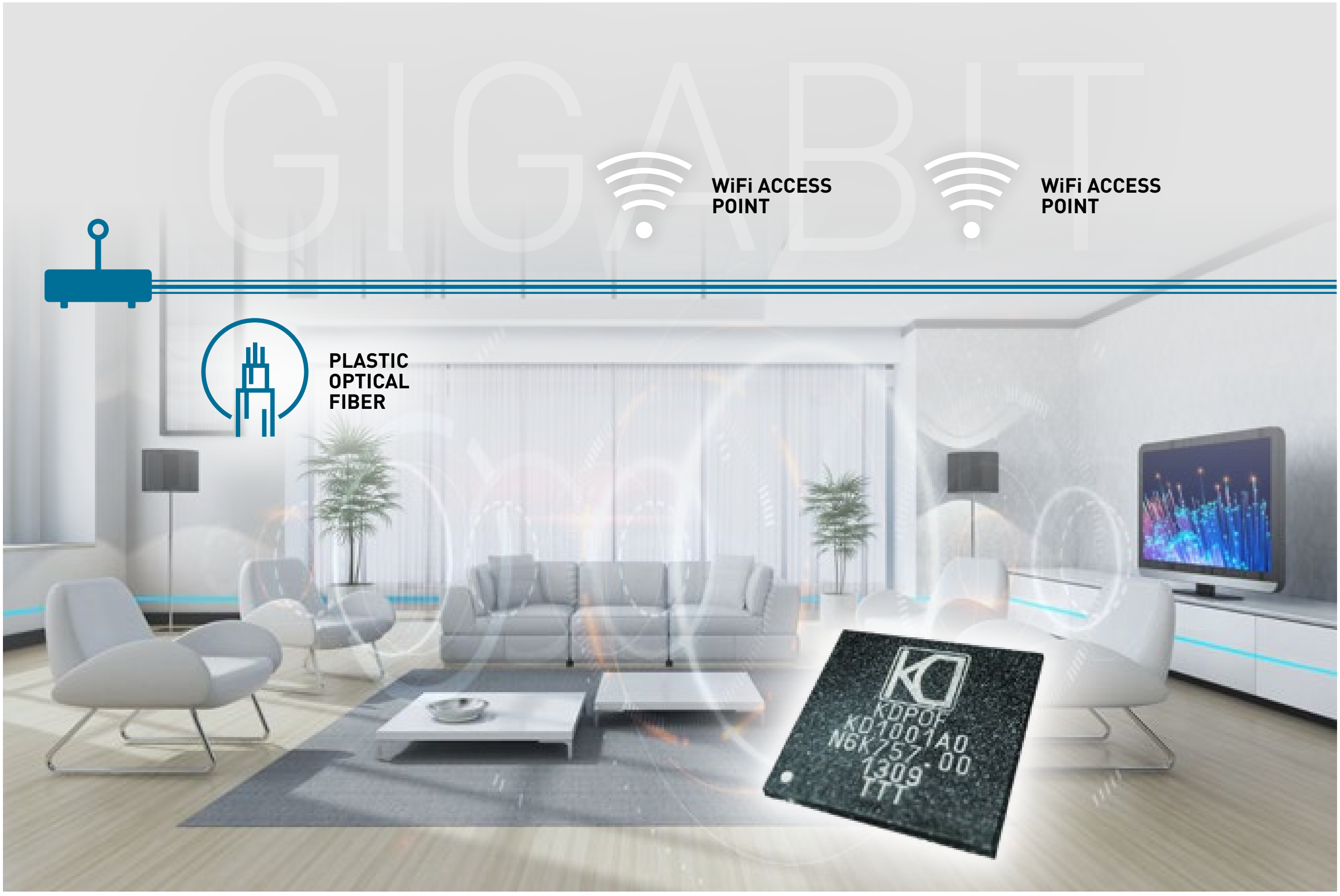
Field Study Proves:

Over 350% Better Performance for Wi-Fi with POF Backbone for Home Networks



KDPOF has conducted a field study to compare Wi-Fi performance using the same additional Wi-Fi Mesh nodes in three different types of homes: single-family houses, multistory houses, and flats. One study group used a POF backbone and the other used a Wi-Fi backbone. Transmission speed was measured in three selected rooms in each case.

Wi-Fi Mesh vs POF Backbone Comparison. Field results

Author: David Sánchez. FAE KDPOF

1 Objective

The availability of higher and higher access speeds into the home boosts the demand for a high performing, easy-to-install and robust home network. There is no debate that Wi-Fi is the most popular and preferred technology for this purpose. However, these increasing requirements have shown the limitations of supporting them via Wi-Fi.

Wi-Fi connection is popular because it is convenient, ubiquitous and present in most devices. However, these are in tradeoff with issues that cannot be overlooked:

- Data bandwidth. Wi-Fi incorporates very high performance engines to provide high speeds, but it requires enough signal strength to support it. Numbers decrease rapidly when not in proximity to the access points.
- Coverage. Wi-Fi signals suffer from severe attenuation because of distance, wall thickness and construction material, and router orientation among other reasons. As a result, the furthest rooms from the main access point may have low speed or no connection.
- Neighbor Interference. This is a very common issue, especially in crowded areas like buildings, where multiple Wi-Fi networks overlap and interfere each other. Wireless frequency channels are not enough to avoid this and then have to be shared. The effect of this interference is a net decrease in speed. Techniques like dynamic frequency selection from the latest Wi-Fi standards try to improve this, but the problem will always be there, getting worse with time.
- Saturation. Within a given home network, the number of nodes tends to increase, and together with the Neighbor Interference issue, the 2.4 GHz band, which Wi-Fi devices have used from the early days of the 802.11 b/g/n standard, is saturated and has reached its capacity limit. The more recent 5 GHz band is already supported by many devices and has helped to ease the saturation situation. However, it is also following the same path. In the future, there will be 6 GHz bands, but these bands will eventually suffer from the same issue.
- Attenuation. Moving to higher frequency bands like 5 GHz theoretically improves the connection speed and the congestion (temporarily). On the other hand, higher frequency bands have higher attenuation with the distance and obstacles found in their path like walls, heating floors or bathrooms. This may help with nearby interference, but decreases the coverage.
- Wi-Fi Time Sharing. How most Wi-Fi systems are built, the math of 100 Mbps for 2 nodes equals to 50 Mbps each and for 10 nodes equals 10 Mbps each does not work. The performance per node would be much lower than this division when the number of nodes increase. This issue will be tackled by Wi-Fi 6 once its proliferation in both access points and end points happen. Unfortunately, there is a long way to go for that.

Nowadays, consumers are offered speeds from 50 Mbps up to 1 Gbps. Consumers are interconnecting more and more devices to one another, and to the Internet. This increase in devices results in an overcrowded network that must be able to handle all the traffic between the devices and to/from the Internet. Applications like online gaming, coupled with more entrenched ones like high resolution video-on-demand, are pushing the requirements towards lower latency, error-free links and much higher speeds.

As consumer expectation is high due to the purchase of several hundred Mbps from their ISP or telecom operator, they are often frustrated by both the perception and experience of a much slower network connection in their homes.

The industry has been chasing solutions to overcome Wi-Fi limitations. From the basic home network based on a single Wi-Fi Access Point integrated in the router of the Service Provider, the trend has been to install more Wi-Fi Access Points rather than increasing the Wi-Fi capabilities of the router. A distributed architecture copes better with distance, coverage and saturation. The choice is which interconnectivity or backbone is used to interconnect those multiple Wi-Fi Access Points.

This document analyzes two different solutions for the mentioned backbone: Wi-Fi itself and a wired backbone based on Plastic Optical Fiber (POF).

2 Wired and Wireless Backbone Solutions

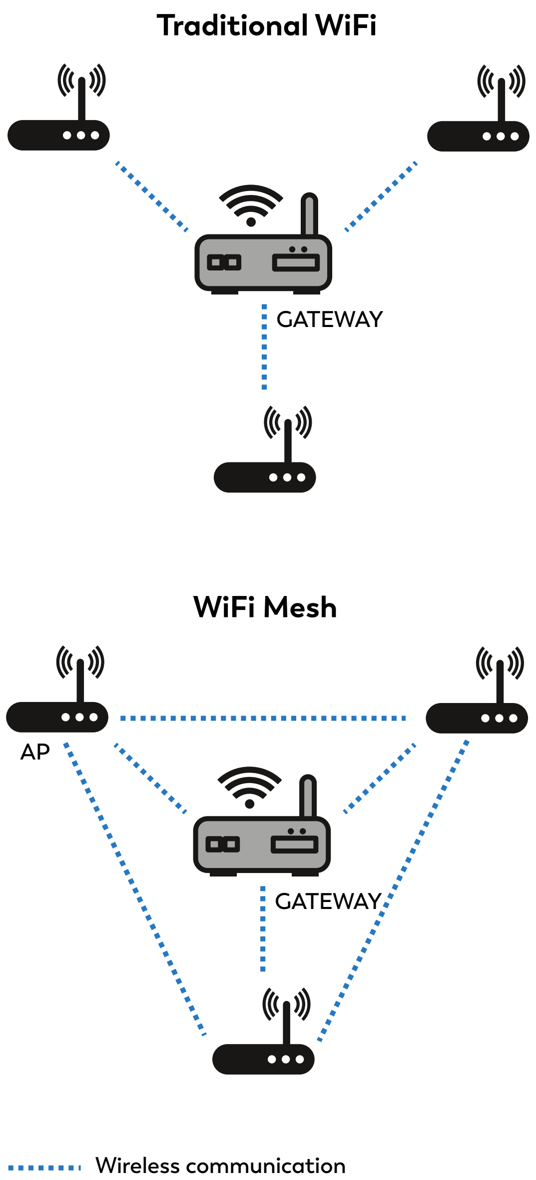
2.1 Wi-Fi Mesh

In a traditional Wi-Fi network, each wireless access point is connected directly to the router. In other words, the Wi-Fi access points do not communicate with any other Wi-Fi access point in the network.

In a Wi-Fi Mesh network, the topology changes in order to improve the coverage. Access points in a Wi-Fi Mesh network may connect with each other directly and not only with the main router as it was the case in a traditional Wi-Fi network. Wi-Fi mesh nodes do not have a hierarchy, and data is effectively routed to and from the nodes to the router directly or through other nodes. Each node may serve as a hop step for others which are further away from the router. This hopping scheme helps the nodes that are farthest from the router to deliver a strong Wi-Fi signal to the connected users, as they are connected to a node which is close to them and relay packets through nodes closer to the router.

The great advantage of mesh networks is that they create a single large Wi-Fi network, with the same SSID and password for the user, based on multiple Wi-Fi nodes. It is based on a roaming system that allows a client to disconnect from a Wi-Fi node at any time and to connect to another one which is closer to their new location in a way that is transparent for the user.

Figure 1: Wi-Fi topologies



Coverage and speed are often confused.

Coverage refers only to the signal strength the user sees in his device. They may see a signal whether or not they are connected to the Internet. Coverage does not warrant speed. It is the number of "lines" the user will see in their device signal indicator.

Speed refers to the data rate (Mbps) at which content can be transferred between the Internet and the user device. Good speed implies there is a good coverage. It is the result the user will get when performing a "speed test".

Range extenders, amplifiers or Wi-Fi mesh technologies improve coverage but do not secure effect on speed. Only the interconnection of Wi-Fi nodes with a dedicated wire (LAN cable or optical fiber) will secure the improvement of speed.

REMEMBER: A stronger signal does not imply faster access to the web!

As mentioned, nodes need to be able to communicate with each other directly. There are two approaches to do this:

- The most common approach is to use a dual band Access Point device (2.4 GHz and 5 GHz) where one channel is used for both backbone and end node con nectivity purposes. This backbone is shared and its capacity depends on the usage of the channel by end nodes.
- The other, more expensive approach uses a dedicated hidden Wi-Fi channel just for inter-node communication. This mesh system is called tri-band, as the Wi-Fi node provides a 2.4 GHz channel and two 5 GHz channels: one for the client devices, and another for inter-node communication (hidden from users).

With a Wi-Fi mesh network, better coverage throughout the entire home may be achieved. Only a single SSID and the ability to hand over between nodes will be offered to the customer. This kind of network provides robustness: if one node goes down, other nodes reconfigure themselves in order to reestablish the mesh. The mesh can be easily improved by adding additional nodes to increase the coverage.

However, when considering speed, this backbone option is exposed to the inherent issues of Wi-Fi: drop in speed due to distance, walls, neighbor networks, saturation of channels... Node location is critical in Wi-Fi meshes. On one hand, when nodes are far from each other, any hop decreases extended speed and latency increases. On the other hand, when nodes are too close, they can interfere each other and cause similar effects.

2.2 Wi-Fi with wired backbone

The alternative to improve the Wi-Fi connectivity (not just coverage but speed) is to use an Ethernet dedicated wired backbone between the mesh access points and the main router. The wired backbone avoids all the issues related to the wireless backbone of Wi-Fi mesh networks.

A dedicated wired solution is the only solution that guarantees the maximum coverage, maximum speed between the access points and the main router, and removes the effect of neighbor interference and saturation in the backbone.

The wired backbone may be based on copper cable (CAT5/6 Ethernet cable) or optical cable (plastic or glass optical fiber).

2.2.1 Copper backbone

Copper unshielded twisted pair (UTP) cables are the most frequent type of wire connections for consumer-grade networks. When gigabit per second speeds are required, then the cable has to meet a category 5e or higher. When installed in a home, the UTP cable must be routed inside dedicated data conduits or installed externally stapled or with external trunking on the wall.

As the wires in a UTP cable conduct current, they should not share the same conduits as the power mains lines. Construction rules in different countries state that conduits for UTP cables must be dedicated just for data communications in order to avoid short circuits and interference. Old buildings do not have such conduit infrastructure dedicated for Datacom, and installers are forced to do an external (outside the walls) installation.

Cat-5e and higher cables are thick and rigid. They are not easy to route on wall surfaces, and the final installation is not nice looking, resulting in frequent customer complaints. In fact, many Service Providers report that the number one cause of “failed” installations for UTP in their statistics is because of users not allowing installers to route UTP cables externally.

2.2.2 Optical backbone

The easiest and most affordable way to create an optical home network, also known as FITH (Fiber In The Home), is using Plastic Optical Fiber (POF). POF is a thin, robust, flexible and easy to handle cable made out of plastic. The light source used in POF networks comes from a red LED, and it is able to transmit at 1 Gbps over up to 50 m of POF cable. The POF cable is terminated in POF outlets, which are devices that make the conversion between the optical signals travelling through the POF and the electrical connection to the final equipment. POF outlets have one or more Gigabit Ethernet ports with RJ45 connectors on the front.

Gigabit POF networks are standard Ethernet technology. The connection of the outlet to the POF line is located on the back side of the outlet; that is the one that is not visible. The POF cable runs through the conduits and connects to the optical port on the back side of the outlet, remaining hidden from the user and allowing much faster installation. When conduits are not available, installing POF on the wall is much less noticeable due to its size. Also, attaching POF to other on-wall existing cables such as electrical ones makes installation faster with no aesthetical impact. POF wires can be established in a “daisy chain” fashion, where the corresponding POF outlets must have two optical ports.

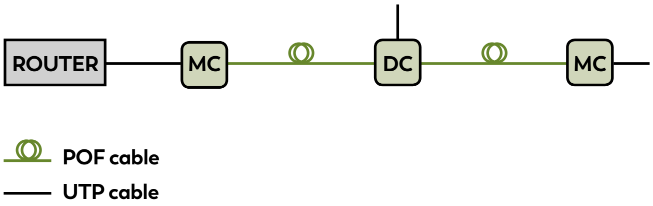


Figure 2: Daisy Chain topology

One of the advantages of installing the POF cable is that it can be cut and connected without any sophisticated tools. No special qualification is required for installers. It is just cut and plug. No polishing or splicing is needed. Installations are quick and easy.

Figure 3: POF cutting and connection

As a dielectric cable, POF can safely share conduits with any other electric wires, such as the mains, telephone, TV, data... without any interference or electrical hazard issues. Thanks to this, POF enjoys a 100 percent installation success rate in home networks.

Moreover, compared with the traditional Optical Fiber, which is made out of glass and not plastic, POF is much more robust. The flexibility of POF allows for easy routing and prevents breaks. The transmitted visible red light is eye-safe, as it is not coming from a laser but a low-cost diode. Network installations using Plastic Optical Fiber are cheaper than equivalent copper UTP or glass optical fiber.

3 Field test description

The objective of the field test is to compare Wi-Fi performance in high-speed home networks using the two backbone solutions described above: **Wi-Fi itself implemented in a Wi-Fi Mesh system** and Wi-Fi connected with a **POF backbone.**

As Wi-Fi signals behave very differently depending on the size, structure and distribution of each particular house, tests have been carried out in 20 dwellings with different topology, number of floors, age and construction materials. All the tested houses originally had a POF installation. The same procedure has been followed for all the tests. The specific location of the Wi-Fi nodes varied between different installations due to the different house sizes and topologies; however, the same Wi-Fi devices have been used in all the tests and houses for both backbones since Wi-Fi Mesh used accepted both Wi-Fi and Wired backhaul.

3.1 Setups and Tests

For all the speed testing, a network application has been used to generate background traffic. This background traffic simulates a typical household situation. On top of the background traffic, a speed test is run in the following rooms: living room, child room and main bedroom.

In each of the rooms, three laptops have been used as end points (clients). Another laptop is used to act as the main router (server), providing service to the three endpoints. The server-laptop is typically placed near the gateway of the house. The test setup is shown in Figure 4. The performance tests were identical for the Wi-Fi mesh solution and for the POF backbone.

Figure 4: General test setup

The Wi-Fi nodes can be configured in the two following modes:

- **Repeater mode:** This is the mode selected for all the devices of the Wi-Fi mesh network, except for the main router, which is configured in access-point mode. When a Wi-Fi device is configured as a repeater, it allows extension of the coverage of the Wi-Fi network in those areas of the home where the router coverage is poor. As explained previously, in this case the Wi-Fi device will connect with the main router through a radio channel. In order to have a good wireless link with the router, the repeater will need to be angled around any obstacle.

  When the device in repeater mode is integrated as a node of the Wi-Fi mesh network, it is not only connected wirelessly with the main router, but with the rest of the nodes of the mesh as well. It is not possible to create a mesh network unless the router supports this topology.

  Nodes should not be too close to the router (same room) in order to avoid interference between them. On the other hand, if the Wi-Fi node is too far from the router, it will not repeat the signal, as it cannot guarantee good communication. It is important to keep in mind that repeater mode does not imply an increase in the speed of the network in the areas where the router already has good coverage. The placement of the Wi-Fi repeater with respect to the router whose Wi-Fi network is to be expanded is the key to obtaining maximum performance. It is advisable to place the repeater in an intermediate area between the router and the area whose signal is to be improved. The equipment used for our test includes a visual signal indicator to identify the best place to place each mesh node.

- **Access-Point mode:** This is the mode that must be set for all the devices for the POF backbone network. Each Wi-Fi device is then connected to the main router via POF. The POF will ensure 1 Gbps speed between the access point and the central router. In this case, no care has to be taken to avoid interference between Wi-Fi signals. Access Points with a POF backbone is a great choice if the user wants to extend their own home Wi-Fi connection when, for example, a brick wall is blocking the Wi-Fi wave propagation.

3.1.1 Wi-Fi Mesh test

This test is done first because it determines the optimum location of the Wi-Fi devices around the house. They are located according to the manufacturer's rules. Three Wi-Fi devices will always be used.

First, a device is placed next to the server laptop, which is simulating the main server. It will be the first communication point between the server and the clients around the home. The Wi-Fi device is configured in access point mode following the manufacturer's instructions and wired with a Cat-6 cable to the server laptop. This device will be the base station for the other Wi-Fi devices. The other Wi-Fi devices are configured in repeater mode and placed according to manufacturer recommendations: neither too close to the base station, to avoid interference, nor too far away, which would imply a high signal attenuation.

Figure 5: Wi-Fi mesh coverage diagram

Figure 5 shows an example of a Wi-Fi mesh installation. It shows how devices in repeater mode are located in different rooms from the main router Wi-Fi device. With this distribution, the devices can connect to each other, establishing a mesh backbone. Once the devices are placed we perform a network search. We should see a single 5 GHz Wi-Fi network. Each of the nodes relays this Wi-Fi network using the same SSID so the user only sees a single network to access.

The last step is to check the connection (ping) between every client connected to a mesh node in each room and the server connected to the main Wi-Fi router in the living room. Finally, the test is launched from the server (living room), which runs a speed test with each end-point client connected to the network (child room and main room).

3.1.2 POF Backbone test

The POF backbone typically runs to all the rooms of interest (living room and bedrooms) with POF outlet terminations in each one. All the outlets are wired together with POF in a daisy chain topology. Most of the houses selected for the testing have a mains wire conduit, which is not a star but closer to a bus topology with several branches. This fact implies that the most suitable topology for the POF, which uses the mains ducts to run, is a daisy chain.

For the POF backbone test, all the Wi-Fi devices are configured in access-point mode.

Figure 6 shows a typical distribution of a POF backbone and the placement of the POF outlets in each room. Every Wi-Fi device is connected to the closest POF outlet with a Cat-6 cable, establishing its own Wi-Fi dual band network.

Figure 6: POF backbone

In this case, connectivity is always optimum since each Wi-Fi node connects by POF just at 1 Gbps to the main router, and not to each other as was the case in the Wi-Fi mesh test.

The **Received Signal Strength Indicator (RSSI)** of the Wi-Fi signals should be similar to the ones shown in the Wi-Fi mesh test because the Wi-Fi devices are in similar locations. However, and this is the key result, a great difference in net speed rates are measured as the POF-connected Wi-Fi devices are not losing any performance from each other since they do not connect wirelessly to the main router. A robust and high capacity 1 Gigabit per second backbone is now connecting each Wi-Fi node to the main router.

End user devices are placed in the same locations as in the Wi-Fi mesh test, so they connect to the wireless device with the best Wi-Fi signal. The connection between every client and the main router is checked before launching the test.

3.2. Tests Results

Results for the Wi-Fi 5 GHz testing are shown in the following graphs. Three parameters affecting the user perception of the Wi-Fi quality have been measured: **Throughput, latency and jitter.**

Throughput is the result of the speed test adding the background traffic of the room under test (see appendix 6.2.1).

Latency is the time it takes a packet to travel through the network, from origin to destination.

Jitter is the variability of the latency.

For Throughput, the average of the furthest link is shown. This link would be the one that has a more limited speed and therefore sets the effectiveness of each backbone option.

For Latency and Jitter, data is clustered together in two groups: "highest" (average of the best three measures in all the population of houses and rooms) and "lowest" (average of the worst three measures in all the population of houses and rooms). The maximum values provide information about potential effect over quality of experience (QoE) related to certain real-time services such as video streaming or online gaming. The lowest values set a baseline on what cannot be improved in a feasible way.

Figure 7 shows the results of the throughput. Here we can see that securing 1 Gbps to each Wi-Fi Mesh device greatly improves the speed. Just as interesting is the result for a wireless backbone, where despite that it is just a 3 Wi-Fi end node network, throughput remains in the range of 100 Mbps. For a higher number of end nodes, which is a normal case in any home, this number is expected to be much lower.

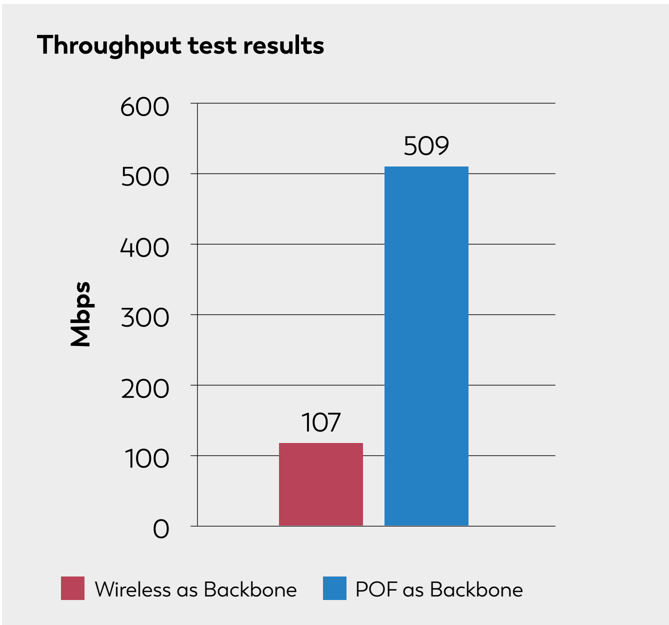


Figure 7: Throughput test results

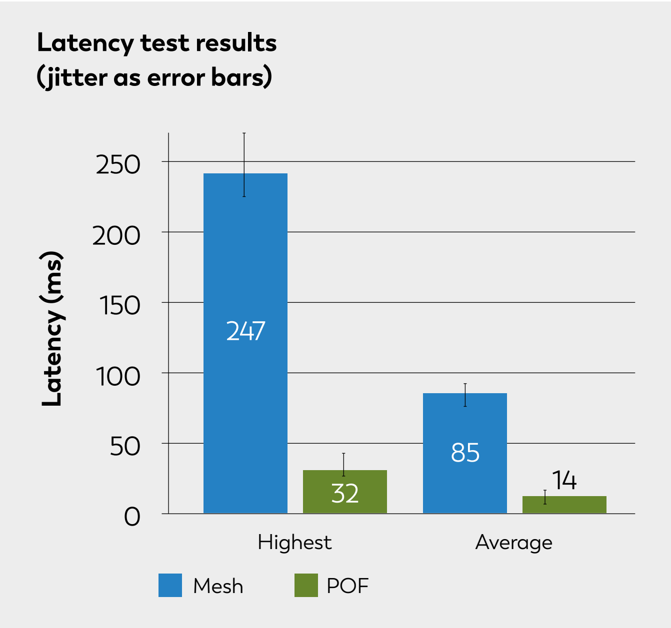


Figure 8: Latency test results

Figure 8 shows the comparison of latency (ms) and jitter (as error bars for each latency data point) using both backbone technologies. In this case, we show the average of the measures taken in all the houses and all the rooms and the corresponding highest figures found. It can be seen that results are clearly better for the POF backbone and implies that the probability to have lagging in online gaming or interrupted video streaming is much higher when using Wi-Fi as backbone.

In Figures 9 and 10 we analyze how the type of house (flat vs. multistorey house) affects throughput. Due to longer distances and walls in the wireless path, extended performance with Wireless backbone decreases in multi-storey homes and probably for the opposite reason slightly increases in flats. However, POF backbone maintains high numbers, always showing that what affects a wireless backbone does not affect a POF backbone at all.

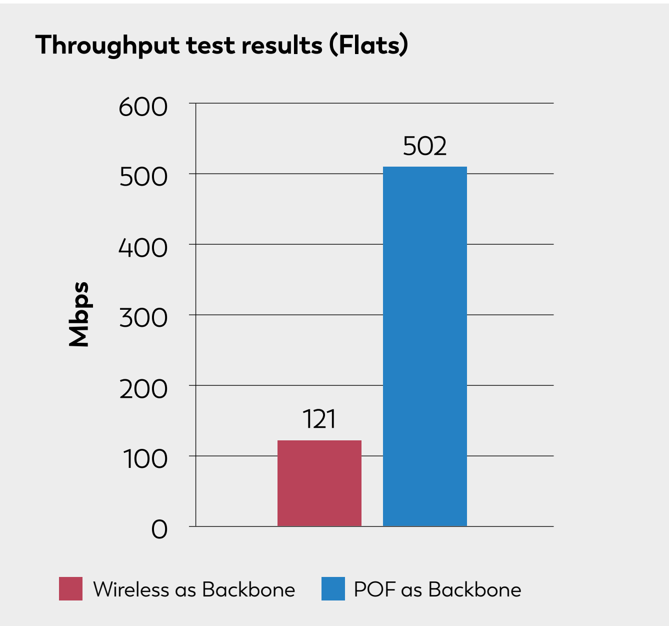


Figure 9: Throughput results for flats

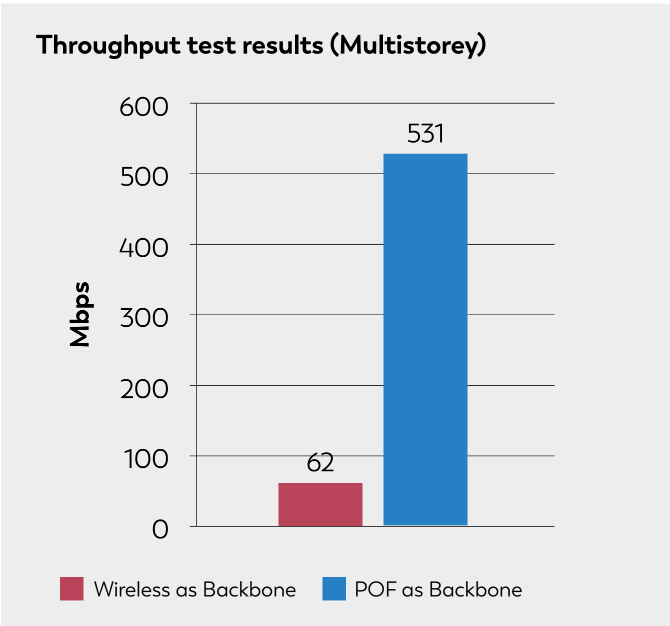


Figure 10: Throughput results for multistorey

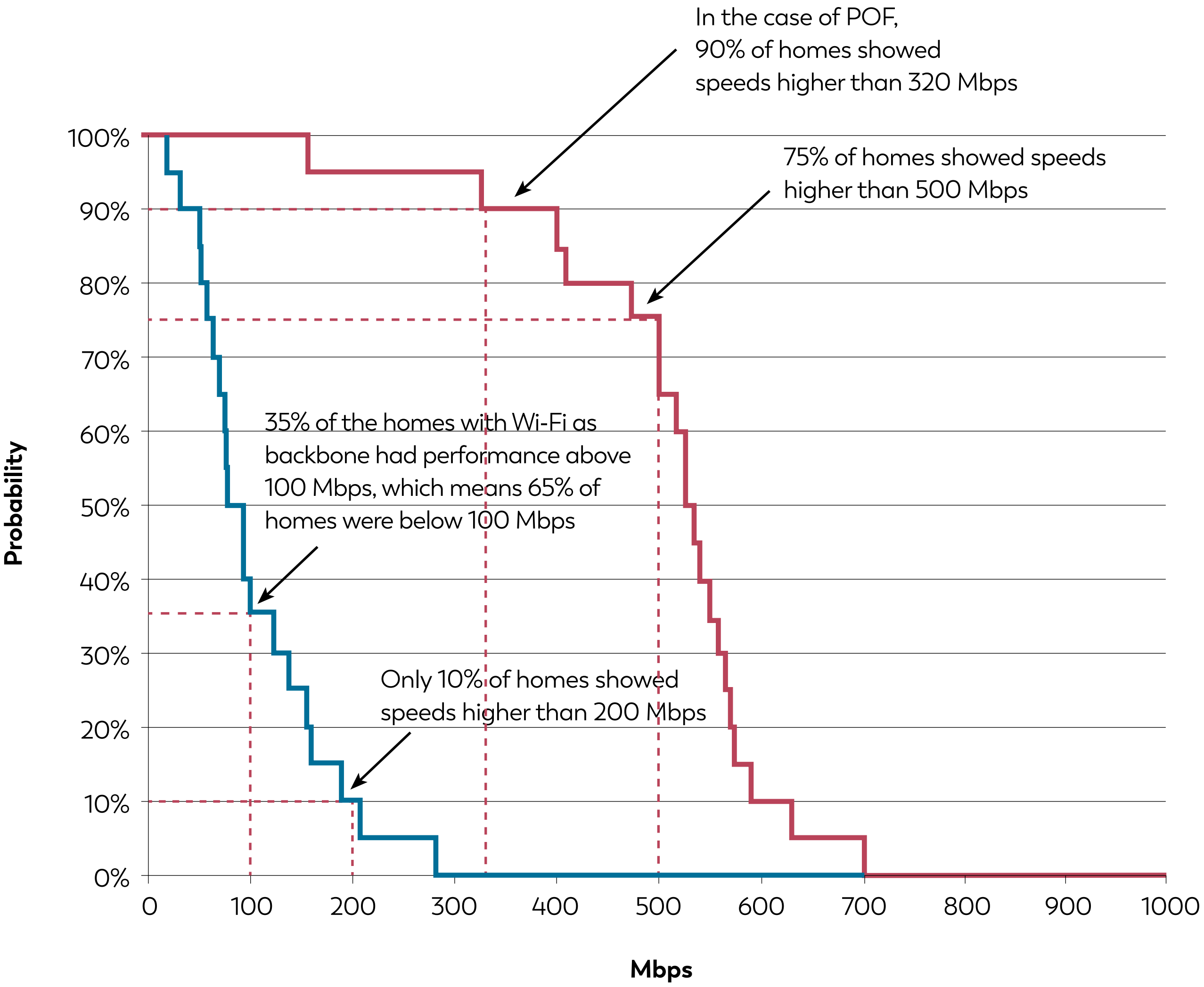


Figure 11: Throughput histogram for all cases

Figure 11 shows a histogram with the percentage of houses that have reached the indicated wireless speed rates, for both the Wi-Fi mesh and POF backbone tests. It can be seen that 90 percent of the houses with a POF backbone will enjoy a minimum speed higher than 320 Mbps, with 75 percent higher than 500 Mbps. On the other hand, only 65 percent of the houses with Wi-Fi mesh will not reach 100 Mbps despite just 3 Wi-Fi end nodes are present in the network.

It is important to note that the results of Wi-Fi mesh may decrease in real life when adding more end nodes and depending on the saturation of 5 GHz band. Adding more Wi-Fi Mesh nodes may improve only the high-end numbers (10 percent of homes), since those may not be so affected by distance, walls, or saturation effects in the tests.

4. Number of Mesh Nodes

As described, the number of additional Wi-Fi Mesh nodes used in the tests for both Wi-Fi backbone and POF backbone were two. Considering that POF was securing 1 Gbps to each Mesh node and the results of the tests were much in favor of POF, a comparison within the same field test was made following the same methodology to see the impact of the number of Mesh nodes in the results by just having one additional Mesh node with POF backbone.

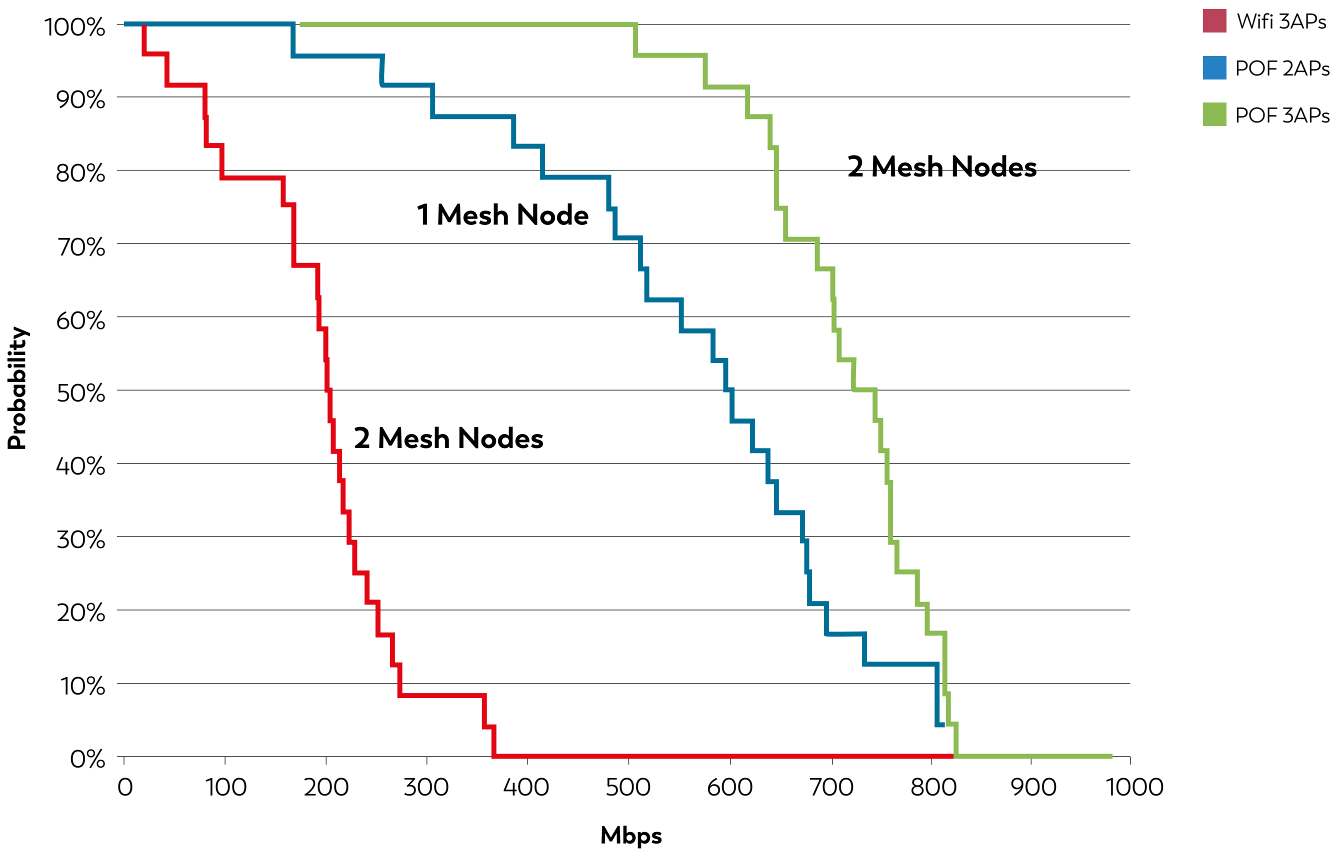


Figure 12: Throughput histogram by added mesh nodes

Figure 12 shows the results of those tests. The interesting outcome is that just adding one Mesh node, the results with the POF backbone are still far better than with two additional Mesh nodes with Wi-Fi backbone. This result indicates that a POF backbone facilitates a lower cost and simpler implementation than a Wi-Fi backbone.

5. Conclusions

- Wired backbone is the most optimal solution to extend and optimize Wi-Fi networks.
- The benefit of POF backbones is best realized in multistorey houses compared to flats.
- Wi-Fi performance is between three and five times faster with POF backbone than with Wi-Fi backbone using exactly the same Wi-Fi mesh nodes.
- Worst cases of Wi-Fi mesh networks are extremely low, showing figures far below 100 Mbps compared to POF backbone, which are over 500 Mbps.
- Given the installation advantages of POF versus UTP cable, the former is the best wired choice to enhance Wi-Fi experience in homes.
- Latency and jitter are much higher with Wi-Fi mesh, which can severely hinder the quality of service. The POF backbone can be an enabling technology for services, such as real-time streaming or online gaming.
- Adding more nodes to the Wi-Fi mesh network does not improve performance but having fewer ones with POF backbone provides far better results.

6. Appendix

6.1 Topologies and Locations

Tests have been done in several locations in the Madrid area and surroundings. Thanks to this distribution, results have been obtained in very different situations.

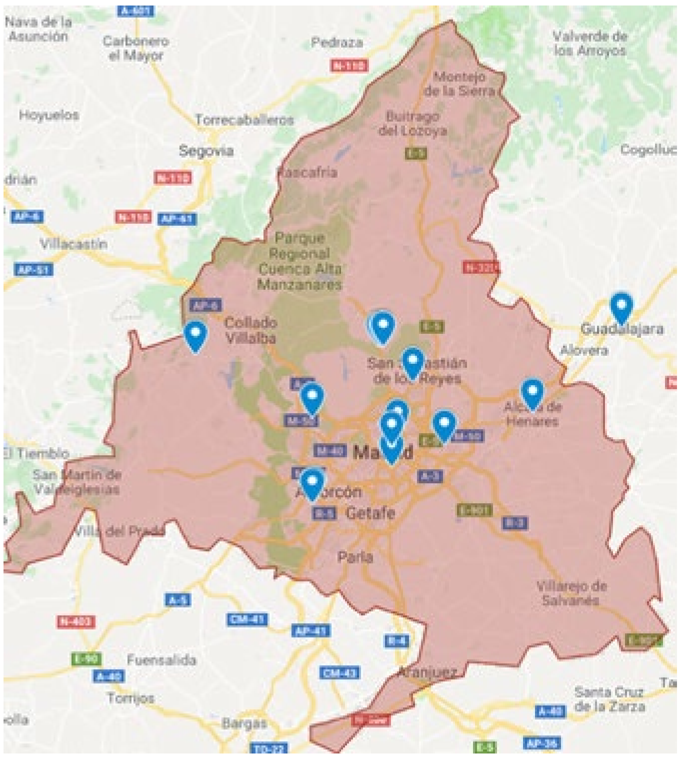


Figure 13: Test locations

6.2 Test Tools

6.2.1 Iperf traffic generation

The Iperf tool has been used to set the background traffic load. Iperf is a widely-used tool for computer network measurement. Iperf version 2.010 is configured to save current statistics every 5 seconds in order to have good measurements. TCP and UDP protocols are used; with TCP, the window size is changed to 4 MB to optimize the test and UDP is used to measure jitter and latency. The maximum result for the speed test with Iperf is expected to be 939 Mbps for TCP traffic, and 954 Mbps for UDP. Speed test is measured between the server (main router) and every client (the nodes), not simultaneously. The throughput is measured first with TCP and then with UDP.

In table 1, the background traffic configured at the Iperf tool is described for each tested room, depending on the typical use case.

				Simulated speed (Mbps)	
Client	**Location**	**Use Case**	**Protocol**	**Up**	**Down**
Client 1	Living room	HD Video	UDP	-	20
	Living room	Web/Mail	TCP	1	5
Client 2	Child bedroom	Peer to Peer	TCP	50	50
	Child bedroom	Online gaming	UDP	2	10
	Child bedroom	Web/Mail	TCP	1	5
Client 3	Main bedroom	4K IPTV	UDP	-	30
	Main bedroom	Web/Mail	TCP	1	5
		TOTAL		**55**	**125**

Table 1. Traffic profile

6.3 Hardware

First, the hardware has been tested in laboratory, with an ideal situation, to measure the maximum bandwidth. The wireless performance was close to 1 Gbps, so the hardware is not a bottleneck for these tests.

To carry out the comparative tests, the same hardware has been used, located in the same rooms but with different configurations. Table 2 summarizes the equipment used.

Device	Model	Manufacturer	Quantity
Laptop	15-BS507NS	HP	4
Media-bridge	RT-AC87U	ASUS	4
Wi-Fi Device	Smart Wi-Fi	Mitrastar ODM for Spanish ISP	2-3

Table 2: Test hardware

6.3.1 Media Bridge

Most of the laptop Wi-Fi cards do not reach rates higher than 400 Mbps. To guarantee the wireless reception of 1 Gbps rates, each laptop (client) is connected to a high-performance Wi-Fi media bridge.

AC2400 Dual Band Gigabit Wi-Fi Router with MU-MIMO, ultra-fast 802.11ac dual-band Wi-Fi router boosts speeds up to 1900 Mbps. The media bridges are used to assure the highest speed connection with Wi-Fi.

Model	RT-AC87U
Microprocessor	Dual-core processor
Capability	802.11b/g/n/ac
Antennas	2.4/5 GHz 4x4 MU-MIMO
Wi-Fi chipset 2,4GHz	Broadcom BCM4360KMLG
Wi-Fi chipset 5GHz	Quantenna QT3840BC
Ports	5 GE / USB 3.0

6.3.2 Wi-Fi Device

These devices are used for the comparative tests, as repeaters for the Wi-Fi mesh and configured as access points for the POF backbone.

When used as repeaters in the mesh network, the RSSI signal is checked in the furthest rooms, taking into account walls or obstacles that attenuate the Wi-Fi signal. Depending on the measured value there are three scenarios:

- **-40 dBm < RSSI:** Devices are too near or there is interference. In this case, a Wi-Fi mesh will not work. Another room with less RSSI should be tried for the location of the Wi-Fi device.

- **-79 dBm < RSSI < -40 dBm:** Signal strength is good at this room for implementing Wi-Fi mesh.

- **-79 dBm > RSSI:** Devices are too far apart or obstacles attenuate the signal. In this case, Wi-Fi mesh may not work. Another room with better RSSI should be tried for the location of the Wi-Fi device.

Placement requirements and RSSI levels are defined by the manufacturer. The access point in mesh mode will work only if the RSSI is between -79 and 40 dB.

Model	Base Port 2
Capability	802.11b/g/n/ac
Antennas	2.4/5 GHz 4x4 MU-MIMO
Wi-Fi chipset	Quantenna QV940
Ports	1GE LAN

KDPOF
pr@kdpof.com +34 918043387 www.kdpof.com
Knowledge Development for POF, S.L. - Ronda de Poniente, 14 2° C-D - 28760 Tres Cantos, Madrid, Spain