AMBEENT

Wi-Fi Console:
A Step for Global Orchestration of the Spectrum

WHITE PAPER

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Executive Summary

With COVID-19 stay-at-home restrictions, millions around the globe have had fast and reliable broadband become their lifeline for work, education, socialization, and entertainment.

Managing the quality of broadband experience in the home is more than ever a priority for service providers, and Wi-Fi is at centerstage of that effort. Wi-Fi utilizes unlicensed spectrum that is of great economic value to society, but it comes at the price of uncertain performance. Generally, what happens in unlicensed bands lacks visibility and is thus hard to manage or prevent because we don't know what to be looking for.

In this paper, we describe neighbor interference as one of the drawbacks of the unlicensed spectrum and how the mix of devices operating in this environment degrades the performance for everyone. Often neighbors end up using the same channel creating an avoidable congestion.

So far, the main approach to solving the indoor Wi-Fi performance has been driven by the integration of additional software in the middleware gateway in hopes to address the issues of coverage and congestion. However, this approach has fallen short of operators' needs as they have to deal with a complex and diverse footprint of access points. **Hence, time-to-market is severely long and not scalable.**

Ambeent proposes a novel, device-centric way to identify and solve Wi-Fi related problems. This approach is collaborative, empowering users to take their Wi-Fi destiny into their own hands and freeing up service providers from a complex and lengthy integration process. It is also a mobile-managed approach, combining both the power of cloud-based computing and artificial intelligence with the simplicity and elegance of a device application. **More importantly, addresses and consolidates all sizes of Wi-Fi networks in a scalable way.**

We present the various features of this agile solution and how it can benefit networks in various deployment scenarios for the home, hospitality, shopping malls, ISPs, and OTTs.

While 5G will support unlicensed and shared spectrum, Wi-Fi has been moving in the other direction, taking on many characteristics of cellular technologies—such as enhanced quality of service (QoS), security and automatic frequency coordination (AFC). .

As the lines between licensed and unlicensed spectrum blur, Wi-Fi will evolve alongside cellular and be part of the broader 5G platform, bringing 5G-like capabilities to non-spectrum owners (speci ically, cable operators, city authorities, or private network providers, among others).

Network operators are looking for ways to become more agile in order to compete. And as functions are becoming virtualized, consumers will be able to select their own 5G applications on demand. Ambeent is positioned to deliver just that with its Wi-Fi spectrum orchestration as a service (SaaS). In about a year or two, the industry will start locking down 6G technologies, where spectrum agility will form the basis of the new standard.

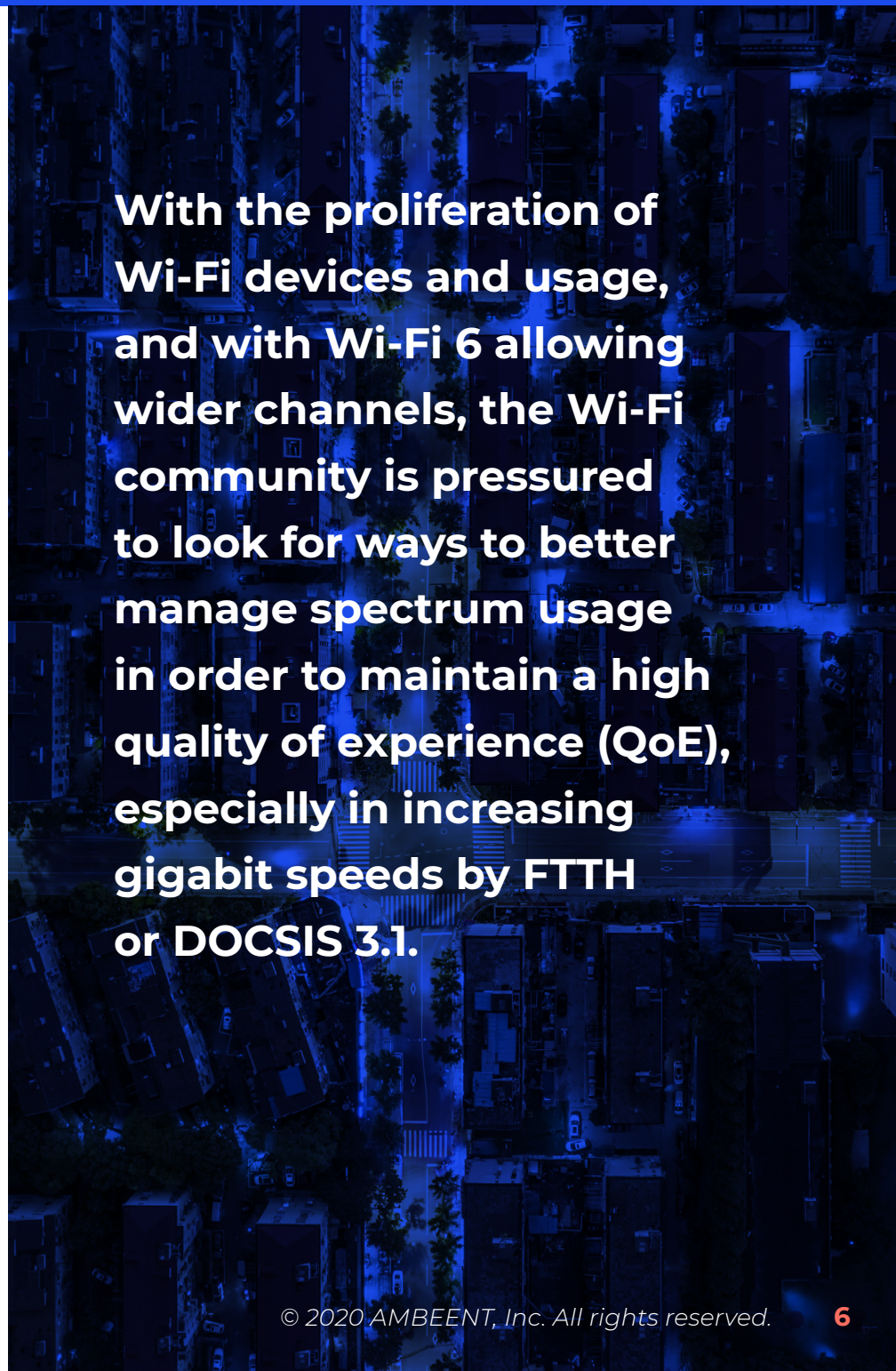
The Spectrum Issues

Unlicensed Spectrum is Unknown Unknown

Unlicensed spectrum is small sections of the radio spectrum in which anybody is allowed to transmit, up to a limit in power, without needing to apply (or usually pay) for a radio operator's license and today the economic value of unlicensed spectrum tops $525B[1].

Wi-Fi is a classic incumbent. Two bands have been allocated at 2.4 GHz and 5 GHz in which anyone is allowed to transmit at no more than 1 watt of power. Wi-Fi can work well as long as everybody observes the rules. However, given the free and decentralized nature of the unlicensed spectrum, many things can go wrong and affect the overall performance of the system. Use of unlicensed spectrum is subject to interference, coverage issues, and poor performance. Generally, what happens in unlicensed bands lacks visibility and is thus hard to manage because we don't know what to be looking for.

[1] *Source: https://medium.com/@WifiForward/new-report-economic-value-of-unlicensed-spectrum-in-the-u-s-tops-525-billion-a8b12dff9046*



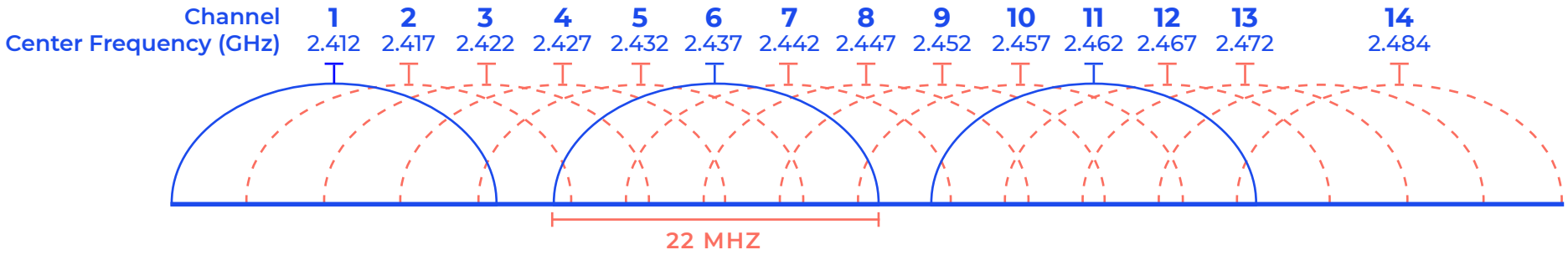
With the proliferation of Wi-Fi devices and usage, and with Wi-Fi 6 allowing wider channels, the Wi-Fi community is pressured to look for ways to better manage spectrum usage in order to maintain a high quality of experience (QoE), especially in increasing gigabit speeds by FTTH or DOCSIS 3.1.

2.4 GHz

In the 2.4 GHz band, 1, 6, and 11 are the only non-overlapping channels. Selecting one or more of these channels is an important part of a correct set-up of a home network. Currently, many wireless routers automatically select the channel upon the initial setup where, depending on the specific wireless environment, could lead to low Wi-Fi speeds and interference. The 2.4 GHz band is divided into fourteen overlapping channels spaced 5 MHz apart and three non-overlapping channels. (See below.)

While older-generation access points that support only 2.4 GHz are becoming increasingly less common, they are still deployed and can cause issues for operators, i.e., their residential customers can experience a high level of interference and quality issues. Specifically, the 2.4 GHz is reported to be "polluted" by noise coming from all kinds of non-Wi-Fi devices, such as microwave ovens, cordless phones, and printers. Therefore, users are encouraged to upgrade to dual band 2.4 and 5 GHz access points where 2.4 GHz would mainly be used to expand the coverage.

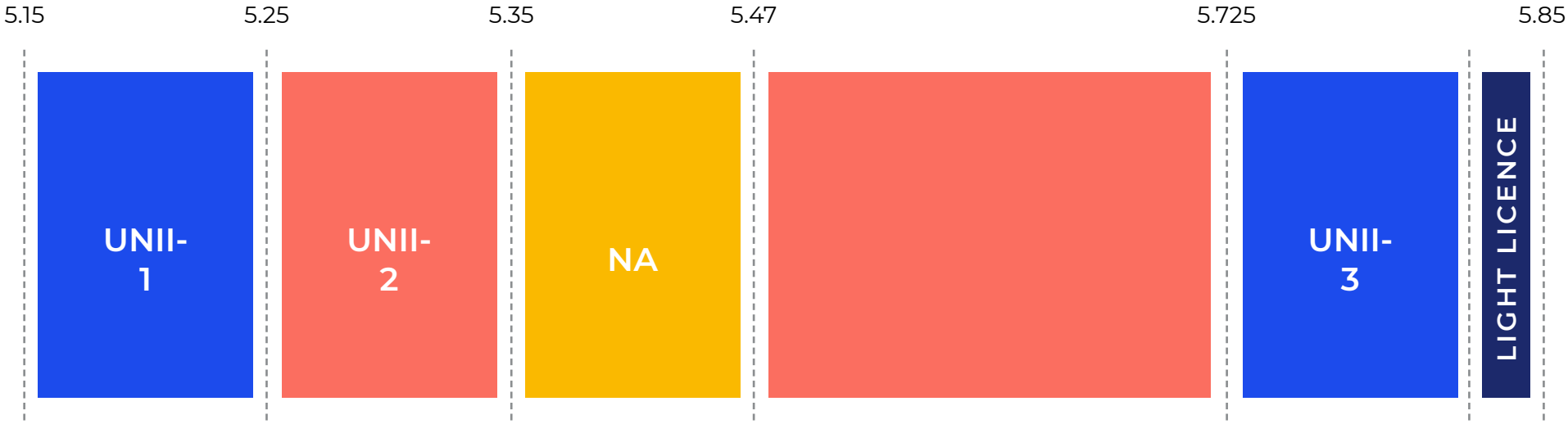
Figure 1: Channels of the 2.4 GHz Band



5 GHz

As the 2.4 GHz band becomes more crowded, many users opt to use the 5 GHz ISM band. This band not only provides more spectrum, but is not as widely used by Wi-Fi and many other appliances (again, such as microwave ovens, etc.). While Wi-Fi is expanding into new spectrum through sharing of the new 6 GHz (USA), other technologies will move into 5 GHz. License-exempt systems that may increase the pressure on 5 GHz include industrial control systems and 5 GHz implementations of LTE (such as Multefire).

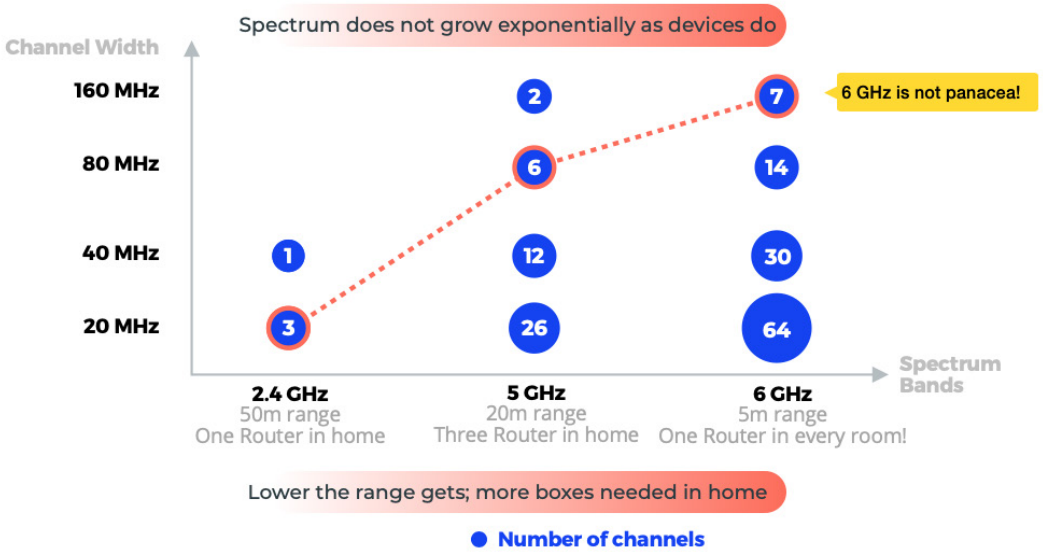
Figure 2: 5 GHz Spectrum Sub-Bands



The middle part of the band—5350-5470 MHz (UNII-2B)—appears to be closed to Wi-Fi. A number of other users—e.g., earth observation satellites, government radars, and drone communications—have made strong claims for this band.

The high end of the band—from 5725-5850 MHz (UNII-3)—is allowed in the U.S. There are signs that other regulators may open up this band; specifically, OFCOM in the U.K. is moving in this direction. The incumbents here are satellite-fixed links.

At the end of the 5 GHz band—from 5850-5925 MHz—there are opportunities for more Wi-Fi usage. This spectrum was reserved ten to twenty years ago by U.S. and European regulators for vehicle-to-vehicle and road tolling communications. Since there are safety and economic aspects to these uses, the end of the 5 GHz band was made a dedicated band, and protocols were developed under IEEE 802.11 for Dedicated Short-Range Communications (DSRC) as a variant of Wi-Fi. However, auto manufacturers have been very slow to roll out equipment, so the Wi-Fi industry has gone back to the regulator to check if there are opportunities to share this band and use it for Wi-Fi in those places where DSRC is not active. This process is still in its early stages, so it remains to be seen if there are some sharing opportunities here.

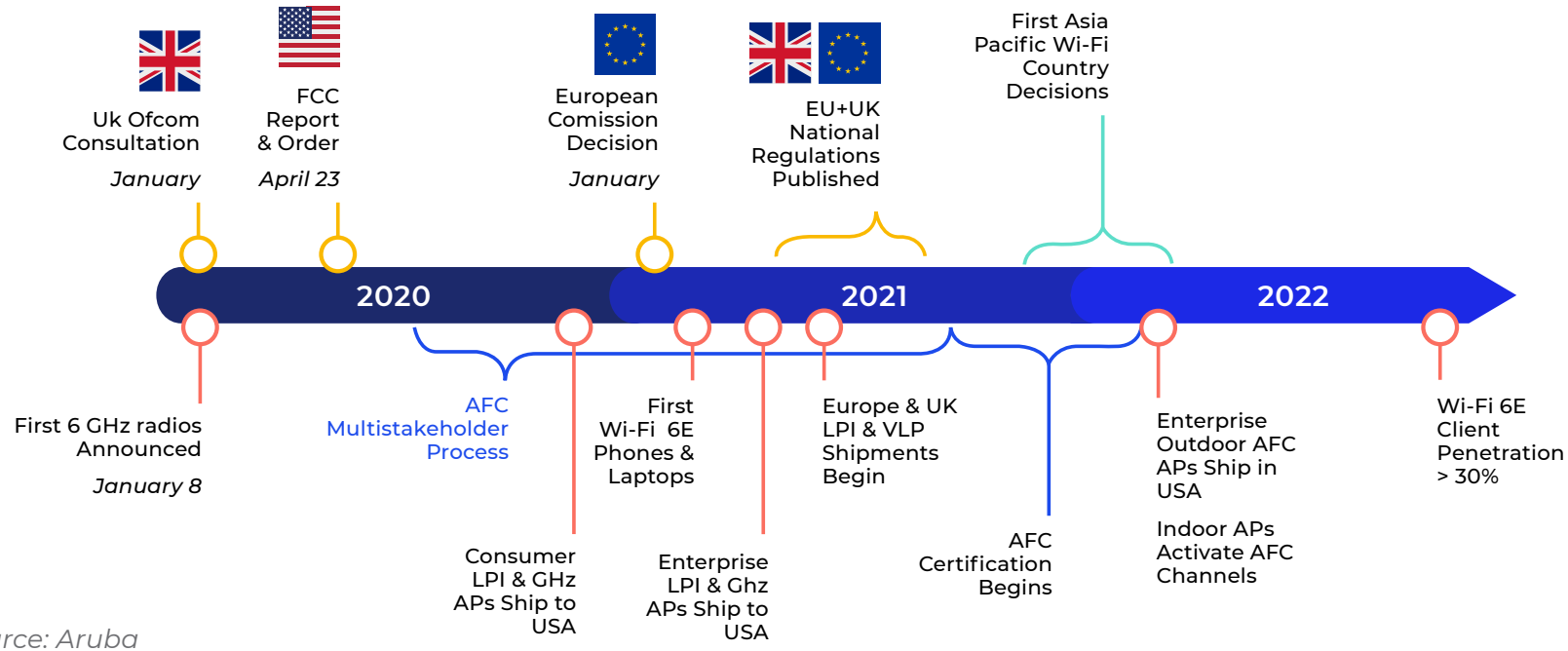


6 GHz

Unlicensed access to the 5.925 – 7.125 GHz band—referred to as the 6 GHz band—is particularly important to the future of Wi-Fi innovation. At the beginning of this year (2020), the Wi-Fi Alliance announced new branding of Wi-Fi 6E in reference to the spectrum extension to the existing Wi-Fi 6 standard capable of supporting all-new 6 GHz frequencies (5.925-7.125 GHz).

On April 23, 2020, the Federal Communications Commission made the opening of 1200 MHz official for use by unlicensed devices in the 6 GHz band (5.925-7.125 GHz). The rules are designed to allow unlicensed devices, such as Wi-Fi, to operate in the 6 GHz band without interfering with the operation of the licensed services which will continue to use this spectrum.

Figure 3: 6 GHz Rollout Timeline



Source: Aruba

The 6 GHz band is currently set aside for licensed users, including carriers and Mobile Virtual Network Operators (MVNOs) who have deployed thousands of point-to-point microwave links to backhaul network traffic. Lightweight management of spectrum usage in the band through a spectrum controller will allow unlicensed and licensed users to co-exist, maximizing spectral efficiency.

The FCC decision nearly triples the amount of spectrum available for Wi-Fi and allows so-called "Low Power Indoor" (LPI) operation right across the 6 GHz range of frequencies. The extreme width of the band means there will be space for a total of seven 160 MHz channels. Routers will have wider channels to work with to accommodate more devices at higher throughput rates.

Figure 4: 6 GHz Sub-Bands

Device Class	Operating Bands	Maximum EIRP	Maximum EIRP Power Spectral Density
Low-Power Access Point and Subordinate Device (indoor only)	**U-NII-5** (5.925-6.425 GHz) **U-NII-6** (6.425 - 6.525 Ghz) **U-NII-7** (6.525 - 6.875 Ghz) **U-NII-8** (6.875 - 7.125 Ghz)	20 MHz: 18 dBm EIRP 40 MHz: 21 dBm EIRP 80 MHz: 24 dBm EIRP 160 MHz: 27 dBm EIRP 320 MHZ: 30 dBm EIRP	5 dBm/MHz
Associated Client Device		20 MHz: 12 dBm EIRP 40 MHz: 15 dBm EIRP 80 MHz: 18 dBm EIRP 160 MHz: 21 dBm EIRP 320 MHZ: 24 dBm EIRP	-1 dBm/MHz

Source: Broadcom

Automatic Frequency Coordination (AFC)

In order to protect the incumbent operators in the 6 GHz—i.e., microwave links from MNOs, utilities, public safety, and transportation, as well as broadcast auxiliary service and cable television relay service—the FCC requires the use of an automatic frequency selection.

Unlicensed use of the 5925-6425 MHz and 6525-6875 MHz sub-bands will be subject to control by an automated frequency coordination (AFC) system, described further below, while unlicensed use of the other two sub-segments is proposed to be limited to lower-power and indoor-only use without the need for database coordination.

Figure 5: AFC Regulations

Device Class	Operating Bands	Maximum EIRP	Maximum EIRP Power Spectral Density
Standard-Power Access Point (AFC Controlled)	**U-NII-5** (5.925-6.425 GHz	36 dBm	20 MHz: 23 dBm/MHz 40 MHz: 20 dBm/MHz 80 MHz: 17 dBm/MHz 160 MHz: 14 dBm/MHz 320 MHZ: 11 dBm/MHz
Associated Client	**U-NII-7** (6.525 - 6.875 Ghz)	30 dBm	20 MHz: 17 dBm/MHz 40 MHz: 14 dBm/MHz 80 MHz: 11 dBm/MHz 160 MHz: 8 dBm/MHz 320 MHZ: 5 dBm/MHz

Source: Broadcom

Because the incumbent services in U-NII-5 and U-NII-7 bands are fixed, the FCC proposes to allow unlicensed use at standard power outdoors and indoors subject to an AFC system. The agency "envision[s] the AFC system to be a simple database that is easy to implement."

AFC exists primarily for outdoor applications but will also apply for higher power indoor usage such as in large warehouses or residential multi-dwelling units. Access points will require a geolocation technology and some way to communicate to the AFC outside of the protected bands. The AFC will be required for indoor higher-power operation above LPI limits and indoor higher-power mobile clients.

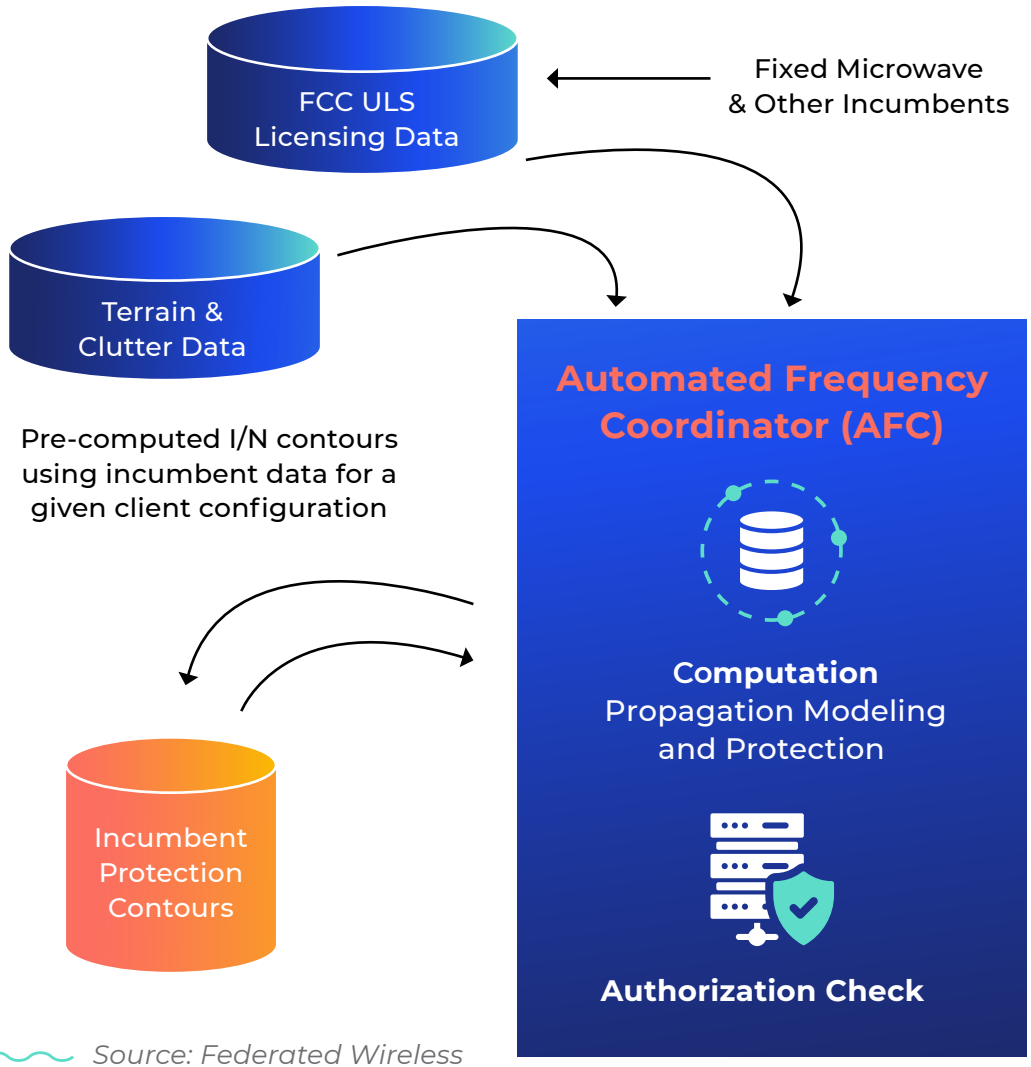
Incumbent Point-to-Point microwave links and FSS earth stations are fixed, highly directional, and seldom change location or operating parameters. Like the TV Bands Database, the AFC "System Operator" is simply enforcing protection zones around static incumbent links based on incumbent-provided licensing data that will be continually updated. A grant to operate a Wi-Fi access point at a location is therefore a one-to-one calculation that is easily verified based on incumbent data.

The AFC system operator will regularly update information on incumbent receivers stored in databases maintained by the FCC, which it will use to automatically calculate and enforce protection contours sufficient to protect Point-to-Point links, denying requests to operate where the Radio LAN's emissions exceed an interference threshold into any individual incumbent link. Automated frequency coordination allows incumbent services to add sites or modify their networks, since FCC databases will continue to be updated by incumbents as they do now, and Radio LAN channel permissions expire automatically if not renewed within a period provided in the FCC's rules.

Figure 6: How AFC Works

Automated Frequency Coordinator (AFC)

Cloud Automation for 5 GHz Sharing



Source: Federated Wireless

Operation

- The AFC calculates an Incumbent Protection Contour around every incumbent receiver based on Licensee and shared access Device operating data
- The AFC protects against interference from both the Device and its Clients by calculating a Service Area
- Permissible operating channels are those where the Service Area does not collide with any Incumbent Protection Contours

The FCC is expected to finalize the rules for 6 GHz unlicensed operation this year, with a number of countries in the European Union and in Asia expected to follow suit by 2022. However, the EU will not allow outdoor operations, as most EU countries do not publish their spectrum use databases for national security or confidentiality reasons. Canada is expected to largely adopt the FCC rule.

Private 5G networks will also be contenders for that band. As CBRS is deployed for LTE, the concept of spectrum sharing will extend to new bands and use cases. Ambeent solution can also be deployed for private 5G/6G networks of the future to mitigate interference in shared spectrum bands.

Wi-Fi Experience is Unknown Knowns

Wi-Fi is the most-used technology to connect indoors—both in the home, the office and even in public spaces such as shopping malls. When Wi-Fi performance is compromised, users become frustrated and look for ways to fix the problem.

Wi-Fi experience can vary a lot and be subject to many environmental factors, such as congestion, noise, and interference. Typically, users and even the operators themselves are unable to identify the sources of poor Wi-Fi performance.

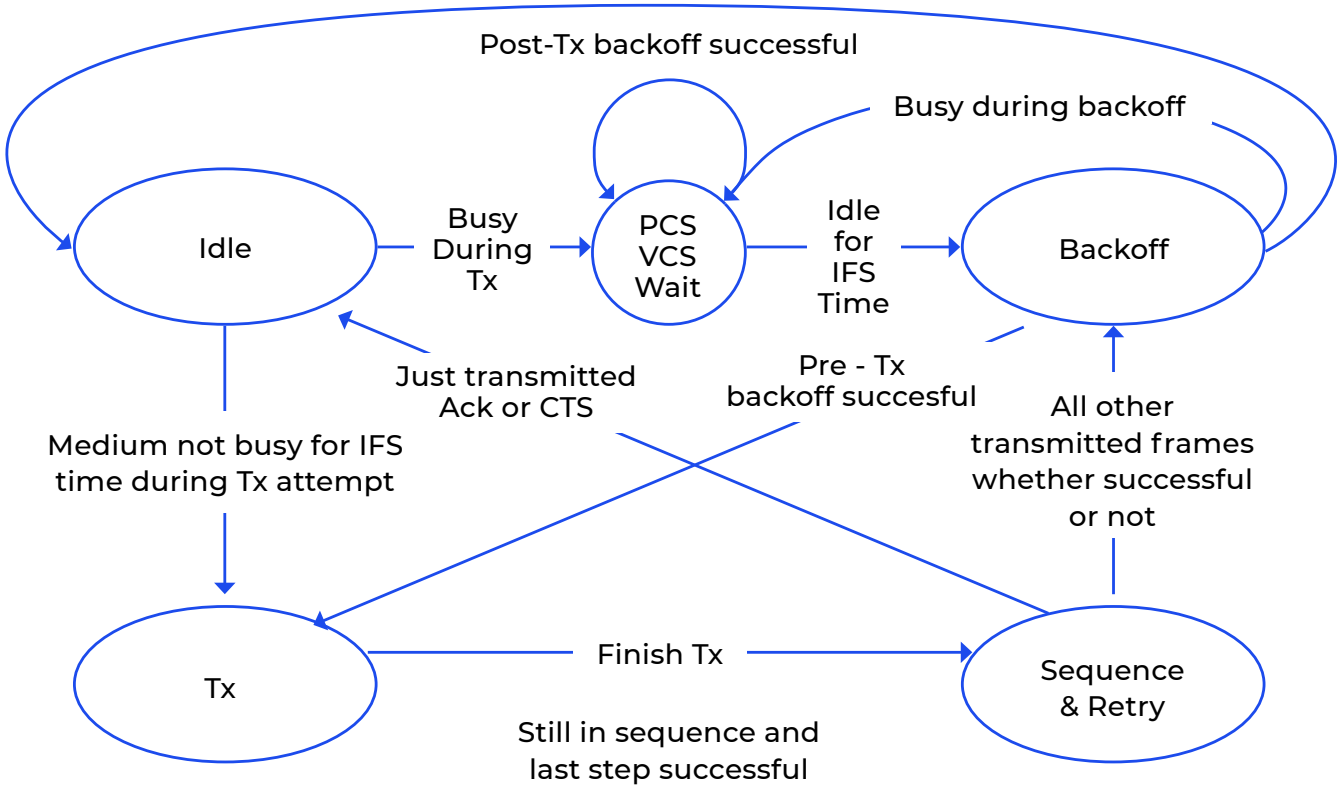
Top factors affecting Wi-Fi performance include poor CPE (Customer Premise Equipment) placement, neighbor interference, dead zones due to the layout of the home, and presence of too many legacy devices operating exclusively at 2.4 GHz.
Wi-Fi experience is plagued with unknown knowns, that is “things we understand but are not aware of,” things that include signal strength, neighbor interference, loads of connected devices, interference from non-802.11 devices, etc.

	Known Knowns	Known Unknowns
General Concept	Things we are aware of and understand	Things we are aware of but don't understand
Wi-Fi Context	Wi-Fi PHY and CSMA/CA protocol are well understood (Note 1) but to make Wi-Fi experience more predictable requires proactively managing the most likely problems	Exact signal propagation characteristics are impossible to predict in a given environment; we can only model the natural physical complexity
	Unknown Knowns	**Unknown Unknowns**
General Concept	Things we understand but are not aware of	Things we are neither aware of nor understand
Wi-Fi Context	Wi-Fi RF characteristics are well known but Wi-Fi experience is susceptible to many things going wrong— such as signal strength, neighbor interference, loads of connected devices, etc.	Use of unlicensed spectrum is subject to interference, coverage issues and poor performance. Generally, what happens in unlicensed bands lacks visibility and is thus hard to manage because we don't know what to be looking for.

Note 1: Carrier-Sense Multiple Access with Collision Avoidance

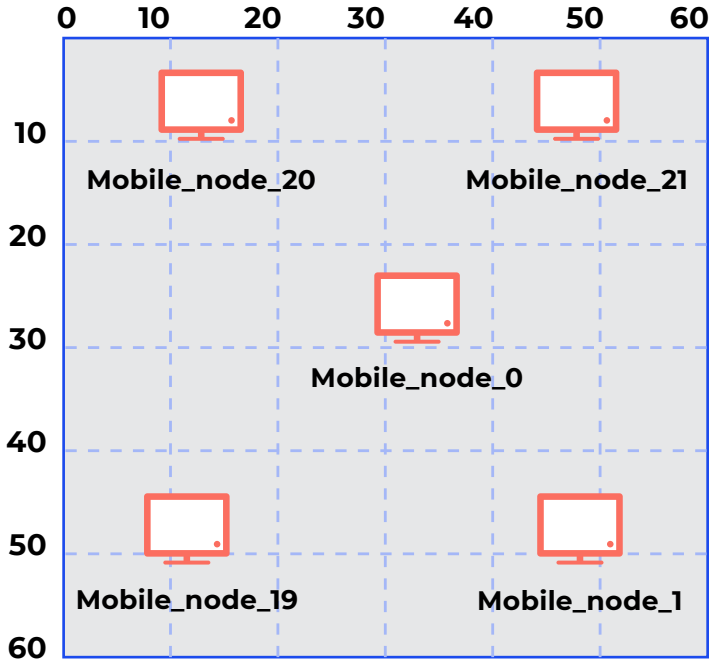
A Detailed View of Neighbor Interference

Performance of an 802.11 network degrades when some stations use a lower data rate than the others. This is common in a network environment since there is a wide variety of Wi-Fi AP generations in use and clients utilize adaptation mechanisms to select a data rate. If the link to the destination is under severe fading and interference, the adaptation mechanism reduces the rate by changing its modulation scheme. Data rate adaptation mechanisms are proprietary and may consider successfully received ACKs or signal-to-noise ratio (SNR). The reason why throughput degrades is hidden under the basic CSMA/CA channel access method[2] and easy to see from the Markov model depicted below.

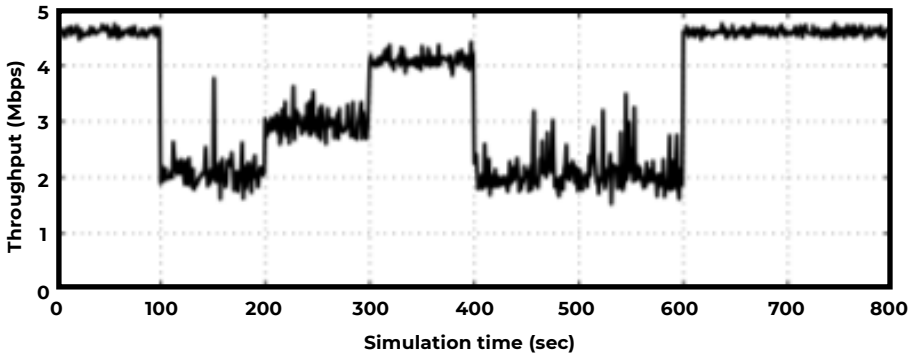


[2] https://ptolemy.berkeley.edu/projects/ofdm/ergen/docs/ergen_PhD.pdf

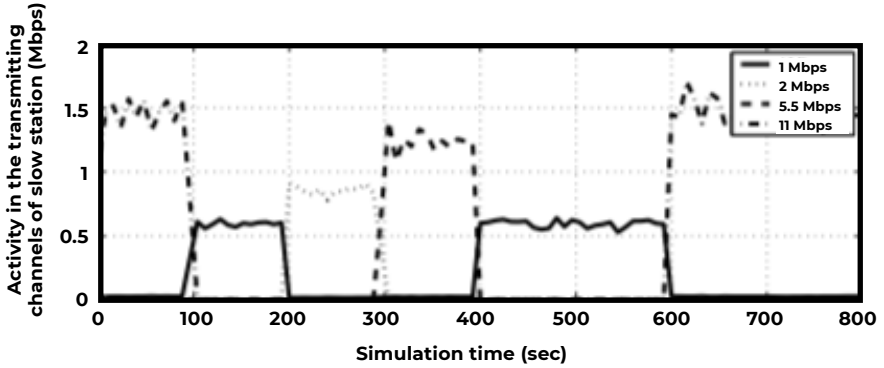
If a station acquires the transmission opportunity, it uses it as long as it is needed. As a result, if a station operates with a lower data rate, airtime used is longer than needed with the same payload. Hence, the channel is not used optimally, reducing the overall performance of the network.



Here we show a simulation in OPNET with a network of five nodes, all with 11 Mbps data rate, but one of them changes its rate with time as a control node.

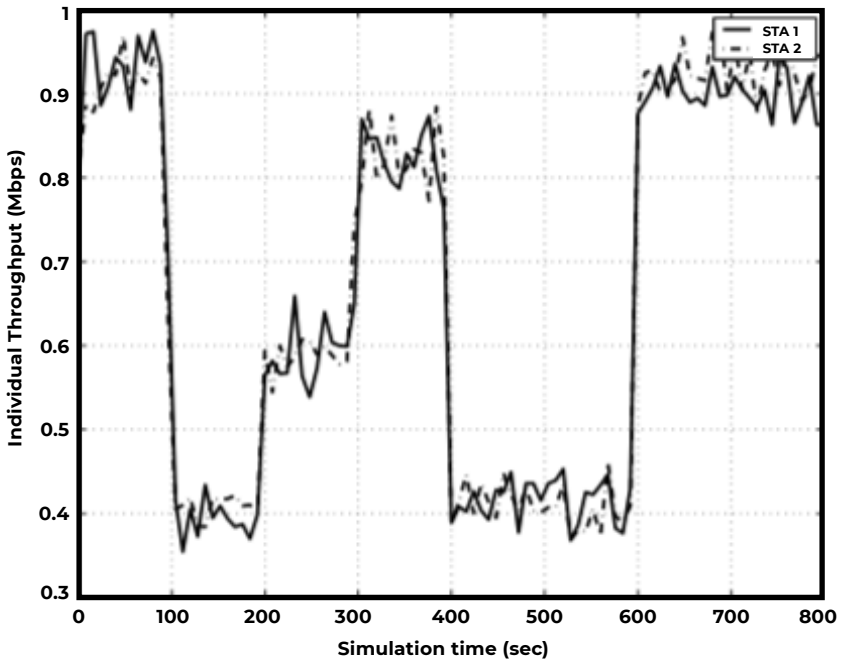


The plot shows the total throughput of the network.



The plot from the above figure shows the activity of the station that changes its data rate. The station starts with 11Mbps data rate, and at t=100sec, drops down the rate to 1Mbps until t=200sec. Between 200sec and 300sec, the station operates at 2Mbps and for the next 100sec it operates at 5.5 Mbps.

Between 400sec and 600sec, the station again operates at 1Mbps and after 600sec, the station is at 11Mbps. As can be seen a lower data rate severely affects the performance of the network; a single station with 1 Mbps decreases the total throughput by half. This kind of data rate mix is very common in a typical network since stations can change their data rate: or it can be limited by the mix IEEE 802.11 standards in use due to backward compatibility.



The left figure, on the other hand, shows another key characteristic that contains only two individual throughputs for fixed and varying stations. We can infer that stations observe the same individual throughput. Hence, stations with higher data rate observe the same throughput with the slow station.

Making Wi-Fi Experience Known Knowns

In order to reduce the number of Unknown Knowns, operators need tools to gain more visibility into their managed home Wi-Fi networks by introducing a spectrum broker which provides the needed orchestration of bands and channels when and where needed.

Ambeent introduces a device-centric and collaborative mechanism as **the only Inter-Home Wi-Fi Performance Solution in the market**. It provides a substantial amount of flexibility that can optimize the Wi-Fi experience based on importance of user activity, such as business calls, online classrooms,

etc. This quality-enhancing solution can be used in homes, as well as other important locations, such as hospitals, shopping malls, multi-story buildings, skyscrapers, hotels, etc.

Ambeent's solution encourages both end users and operators to unleash the maximum potential of Wi-Fi and increase Internet speed.

Ambeent offers a unique platform based on cloud and artificial intelligence to bring order and dynamism to chaotic unlicensed spectrum among all sizes of Wi-Fi networks. Ambeent technology can reach hundreds of millions of access points to optimize the performance of Wi-Fi worldwide, and provide instant solutions for consumer, enterprise, and telco Wi-Fi users.

	App on Device	Agent on Access Point / Gateway Required?	Cloud Dashboard	Data Collection	Inter-Home Wi-Fi Collaboration
Ambeent	Yes	No	Yes	**Data directly from users- devices**	Yes
Others	Yes	Yes	Yes	**Only access point data**	No

Features of Spectrum Orchestration

Ambeent aims at enabling collaborative processing of the Wi-Fi performance data and introduces a web service called Wi-Fi Console to bring all sizes of Wi-Fi networks into the umbrella. The console can be activated easily for home, enterprise, telco, and OTT customers. Once signed up[3], a group code is generated and used to link devices. This code is entered into the client apps in order to link the data coming from device to a specific console. A client can either download the Ambeent WiFi Console App through an SDK on the device or through Google Play or Apple App Store.

[3] enterprise.ambeent.ai

The Ambeent Wi-Fi Console provides a user-friendly dashboard with the key performance indicators (KPIs) that IT departments of operators, hotels brands, or businesses care about in order to be able to monitor the health of their or their customer's Wi-Fi networks. Those KPIs include:

Figure 7: Wi-Fi Console Dashboard 1

Source: Ambeent Inc.

Key Features

1. **Active Users** represent the number of devices that are active in the network. This metric provides a high-level view of how crowded the network is at a given point in time or will be in the future.

2. **Routers Detected** represents the number of neighboring SSIDs (service set identifiers) that the application detects through the scanning of neighboring access points. This can be a good indicator of how busy the RF environment is (or will be) in a given area and a period of time.

3. **Measurements** are the number of scans sent to the cloud, including neighboring SSIDs, speed test, and latency.

4. **Fidelity** is based on the signal-to-noise ratio (SNR) and compares the level of the Wi-Fi signal to the level of neighboring interferers.

5. **Speed Test** measures the end-to-end throughput from your device to our specific server.

Figure 8: Wi-Fi Console Dashboard 2

Source: Ambeent Inc.

6. **Data Rate** provides the maximum physical layer rate (theoretical value) that your device is allowed to transmit data at a given instance. However, in the real world, there will be interference and losses which will result in a lower bit rate. The throughput can be seen as a practical value that the wireless link can achieve.

7. **Wi-Fi Health** combines how well your router is placed and how much coverage capacity your router has.

8. **Router Placement** is how well your router (CPE – Customer Premise Equipment) receives its signals.

9. **Coverage** indicates whether you have shortage in coverage or not.

10. **Wi-Fi Speed** is the estimated throughput between your device and your modem/router.

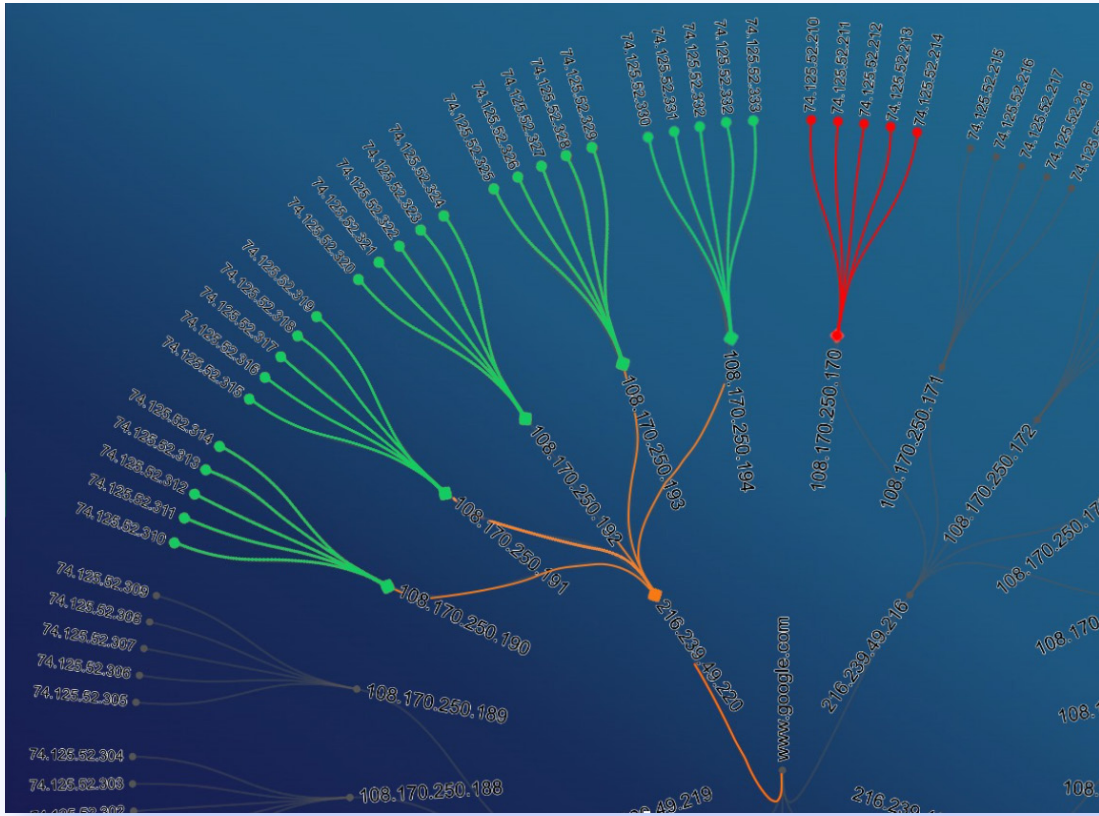
11. **Local Latency** represents the delay between your device and your router.

12. **Number of Connected Devices** indicates how many Wi-Fi devices are connected to your router at a given moment.

Connectivity—First, Wi-Fi, or Wired Problem?

Console collaboratively monitors the end-to-end connectivity and makes sure there is no black hole in the network and the transit path works flawlessly. Ambeent system tracks the bottle-necks in the path and performs also BGP[4]/MPLS troubleshooting from the customer side and makes sure the prefix propagation is across the network. Ambeent also classifies the IP blocks and benchmarks the hops by grouping the subscribers. There are cases when the Internet is down in the backhaul, and many customers attempt to spoil the CPE parameters.

Figure 9: POP and IP Block Monitoring in the Backhaul from Device



Source: Ambeent Inc.

[4] Border Gateway Protocol (BGP)

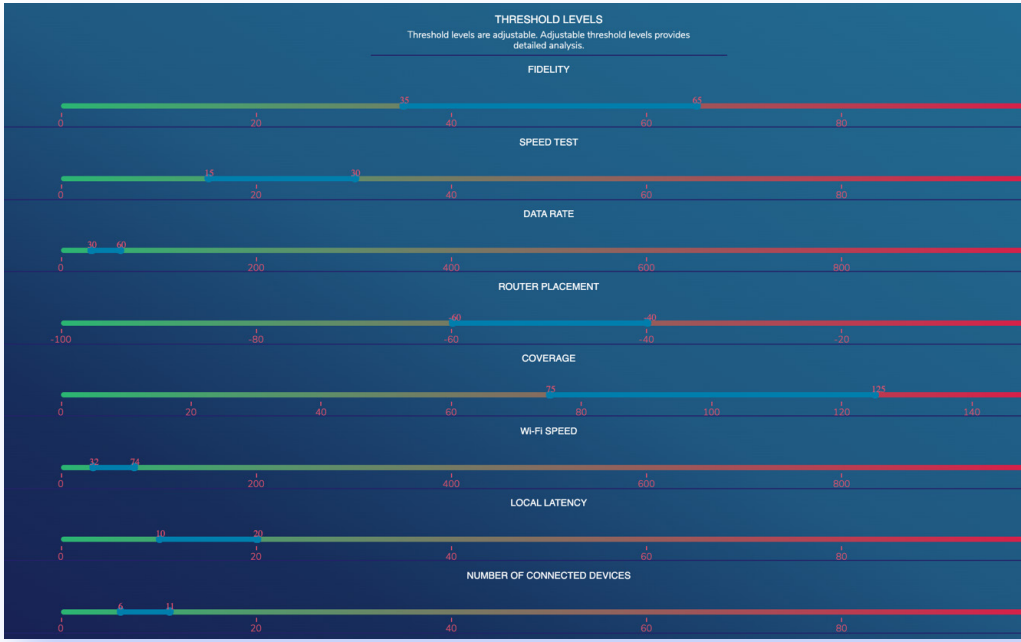
Details

Customer insight is provided as a subscriber-dashboard and with appropriate APIs to be integrated into the customer's CRM. Subscriber-dashboard is a first-stop for the contact center operation to provide insights, as well as AI-based recommendations such as "Your position is good for web browsing but not for Zoom!" or "You have coverage holes, better to upgrade to mesh!" etc.

Settings

Each operator, business, or venue owner can set their own parameters that reflect their own service level agreements or their quality of experience objectives. The settings page provides easy to change threshold levels for each of eight key parameters shown in the screenshot on the right side.

Figure 10: Wi-Fi Console Settings



Source: Ambeent Inc.

AI-Based Spectrum Broker

Artificial Intelligence (AI) and its favorite child, machine learning applied to Wi-Fi, promises to solve a significant problem—the cost of troubleshooting the many potential connection problems that can occur from many possible sources.

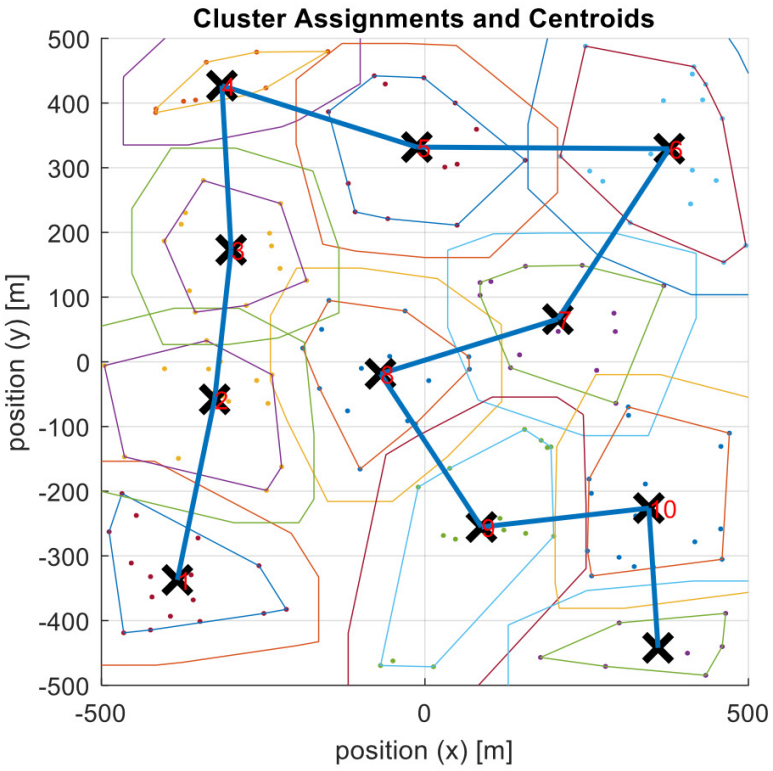
The intelligence and algorithms sit both at the edge on the device, as well as in the cloud where a large number of devices are feeding the machine-learning algorithm in a virtuous circle which makes it more accurate and valuable to anticipate and fix new problems.

Artificial Intelligence will allow the key characteristics of problems in the Wi-Fi network to be picked out from the big data that is the mass of traffic data, fix known problems directly, analyze trends in performance, and predict future requirements to avoid problems altogether in the future. This would allow the Wi-Fi network management system to constantly add to its knowledge base, extend its repertoire of known problems and solutions, and raise standards of user experience even higher.

In general, the main three steps include: optimize, classify, and predict.

Optimize. Ambeent provides a smart band, channel, and transmit power allocation mechanism. This mechanism is agile & dynamic and works with partial availability. Optimization systems create a relational aggregated graph to construct AP-to-AP and AP-to-device relations. This thorough view of the wireless network is then utilized for optimization.

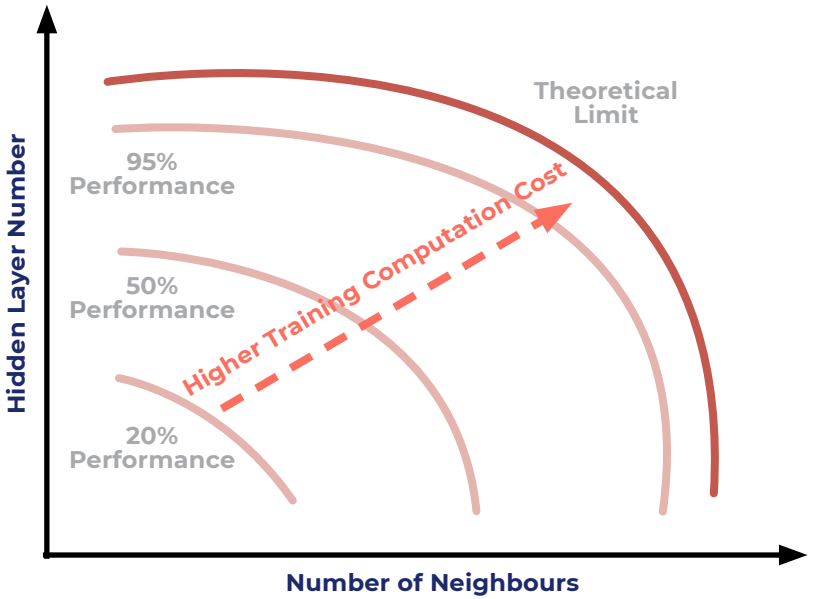
Figure 11: Spectrum Allocation with AI-Adaptive Clustering and Heuristic Optimization *(access points are represented by X)*



Source: Ambeent Inc.

However, as density of neighbors increases, the computational load that is required to solve an optimization problem also increases. Ambeent introduces a novel AI-based solver that first decomposes the graph into dynamic clusters as shown above, then applies a heuristic deep-learning method to reduce computation time of optimization for fast-switching recommendations for the right band or channel. This is to mitigate the increasing number of collisions and errors in the network which increases network slowdowns and thus penalizes all the users. Optimization aims at avoiding those collisions.

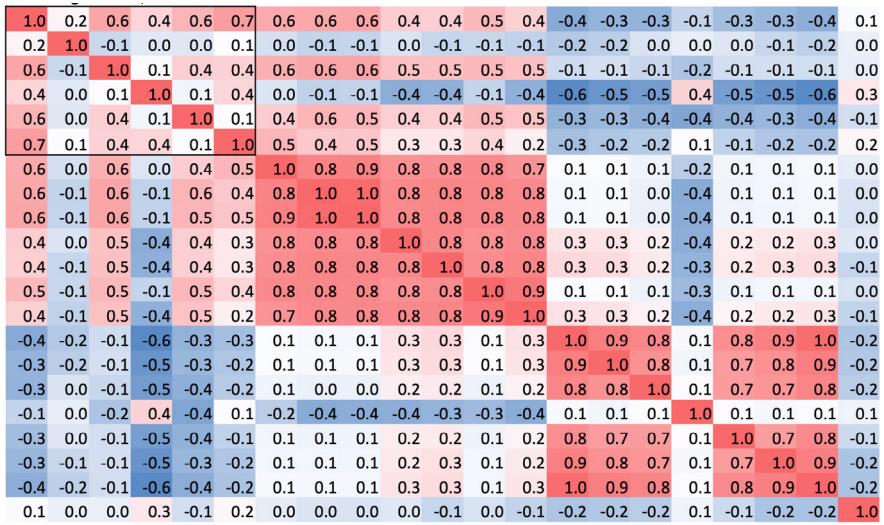
Figure 12: Neighbors' Interference Impact and How Increasing Deep Learning Layers Compensate



Classify. When data is aggregated and processed collaboratively, it can serve to identify the root cause of performance issues. What is the optimum level of network performance? How far is the network from operating at optimum? Which APs, WLANs, and users are most affected? Which are the most impactful issues identified for prioritization?

Moreover, each subscriber behavior is identified and classified into well-known trouble-shoot problems by support vector machines[5] —including dead spots, weak signals, outdated equipment, faulty installation, backhaul problems, etc. This information is useful when combined with subscriber lists that trigger real complaints. The deep learning is trained accordingly, and engines start flagging— whether a subscriber is likely to file a complaint or not—with respect to their Wi-Fi conditions. This information is then used by the service provider to take action and make it available at the contact centers before a call happens.

Figure 13: Support Vector Machine— A Likelihood Comparison Table Between Cases

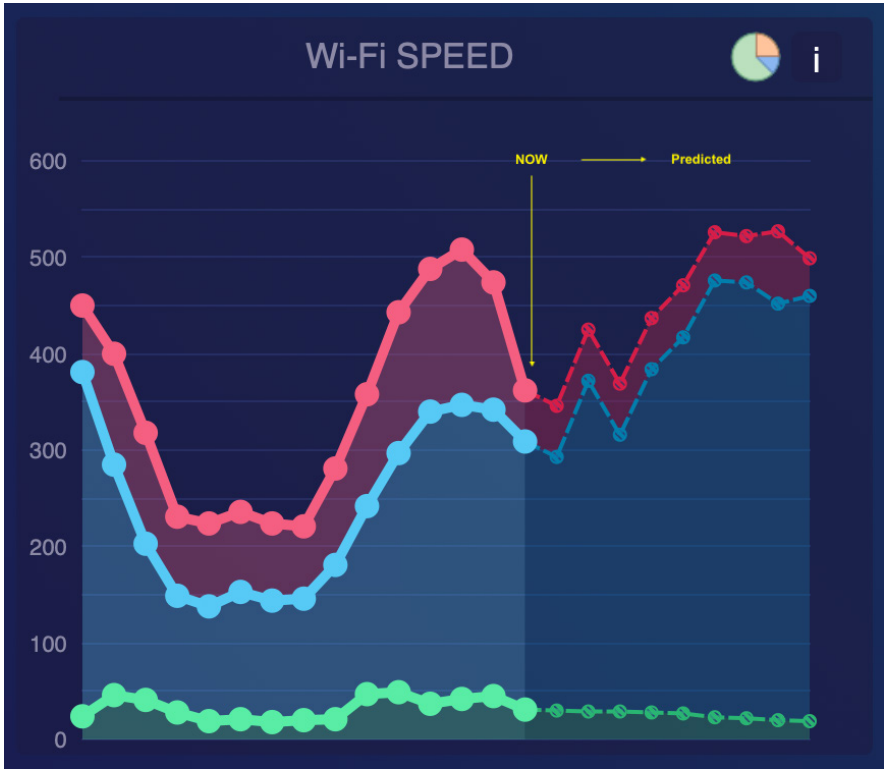


Source: Ambeent Inc.

[5] In machine learning, the support vector machine (SVM) are supervised learning models with associated learning algorithms that analyze data used for classification and regression analysis. Details of SVM are beyond the scope of this white paper – Source: Wikipedia.

Predict. Wi-Fi Console also runs an extensive prediction engine where AI can then make any number of things happen, from load-balancing to auto-correcting a network issue. For all the items in the dashboard, there is a forecast created. For instance, Wi-Fi speed shown below provides what will happen next. As can be seen from Figure 14 shown on the right, Wi-Fi speeds in good category (green) will decrease and medium (blue) and bad (red) groups will increase. An operator can infer from this graph that Wi-Fi will be choked in the next upcoming days.

Figure 14: Prediction of Number of Sessions in the Wi-Fi Network



Source: Ambeent Inc.

Benefits for Providers

While data traffic and demand using the unlicensed spectrum is growing, the present wireless network architecture on unlicensed spectrum suffers from uncoordinated spectrum utilization in a growing number of Wi-Fi access points and technologies. Insufficient coordination among a large number of APs that use overlapping channels leads to interference among them, resulting in reduced efficiency and lower throughput. Inefficiency also results in re-transmissions, which not only reduces throughput, but also wastes energy.

Shifting from a decentralized to a centralized management system on the unlicensed spectrum is critical to obtaining the maximum possible degree of efficiency and increasing overall wireless quality of service (QoS). What is needed is a smart and dynamic allocation of the channels based on a number of parameters, which we will detail later.

Because Ambeent's innovative approach enables the first user to enjoy the benefits of smart allocation of channels, it is incentivized to spread the word to its neighbors and friends and generate a viral spread of the solution without having to resort to the operator's permission or involvement. This is a very low-cost entry which is self-driven by positive results.

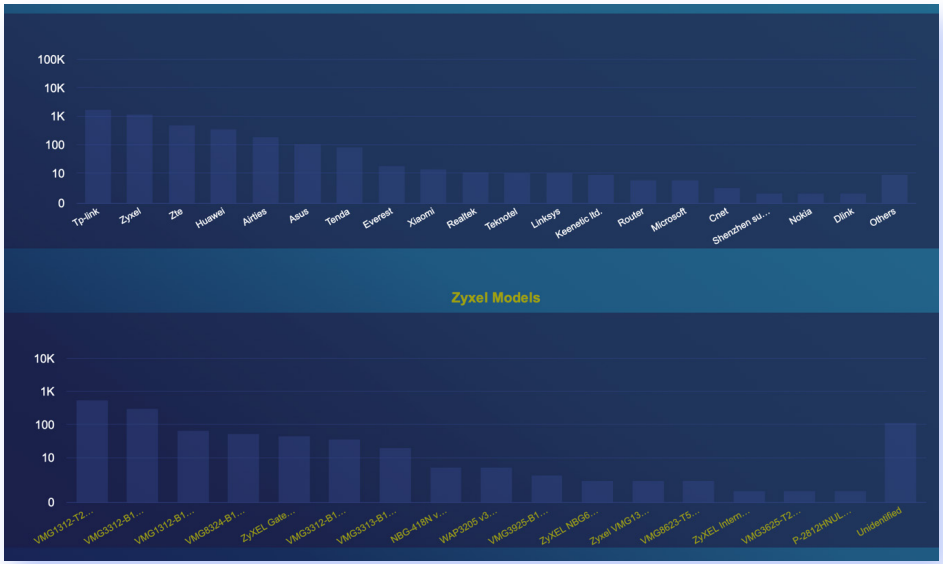
In order to better illustrate the benefits of using a user-centric and collaborative approach, let's look at three use cases.

Mixed Make & Models – Impossible to Consolidate

There are hundreds of gateways, access points, set-top-boxes, and modems from dozens of vendors encompassing various generations of Wi-Fi, which make the job of consolidating all these devices virtually impossible for a given operator. Further, with the emergence of new technologies (such as IoT (Internet-of-Things)), the complexity of CPE is going to increase, thereby increasing the probability of software malfunction and leading to the requirement of harder testing and an increase in time-to-market. This creates a headache for operators as they look to deploy new services and features on top of such a disparate footprint and limits the speed at which they can scale their new deployments. It is estimated that an operator has to deal with between ten and twenty models of gateways from different vendors in its broadband network.

As a result, decentralizing the application (through some push mechanism or integrating the Ambeent's SDK in another existing operator app) on the device enables any operator to deploy the Ambeent solution without delays and regardless of how fragmented and complex their access point footprint is.

Figure 15: Many Models to Integrate



Source: Ambeent Inc.

Zero Integration

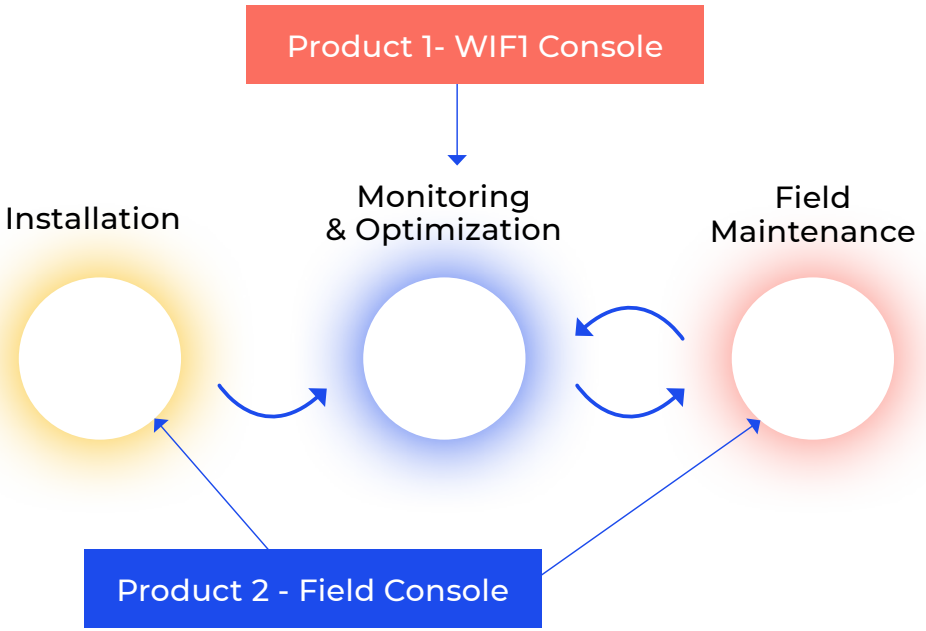
Operators are notorious for being very diligent about introducing a new technology, which translates into very long deployment cycles of typically eighteen to twenty-four months. This is a long time for a technology that evolves very quickly with ongoing innovations. The operator must invest quite some time performing integration, both at the gateway and central level, to ensure the new software runs smoothly and delivers on its promises.

A benefit to having a decentralized function on the device rather than the gateway is the ability to take full advantage of the cloud-based stack across the devices, homes, and even networks with zero integration. The application SDK communicates to the cloud, its local parameters, key metrics, and the accumulated information, benefits all the device users, preventing channel interference, and enforcing band or channel steering when needed.

End to End – Installation, Monitoring and Field Service

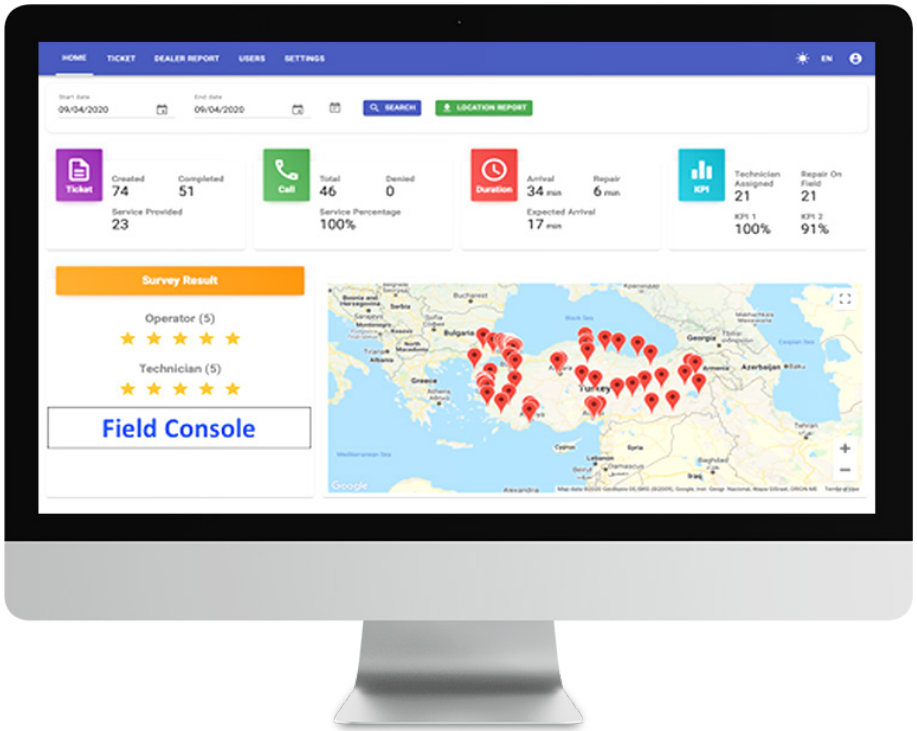
During the installation of the home gateway, technicians are often blind about what is going in the immediate RF environment. That often leads to repeat truck rolls, which are expensive to operators. Ambeent solves the problem by providing a tool for technicians to monitor the RF environment, and especially interference coming from neighbors to improve the probability that the installation will be swift and successful, leading to a decrease in service calls or wrongful hardware replacement. The **field console** provides the tools to coordinate the installers and customers to better do their jobs.

Figure 16: Ambeent's End-to End ISP Services



Source: Ambeent Inc.

Figure 17: Field Console in Action



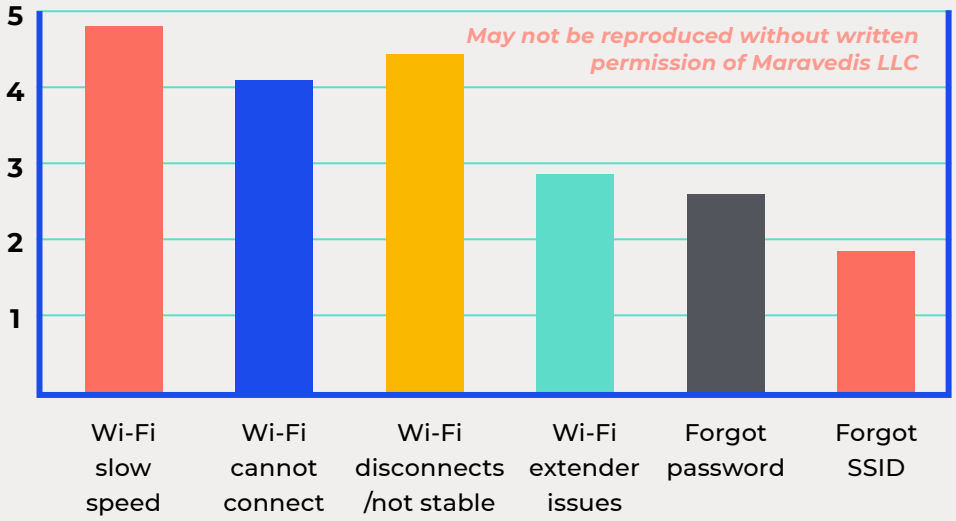
Source: Ambeent Inc.

Select Use Cases

Telco – First Responder for Call Center

The number of devices in the home is exploding, thus creating more competition to access this limited unlicensed spectrum in the 2.4 GHz and 5-6 GHz bands. Not only is the number of connected devices in the home growing, but the proportion of high capacity devices—such as VR and 4K TVs—is also increasing, requiring high bandwidth and driving multi-AP growth. Those devices and related applications also require lower levels of latency, an increasingly important measure of quality of experience for home Wi-Fi.

Figure 18: Ranking of Main Reasons for Customers' Calls for Support (N=220)



Maravedis research[6] shows that poor access point placement is the #1 cause of poor Wi-Fi performance. While there are many factors that can affect home Wi-Fi operation, the placement of routers—wireless access points (APs)—can be one of the most significant factors in performance. Good router placement must provide not only adequate coverage for all clients on a network, but also provide adequate throughput, good connectivity, and minimal interference.

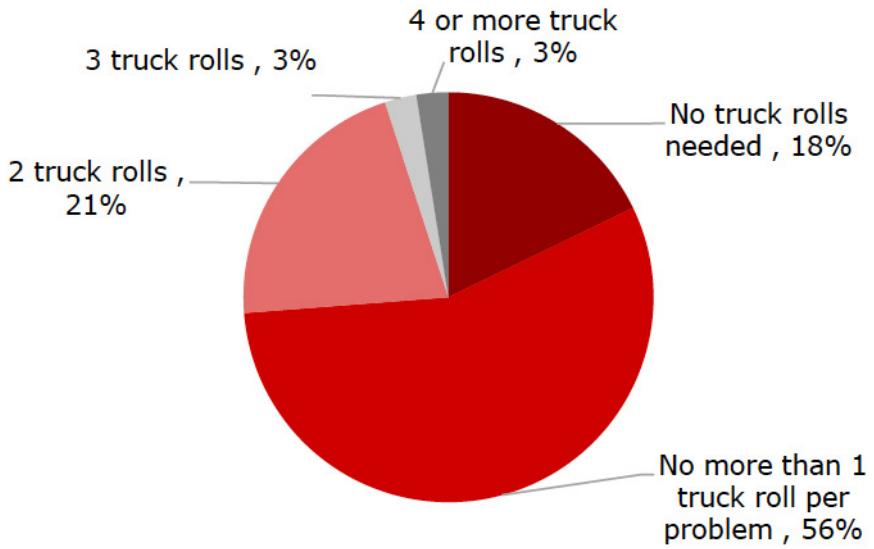
[6]*Managed Home Wi-Fi Networks for the Smart Home 2020-2025*

Source: Managed Home Wi-Fi Networks for the Smart Home 2020-2025, Maravedis

Currently, there are no effective tools available to operators to efficiently evaluate QoE of Wi-Fi subscribers. Similarly, operators are unable to diagnose and solve Wi-Fi-related issues or to differentiate Wi-Fi-related degradations from other causes of poor customer experience.

Likewise, subscribers are typically unable to resolve their Wi-Fi issues on their own and have to contact their service providers. For service providers, this lack of customer inability to solve Wi-Fi problems results in high operating costs stemming from ineffective or lengthy support calls, costly "truck rolls" for on-site service, and CPE (Customer Premise Equipment) replacement. Accordingly, due to the aforementioned lack of effective tools to diagnose and solve Wi-Fi-related issues, operators' attempts are frequently ineffective. This leads to many return calls and visits, generating higher levels of customer dissatisfaction. A recent white paper[7] from Heavy Reading shows the number of truck rolls required to solve home connectivity issues can be quite high.

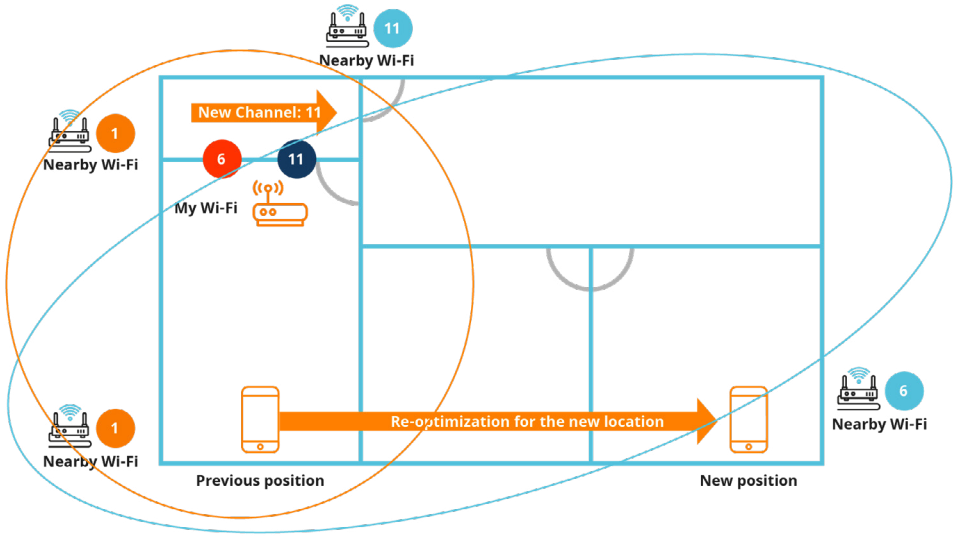
Figure 19: Average Number of Truck Rolls for Each Home Networking Problem



[7]Source: Tackling the Gigabit Home Networking Challenges – A Heavy Reading white paper produced for VeEX

As shown in Figure 20 below, by having the device and thus the user scan the immediate channel conditions instead of relying on a centralized gateway, the system is much more precise and dynamic. If, for example, the user is using channel 6, and walks to the kitchen where the neighbor also uses channel 6, the algorithm will tell the device to move to another channel, such as 11 (again, as shown in the figure below).

Figure 20: Home Deployment



Source: Ambeent Inc.

Another aspect is the benefit the application has for running smoothly OTT applications such as Netflix and other video streaming. **The solution is laying the groundwork for application aware spectrum allocation in order to take into account throughput requirements of each user or device in the home. When neighbors exceed the number of over-lapping channels, the need to allocate channels according to session types is inevitable.**

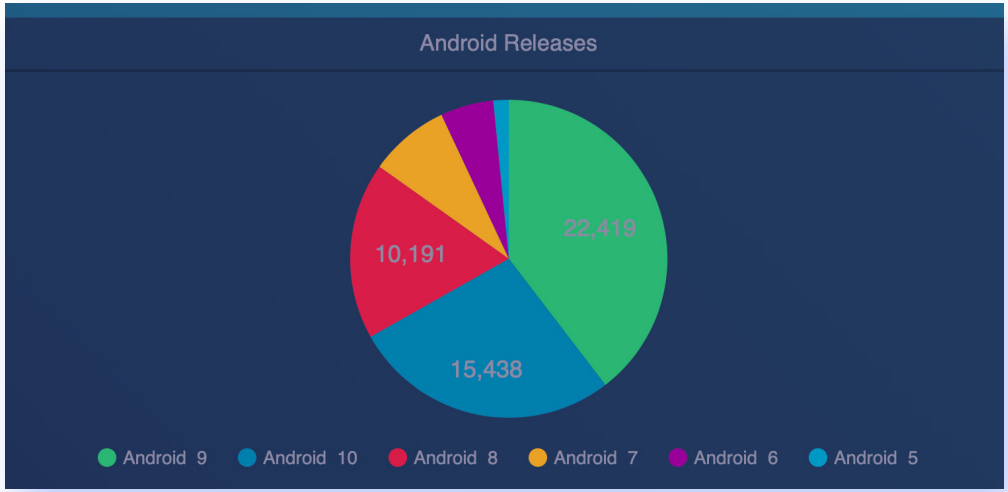
Indeed, a 4K TV streaming video or a Zoom video conference in the time of COVID-19 will have different throughput and latency needs than web browsing or email activity; therefore, applications requiring high throughput will require a priority access to clean channels, which will result in a better quality of expe-rience overall. Furthermore, a service provider will monitor the range of devices and operating systems in use by customers. The operator will be able to detect legacy devices and forecast the upgrades.

Those are important implications for service providers serving home customers. Indeed, the ability to diagnose and solve problems more quickly will result in a better customer experience, a higher net promoter score, and lower churn for the operator. It will also have positive impact on the operator bottom line by reducing OPEX because of lesser and shorter calls, as well as less truck rolls and wrongful hardware replacements. As we discuss in the upcoming features, the tools provided by Ambeent to the operators will only become more powerful as machine learning becomes more refined as the use of the application increases.

Figure 21: Tracking the Device Distribution

Source: Ambeent Inc.

Figure 22: Tracking OS Distribution—Predicting the Upgrades



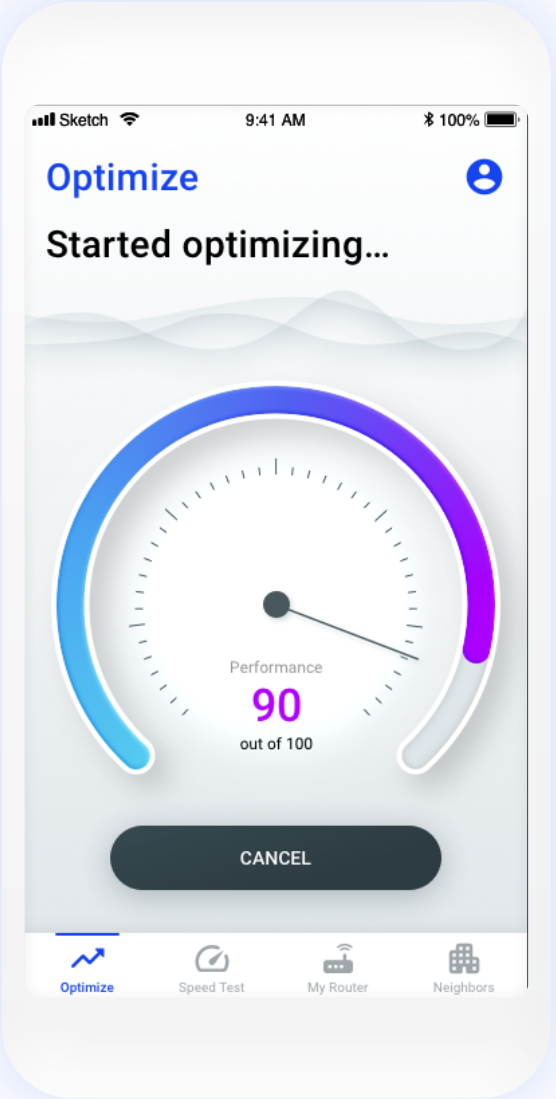
Source: Ambeent Inc.

Consumer – Home Wi-Fi

In the same vein, subscribers are looking for tools to resolve their Wi-Fi issues on their own without having to contact their service providers. Ambeent's WiFi Console apps and Wi-Fi Console cloud service provide consumers with the necessary insights and optimization.

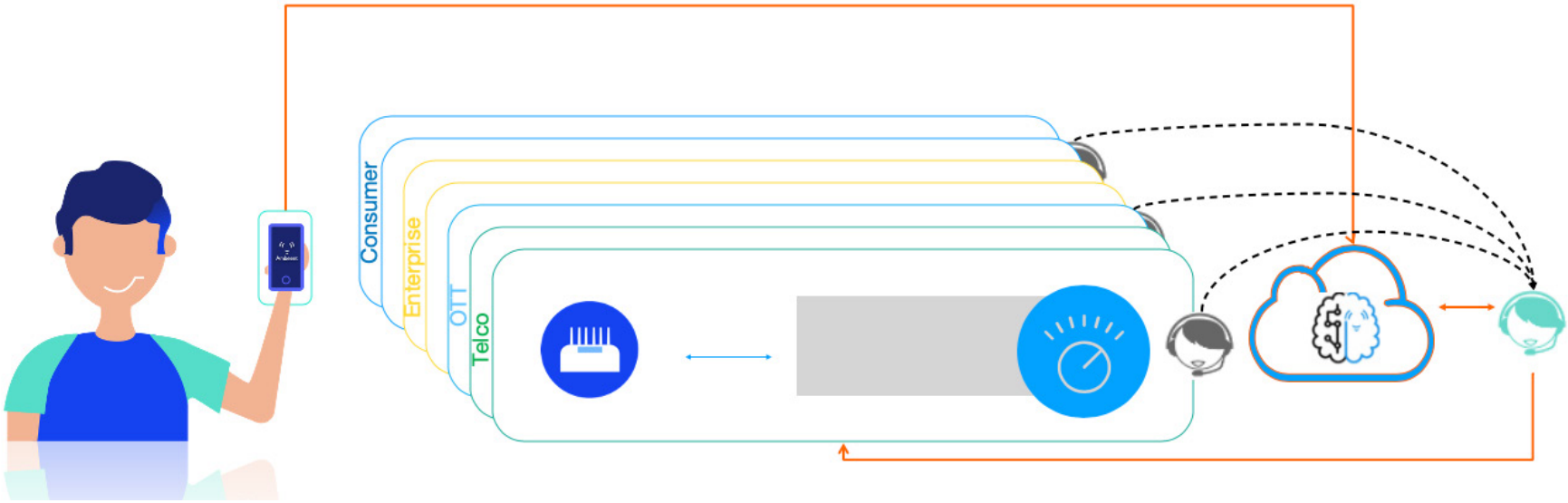
This app acts as the first line of resolution of home Wi-Fi problems and will result in a lesser number and duration of service calls, thus generating notable savings to the service provider in OPEX, lower churn, and higher net promoter scores.

Figure 23: Consumer Wi-Fi Self-Cure App



Source: Ambeent Inc.

Figure 24: Ambeent Wi-Fi Future



Source: *A Universal First Troubleshoot by Ambeent*

User Activity-Based Optimization

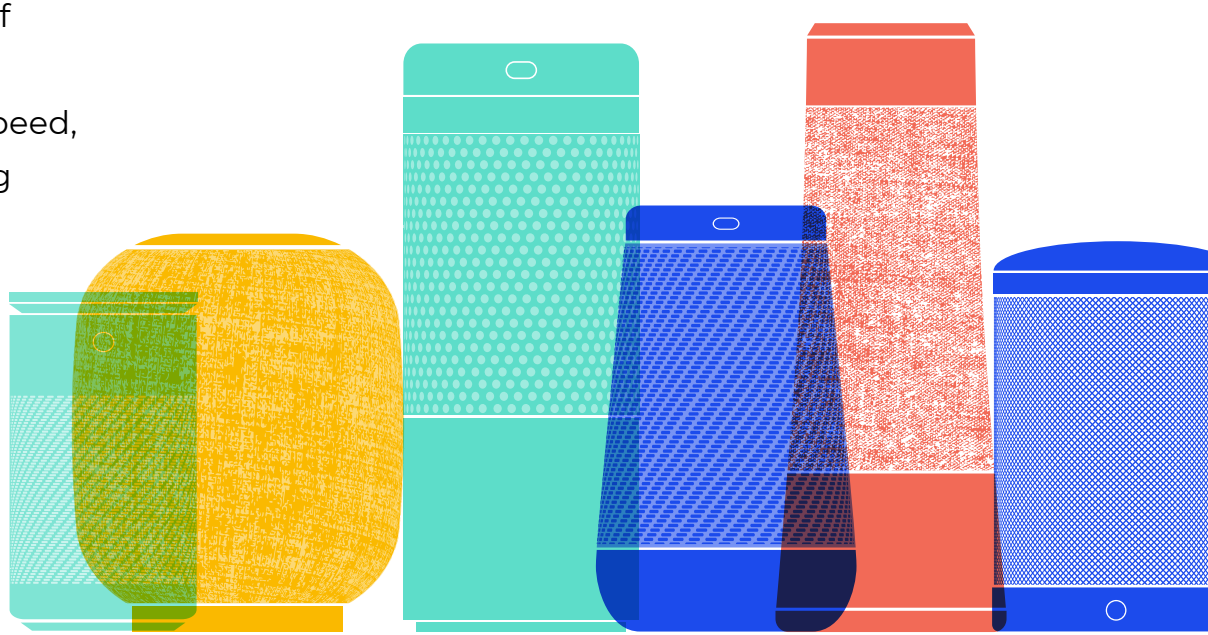
Ambeent provides a very flexible platform that can optimize the Wi-Fi experience based on importance of user activity. COVID-19 provided the opportunity to many individuals to learn how to work and learn from home. However, this peak increase in Wi-Fi usage also showed vulnerabilities of the network, especially in congested household environment, and there is no prioritization mechanism. For example, for an adult giving a presentation for a business meeting, he/she can use Ambeent's solution to prioritize their router in the vicinity to ensure no interruption or dropping connection due to other individuals' internet usage. Similar examples can be further elaborated: listening to online classes, taking exams, giving presentations, or watching a 4K video etc.

Voice Assistance

When voice assistants began to emerge in 2011 with the introduction of Siri, no one could have predicted that this novelty would become a driver for tech innovation. Now nearly eight years later, it's estimated that every sixth American owns a smart speaker (Google Home, Amazon Echo) and eMarketer forecasts that nearly 100 million smartphone users will be using voice assistants in 2020.

The main driver of the shift towards voice user interfaces is the changing user demands. There is an increased overall awareness and a higher level of comfort demonstrated specifically by millennial consumers. In this ever-evolving digital world, speed, efficiency, and convenience are constantly being optimized.

The mass adoption of artificial intelligence in users' everyday lives is also fueling the shift towards voice applications. The number of IoT devices such as smart thermostats, appliances, and speakers are giving voice assistants more utility in a connected user's life. Smart speakers are the number one way we are seeing voice being used; however, it only starts there. Many industry experts even predict that nearly every application will integrate voice technology in some way in the next 5 years.



Below we present some scenarios where Ambeent solution can be used with voice assistance to improve the quality of experience in the home.

1. A parent, Sam, has a 9am presentation and is worried about his internet connection. With the current settings, Sam is unable to guarantee his meeting will not be disconnected if a household member decides to simultaneously stream or download a large file. What if he could set priorities for his device, his computer or by simply telling Alexa to “prioritize my computer”? Alexa can use Ambeent’s optimization framework to thoroughly optimize the traffic with respect to Sam’s computer and location in the house.

2. Further, if neighbors are also involved, Alexa will prioritize him and allocate an interference free channel during the session.

3. When your device stops working, you search the problem online or call the helpline/call center. Most online resources are not direct and sometimes the issue is complex which requires you to still call the helpline. However, you often get frustrated with the call centers' script, as they are coming in blind, to try and fix the problem, knowing you already tried half the items, and sometimes they still can't find the problem, requiring you to ship the item back for inspection or send a technician to your home. In most cases, issues arise due to internet connectivity not due to device malfunctioning. With Ambeent's solution, you can immediately identify the internet issue and fix the issue, saving you time and frustration.

   For example, if your TV has an issue with Wi-Fi connectivity, the call center can immediately inform the user via Alexa about this issue, indicating the internet connection speed over the past week, identifying non-optimal modem location, an internet service provider error in your location, or neighborhood interference issue. Ambeent can provide an optimal solution, such as finding an alternative router location, recommending an equipment replacement or contacting your service provider depending on your location. Ambeent simplifies everything. Users can be better informed and find a solution without frustration. Companies can reduce call center costs and increase profit margins with more satisfied customers.

Enterprise - Hospitality:

Sea View Out - Wi-Fi View In

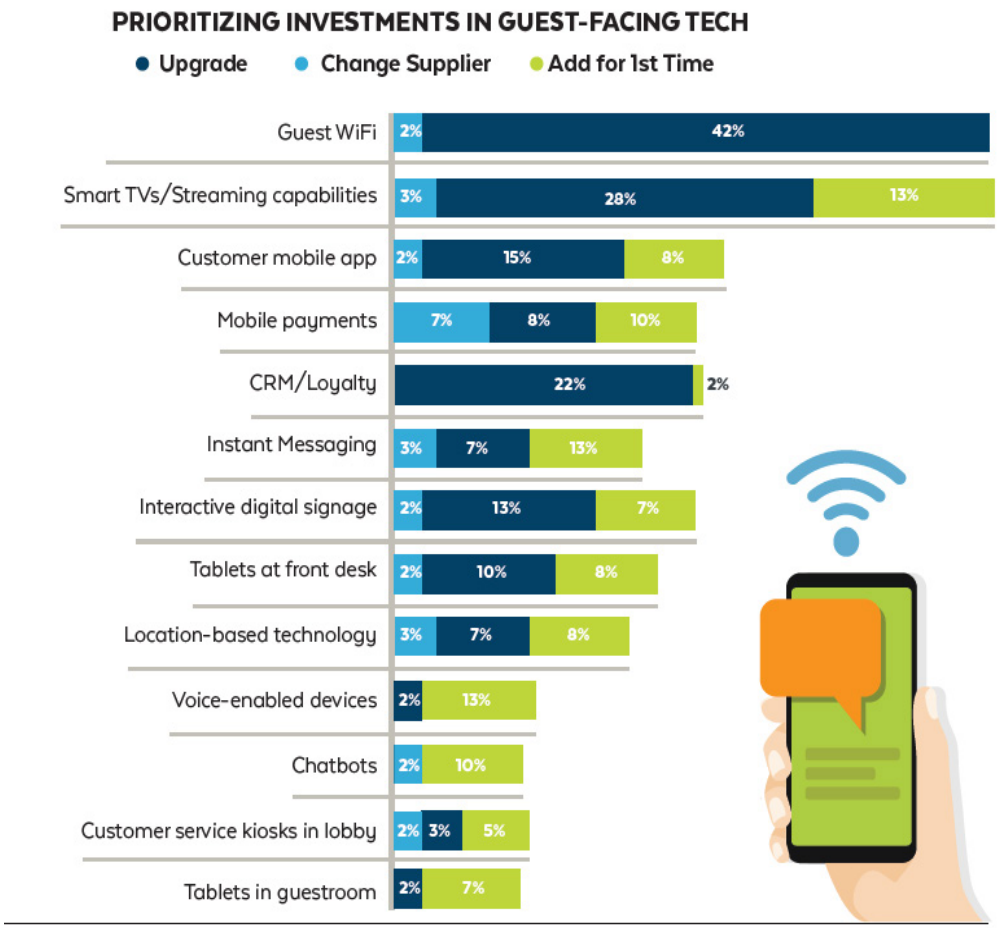
Wi-Fi tops the list of factors influencing booking decisions by hotel guests. At 89% of respondents to Hospitality Technology's survey citing this amenity as a decision factor, free Wi-Fi beats even the ability to see photos and videos of the hotel before booking (84%) and ease of the online booking process (81%).[8]

But besides Wi-Fi being free, guests expect their Wi-Fi to be secure and fast. Most large hotels have outsourced their Wi-Fi functions to third-party-managed service providers (MSPs) who manage and provide support for all things Wi-Fi related. Those same MSPs are the ones who can deploy new technologies and provide them as a new service to hotel brands.

In this context, hotels can use the Ambeent's solution to monitor the activity in their network and anticipate interference and congestion issues ahead of time. The MAP function enables the user to pinpoint a particular location or AP, which comes in handy when hotels often manage multiple locations.

As the graph below shows, guest Wi-Fi remains high in hotel's investment priorities.

Figure 25: Top Technology Investment Priorities in the Hospitality Industry



Source: 2019 Lodging Technology Study

[8]*Customer Priorities for Booking Hotel Rooms with Free Wi-Fi a Major Driver (HT 2017 Lodging Technology Study)*

Enterprise - Shopping Mall

According to the International Council of Shopping Centers (ICSC), there are over 200,000 shopping malls around the world ranging from less than 30,000 square feet, to mammoth +800,000 square feet. That represents millions of square feet of indoor space welcoming hundreds of millions of visitors per year. No matter their size and where they are located, shopping malls have become the heart of civic life in thousands of communities worldwide, from the largest urban cities to the smallest farming villages. Shopping malls provide an important, socially-open, third space between work and home, where individuals can feel a sense of belonging within a central marketplace offering goods and services.

With over 90% of sales still occurring in physical locations, shopping malls remain central to the success of global retail. The rise of sophisticated omni-channel retail strategies have demonstrated that brick-and-mortar stores are an integral part of the consumer experience and are as relevant now as they have ever been.

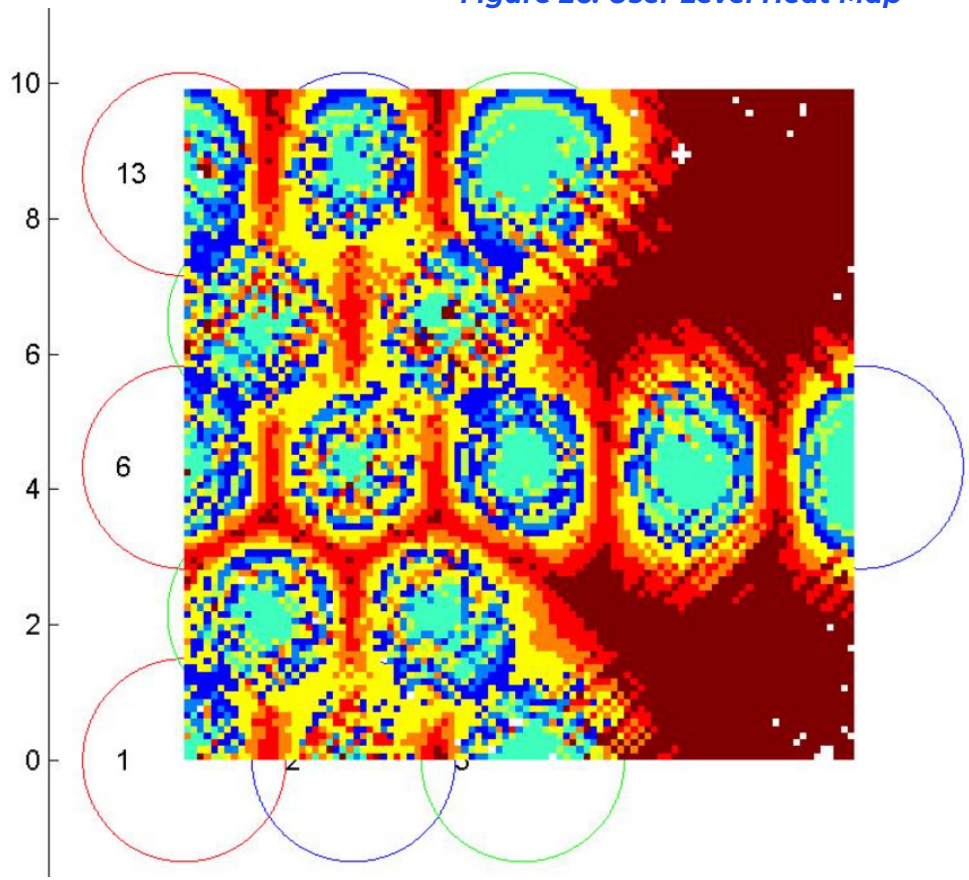
Malls are an ideal ground for experimenting new retail formats, designs, and technologies—such as guest Wi-Fi. They are increasingly acting as an enabler for omni-channel retailing, providing enhanced services for customers, and assisting retailers with their distribution and fulfillment strategies by way of offering guest Wi-Fi, centralized click-and-collect services, and collection lockers for online retailers (such as Amazon).

Guest Wi-Fi provides the opportunity for shopping malls and tenants to acquire customer insights from their Wi-Fi network (including, e.g., footfall traffic), which of course will impact rent and shopping mall revenues. Guest Wi-Fi can also be used to assist customers with mall navigation, timely information and alerts, and providing a more personalized shopping experience.

However, such a Wi-Fi network must be dependable and stable for both retailers and their customers. Each independent retail Wi-Fi network contributes to crowding the RF environment inside a mall, thus raising the need to provide some order to networks competing for airtime in overlapping channels. Unfortunately, each retailer uses a different access point from different vendors who are notorious for not interoperating with each other. And when controllers are used, they only control the same vendor access points.

To solve this, Ambeent utilizes existing mall apps by integrating its SDK, and the cloud solution acts as a broker over many Wi-Fi networks under different ownership and manages the spectrum and transmit power allocation by using the user-side heat map constructed from information of the devices. This is a great example where spectrum orchestration brings RF order in an otherwise chaotic and unpredictable environment.

Figure 26: User Level Heat Map



Source: Ambeent Inc.

Enterprise - OTT

OTT refers to the practice of delivering media over the internet, and bypassing traditional telecom infrastructure such as cable, broadband, and satellite platforms to provide services to the end-user.

Today, with many service providers in the ecosystem delivering a high quality of user experience, streaming consistency and seamless delivery of content are critical. However, ensuring such a consistency across an increasingly wider range of OTT devices used to access the available content is becoming a challenge to the OTT service providers. Therefore, a good Quality Assurance strategy includes testing the entire service along with associated components for a more in-depth analysis of their performance in different conditions including the last meters in the home, which are served with Wi-Fi.

OTT is any video streamed on "a device that can connect to a TV, or functionality within the TV itself, to facilitate the delivery of internet-based video content, such as Roku, Apple TV, Smart TVs, game consoles, etc."

- 50% of Wi-Fi-connected homes in the USA use these OTT apps for around 100 minutes per day.[9]
- Experts believe OTT app usage will grow to a $120 billion industry by 2022. And, that looks like it's on pace to be achieved.
- 40% of those Wi-Fi connected homes already use a device like a Roku Box or Apple TV to stream videos directly to their television, and it won't be long until the rest of us catch on.

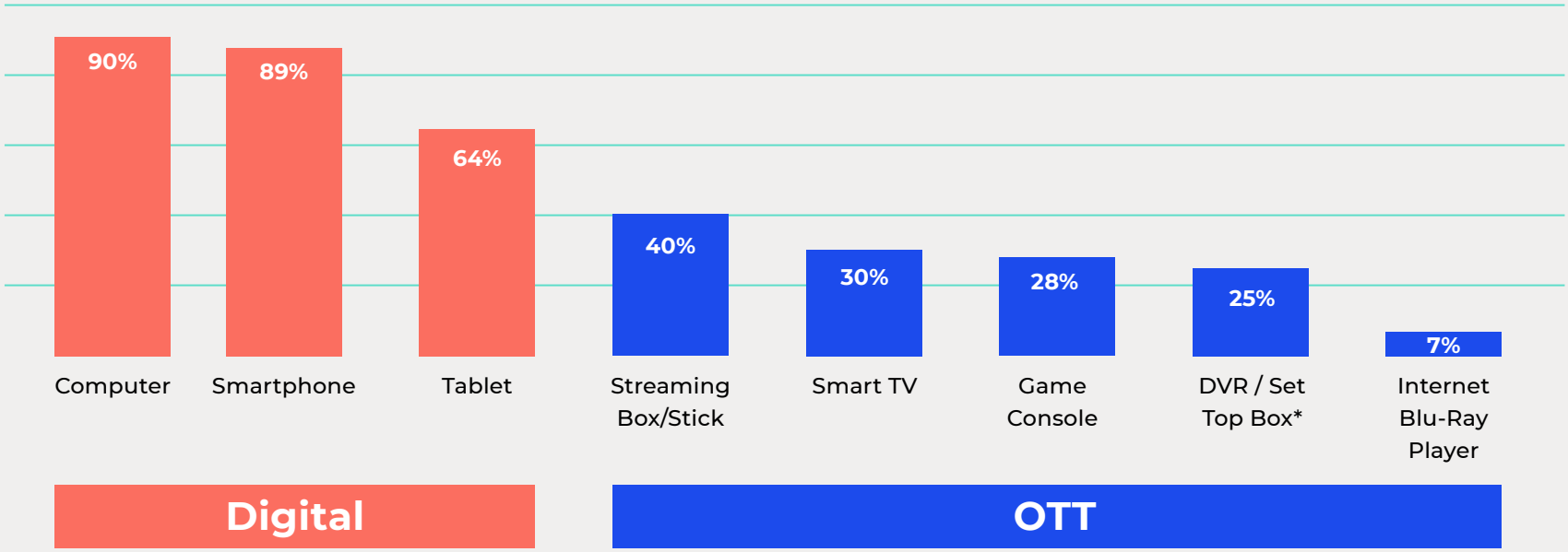
[9] *https://www.comscore.com/Insights/Presentations-and-Whitepapers/2017/State-of-OTT*

The solution helps OTT providers track the Wi-Fi quality in the premises and further signals subscribers the recommendations. For instance, a collaboration app can recommend taking a different position before starting a session or recommend switching to another AP, etc.

Figure 27: OTT Penetration in US Homes

Connected Home Device Penetration Among U.S. Wi-Fi Households

Media Devices

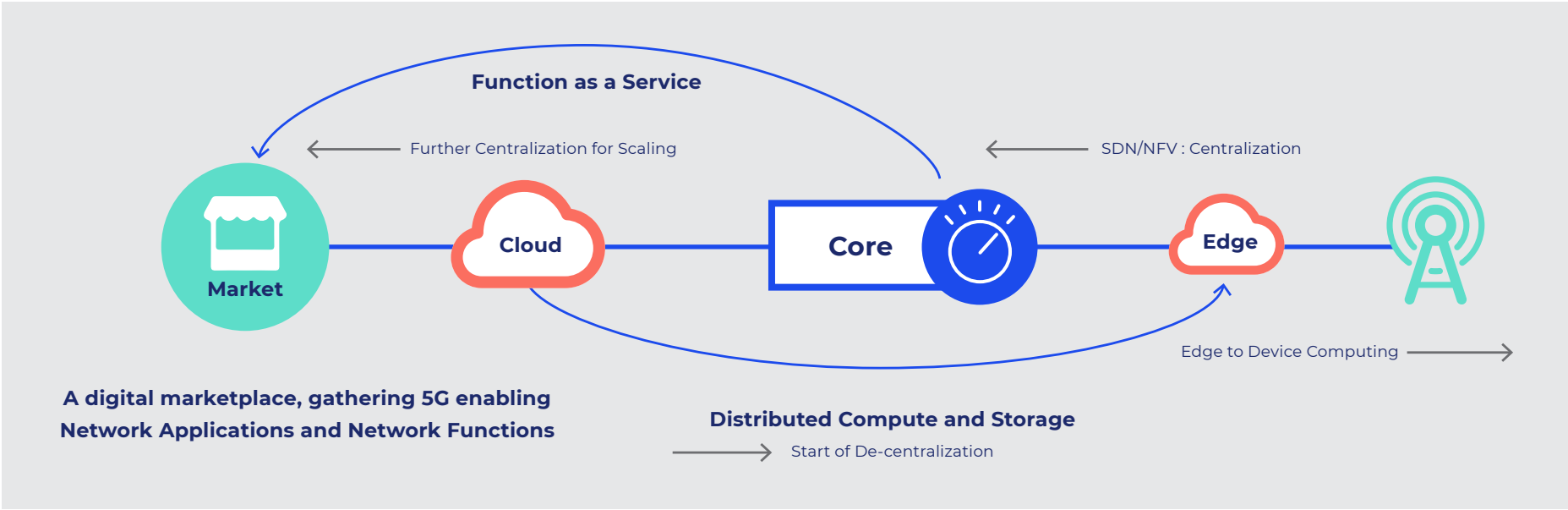


Source comScore Connected Home, U.S, April 2017
**DVR / Set Top Boxes only include those that are internet-enabled*

Wi-Fi Orchestration Fits into 5G and Tops in 6G

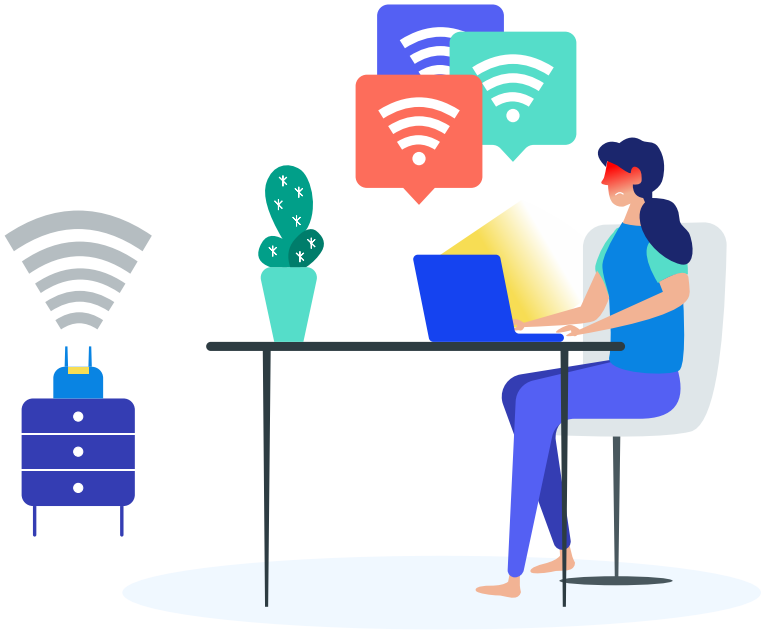
Wi-Fi will be part of 5G and a key component in critical indoor 5G use cases, including the connected home. While 5G will support unlicensed and shared spectrum, Wi-Fi has been moving in the other direction, taking on many characteristics of cellular technologies such as enhanced quality of service, security, and other features. As the lines between licensed and unlicensed spectrum blur, Wi-Fi will evolve alongside cellular and be part of the broader 5G platform, bringing 5G-like capabilities to non-spectrum owners such as cable operators, city authorities, or private network providers.

Figure 28: Key Network Architecture Trends in the Context of 5G



Source: Ambeent Inc.

Densification is the practice of adding capacity and coverage in a targeted way by adding Wi-Fi or cellular small cells to the network. The cells can be mounted on street furniture, or deployed indoors, attached to an enterprise Ethernet connection. As attention moves from coverage to capacity, operators talk more commonly about heterogeneous networks (HetNets) which integrate any combination of cell sizes, base station configurations, and spectrum bands, including Wi-Fi and LPWANs such as LoRa.



Virtualization is a way for an operator to use their spectrum and capacity resources more efficiently and flexibly, as well as to reduce CAPEX and OPEX costs. For these reasons, they are turning to architectures which decouple the actual functions of the network from the hardware. Instead of deploying dedicated appliances to support functions (such as radio access or security gateways), they are implementing some or all network functions in software as virtual machines (VMs), which can run on off-the-shelf hardware, in local premises or switching centers, or in the cloud. The system creates tunnels between the VMs so they can be reconfigured on the fly without affecting the whole system. This has already been implemented in some enterprise and carrier Wi-Fi systems. Some of these functions will also be available in a digital marketplace available for anyone to buy as they need instead of being deployed centrally by an operator.

SDN-Driven Orchestration

In addition, many operators are moving to software-defined networks (SDNs). These are programmable and highly flexible. They separate the control and data planes, centralizing the control and orchestration of the huge number of VMs, and allocating resources like storage and bandwidth dynamically wherever they are required. The network is fully programmable, using standard interfaces, common developer tools, and programmable APIs for adapting core network behavior in near-real time.

All this enables new services to be launched and expanded (or dialed down) very quickly, according to usage patterns, avoiding the need for over-provisioning. It also makes it possible to integrate multiple networks on a fully flexible basis, allocating tasks to different connections as required, and treating all the networks as a common pool of capacity.

Further, 6G networks will require more flexibility for software-driven modulation and ability to switch between radio frequencies without breaking a connection. Hence, in a dense network with hundreds of Wi-Fi and cellular access points, orchestration from a standardized spectrum control-ler will be key enabler of quality of experience.

Conclusion

Wi-Fi is the most used technology to connect indoors—both in the home, the office, and even in public spaces such as shopping malls. Unlicensed spectrum is of great economic value to society, but it comes with the price of uncertainty. When Wi-Fi performance is compromised, users become frustrated and look for ways to fix the problem. Generally, what happens in unlicensed bands lacks visibility and is thus hard to prevent, because we don't know what to be looking for. In this paper, we describe neighbor interference as one of the drawbacks of operating in unlicensed mode and how the mix of devices operating in the environment degrades the performance for everyone.

We presented and made the case for an innovative approach to tackle this Wi-Fi waste that is device-based and collaborative. Ambeent introduces a Wi-Fi Console for all sizes—fed by a remote-controlled Wi-Fi app that optimizes parameters to reduce the neighbor interference problem. **Ambeent's technology is the only Inter-Home Wi-Fi Performance Solution in the market.**

We presented the various features of this agile solution and how it can benefit networks in various deployment scenarios for the home, hospitality, shopping malls, ISPs, and OTTs. This solution offered by Ambeent enables smart monitoring and optimization of channel allocation that is location- and application-aware and lends itself to a collaborative approach. As the lines between Wi-Fi and 5G are blurring, network operators are looking for ways to become more agile to compete. Functions are becoming virtualized, and consumers are empowered to select their own 5G applications on demand. And Ambeent is positioned to deliver that with Wi-Fi spectrum orchestration as a service.

Ambeent

Thank You

Contact Us

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