Enhancing Wi-Fi QoE With Targeted Approach

A Technical Paper prepared for SCTE•ISBE by

Bart Vercammen
CTO Customer Premises Equipment BU
Technicolor
Prins Boudewijnlaan 47, B-2650 Edegem, Belgium
+32 3 443 6 519
Bart.Vercammen@technicolor.com

Jos Delbar
Director Product Management Managed Services
Technicolor
Prins Boudewijnlaan 47, B-2650 Edegem, Belgium
+32 3 443 64 16
Jos.Delbar@technicolor.com

Table of Contents

Title **Page Number**

List of Figures

Title **Page Number**

Introduction

A subscriber's Wi-Fi quality of experience (QoE) has been an industry focus for many years. On the CPE side, the approach has long been to increase the MIMO configurations with each generation as well as to maximize the power budget by using better components, to provide maximum coverage at adequate speeds from a single access point location.

Now, as the industry pivots towards access point disaggregation, by adding Wi-Fi extenders in multiple locations in the home, we must find a way to deploy these additional devices in CAPEX and OPEX efficient ways. Typically, multiple access points immediately trigger a quest for the best roaming solution.

However, Technicolor believes this is a misplaced area of focus, firstly because an extender is often not a solution to the problem, on the contrary. It is imperative to first proactively determine which households will actually benefit from an extender, allowing a Service Provider (SP) to better plan its CAPEX investments. Secondly, these roaming solutions will commoditize over time, as standardization increases and client devices (STAs)[1] implement better roaming algorithms and standardization increases.

Technicolor recommends a five-step plan to allow a Service Provider to further enhance a subscriber's Wi-Fi QoE, in CAPEX and OPEX strategic and efficient ways:

1) Diagnostics: Create Wi-Fi QoE visibility into your installed base.
2) RRM (Radio Resource Management): Optimize the installed base. Technicolor has field data from millions of devices that shows how effective RRM/SON (Self Optimizing Networks) activity can substantially reduce OPEX cost thanks to increased QoE.
3) CAPEX strategies: The ability to target specific older gateways models whose replacement would significantly improve subscribers' QoE, as well as proactively identifying subscribers who can benefit from extenders.
4) Self-installation: Deploying solutions that are zero touch, combined with the right security, are essential to drive mass market adoption without the need for professional installation.
5) Client steering: Finally, for the percentage of subscribers requiring multiple access points, effective steering solutions provide additional capacity and provide the final boost to a yet higher QoE.

[1] A Wi-Fi client is also called an STA (station). We will use the word STA consistently when referring to Wi-Fi clients. However we will keep on using the word client steering as this is a commonly used term in the industry.

Wi-Fi QoE: a stepped approach

1. A Burning Platform

In today's consumer's world, with ever increasing content sources and streaming services, with a rising number of consumer devices that need to be supported in the home, Service Providers around the world are facing more and more challenges to deliver the optimal performance of the in-home network that satisfies subscribers' user experience in the home.

With Wi-Fi being the most predominant – head and shoulders above alternatives – distribution medium in the home, there's an increased focus on how to achieve the most optimal Wi-Fi performance in the home.

Since several years, for Service Providers, Wi-Fi quality of experience has been a problem**.** What makes it worse is that there is no uniform way for Service Providers to uncover and tackle the issues stemming from poor Wi-Fi QoE. More than often these problems get funneled through the helpdesk as "I have no Internet" or "My Internet is slow"**.** In reality the root causes can vary from Wi-Fi interference coming from Wi-Fi and non-Wi-Fi sources, through poor Wi-Fi coverage, to saturation of the Wi-Fi medium or any combination of the above. In addition, Service Providers are facing difficulties to diagnose those Wi-Fi issues at their subscriber's residence.

But, recently, retail Wi-Fi is now driving a wedge between the Service Provider and their subscribers, threatening to disintermediate the subscriber's broadband access from the Wi-Fi network. This imposes the Service Provider's to lose…

- Customer intimacy
- Brand recognition
- Revenue opportunities

… while subscribers still expect the Service Provider to provide increasing bandwidth (CAPEX investment) and technical support (OPEX cost). Together this might result in the Service Provider losing control of the Connected Home.

Technicolor, however, believes that Service Providers still have a window of opportunity to gain control of the Wi-Fi performance in the home by rolling out a Managed Wi-Fi solution consisting of:

- Wi-Fi insights and diagnostics
- Wi-Fi network optimization (channel planning)
- Better/more Wi-Fi access points
- Easy Wi-Fi set up and configuration
- Wi-Fi client mobility (active steering)

As we will show in the next sections these elements help our Service Provider customers to achieve dramatic improvements in customer experience.

2. Case for Customer Wi-Fi Experience Management

Consumers have, over the last few years, progressively and frustratingly, suffered from a lack of full home and high-quality Wi-Fi coverage from their Service Provider. Service Providers have been tackling this challenge head-on, rolling out a steady progression of routers whose Wi-Fi performance exceeds that of the generation prior. It is fair to say that the industry is asymptotically approaching the maximum coverage and quality that can be provided from a single device location, and now attention starts to turn to the next wave, which is adding one or more additional Access Point devices – Wi-Fi Range Extenders – to the home.

The beautiful coincidence is that each additional Wi-Fi Extender is more likely to be in a "public" area of the home. This allows a Service Provider to blend a need – to further enhance the delivery of its broadband service via Wi-Fi – with an opportunity – to insert a device in the living areas of the home which creates an emotional link with the end user. Next, to the increasing competitive threat from retail "Mesh"-systems, this generates the trigger for Service Providers to invest in extenders and "Mesh".

Is the Wi-Fi Extender the next Holy Grail? Yes and no. Yes, because we all know that Wi-Fi coverage is an issue that is present in the market and extenders provide a solution to that. Even more, when the average access and download speeds are increasing gradually, the need to have that same speed delivered anywhere in the home increases as well. And that is going to increase the need for extenders. So, having extenders as part of the solution is good.

However, from our real-world and large-scale collection of Wi-Fi quality of experience data (see Figure 1), we have learned that 41% of Wi-Fi QoE problems are caused by Wi-Fi interference issues, and 49% are caused by coverage issues; leaving 10% are caused by saturation issues (See paragraph 3.1.2 for an explanation on these categories). This means that 51% (= 41% + 10%) of Wi-Fi problems will not be solved by bringing in Wi-Fi Range Extenders. In fact, for these cases, Wi-Fi Range Extenders will only make matters worse. See paragraph 3.1.3 for an explanation on why this is the case.

Hence deploying Wi-Fi Range Extenders to the wrong part of the subscriber base will not only make matters worse but will also be a wasteful allocation of CAPEX. Deploying Wi-Fi Range Extenders to the right part of the subscriber base, and deploying the minimum necessary number of them, is the golden ticket.

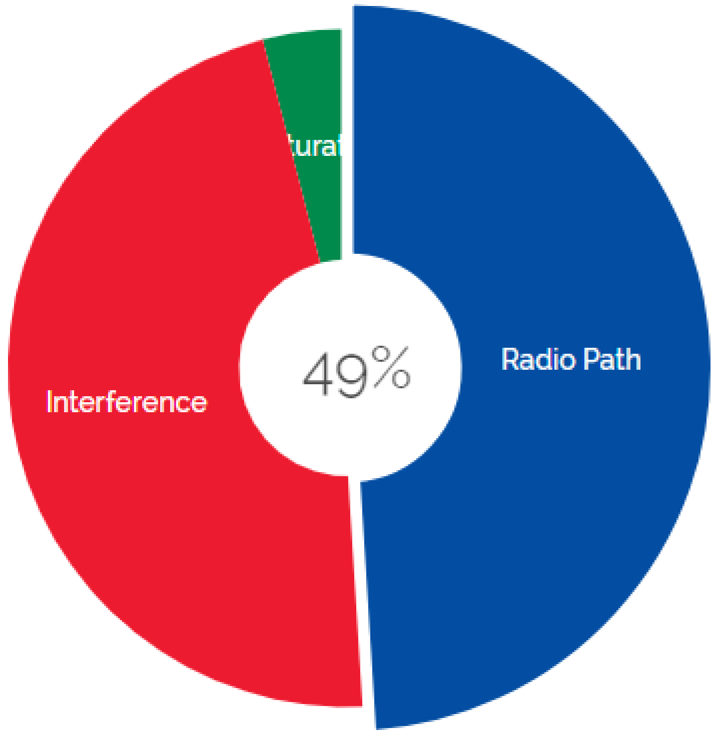

Figure 1 - Relative contribution of interference, radio path (coverage) and saturation issues to Wi-Fi quality of experience problems[2]

It is crucially important for the Service Provider to know whether it is necessary or appropriate to install a new Wi-Fi Range Extender in the home, or whether such action will simply aggravate the issues. The key is knowing which subscriber suffers from which problems and how to solve them.

Is the subscriber suffering from interference from neighboring networks (so called "hidden nodes")? A hidden node is a problem that is very common in Wi-Fi and the root cause of many problems typical of denser areas. The problem arises when two neighboring access points are using the same Wi-Fi channel, but are not visible to each other. A STA (station) that is somewhere in between can however see both networks. Since both networks are on the same channel, the station starts experiencing issues because both access points are happily sending traffic at the same time. Adding Wi-Fi Range Extenders will only make it worse, by creating additional interference. Instead, deploying macro Wi-Fi network optimization to coerce the existing Wi-Fi routers to select clearer channels is a better solution. Additionally, deploying intelligent client band steering to coerce Wi-Fi STAs to use the clearer 5GHz frequency as a solution. Let's take an example to illustrate this. From the deployment mentioned (Technicolor, 2018) we see that nearly 60% of all STAs are only connecting to 2.4GHz. This off course does not tell the full story as only 38%[3] of the STAs are dual band capable[4]. But it indicates that 5GHz is not used ubiquitously.

[2] (Technicolor, 2018)
[3] (Technicolor, 2018)
[4] There are two comments to make here. First of all not all STAs support 5GHz, some mainly older ones might only support 2.4GHz. Secondly this deployment is still using 2 different SSIDs so this shows that people often only fill in their 2.4Gh credentials and not the 5GHz ones.

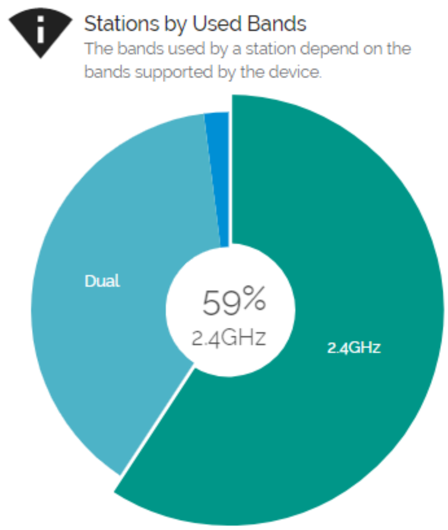

Figure 2 - Band usage by Stations (Technicolor, 2018)

This becomes even more visible when analyzing the stations that are dual band capable. When we analyse this population (Technicolor, 2018)[5] in Figure 3 it is clearly visible that 42% of those clients is not connecting to 5GHz even though they are capable to do so. The reason for this is two-fold. The main root cause is that in this deployment (Technicolor, 2018) the 2.4GHz and 5GHz bands have different SSIDs which indicates consumers don't bother filling in the 5GHz SSID and hence connect only to 2.4GHz. Another reason is that certain phones prefer being on 2.4GHz whether due to stickiness, environment conditions…This clearly demonstrates the need to unify the Wi-Fi experience in the home by combining single SSIDs with the correct band steering techniques.

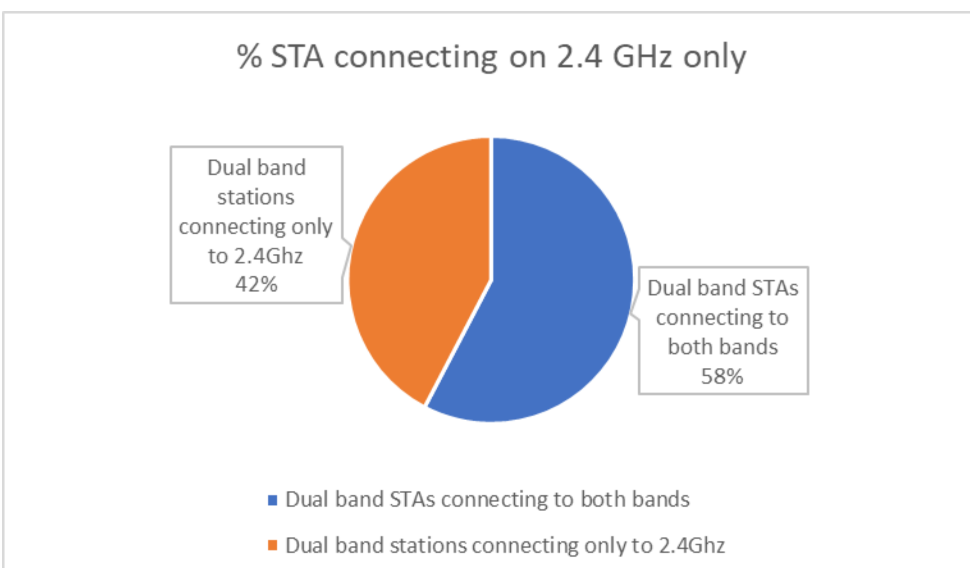

Figure 3: % of STAs connecting on 2.4GHz only

[5] We only analyzed dual band capable STAs that were connected to dual band APs

Is the main issue indeed stemming from a lack of coverage? Of course, deploying Wi-Fi Range Extenders will alleviate this problem. But which homes lack coverage? How many extra Wi-Fi Range Extenders are needed to provide the optimal level of coverage? This is not only important for efficient Wi-Fi network performance, but also for corresponding Wi-Fi extender CAPEX efficiency.

By taking a step back, and first gaining more insight into your Wi-Fi installed base, performance metrics, and root causes of Wi-Fi issues, you will be able to make better decisions on how and where to invest CAPEX. By deploying a good RRM-SON solution, you will be able to dramatically decrease the amount of Wi-Fi issues, without deploying additional hardware. This stepped approach to a whole home Managed Wi-Fi ecosystem to manage the Wi-Fi experience is the essence of the success of Service Providers in the battle for “who owns the SSID?”, and the SSID must be owned to be able to capture many of the applications and services that are on the horizon.

3. Steps to a whole home Managed Wi-Fi solution

For the Service Provider, delivering Wi-Fi as part of a broadband service is a double-edged sword. On one hand, the promise of superior Wi-Fi performance is a key selling argument for operators and a top reason to buy for subscribers. On the other hand, day-to-day Wi-Fi issues are a major source of frustration and Wi-Fi consistently appears in the top of the ranking for helpdesk calls. If operators do not succeed in managing their Wi-Fi service in a better way, subscribers will eventually turn to alternative solutions offered by the direct competition or even by the retail players. Along with alienating the subscriber, opportunities for marketing additional value-added services beyond broadband are lost.
Continuously improving the performance and the user experience of Wi-Fi products and services should be a firm objective. Service Providers need to understand that being successful requires taking a holistic approach that goes far beyond the deployment of additional Wi-Fi access points. Equally, if not more important, are the software, the user interfaces and the deeper integration with network systems. All of these elements come together in the five steps to deliver a successful Managed Wi-Fi solution. This is what Technicolor refers to as the Wi-Fi QoE wheel.

Figure 4 - The Wi-Fi QoE wheel : the 5 Steps for a succesfull Wi-Fi QoE

Obviously, each individual step executed in the right order is key to ensure the maximum Wi-Fi QoE for consumers. Most RRM-SON solutions go directly to step 2 of the wheel – network optimization – and most mesh solutions typically focus on step 5 – client steering, but we wish to stress the importance of getting the full spectrum of Wi-Fi use cases right. If the basics are not covered (i.e. primary access point management, first time extender installation, getting devices properly connected to Wi-Fi, discriminating between subscribers who need mesh and who do not …) then most subscribers will still perceive a poor Wi-Fi user experience no matter how advanced other aspects of the solution are. A comprehensive Wi-Fi QoE solution addresses the full set of use cases.

3.1. Comprehensive Wi-Fi diagnostics

The foundation of a successful managed Wi-Fi solution that delivers a great QoE is insight and this insight stems from data. The appropriate type and amount of data is needed to identify what is right and wrong with the Wi-Fi QoE in the home and to determine the root cause of the issues. Only then can the right course of action be determined to help improve the Wi-Fi.

In the following paragraphs we are going to use some examples from real life use cases. In order to better understand the figures and how they are measured, let's assume you have a monitoring system that is able to indicate and measure what the full theoretical Wi-Fi performance is of the STA taking into account the capabilities (Wi-Fi standard, MIMO) between AP and STA, for each STA. In each figure, you will typically see a normalized view of the Wi-Fi performance over time for a device. In the X-axis you have the time scale, on the Y-scale you have the %-scale (0-100%). 100% means the full theoretical performance that the device can have. Every vertical line indicates a time where that device was connected, and the colors indicate where and how performance was used/available/lost. Blue indicates lost performance due to physics (too far from AP), Red means the same but due to interference, Yellow means performance lost due to other Wi-Fi traffic in your network. Dark green means used capacity (real bandwidth used by that device) and light green means available capacity. This should help in reading and understanding the examples better that follow in the text.

3.1.1. Measuring Wi-Fi QoE

The first thing is of course to measure the Wi-Fi QoE correctly. This might seem obvious, but the reality is often different. Let's take as an example the home of Mr. Robinson[6], who is using his tablet frequently. As one can immediately see from Figure 5, Mr. Robinson is using his tablet quite far from his AP and has a lot of issues due to physics[7] if you look at the amount of blue present in the picture. Physics typically results in a bad RSSI that results in a low modulation speed on the Wi-Fi medium and as a consequence a low throughput. Hence looking at this from a pure speed perspective, which is common practice in diagnosing Wi-Fi, the immediate conclusion is that this person needs immediate attention and care, and even that this customer should be offered an extra access point to fix his issues.

However, from a Wi-Fi QoE perspective the story is much different. In reality, Mr. Robinson is perfectly happy with his Wi-Fi at home, as he is only using it for casual surfing and mailing. Mr. Robinson is not a heavy service intense user and was quite surprised when he was contacted to "solve" his Wi-Fi issues. Although an extender would greatly improve his Wi-Fi performance, from a QoE perspective, there is currently no need for it. Once his user profile changes through using Netflix e.g. the story may change. But today, Mr. Robinson is a content customer, he is not likely to churn due to Wi-Fi issues, he is

[6] Fictitious name used for this example
[7] This is e.g. typical ly very visible through a bad RSSI (Received Signal Strength Indication)

unlikely to call the helpdesk, and likely has no appetite for buying an extender or a managed Wi-Fi service.

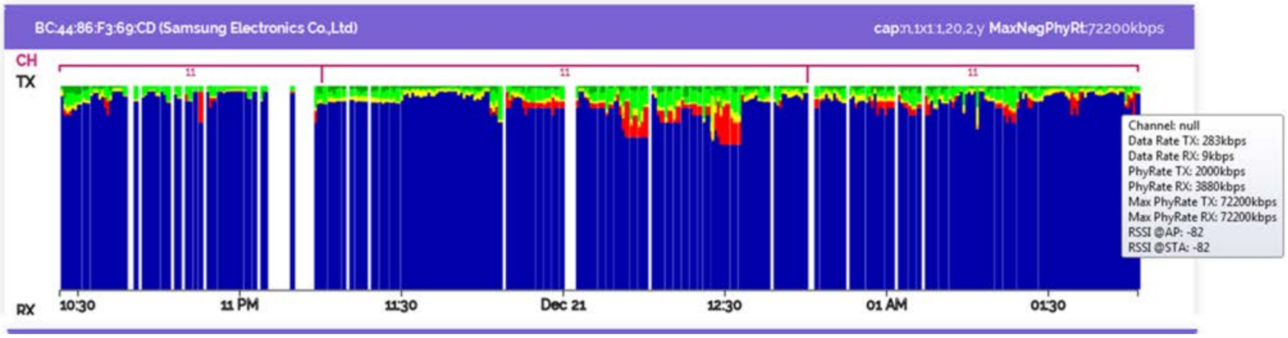

Figure 5 - Wi-Fi performance of Mr. Robinson's home

A similar example can be taken by looking at the home of the Johnson family in Figure 6. They like watching Netflix movies from their PlayStation and consume quite a lot of Wi-Fi bandwidth. This is visible through the large dark green lines in the left of the figure. These lines and the corresponding bandwidth consumption is much higher than Mr. Robinson from above. The bandwidth capacity they have however is also larger than Mr. Robinson (visible through the light green). When analyzing both Figure 5 and Figure 6 one can quickly see that the total bandwidth as the sum of both the used (dark green color) and the available bandwidth (light green color) in both homes shows a big difference. A technician that looks at this data would conclude that the Wi-Fi performance of the Johnson family is more than adequate (around 70-80% of the theoretical bandwidth during the majority of time) and, if you compare them with the Robinson's home, they would not get attention as their Wi-Fi performance looks good compared to the Robinson's. The Johnson family is however not doing as great as we would expect from their sheer Wi-Fi performance. At 10:45PM their AP switched to channel 11[8] and suddenly a lot of interference[9] starts to appear. Although the Wi-Fi performance they achieve is still good, the capacity they need is more than what is available in the system with the interference being present. The result is that the movies watched on Netflix start to get impacted and the Johnson's suffer from pixelization or serial buffering. Contrary to what may be expected, this family is not happy with their Wi-Fi, and is more likely to place an unhappy call to the helpdesk or even churn.

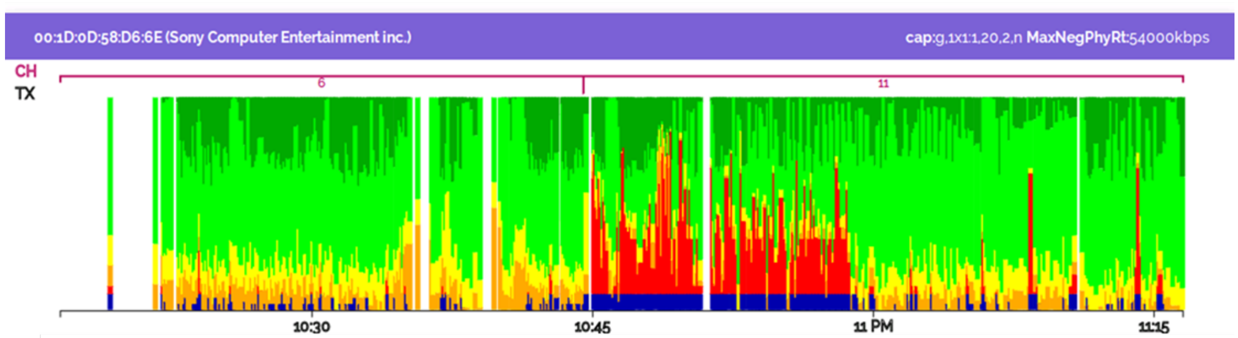

Figure 6 - Wi-Fi performance of the Johnson family

[8] A typical action done by AP by means of their ACS (Automatic Channel Selection) function.
[9] The red bars on the graph represent the interference

These two examples show that it is essential for every managed Wi-Fi solution to correctly measure the Wi-Fi QoE before anything else can be done. Looking just at effective speed is not enough, looking at range is not enough and taking a" in the moment" snapshot of performance is also not enough.

3.1.2. Segmentation of the issues

When measuring the Wi-Fi QoE correctly and accurately over time, the consequence is that it allows the Service Provider to distinguish where to focus their attention. First and foremost, it allows the Service Provider to filter the false positives from the operational flows. From various deployments, Technicolor measures that roughly around 50%-70% of a population[10] has no Wi-Fi performance issues at all at any given moment in time. Typically, with a lot of deployments various "No Internet" issues are impossible to diagnose and, in some cases, assumed to be Wi-Fi related with a consequence of long investigations, box-swaps or even truck rolls. This can all be avoided with a good, time-based Wi-Fi QoE monitoring solution. When doing diagnostics through continuous monitoring of Wi-Fi QoE, a helpdesk operator can look at summary information of that subscriber when a call comes in. An automatic verification could then alert the operator that the Wi-Fi for that subscriber shows no deficiencies. As such with one glimpse of an eye a helpdesk operator can determine that Wi-Fi performance issues have nothing to do with the call and can focus their attention on other problems.

Throughout this paper we always talk about Wi-Fi QoE as heavily linked to the performance that is achieved with the devices that are being used, at the times where they are being used. However not all Wi-Fi issues seen by customers are always performance related. Typing wrong Wi-Fi passwords when connecting for the first time to a network is an often-recurring issue, despite various attempts in the industry to make this as zero-touch as possible[11]. From recent deployments we can see as much as 7% of all households (Technicolor, 2018) suffer from failed connection attempts due to wrong passwords[12]. These items have a corresponding negative effect on Wi-Fi QoE, but they require a more dedicated treatment which we will not tackle here in detail. The exception is the 4th step of the Wi-Fi QoE, which is heavily linked to this, and we discuss this in paragraph 3.4.

Measuring correctly the Wi-Fi QoE also provides a good indication of the severity within a certain population. This can be very helpful for Service Providers who wish to proactively approach and fix the most affected end-users thereby making a good judgment on who to tackle first.

3.1.3. Define the right diagnosis and its importance

As soon as a Wi-Fi QoE problem has been determined and segmented for further investigation, the most crucial step becomes determining the right diagnosis of the Wi-Fi QoE issue as well as its importance.

The root cause for Wi-Fi QoE issues can vary and fall into 3 kinds of domains:

1. **Physics issues:** A typical physics issue is a lack of coverage (too far away from the AP) or an environment that is degrading the Wi-Fi signal heavily (concrete walls, metal reinforcements…). This is the issue that most people are thinking of when it comes to Wi-Fi QoE issues
2. **Saturation issues:** Another issue that is commonplace, is a Wi-Fi QoE that is heavily degraded due to a complete overutilization of the medium. This can be due to one STA completely filling the Wi-Fi network with P2P downloads or the sum of the bandwidth of all STAs in the network that is completely filling the medium. Although this is a severe issue in certain specific

[10] Data taken from (Technicolor, 2018)
[11] Items like QR codes, WPS (Wi-Fi Protected Setup) …
[12] Data taken from (Technicolor, 2018)

environments, it remains a relatively minor group of issues compared to the others as can be seen in Figure 1

3. **<u>Interference issues:</u>** This is the most underestimated category of issues, not only because of its contribution to the overall amount of issues (see Figure 1), but even more so due to its complexity to correctly diagnose and identify the root cause. Interference can have many forms, ranging from a simple RF interferer in a certain Wi-Fi band, too far away Wi-Fi networks generating collisions as they don't see each other[13]. The location of the interferer being closer to the AP or closer to the STA (Station) also matters when determining the root cause.

A Wi-Fi QoE problem can have multiple reasons that are widespread. Having the diagnosis wrong can lead to massive discrepancies in how to tackle the issue. It is obvious that a coverage problem requires a different approach than an interference issue.

Let's use the example of a hidden node (as we explained in paragraph 2) to illustrate this. A hidden node is created because the AP and the STA see a different list of nearby APs and due to the fact the STA sees another AP on the same channel than the one he is connected to this gives collisions. This is seen as an interference issue. By deploying extenders you risk to create hidden nodes or make things only worse. Because when you install an extender this extender has to follow the channel as indicated by the main AP[14] and due to the function of an extender you make that Wi-Fi network larger. Hence the probability that a STA and an AP see things differently and risk collisions is only getting bigger. That is why using extenders should only be done in clear cases where physics are the root cause of the issues.

When we all think of Wi-Fi, we typically reason around one category of issues as mentioned above. The reality is often much more complex. With the lessons learned from a number of large deployments (Technicolor, 2018) we know that in 92% of the cases (see Figure 7 the problems that are being diagnosed for a given home are not linked to just one of these three specific categories of issues. In only 8% of the cases the Wi-Fi QoE issues can be reduced to a single root cause.

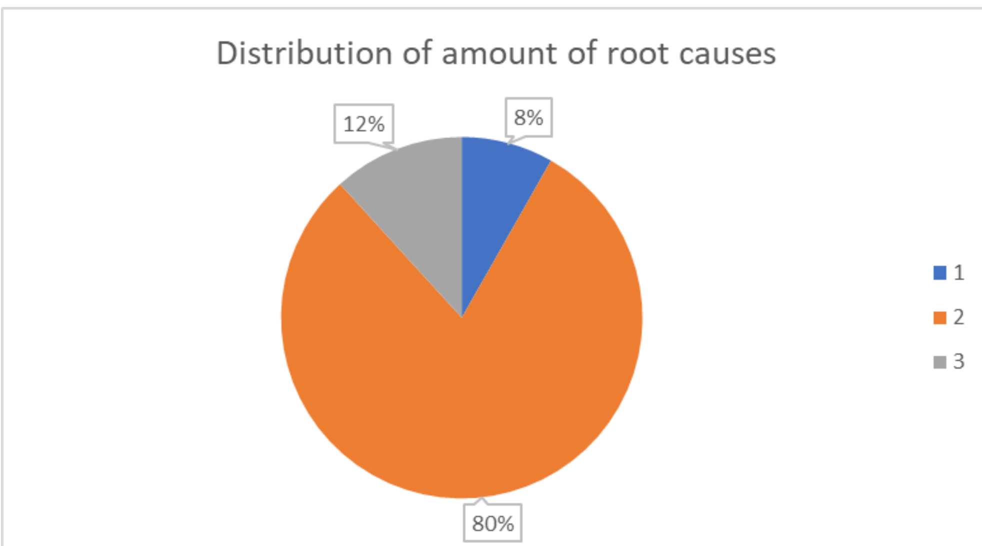

Figure 7 - Distribution of amount of root causes in large deployments

[13] So called hidden nodes
[14] Assuming the hidden node appears on the band to be repeated. When using different bands on the backbone link and the link to the STA the situation can be different

This is one of the most important findings we as Technicolor have seen in our field experience. There is no such thing as one solution fits all. There is no such thing as a single solution to a problem. This only happens in lab environments and to give easy and clear examples. In real life it happens but rarely. A structured and methodological approach needs to be followed.

When the problem involves more than one kind of issue, it becomes imperative to determine the relative contribution of each category to the overall Wi-Fi QoE. This allows the Service Provider to focus his attention on these issues that contribute most to the degradation of the user experience. If that information is not available, one risk is a focus on fixing issues, with only marginal gain and at an enormous cost. Seeing the amount of multi-category issues, the structuring of priorities becomes critical

3.1.4. Define the right cure

Diagnosing the Wi-Fi QoE is the hardest and most critical part in order to improve the Wi-Fi QoE. What remains is determining and applying the right cure to the problem. If we go back to the different categories of issues, the spectrum of possible cures is wider than one might think.

Physics issues are not only solved by placing extenders in the home but, as we will see in paragraph 3.3, moving AP's to optimal locations and/or defining the suitable AP model for each subscriber. This can assist in solving a lot of issues.

Interference issues will get solved by selecting the right bands and channels to operate in as an AP. But the situation is more complex than that and a possible solution could also be to let an end-user activate its 5GHz profile on its devices to work around certain interference issues

Solving Saturation issues requires a bit more attention. In most cases, adapting the bands and channels is also the right solution. However, when there is already a plethora of devices in the air, the right solution can be to spread devices around to the available bands (load balancing). Another solution for that problem could be to prioritize certain devices over others when the overall available bandwidth remains the bottleneck.

Before diving into the fix, it is equally important to identify what those cures are, and which ones can be tackled proactively without end user action or consent. Therefore, the next step in enhancing the Wi-Fi QoE is attacking those issues that can be dealt with remotely and even proactively.

3.2. RRM (Wi-Fi network optimization)

Now that all Wi-Fi QoE issues have been diagnosed and the cure(s) have been identified, it is also time to start tackling those issues that can improve the Wi-Fi QoE automatically without end-user notification or involvement. Such automatic improvements help massively in working proactively with customers. Instead of waiting for the call or the identification of issues at the end user, working proactively in the background to improve his Wi-Fi QoE is a great mechanism to avoid churn and increase NPS.

Such proactive techniques typically fall in the domain of RRM. Through AI techniques and advanced analytics, the best channel/band is determined for the AP's in your home. This optimization of the radio network in the home aids in reducing many of the QoE issues in the interference category. Let's look at another example: the home of Pamela on Figure 8. Until shortly before 7PM the AP in Pamela's home was suffering quite badly from interference. This interference has eaten up almost all of her capacity. This combined with the fact that Pamala's laptop is not really close to the AP, leaves almost no data left to consume. Pamela has not yet noticed this issue as she is not using any bandwidth[15]. The Managed Wi-Fi solution has identified this potential problem, has diagnosed it as an interference issue, and now the RRM function is stepping in to proactively fix it. Just before 7PM the RRM function switches the channel of the AP to channel 13[16] and as you see from the graph the interference disappears[17]. Suddenly Pamela enjoys more than enough capacity for her needs. This action has been performed just in time as the fix occurs shortly before she starts consuming bandwidth. Without the RRM intervention this would have caused Wi-Fi QoE issues and would have generated a helpdesk call and frustration.

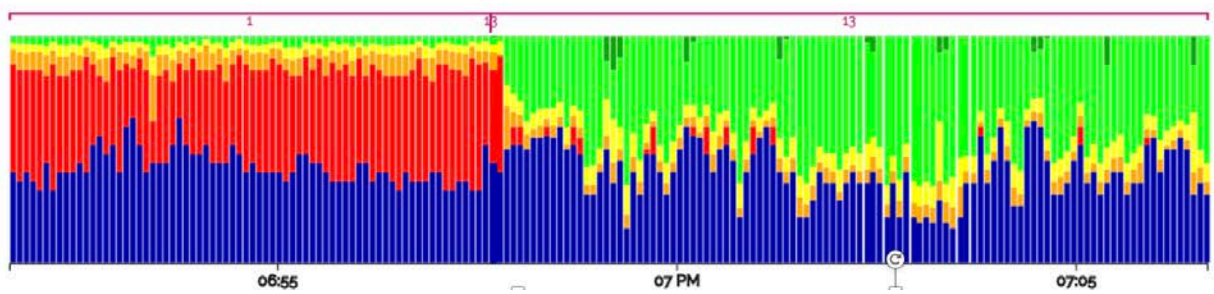

Figure 8 - An example on the effects of RRM on Wi-Fi QoE: Pamela's home[18]

The fact that these actions can be performed anytime without any need for end user interaction allows for continuous and proactive optimization of the Wi-Fi QoE when it comes to interference related issues. This optimization generates a better and more consistent end user experience without any hassle for the consumer. This optimization can be done both on an individual home basis and can also work with perfect effectiveness for complete MDUs (Multi-dwelling units) and neighborhoods that are under control of the RRM function. More than their retail competitors, a Service Provider often has control over a large part of the visible AP's. Where a Service Provider controls a large number of APs in one neighborhood, MDU, or campus, they have a clear advantage in improving the Wi-Fi QoE over retail solutions which are more scattered and unlikely to be able to play the wide area RRM game.

The reduction on Wi-Fi QoE issues can be significant and have a huge impact on both helpdesk call rates as well as customer satisfaction. If we do an analysis on how much such an RRM function brings in real life, let's go back to the data from (Technicolor, 2018). In that installed base, there were two groups of people monitored[19]. For one group there was merely monitoring and no intervention (we called that the control group) and in the other group we stared intervening after 1 week (the proactive group). The first week we only monitored both groups to demonstrate that both populations were equal in behavior. In Figure 9 one can see for every day monitored the amount of Wi-Fi QoE issues in the Y-axis[20]. A higher bar in the graph means there have been more QoE issues in that time period than during a period with a lower bar. After one week, the RRM function started to optimize the channels for the proactive group. As one can see from the graph this drastically improved the Wi-Fi QoE, in the order of 20%-30% improvement[21]. If we translate this into OPEX savings this resulted in a reduction of 30% in first line helpdesk calls (Technicolor, 2018).

[15] There is no dark green visible in the graph that is representing the consumption of traffic
[16] For avoidance of doubt: channel 13 is taken from an example in EU where channel 13 is allowed. In NAM this is not allowed
[17] The physics issue remains and this is logical as nothing is changing to the position of the laptop
[18] For explanation of the colors and bars, see Figure 5
[19] Each of them around 50% of the population and statistically relevant (more than 0.5M households)
[20] We normalized the Y-axis to 100% to clearly indicate the delta's
[21] In (Technicolor, 2018) we witnessed an improvement of 24%

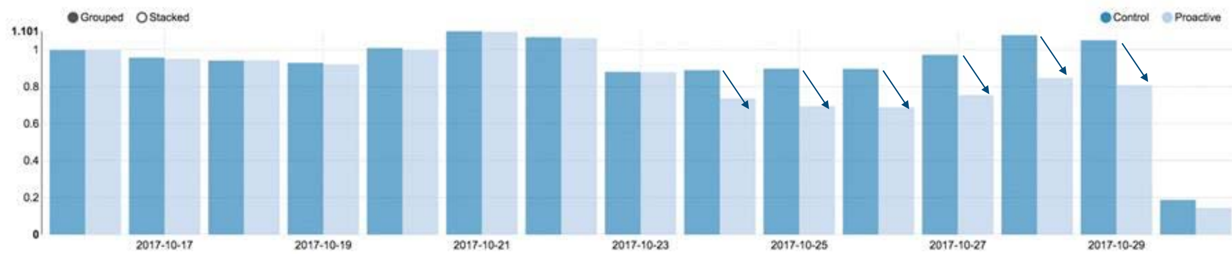

Figure 9 - Quantitative improvement of Wi-Fi QoE by means of RRM

Another way of demonstrating the value can be seen in Figure 10, where we have aggregated the amount of homes where the Wi-Fi QoE is optimal and suboptimal. This figure shows a comparison of the optimal QoE across several deployed ISPs and with clear indication whether RRM is activated or not. The results show a clear effect of enabling RRM across the several ISPs. The amount of homes with an optimal Wi-Fi QoE is in the range of 20% higher with RRM enabled.

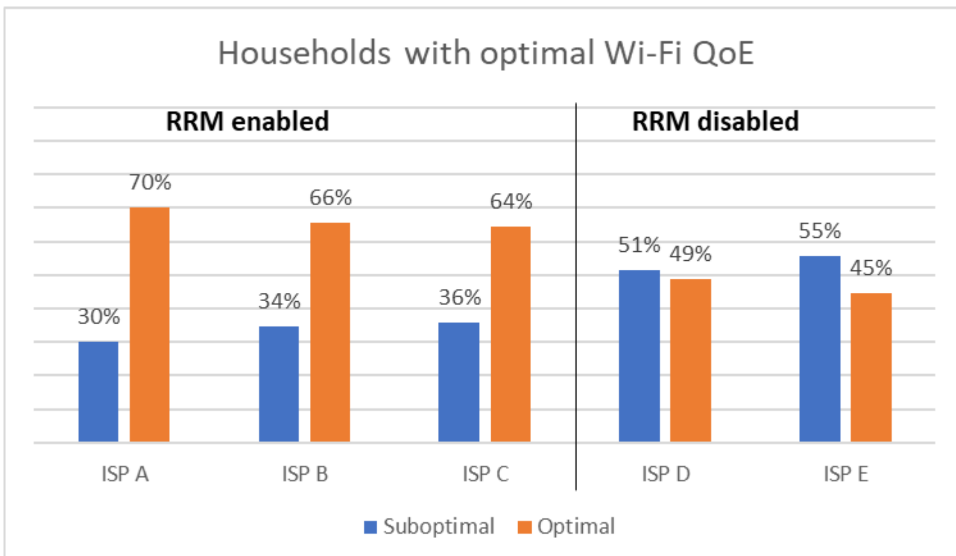

Figure 10 - The impact of RRM on optimal Wi-Fi across several deployments

With the arrival of extenders and mesh systems, the importance of an RRM function will only increase. The explosion of managed and unmanaged AP's in homes increase the usage of the Wi-Fi spectrum[22] and the presence of interference issues impacting Wi-Fi QoE. So, the numbers as shown in 8 will only increase the effect of proper RRM.

We did not cover yet the aspect of variations over time which adds another dimension in the complexity that needs to be considered. Wi-Fi issues in the interference category are in many cases intermittent in time. This means that certain interference sources appear and disappear in regular or even irregular intervals. An MDU, for example, will be largely empty during day time when people are at work, but will be very busy during the evenings and weekends. Hence the interference and disturbance that is generated by the inhabitants will show different patterns during the days vs the night. The same applies to office buildings but in the opposite time intervals. There, usage will be higher during the day but very limited in the evenings and weekends. Therefore, it is important that these RRM functions run at regular intervals as

[22] Even an AP that is not consuming BW from STAs has an impact on the Wi-Fi network

the bands and channels that need to be chosen will continuously change over time. This also requires that these RRM functions monitor the Wi-Fi environment on a continuous basis, so they can intervene whenever needed.

3.3. CAPEX Strategies

While many Wi-Fi issues can be attributed to interference and to saturation, both of which can be dealt with automatically and without the deployment of additional devices, some issues come down to a lack of coverage and require manual intervention: the deployment of better and/or more Wi-Fi access points.

The majority of the readers will immediately think of rolling out extenders to address this, however the reality is often different. First, an extender should not be sold/given to any/every subscriber. A massive advertising campaign about the new model of extender is not going to contribute to a substantially improved Wi-Fi QoE. As we demonstrated in paragraph 3.1.3, end users suffering from mainly or only interference and saturation will not be helped by installing an extender. On the contrary, their Wi-Fi QoE will get worse. If we look at (Technicolor, 2018) we can distinguish that only 33% of the installed base is benefiting from an extender. This is visible in Figure 11 where we looked at the full installed base and looked at the % of households where coverage issues could be solved by adding an extender.

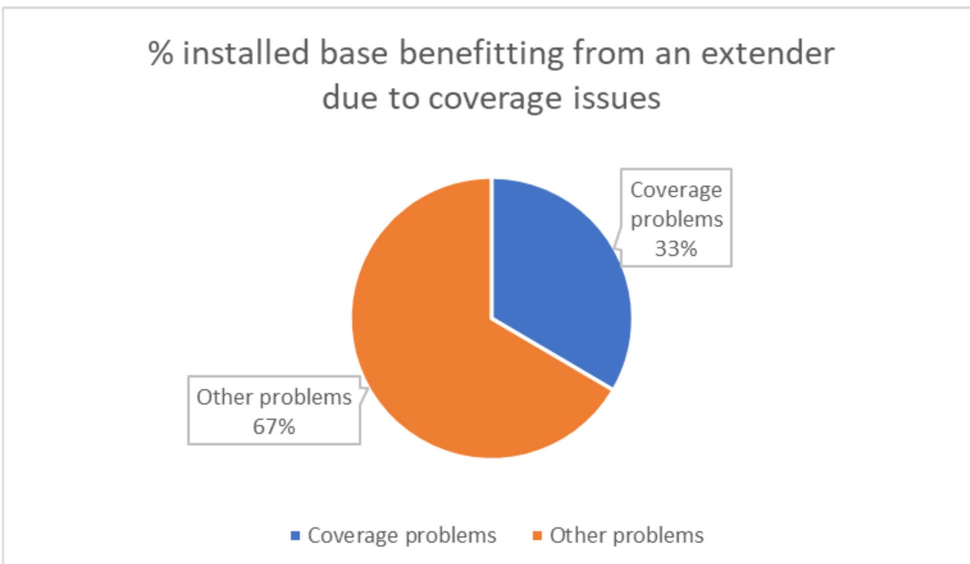

Figure 11 - % of installed base benefitting from an extender due to coverage issues

Second, it is better to first look at the existing installed base of AP's. Every year, Service Providers are struggling to identify how much CAPEX should be spent in replacing their legacy base of gateways/AP's. This is very costly, and the benefits are typically unquantifiable/unknown. With a clear root cause analysis of the Wi-Fi QoE issues, it can be identified which impacted subscribers will actually benefit from replacing their AP by a more recent and better performing one. This will lead to CAPEX savings due to a better replacement strategy, It also avoids unnecessary CAPEX that is spent on extenders that might not be needed anymore, once the main gateway is swapped out. In (Technicolor, 2018) we managed to prove that only 17% of the older installed based needed to be proactively swapped out to avoid Wi-Fi QoE issues. This leads to a saving of more than 80% on a budget to swap gateways in homes.

And finally, this stepped approach allows the Service Provider to have a more targeted and successful approach in deploying extenders. It not only saves CAPEX by supplying them only to consumers who have a need for them, but it also allows it to work in a more proactive way to eliminate churn. In current deployments, Service Providers have no other option than to push extenders to all subscribers through advertising and retail shops or wait until the customer calls the helpdesk with problems, or churns. With advanced Wi-Fi QoE analytics, Service Providers can proactively utilize a targeted approach that will decrease CAPEX and increase customer satisfaction.

3.4. Self-Installation

A step in the process that is often seen as obvious is the self-installation of Wi-Fi extenders. Reality however is different. Once shipping managed Wi-Fi systems to customers, either by sending extra AP's or even by sending a complete kit, the manner of install is, in many cases, not trivial.

In the majority of active deployments today Service Providers still use multiple SSID names and passwords for the different Wi-Fi bands on the main AP. When moving to a full managed Wi-Fi system there also needs to be a migration to a single SSID deployment. Albeit technically quite easy to do, in practice it is more difficult to execute. Customers might have installed devices on both bands or only one and you cannot just remove one of the SSIDs without informing the end user or risking that certain STAs don't connect anymore[23]

Next to that, a good self-install starts by giving subscribers a 'plug and play' experience that leverages smart industrial design and frictionless user interfaces. Onboarding procedures need to be designed to be simple and clear, so that even subscribers who are not technologically savvy will succeed. For the more "connected" subscribers, one could offer an intuitive smartphone application, and this could be complemented with voice control AI. Common scenarios for daily use (e.g. setting up a guest network) need to be made easy. Finally, all devices must be able to be managed remotely by the Service Provider.

3.5. Intelligent Client Steering

The last step in optimizing the Wi-Fi QoE is done by roaming STAs from one AP or band to another when certain criteria are met. In the industry, this is often the first topic that is interrogated, so why do we put this as the last topic in our quest for optimizing the Wi-Fi QoE?

The reason is quite straightforward and has already been mentioned a couple of times. Steering only brings benefits to certain type of issues, namely interference and saturation.

1. **Interference:** As we discussed already in paragraph 3.1.3, interference can have many root causes. Client steering can help in reducing immediate interference issues, but it can't completely solve them. When moving from one access point to another one (or to another band) the client steering mechanism relies on the fact that every AP has chosen its optimal channel. If not, you might jump or get steered to another AP that has similar, or even worse, issues. That is why it is imperative that this steering happens only after channel optimizations have been done through the RRM function. Client steering can indeed help to overcome sudden jumps of interference but then only for a little while till the RRM optimizes the overall situation again and this depends on his frequency and scalability

[23] In the case that a customer only had installed a 2,4GHz SSID on his phone and the 5GHz SSID is the one that was maintained after the migration, the station will not connect anymore to Wi-Fi as the STA does not have the right SSID and password configured

2. **Saturation:** Client Steering will help in addressing issues that are completely saturated by acting in two ways. First of all, it will spread STAs around the various access points and, even more importantly, around the various bands. This is called load balancing. Second, it can also take action in extreme cases by prioritizing certain traffic (eg. Video) over normal traffic in order to guarantee a certain QoE

In summary, client steering can bring further marginal improvement to the Wi-Fi QoE after all other, more significant optimizations have been done, to deal with more instantaneous and intermittent interference problems. It can also deal with saturation issues through load balancing and through prioritization of certain traffic types and use cases. This what we also call Intelligent Steering and is the cherry on the top of the cake. The important thing to note here is that this steering needs to be done to improve the Wi-Fi QoE proactively (and even reactively) and that this does not require any end user intervention. Especially that last part is essential. Due to various implementations on client devices such as smartphones, an intelligent steering solution needs to take care in how/when to do this with certain types of devices. Due to the STAs' own intelligent implementations, they often have their own preferences of where they want to connect[24]. When not being careful, this can lead to a user experience that is heavily impacted by trying to steer too frequently or quickly.

Let's illustrate this with a real-life example as depicted in Figure 12. Assume a home environment with two access points installed together with a Wi-Fi roaming solution that determines which AP is best for the STA to be connected to and that will ensure the STA is roamed to the correct AP when needed. The first AP (called AP1) is on channel 6 and the second AP is on channel 1[25]. As an STA we have taken an iPhone with IOS11 for this test. We have deliberately chosen this device as this is publicly known[26] to have an intelligent behavior when it comes to selecting the Wi-Fi networks it wants to be connected to.

In the starting position for the test the phone is connected to AP1 without any issues and with a more than decent RSSI. The user experiences no issues whatsoever. At a certain point in time (Step 2) there is an RF interferer arriving on the Wi-Fi channel 6 of AP1. This can typically be a hidden node as explained before which will be invisible to AP1 and will not trigger an ACS rescan[27]. A good roaming solution will detect this disturber and take immediate action to roam the STA away from AP1. Seen the fact that AP2 is in range of AP2 it will decide to roam the phone to AP2 (Step 3). The phone follows and connects to AP2 however the link is a bit worse in terms of RSSI because the phone is further away from AP2. But this is still better than being connected to the disturbed AP1. However, the phone does not know anything about this disturber on AP1 and only sees that AP1 has a better RSSI than AP2. Because of its implementation[28] the phone will disconnect from AP2 as the RSSI is below the threshold and will reconnect to AP1. The roaming solution will react and move the phone back again to AP2 (Step 4).

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[24] See (Chowdhry, 2017)

[25] For simplicity in explaining we assume to be using the 2.4GHz frequency band but the conclusions are equally valid on 5GHz or a mixture of both
[26] See (Apple, 2017)
[27] ACS rescan: the automatic channel selection of the AP when triggered will scan the environment and select an other and better Wi-Fi channel
[28] See (Apple, 2017)

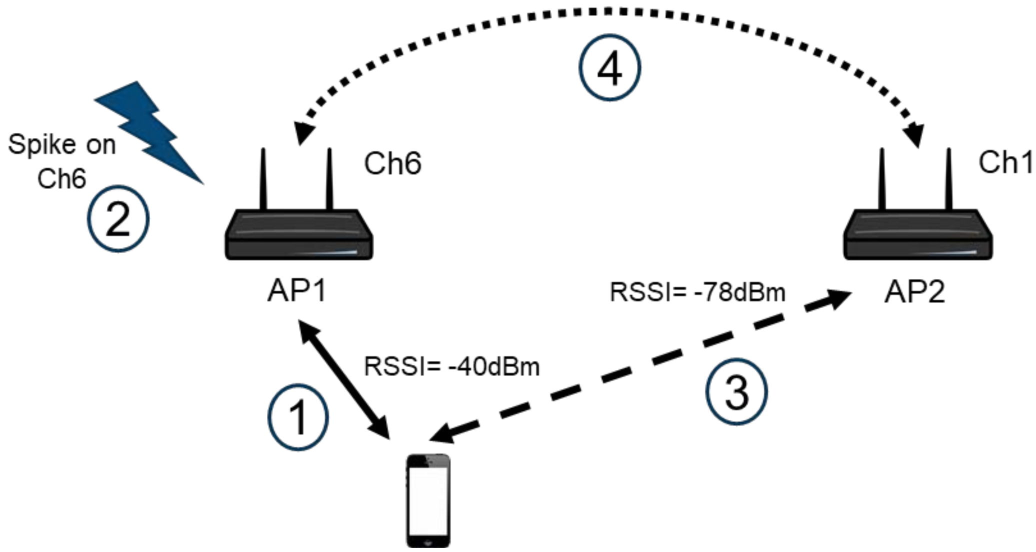

Figure 12 - Instable roaming behaviour

The implementation of the roaming solution will determine the reaction speed to roam the phone back to AP2 as well as the mechanism of roaming. The end-user experience is heavily dependent on it. The faster and more frequently the roaming solution will intervene the more interrupts the end-user will notice. If the mechanism is restricted to 802.11v this behavior will go on forever. The result is even worse when the roaming solution uses MAC ACL mechanisms[29] to deauthenticate the phone from the AP. In that case the phone will even decide that it is so bad and will never connect autonomously again to any of the two APs and instead revert back to the cellular network.

This test clearly demonstrates the unwanted effects of a roaming solution that does not take into account the specific implementations of STAs which are becoming more and more intelligent. Not doing so can result in a very bad user experience.

Conclusion

In this paper, we demonstrated that a 5-step approach[30] to proactively and reactively tackle Wi-Fi QoE dramatically improves the situation. If we look back at the distribution of categories we introduced in Figure 1, each of our 5 steps contribute, in a coordinated way, to reducing Wi-Fi QoE issues as depicted in Figure 13. This figure illustrates when the necessary root causes have been identified (Step 1), proactive channel planning both in the home and in the neighborhood, work on the interference category. CAPEX strategies mainly have an impact on radio path issues and client steering can diminish the remainder of Wi-Fi QoE issues in all categories.

[29] MAC ACL is well known in Wi-Fi and is a access control list containing the MAC addresses of devices that are allowed to connect to the AP and which ones are blacklisted and can't connect to the AP. When using a MAC ACL mechanism to roam this means that the roaming solution will throw off the STA from the AP and then put the MAC address of the STA on the blacklist of the MAC ACL hence prohibiting the STA to connect back to the AP.
[30] See Figure 4

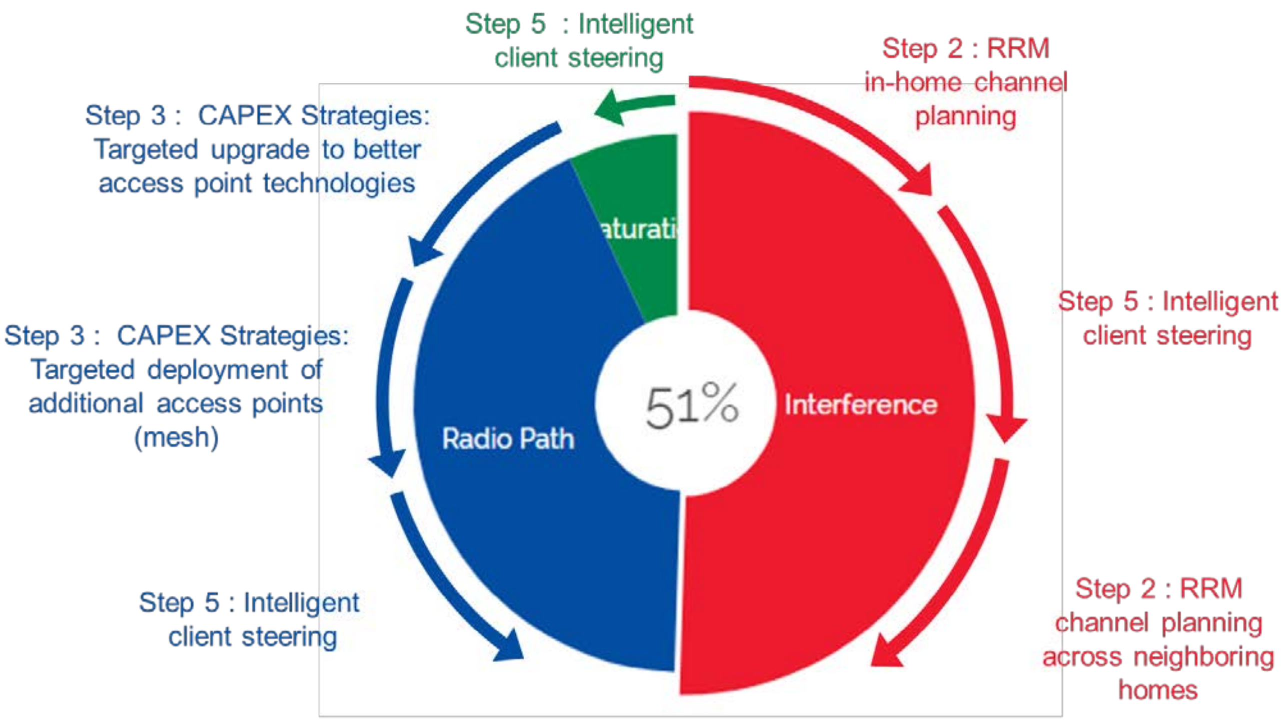

Figure 13 - How the different steps help in reducing the Wi-Fi QoE

The impact on CAPEX and OPEX expenditures are massive. Experience in deploying this Wi-Fi QoE wheel demonstrates that savings can be made in a variety of areas (Technicolor, 2018)

- Reduction in % of first calls: up to 30%
- Reduction in % of repeat calls: up to 40%
- Reduction in the amount of unidentified Wi-Fi issues: up to 90%
- Increase in the amount of first call resolution
- Reduction in the call duration
- Reduction in the amount of truck rolls
- Reduction in the amount of CAPEX spent in box swaps
- Reduction in the amount of CAPEX spent on extenders

The most important thing that is increased is the amount of customer satisfaction and the NPS (Net Promoter Score).

Abbreviations

AP	access point
SP	Service Provider
CAPEX	Capital Expense
OPEX	Operational Expense
SSID	Service Set Identifier – another name for the name of your Wi-Fi network
RRM-SON	Radio Resource Management – Self Optimizing Networks
QoE	Quality of Experience
RSSI	Received Signal Strength Indication
ACS	Automatic Channel Selection
BW	Bandwidth
MDU	Multi-Dwelling Unit
NPS	Net Promoter Score
STA	Station
MAC ACL	Medium Access Control Access Control List
ISP	Internet Service Provider

Bibliography & References

Apple. (2017, November 8). *macOS wireless roaming for enterprise customers*. Retrieved from Apple Support: https://support.apple.com/en-us/HT206207

Chowdhry, A. (2017, July 26). *Apple iOS 11 Is Going To Fix A Pesky Wi-Fi Issue*. Retrieved from Forbes: https://www.forbes.com/sites/amitchowdhry/2017/07/26/wi-fi-auto-join/#7aae030e73cf

Technicolor. (2018). Data taken from a 2.5M live deployment of households.