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Research Article

A Test Method to Determine the Optimum Position for the Wi-Fi Module in a Smart TV

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Abstract: Internal Wi-Fi modules are extensively utilized in Smart LED TV sets, as they are a key component in ensuring reliable wireless connectivity. Interference caused by various electronic components, such as the power supply unit (PSU), system on chip (SoC), LED backlighting circuits, HDMI and USB ports, as well as internal speakers located inside the TV cabinet, needs to be minimized. This minimization is crucial to maintain a robust and uninterrupted Wi-Fi connection between the TV set and the Access Point. This study provides a detailed and comparative analysis of how to properly position Wi-Fi modules for optimal performance and maximum efficiency. The focus is on determining the most suitable location within the TV cabinet to reduce signal interference. Through experiments conducted on nine Android OS-based LED TVs, the areas with minimal signal disruption were identified. Furthermore, the study illustrates how strategic placement of the Wi-Fi module can significantly optimize overall connectivity.

Keywords: *Wi-Fi Module, Mainboard, PSU, TCON Board, Performance, Comparison, Television, LVDS Cable, Speaker.*

Akıllı TV'de Wi-Fi Modulünün En Uygun Konumunu Belirlemek İçin Bir Test Yöntemi

Öz. Akıllı LED TV'lerde yaygın olarak kullanılan dahili Wi-Fi modülü, güvenilir kablosuz bağlantıyı sağlamak için en önemli bileşendir. TV kabininde bulunan güç kaynağı ünitesi (PSU), yongada sistem (SoC), LED arka aydınlatma devreleri, HDMI ve USB portları ile dahili hoparlörler gibi çeşitli elektronik bileşenlerin neden olduğu parazitlerin en aza indirilmesi, TV ile erişim noktası arasında sağlam ve kesintisiz bir Wi-Fi bağlantısı sağlamak için kritik öneme sahiptir. Bu çalışma, Wi-Fi modüllerini doğru şekilde konumlandırarak optimum performans ve maksimum verimliliği sağlama konusundaki ayrıntılı ve karşılaştırmalı bir analizi sunmaktadır. Odak noktası, TV kabini içinde sinyal parazitini azaltacak en uygun yeri belirlemektir. Dokuz Android işletim sistem tabanlı LED TV üzerinde gerçekleştirilen deneyler sonucunda, sinyalin en az kesintiye uğradığı alanlar belirlenmiştir. Ayrıca, bu çalışma Wi-Fi modülünün stratejik yerleşimiyle genel bağlantının nasıl optimize edilebileceğini göstermektedir.

Anahtar kelimeler: *Wi-Fi Modulü, Anakart, PSU, TCON Kartı, Performans, Karşılaştırma, Televizyon, LVDS Kablosu, Hoparlör.*

1. Introduction

With the widespread adoption of Smart TVs and streaming platforms, alongside the increasing video and audio bitrates required for UHD content [1], it has become essential for TVs to maintain a healthy, uninterrupted, and fast wireless network connection. Several factors contribute to ensuring a reliable wireless network connection in TV sets.

One critical aspect is positioning the Wi-Fi module in an optimal location to ensure better signal reception. This plays a vital role in maintaining a stable and strong connection between the TV and the Wi-Fi router [2, 3]. In addition, the placement of the Wi-Fi module should minimize signal

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interference from other internal components, such as the mainboard and other electronic parts within the TV.

Reducing interference helps maintain a cleaner and more reliable Wi-Fi signal [2, 4].

Another key factor is avoiding physical obstructions, such as metal components or densely packed electronics, around the Wi-Fi module. This minimizes signal blockage, allowing for stronger and more consistent Wi-Fi performance [5, 6, 7]. Furthermore, placing the Wi-Fi module at a sufficient distance from potential interference sources helps prevent signal degradation caused by electromagnetic interference (EMI) from other electronic components [4, 8].

Improved signal strength is also crucial for achieving higher data rates, reduced latency, and overall better performance during streaming and other online activities [9]. The strategic routing of cables connected to the Wi-Fi module can further contribute to signal quality, as proper cable management reduces the risk of signal degradation. Additionally, locating the module away from heat-generating areas helps maintain the module's operational efficiency, thus sustaining optimal Wi-Fi performance [10].

If the Wi-Fi module features external antennas, their strategic placement can enhance signal reception by reducing interference [11] and maximizing coverage [12]. Ultimately, each of these considerations contributes to improved Wi-Fi performance, ensuring that the TV provides a seamless streaming experience for users.

This study focuses on optimizing Wi-Fi performance in Smart TVs at the hardware level. While studies such as those by Alam et al. [1] and Mozaffariahrar et al. [2] examine network-level challenges, they do not address the impact of electronic components inside the TV cabinet on the Wi-Fi module. Haider et al. [4] discuss wireless network interference more broadly, while Aileen et al. [5] explore how building materials affect Wi-Fi signal strength. Alper and Döner [12] provide general guidance on the placement of the Wi-Fi module on chassis materials but do not focus on the Smart TV environment. This study presents a detailed test method specifically examining signal degradation caused by internal components such as the mainboard, PSU, and TCON board, to optimize the placement of the Wi-Fi module.

The aim of this study is to determine the optimal location of the Wi-Fi module inside the cabinet during the design phase to prevent Wi-Fi performance issues and connection dropouts in Smart LED TVs. Through experiments conducted on multiple Android OS-based LED TVs, practical solutions for Wi-Fi module placement are offered, and an innovative approach is developed to enhance Wi-Fi performance in Smart TVs. The unique contribution of this study lies in its ability to address the challenges posed by internal components, providing an optimized hardware-level solution for Wi-Fi module placement.

The paper is arranged as follows: In the second section, details on the test method, such as the test environment, test positions for the Wi-Fi module, and test procedure, are provided. In the third section, the experimental results of the study are presented. The paper concludes with the final section.

2. Test Method

This section provides details of the proposed test method. The test environment, test equipment, possible locations for the Wi-Fi module inside the TV cabinet, and the test procedure are explained. The interior of a typical LED TV cabinet is shown in Figure 1 below.

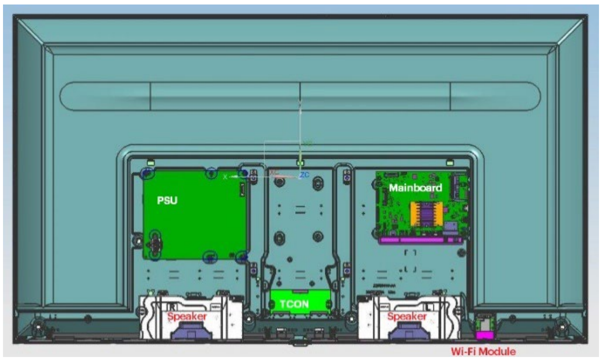

Figure 1. *LED TV Back View*

Figure 2 below shows the placement of the Wi-Fi module inside the TV cabinet and the position of the Wi-Fi measurement antenna.

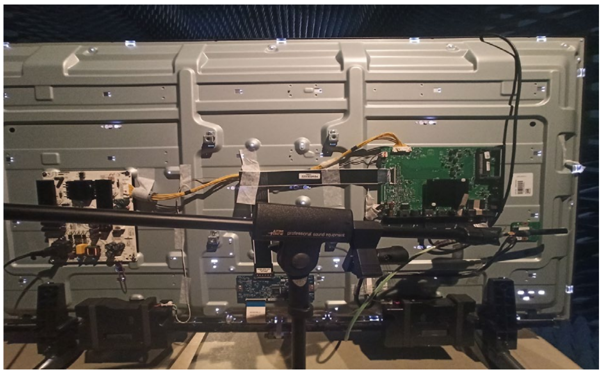

Figure 2. *A View of Wi-Fi Module and Wi-Fi Measurement Antenna*

Figure 3 below shows the overall test environment and measurement system.

Figure 3. *An Overview of the Test Environment and the Measurement System*

The test environment consists of an anechoic Wi-Fi test chamber, a control PC, a WLAN test device and an antenna as shown in Figure 4 below. The output operating frequency and power range of the WLAN Test Device shown in Figure 1 are provided in Table 1 below.

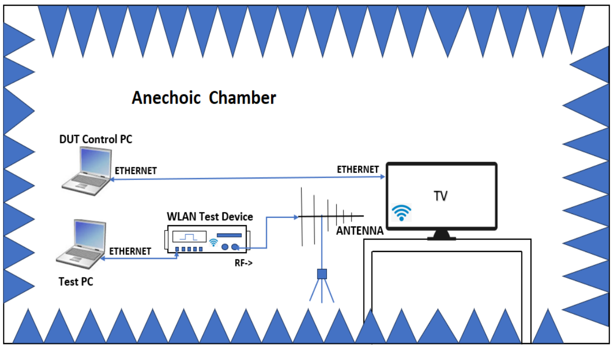

Figure 4. Illustration of the Test Environment

Table 1. Output Frequency and Power Range of the WLAN Test Device

Parameter	Ports	Range
Output Frequency Range	RF1	860 to 1000MHz
		1770 to 2660 MHz
		3300 to 3800 MHz
		4900 to 6000 MHz
Output Power Range (CW)	RF2	+10 to -95 dBm (≤2600 MHz)
		0 to -95 dBm (>2600 MHz)

The test method involves measuring the minimum Wi-Fi Rx signal sensitivity level [13]. First, test points are identified in the two-dimensional plane inside the back cover of the TV. These positions are clustered around the three boards inside the TV (Mainboard, Power Supply, TCON). The determined positions are numbered as shown in Figure 5. The minimum Wi-Fi Rx signal sensitivity level measurement is repeated and noted for each designated position of the Wi-Fi module.

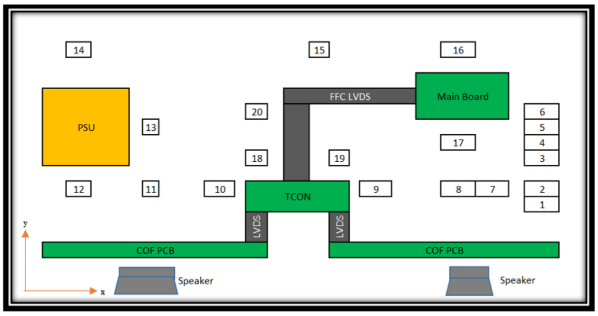

Figure 5. Test Positions of Wi-Fi Module

The test procedure measures the Wi-Fi receiver sensitivity of the DUT (Device Under Test) using the WLAN tester. It determines the packet error rate (PER) by counting the number of acknowledgment (ACK) control frames received from the DUT in response to repeated unicast data packets transmitted by the WLAN tester. No other traffic generation should be enabled during this test. The PER is generally defined as the ratio of packets lost divided by the number of packets transmitted to the DUT [14]. The test procedure is as follows:

1. Connect the Wi-Fi antenna to the RF port of the WLAN test device.
2. Fix the Wi-Fi antenna in close proximity to the antennas of the TV's Wi-Fi module.
3. Establish an Ethernet connection between the WLAN test device and the PC.
4. Set the path loss on the WLAN test device.
5. A waveform (11n, MCS0, 20M) is used as the Wi-Fi test signal in Rx sensitivity [15] measurement. In IEEE 802.11 standards, MCS stands for "Modulation and Coding Scheme." MCS0 specifically refers to the lowest or the basic Modulation and Coding Scheme within a particular Wi-Fi standard. The term is commonly associated with Wi-Fi technologies like 802.11n and 802.11ac [16]. For 802.11n, MCS0 corresponds to BPSK (Binary Phase Shift Keying) modulation with a coding rate of 1/2.
6. Adjust the power level of the Wi-Fi test signal to -80 dBm in the generator section of the WLAN test device.
7. Disable Bluetooth on the Device Under Test (DUT).
8. Decrease the power level of the received Wi-Fi test signal on the DUT until the Packet Error Rate (PER) reaches 10%.
9. Record the last power level, where the PER is less than 10%, as the minimum Receiver (Rx) RF Sensitivity Level in dBm [17].

$$Rx\ Sensitivity\ (dBm) = 10 \times log_{10}\left(\frac{P}{1mW}\right) \quad (1)$$

where P is the received signal power, in milliwatts (mW).

10. Compare the measured min. Rx Sensitivity Level value with the specified specification value.

3. Experimental Results and Discussion

In this section experimental test results of the study are given. The spec value used in the test is determined with a 4 dB safety margin based on the specification value published by IEEE for MCS0 20MHz (See Table 2), and it is set to -86 dBm.

Table 2. IEEE Specs for Receiver minimum input level sensitivity (IEEE Std 802.11ac-2013)

MCS	Modulation	Code Rate	Minimum Sensitivity [dBm]			
MCS0	BPSK	1/2	-82	-70	-76	-73
MCS1	QPSK	1/2	-79	-76	-73	-70
MCS2	QPSK	3/4	-77	-74	-71	-68
MCS3	16-QAM	1/2	-74	-71	-68	-65
MCS4	16-QAM	3/4	-70	-67	-64	-61
MCS5	64-QAM	2/3	-66	-63	-60	-57
MCS6	64-QAM	3/4	-65	-62	-59	-56
MCS7	64-QAM	5/6	-64	-61	-58	-55
MCS8	256-QAM	3/4	-59	-56	-53	-50
MCS9	256-QAM	5/6	-57	-54	-51	-48

In this study, a total of nine different Android OS-based LED TVs were used for the measurements. Each of these TVs is treated as a separate sample to ensure that the results reflect a range of device configurations and possible variations in hardware. As indicated in Table 2, the term "Sample" refers to each individual TV unit, and the corresponding sensitivity levels are listed for each of the 20 test points.

Table 3. The Measurement Results of Average Rx Sensitivity Levels for Each Test Point

Test Point	Test Result [dBm]								
	Sample	Sample	Sample	Sample	Sample	Sample	Sample	Sample	Sample
1	-92	-88.5	-92	-86.5	-87	-88.5	-88.5	-87.25	-83
2	-90.25	-90.25	-89.5	-90.25	-90.5	-88.65	-89.25	-90.25	-88.25
3	-84.85	-92	-88.5	-86.25	-90	-87.75	-88.25	-92	-87.75
4	-83.25	-86.5	-87.5	-90.75	-86.25	-83.25	-83	-89	-90.5
5	-80.25	-83	-83.5	-86.75	-77.5	-84.25	-79.5	-91	-82
6	-80.75	-78.5	-83.5	-81	-85	-83.25	-81.5	-81.5	-77.5
7	-87.25	-87.75	-90	-87	-84.75	-90	-85.75	-88.25	-90.5
8	-86.75	-88.5	-88.5	-85.5	-83.5	-85.5	-89.25	-86	-87.5
9	-78.5	-84.75	-78.75	-84.25	-83	-76.5	-86	-90	-83.5
10	-81.25	-85.25	-83.25	-80	-79	-80.75	-83.75	-91	-90.75
11	-92.25	-87.5	-85.25	-89.75	-88.75	-88.5	-86.75	-87.25	-86
12	-91	-87.5	-86	-89.5	-90.5	-92.25	-87	-93.5	-91.25
13	-89.5	-89	-88.55	-86.5	-87.5	-90.75	-86.25	-89.5	-86.75
14	-91	-89.75	-91.5	-87	-86.5	-92	-90.5	-92	-90
15	-93	-90.75	-90.5	-91.25	-86.75	-93.5	-81	-90.75	-89.25
16	-86.75	-87	-87.5	-82	-82.75	-88.75	-85.5	-88	-86.5
17	-76.5	-81	-85.5	-81.5	-82	-84.5	-85	-88.25	-75.5
18	-79.5	-87.5	-87.25	-85.75	-88.75	-88.25	-89	-85	-83
19	-88.25	-89.5	-84.75	-87.5	-88.5	-81.25	-84	-87.5	-82
20	-86	-90.5	-88.25	-88.5	-89.75	-89	-84.5	-86	-85.5

Measurement results of -86 dBm or lower are indicated in blue, while results higher than -86 dBm are shown in yellow. The triple color scale used in the "Test Point" column of the table is explained below:

Green: At most 2 yellow test results
Orange: 3 to 5 yellow test results
Red: 6 to 8 yellow test results

Figure 6 below is a graphical representation of the Wi-Fi Rx sensitivity test results.

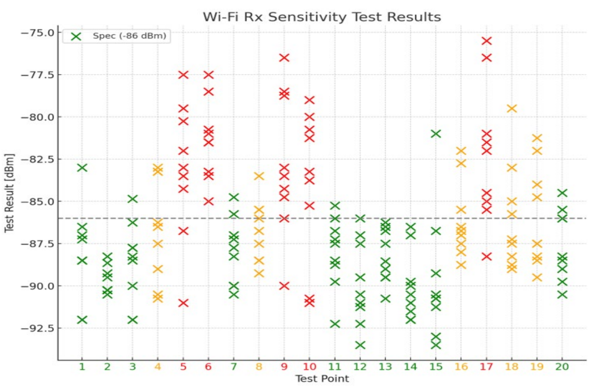

Figure 6. *Wi-Fi Rx Sensitivity Test Results*

The areas inside the TV cabinet where the Wi-Fi module performs well, areas with moderate issues, and areas with severe performance degradation are visually presented in Figure 7.

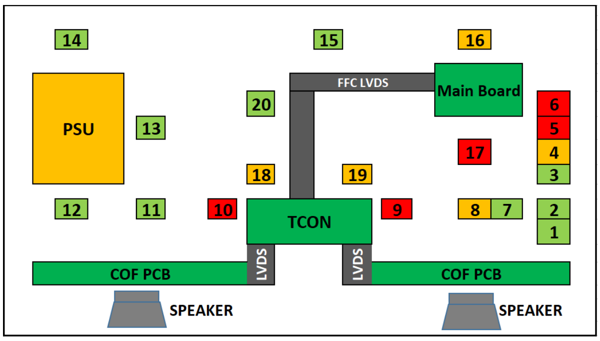

Figure 7. *Test Results Summary*

Integrated circuits (ICs) creating electromagnetic interference on the motherboard are located near the bottom right part of the motherboard. Therefore, the worst Wi-Fi Rx Sensitivity Level values around the motherboard are measured at test points 5, 6, and 17. Poor Wi-Fi Rx Sensitivity Level values are observed at test points 9 and 10, which are close to the TCON card. The results of measurements around the power supply unit (PSU) indicate that the PSU does not significantly negatively impact the Wi-Fi Rx Sensitivity Level performance.

While positions 1, 2, 3, and 7 were determined as generally optimal for the tested devices, the methodology is designed to be adaptable. This adaptability allows for determining the most suitable placement for the Wi-Fi module in specific devices, based on their unique hardware configurations and interference characteristics.

4. Conclusion

This study was conducted with 9 different UHD LED TVs in screen sizes of 43", 50", 55", and 65". The impact of electromagnetic interference generated by the electronic boards inside the cabinet on the TV's Wi-Fi Rx Sensitivity level has been analyzed. The proposed test methodology guides electronic hardware design and mechanical design teams in determining the optimal placement of the Wi-Fi module within the cabinet during the design stage. This method helps prevent potential customer complaints related to TV Wi-Fi connection performance. As a result, it was determined that the areas farthest from the motherboard and TCON card are safe in terms of Wi-Fi Rx performance. The optimum positions for a Wi-Fi module are areas 1, 2, 3 and 7. Other areas (11, 12, 13, 14, 15, 20) are not suitable due to increase in the cable length between the module and the mainboard and cable routing complexity. In addition to determining the generally optimal locations for the Wi-Fi module, this study provides a flexible framework. The proposed methodology allows for identifying device-specific optimal placements, accommodating variations in hardware design and electromagnetic interference patterns. This adaptability ensures the method's utility across different Smart TV models and configurations.

Author Contribution

Formal analysis – Barış Özden (BO); Investigation – BO and Erol Çalık (EC); Experimental Performance - BO; Data Collection - EC; Processing – BO and EC; Literature review - EC; Writing - BO; review and editing - BO and EC.

Declaration of Competing Interest

The authors declared no conflicts of interest with respect to the research, authorship, and/or publication of this article.

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