A Study on the Wi-Fi Radio Signal Attenuation In Various Construction Materials (Obstacles)

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***Abstract*—** The paper views in details a Wi-Fi radio signal passing throughout various construction obstacles in the experimental equipment which was specially developed and made by the authors. Based on study results the data of various materials influence on the radio signal distribution have been obtained. The comparative diagrams of the signal levels on the power and quality for various materials were constructed.

Keywords— Mobile Communication; Wi-Fi; signal attenuation (fading); construction obstacles; experimental equipment

I. Introduction

Using Wi-Fi to data transfer over short distances is used everywhere. But often it is necessary to take into account the negative impact of various building structures when installing a Wi-Fi network. Full-scale studies on this problem have not been conducted, although there are many studies on Wi-Fi technology or implementations of new technologies with improved characteristics.

In paper [1] the new IEEE 802.11ah, which is a promising communication standard, is being analyzed. This standard supports a large number of devices in the Internet of Things (IoT). It provides attractive features such as: improved scalability, low power consumption and large area coverage. In paper, the authors analyze IEEE 802.11ah performance and compare it with the known alternative IEEE 802.15.4. The simulation results show that new 802.11ah standard works better than 802.15.4 in terms of association time, bandwidth, delay and coverage range.

The paper [2] is devoted to the implementation of the new technology 60-GHz Wi-Fi based on the IEEE s802.11ad standard. This frequency range become attractive in recent years due to the high potential of large bandwidth in the unlicensed 60 GHz band, which allows data transfer with a several gigabit rate. However, the commercialization of 60-GHz Wi-Fi is not yet widely used, mainly because of the high coverage limitations, as well as the lack of a various applications.

Thanks to the promising applications in e-health and entertainment services, a wireless body area network (WBAN) also receives a close attention [3]. One of the most important tasks for WBAN is to monitor and maintain the quality of service (QoS). In the paper being described, the authors reviewed the probabilities of delivery and delay in a dynamic environment determined by human mobility. The authors also reviewed another important problem - ensuring energy efficiency in such network with limited resources.

The quite interesting paper [4] is devoted to an experimental study of the acceptable Wi-Fi radiation level. Studies were conducted on a Wi-Fi network in a typical room inside the building. The experiments were carried out by quantifying the exposure levels found in different parts of the building when the router terminal devices are in certain positions. In addition, an influence on the traffic type radiation power, which is transferred through the network, was studied. The exposure evaluation was carried out by collecting measurements using the new dosimeter "EME Spy-140" in a real scenario and comparing the results with the corresponding theoretical levels and other studies. 4,875 samples were collected, 25 places in the building were analyzed. The ROS-MLE method was used to adjust the levels to statistical distributions. The maximum exposure for WLAN (WiFi network being studied is disabled) was 0.039 V/m. Using WiFi network in operation, maximum exposure increases to 2.6 V/m in the far field region of the transmitters (with 90th percentile of 2.2 V/m). Regarding the traffic type, fluctuations up to 10 dB were detected for the exact same position, depending on whether the Web or P2P traffic is being sent. Differences in 62 dB were found in the average values between the different rooms in the building. All values below the threshold of 61 V/m are set by standards (at least 12 times lower). Certainly, this type of research is of great importance to raise awareness that radiation emanating from this technology is not insignificant and should be monitored, and also provides an overview of the level fluctuations in this context.

The authors conduct researches of various aspects of an automated control system complex for earth-moving and construction machines [5-12]. As a part of research special attention was paid to detailed review of the Wi-Fi technology. This paper describes the results of pilot studies on the equipment which was specially developed and made by the authors.

The experiment consisted of the following: Experimental Equipment was developed for measuring the radio signal attenuation (fading) in range of 2.4 GHz passing through the construction obstacles made from various materials and with different distances up to obstacles (the picture of equipment is given below, figure 1).

The wireless communication channel between two computers with the built-in Wi-Fi devices was adjusted and data transmission was carried out between them. Originally data was being transmitted inside the case without obstacles on the signal distribution path, and then the partitions made from various construction materials have been used as obstacles (glass, wood, particleboard, gypsum cardboard, ceramics, concrete, Plexiglas etc.)

On the basis of the pilot study, the radio waves propagation model in various construction obstacles at 2.4 GHz frequency range was studied.

II. EXPERIMENTATION

The Experimental Equipment consists of two computers with built-in Wi-Fi devices with the case made of galvanized iron in-between. The case has two cut-slots. Panels made from various materials were inserted into these cut-slots in the course of experiment. The Scheme of Equipment is presented below on Figure 2.

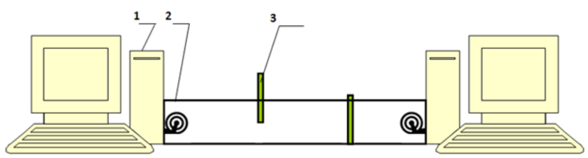

Fig.1. Experimental Equipment

1 – Computer with build in TL-WN353G 54M device – 2 pieces;

2 – Case – 1 piece;

3 – Set of Panels.

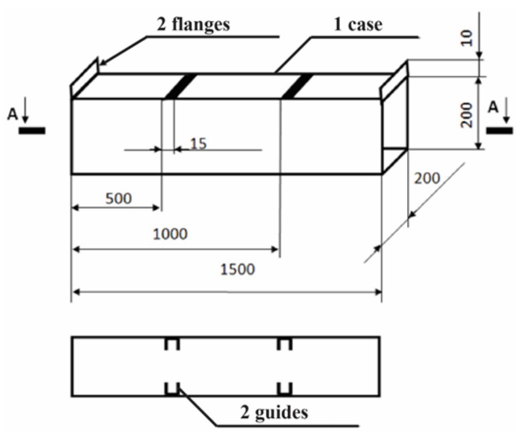

Fig.2. Sketch of the case

Besides carrying out the experiments stated in this paper it was supposed further usage of this Experimental Equipment for carrying out any experiments with Wi-Fi signal in the closed space.

During production of Experimental Equipment the Authors have developed and defined the following restrictions in materials and Equipment and accessories sizes (Table 1):

- Limit size deviation ± 1 mm;
- The Case and Slots material: Sheet steel 3 pcs, 1 mm;
- The Case and Slots are made by the bending method;
- The Case joint is folded;
- The Slots are fasten to the case by a riveting method which provides parallelism for the opposite details in range of ± 1 mm.

The Equipment photo is on Figure 3

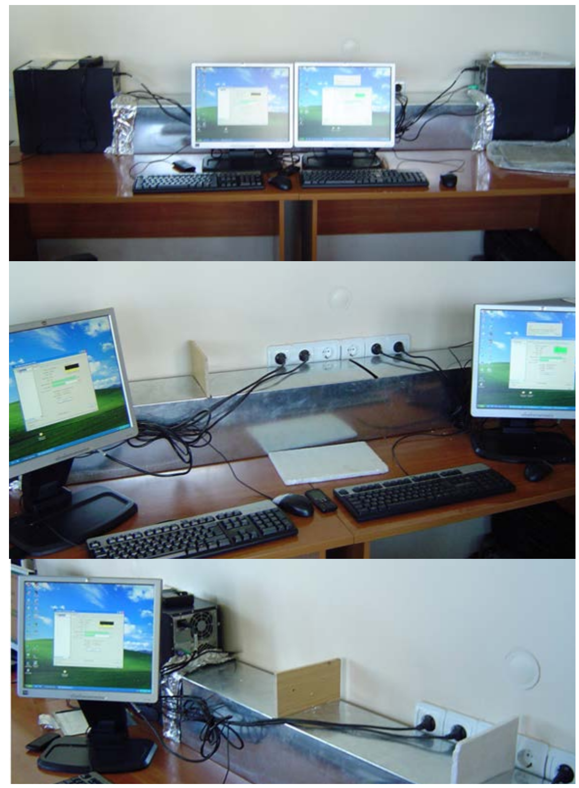

Fig.3. Experimental Equipment photo

The following equipment was used for the experiment:

two Personal Computers with two-core AMD Athlon 64 X2 4400+, basic motherboards and video adapters, and with support of wireless Wi-Fi network;

2 wireless Wi-Fi deices – TL-WN353G 54M Wireless PCI Adapter by TP-LINK, to create a wireless network with specifications in Table II;

The wave-guide – independently designed, made and installed by the authors;

The Set of Panels made from construction materials (wood, glass, ceramics, gypsum cardboard, concrete, Plexiglas).

TABLE I. THE SET OF PANELS

Panel material	Panel size, mm	Panel thickness, mm	Q-ty
Particle board	200×300	15	2
Gypsum cardboard	200×300	15	2
Ceramics	200×300	15	2
Glass	200×300	15	2
Concrete	200×300	15	2
Plexiglas	200×300	15	2

TABLE II. SPECIFICATIONS OF THE TL-WN353G 54M WIRELESS PCI ADAPTER BY TP-LINK

Parameters	Data
Supported standards	IEEE 802.11 IEEE 802.11b IEEE 802.11g IEEE 802.11n
Operation distance, m	Indoor - up to 100 Outdoor - up to 400
Operating temperature , ° C	0 - 40
Frequency range, GHz	2,4 – 2,4835
Data transfer rate, Mbit/s	up to 150 Mbit / s (802.11n) 54 Mbit / s 48 Mbit / s 36 Mbit / s 24 Mbps 22 Mbps 18 Mbps 12 Mbps 11 Mbps 9 Mbps 6 Mbps 5.5 Mbps 2 Mbps 1Mbps
Receiver sensitivity at possible errant data batch less than 8% and batch size 1024 bite	54 Mbps OFDM, -72.1 dBm 11 Mbit / s CCK, -86.0 dBm 6 Mbps OFDM, -90.5 dBm 2 Mbps QPSK, -91.6 dBm
Current consumption, mA	Standby mode – 40 Transfer mode – 450 Receive mode – 260
Modulation form	OFDM, CCK, QPSK, BPSK

During the first part of experiment the wireless communication channel between two computers with the built-in Wi-Fi adapters was adjusted without data transmission. I.e. only service packets were being transferred. The wave-guide was not connected. During the data transfer from the transmitter (TX) to the receiver (RX) the 10 readings of signal strength and signal quality at the TX and signal strength and signal quality at the RX was carried out. The signal levels measurements are resulted in Table III.

TABLE III. SIGNAL LEVELS WITHOUT WAVEGUIDE

Characteristic	Strength, %	Quality,%
The signal level at the TX	99,8	83,1
The signal level at the RX	99,5	79,6

The Figure 4 shows comparative graphs of the instant values for signal level on strength and quality at the TX and at the RX and their average values without wave-guide.

After that the Wave-guide was installed between the transmitter and the receiver and the measurement of a signal level at the transmitter and the receiver on the strength and quality was carried out. Simultaneously, the 10 readings at TX and RX were performed. The Signal Levels (average data) by strength and quality at TX and RX in case of Panels without data transfer are described in Table IV.

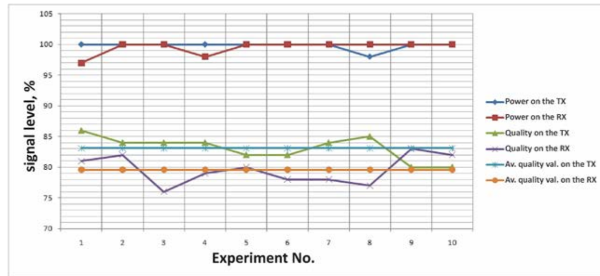

Fig.4. Levels of the TX and RX without wave-guide

TABLE IV. SIGNAL LEVELS WITHOUT PANELS

Characteristic	Strength, %	Quality,%
The signal level at the TX	94,1	61,1
The signal level at the RX	93,3	55,6

Figure 5 shows comparative graphs of the instant values for signal level on strength and quality at the TX and the RX and their average values with connected wave-guide.

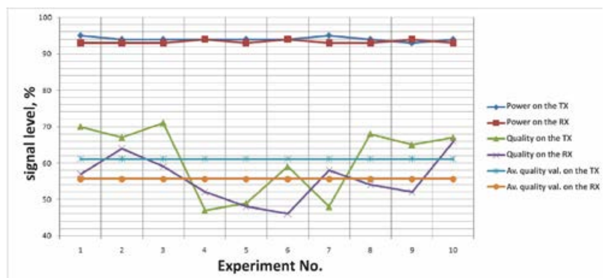

Fig.5. Signal levels for TX and Rx with connected waveguide

Figure 6 shows comparative graphs of the signal level average values on quality at TX and RX with connected wave-guide and without wave-guide.

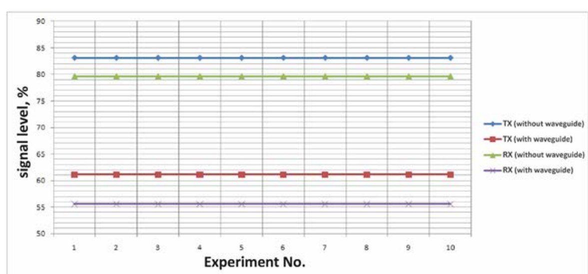

Fig.6. Signal levels on quality at TX and RX with connected wave-guide and without wave-guide.

Then, the Panels made from various materials were inserted serially into Slot-1, then into Slot-2, and finally into both Slots simultaneously. The data on strength and quality of the signal at TX and RX was observed and saved every 20 seconds. Average values of collected data are shown in Table V.

Figure 7 shows the signal level average values on quality at the TX for different materials in case of different Panels inserted into the Slot-1.

The Figure 8 shows the signal average values on quality at the RX for different materials in case of different Panels inserted into the Slot-1.

TABLE V. THE SIGNAL LEVELS WITHOUT DATA TRANSFER

Material	1st panel		2nd panel		Both panels	
TX / *RX*	*Strength*	*Quality*	*Strength*	*Quality*	*Strength*	*Quality*
Wood	97,2	58,5	86,4	46	84,7	48,2
Wood	92,4	51,8	91,1	44,4	93,8	45,1
Gypsum	86,1	48,0	86,5	46,3	88,9	29,3
Gypsum	92,5	41,1	94,0	38,7	94,0	36,7
Concrete	86,1	41,5	93,8	74,8	99,2	78,4
Concrete	94,1	35,5	95,7	76,7	99,0	74,5
Styrofoam	92,8	62,3	93,6	49,6	92,6	49,6
Styrofoam	93,9	54,9	94,0	59,7	94,4	60,0
Ceramics	92,1	39,1	90,3	36,9	87,9	45,6
Ceramics	93,8	44,2	92,6	51,0	90,0	45,4
Glass	89,9	40,5	92,5	37,5	91,3	46,7
Glass	92,6	44,4	93,9	44,6	93,9	50,1
Plexiglas	98,2	76,3	100	79,2	98,8	80,1
Plexiglas	98,8	76,5	100	81,2	98,8	80,5

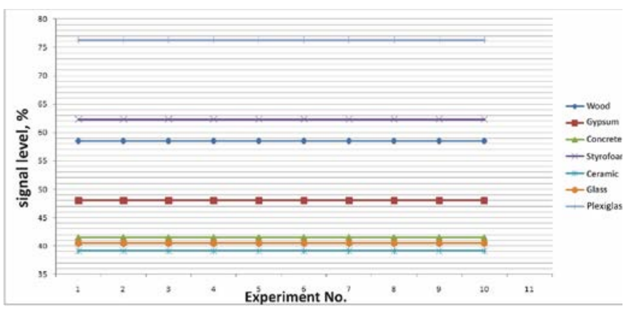

Fig.7. The signal levels at the TX, the Panel in Slot-1

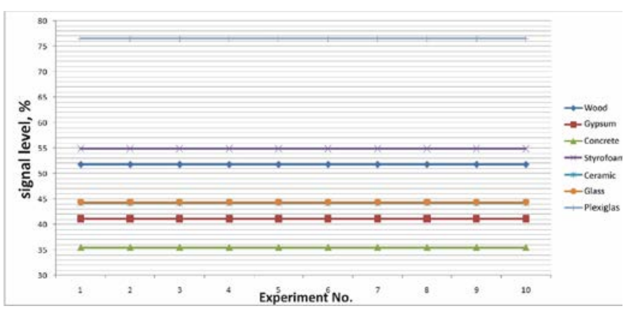

Fig.8. The signal levels at the RX, the Panel in Slot-1

The Figure 9 shows the signal average values on quality at the TX for different materials in case of different Panels inserted into the Slot-2.

The Figure 10 shows the signal average values on quality at the RX for different materials in case of different Panels inserted into the Slot-2.

The Figure 11 shows the signal average values on quality at the TX for different materials in case of Panels inserted both into the Slot-1 and the Slot-2.

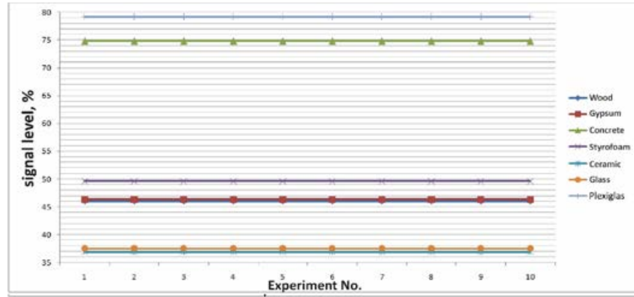

Fig.9. The signal levels at the TX, the Panel in Slot-2

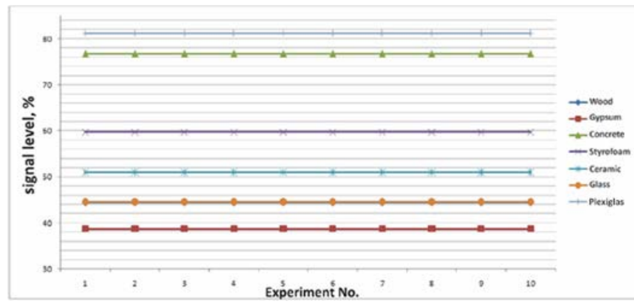

Fig.10. The signal levels at the RX, the Panel in Slot-2

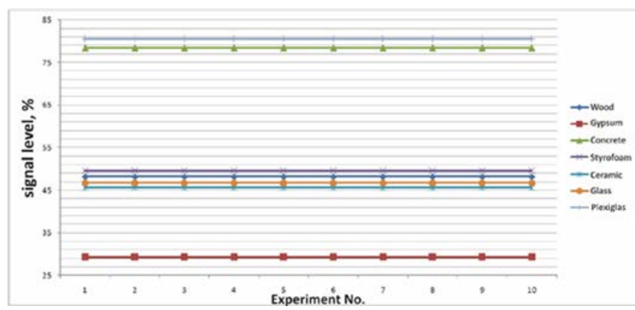

Fig.11. The signal levels at the TX, the Panels in Slot-1 and Slot 2

The Figure 12 shows the signal average values on quality at the RX for different materials in case of Panels inserted both into the Slot-1 and the Slot-2.

In the second part of experiment the wireless communication channel was also adjusted between two computers and data transmission was carried out in-between TX and RX.

The measurement results of the signal levels (average data) without wave-guide are presented in Table VI.

Figure 13 shows comparative graphs of the signal level instant values on strength and quality at the TX and at the RX and their average values without wave-guide.

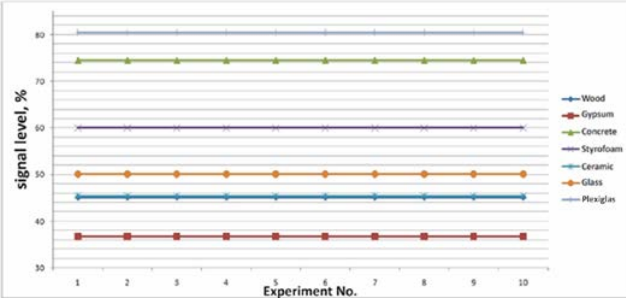

Fig.12. The signal levels at the RX, the Panels in Slot-1 and Slot-2

TABLE VI. THE SIGNAL LEVELS WITHOUT WAVE-GUIDE

Characteristic	Strength, %	Quality, %
The signal level at the TX	100	85,9
The signal level at the RX	100	79,2

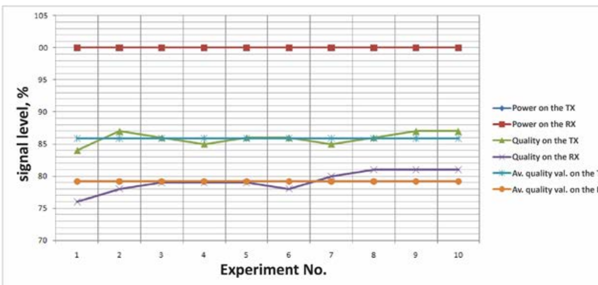

Fig.13. The signal levels at the TX and at the RX with data transfer and without wave-guide

Then the wave-guide was installed between the transmitter and the receiver and the signal level measurement at the transmitter and the receiver on the strength and quality was carried out. The average signal levels are shown in Table VII.

TABLE VII. THE SIGNAL LEVELS WITHOUT PANELS

Characteristic	Strength, %	Quality , %
The signal level at the TX	94,0	51,0
The signal level at the RX	94,0	49,9

Figure 14 shows comparative graphs of the signal level instant values on strength and quality at the TX and at the RX and their average values with connected wave-guide.

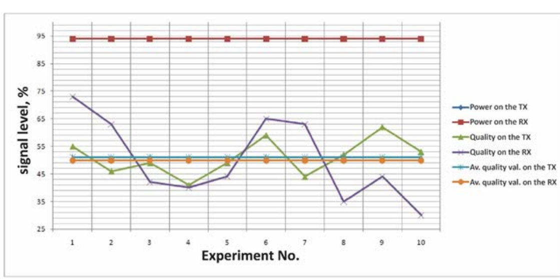

Fig.14. The data transfer signal levels at the TX and at the RX with connected wave-guide

Figure 15 shows comparative graphs of the average values of signal level on quality at the TX and at the RX with connected wave-guide and without wave-guide within data transfer.

After that the Panels were being inserted alternately into both Slots and the data on strength and quality was collected. The average values of these data are shown in Table VIII.

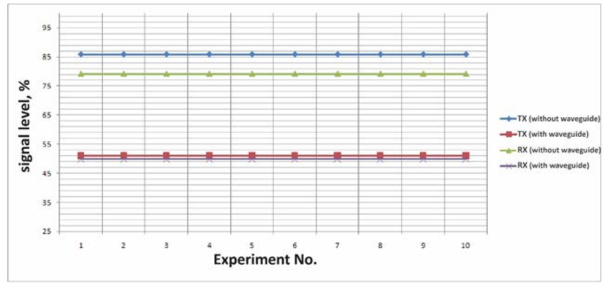

Fig.15. The data transfer signal levels at the TX and at the RX with connected wave-guide

TABLE VIII. THE SIGNAL LEVELS WITHIN DATA TRANSFER

Material	1st panel		2nd panel		Both panels	
TX / *RX*	*Strength*	*Quality*	*Strength*	*Quality*	*Strength*	*Quality*
Wood	90,8	50,4	92,5	51,4	92,5	49,6
Wood	92,6	49,2	94,1	43,0	94,0	36,3
Gypsum	92,8	50,6	91,2	42,5	85,3	41,9
Gypsum	94,0	37,5	94,0	37,2	94,0	48,7
Concrete	92,1	46,1	94,0	76,1	98,4	81,0
Concrete	94,1	38,0	95,8	77,8	100	74,5
Styrofoam	90,0	53,7	93,0	57,4	91,2	47,3
Styrofoam	93,9	49,7	94,0	55,6	94,0	56,2
Ceramics	91,0	37,9	91,1	41,1	92,0	39,9
Ceramics	94,0	44,3	94,0	44,8	94,0	43,9
Glass	90,8	40,9	89,4	43,9	87,4	53,3
Glass	94,0	44,7	94,0	49,7	94,0	50,6
Plexiglas	99,6	78,5	100	83,9	99,6	80,6
Plexiglas	100	73,2	100	75,5	100	79,0

The results collected during experiment have shown that passing of radio signal indoors differs from its passing in wave-guide. In case of installing the panels from various materials between the receiver and the transmitter the nature of the radio signal propagation also changes.

III. CONCLUSION

In conclusion it should be noted that the developed and created Experimental Equipment for measuring the radio signal attenuation in range of 2.4 GHz passing through the construction obstacles made from various materials allows to conduct different pilot studies for use in construction branch during design, construction and operation of buildings.

Based on study results the data of influence of various materials on radio signal propagation have been obtained. Comparative graphs of signal levels on the strength and quality for various materials were constructed. During the experiment and on the basis of the following analysis of the received results such facts has been found out that losses depend on distance between the transmitter and the panel, as well as on the number of panels and the panel material. This dependence has nonlinear character, therefore it is difficult to describe it by existing methods of the radio waves internal propagation modeling.

Besides this, the presented Experimental Equipment makes possible to create various disturbance or interference situations and also to replace adapters in computers to any other that significantly expands research areas.

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