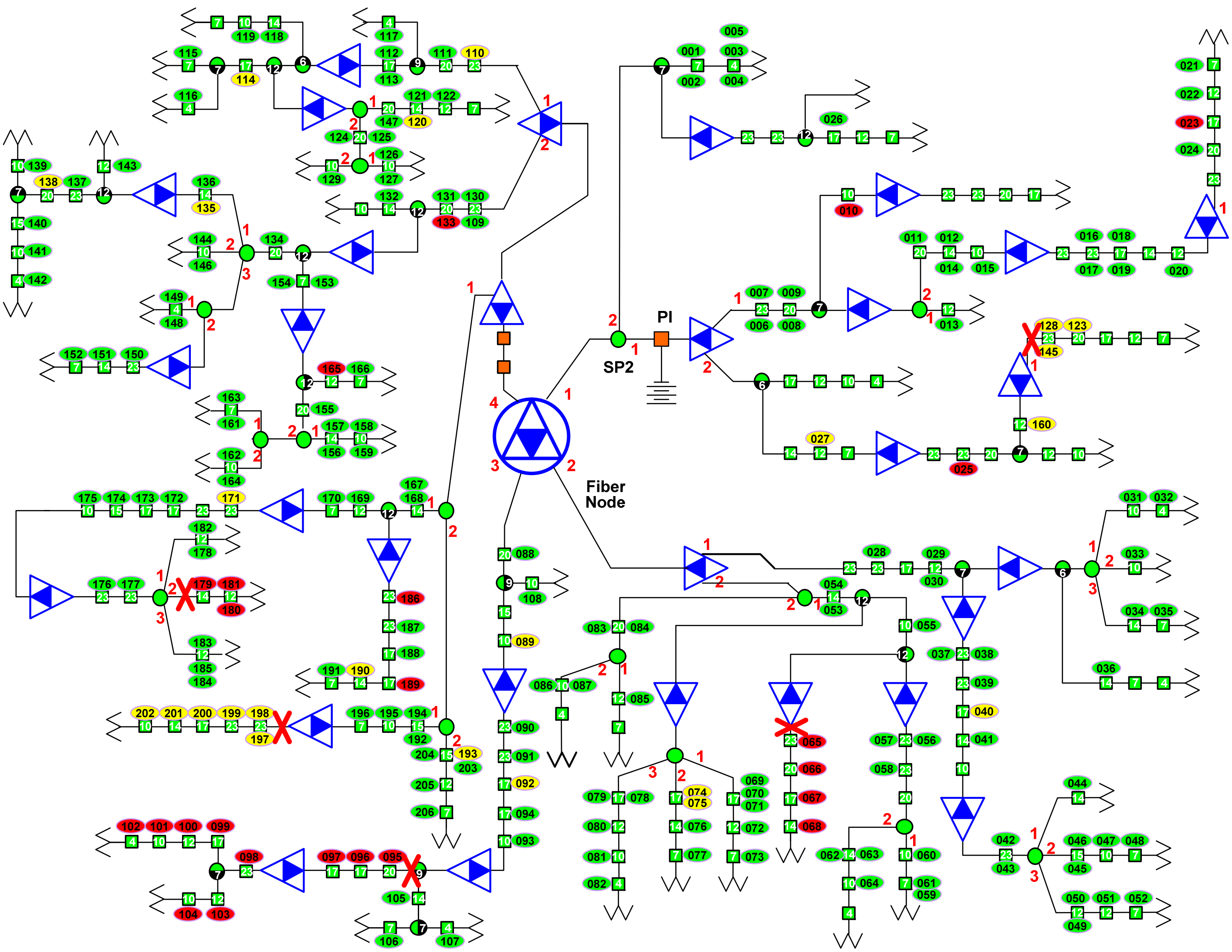


**Figure 5 Fiber Node Topology Showing Service Outage (Service Downtime & Degraded Service Uptime)**

It is worth mentioning that the different thresholds that the operator decides upon regarding performance metrics, customer type relevance, rendering device importance are dynamic and different for every operator and are based on the specific customer demographics, plant conditions and numerous other factors.

## *8.0 Objective vs. Subjective Service Evaluation Mechanisms*

Tangible metrics such as packet loss, latency, jitter, capacity provide us with an indirect mean of assessing the service experience of a customer. At best these objective measures can provide an average customer quality of experience assessment. Such objective assessment should be combined with actual customer's (subjective) assessment of their service experience. These subjective assessments should be facilitated to the customer through online feedback, follow up calls and through the analysis and classification of customer calls. In today's always connected environment, if multiple and practical means of feedback are facilitated such as through twitter, blogs, apps etc., customers will provide it.

It is proposed here to use the customer's feedback in the evaluation of Quality of Experience of a service whenever the customer subjective evaluation indicates a worst condition than the average objective assessment obtained through the performance metrics.

### 8.1 - Customer Feedback on Services

Quality of experience is a somewhat subjective criteria. It varies from customer to customer and depends on which service it refers to. Therefore it is important to get a sense about what information to collect in the form of feedback from the user of a particular service. Customer feedback in the CATV industry has been measured by the number of calls reporting problems they get. Although calls are important, many times calls are received when the issue at hand is severe. It is not always good to wait until a customer calls to resolve an issue. It is also important to enhance the ways customer can provide feedback to better assess service satisfaction levels. A customer's service feedback doesn't have to be explicit, it doesn't have to be initiated by the customer. It can be implicit, churn or dropping a service are indicators of customer preferences shifting.

Customer should be facilitated in providing feedback. For example, a customer could provide feedback through the remote control, STB, PC & phone. The online feedback has to be design so that a mean opinion score of the service can be derived.

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For a single user, a customer can provide data to generate a service opinion score from feedback, number of calls and online feedback.

$$\text{Service Opinion Score} = \text{SOS(churn, calls, online feedback)} \quad (12)$$

By aggregating the service opinion scores from a customer to all the customers sharing the service a service mean opinion score can be generated.

Service Mean Opinion Score = sum (SOS)/#of respondents (13)

The service mean opinion score can use the same rating as MOS scores are used for voice services

| MOS | Quality | Degradation |
|---|---|---|
| **5** | Excellent | Imperceptible |
| **4** | Good | Perceptible but not annoying |
| **3** | Fair | Slightly annoying |
| **2** | Poor | Annoying |
| **1** | Bad | Very annoying |

The goal is to combine the subjective MOS evaluation measures obtained through feedback mechanisms with the objective performance evaluation that is derived by calculating the service degradation factor. Once a reliable correlation mechanism is established between the objective and the subjective measures, a conservative approach that takes all the objective measures for each customer unless the subjective measure results in a worst service rating that is worst than the objective measure.

| | R Factor | MOS |
|---|---|---|
| **Maximum obtainable for G.711** | **93** | **4.4** |
| **Very satisfied** | **90-100** | **4.3-5.0** |
| **Satisfied** | **80-90** | **4.0-4.3** |
| **Some users satisfied** | **70-80** | **3.6-4.0** |
| **Many users dissatisfied** | **60-70** | **3.1-3.6** |
| **Nearly all users dissatisfied** | **50-60** | **2.6-3.1** |
| **Not recommended** | **0-50** | **1.0-2.6** |

## *9.0 Quality of Experience Metric*

Quality of Experience is determined through the combined impact of several factors described before. They are Effective Service Availability, Customer Type Relevance Factor (CTR), Application and Service Rendering Device Factor (RDF) and customer service feedback through the Service Opinion Score (SOS). The expression below describes a way to quantify Quality of Experience. The actual factors will have to be determined through extensive measurements and evaluation.

$$QoE = \sum_{i}^{N} \mathrm{EffServAvail}_{\mathrm{i}} [\text{mininum of } \{\mathrm{ObjectivePerfEval}, \mathrm{SubjectivePerfEval}\}] \quad (14)$$

Where the objective performance evaluation metric is the service degradation factor (SDF) and the subjective performance evaluation metric is the service opinion score (SOS). Replacing SDF and SOS into the previous equation we have:

$$QoE = \sum_{i}^{N} \mathrm{EffServAvail}_{\mathrm{i}} [\text{mininum of } \{\mathrm{SDF}(\mathrm{PerformanceMetrics}, \mathrm{RDF}, \mathrm{CTR}), \mathrm{SOS}\}] \quad (15)$$

where SDF is the service degradation factor which depends on the performance metrics, the rendering device factor (RDF) and the customer type relevance factor(CTR). SOS is the service opinion score.

The performance metrics are a function of network reliability, network configuration and network capacity. Similarly the service opinion score is generated from direct customer feedback and modified by the indirect feedback that churn and customer calls provide.

Figure 6~~Figure 6~~ shows a Quality of Experience diagram with different contributing factors that directly and indirectly influence quality of experience.

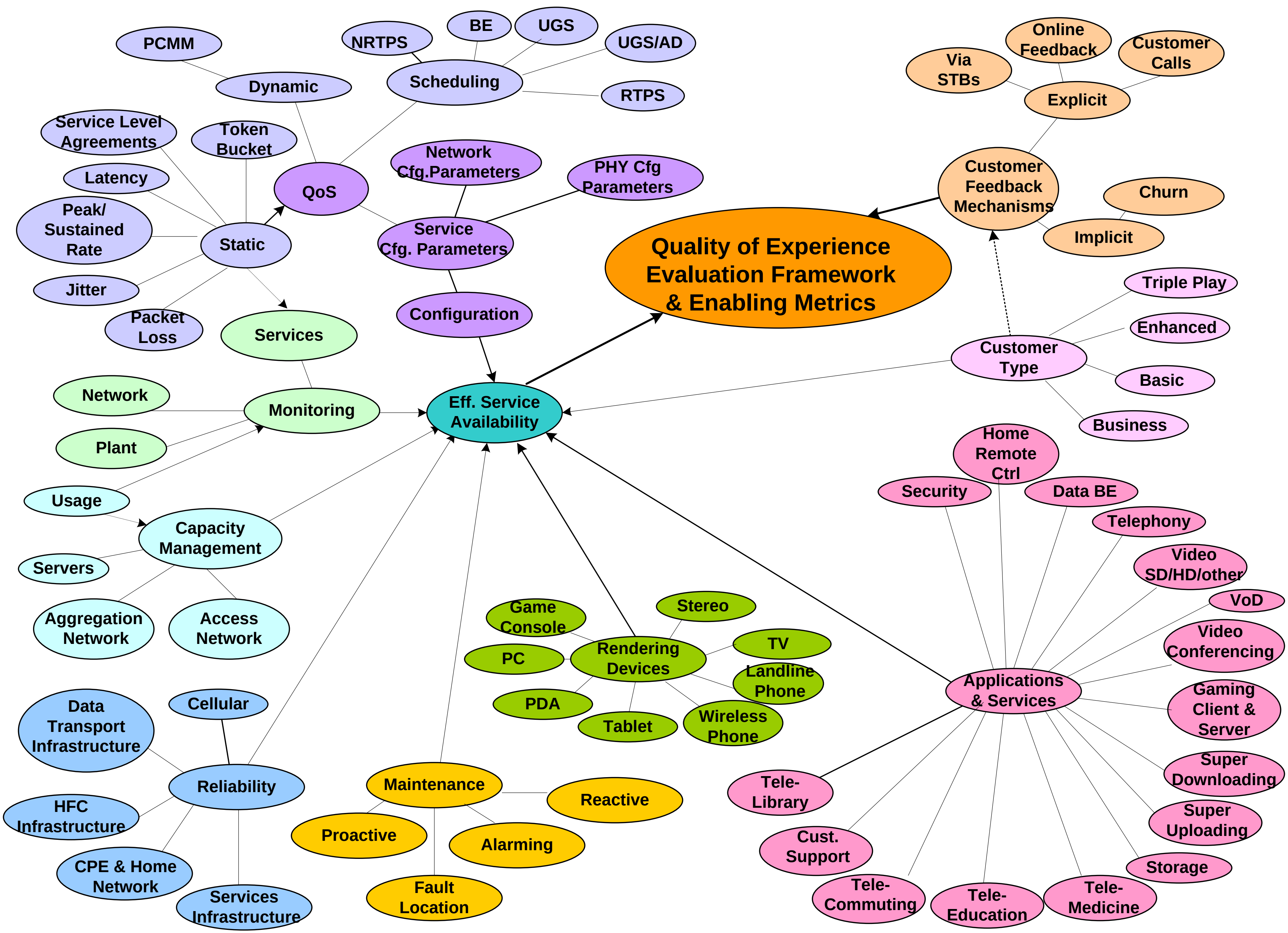


**Figure 6 Quality of Experience Dependency Factors Diagram**