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IZLOŽENOST UČENIKA SREDNJE ELEKTROTEHNIČKE ŠKOLE „NIKOLA TESLA” BEŽIČNOM ELEKTROMAGNETNOM ZRAČENJU

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SAŽETAK

Uvod/Cilj: Bežično elektromagnetno zračenje rutera je svakodnevna pojava u životu i radu savremenog čoveka. Oni se široko primenjuju u mnogim profesionalnim, javnim i domaćim objektima, što znači da ljudi svih uzrasta mogu stalno biti izloženi elektromagnetnom zračenju ovog uređaja. Cilj istraživanja je bio da se utvrdi jačina električnog polja, jačina magnetnog polja i elektromagnetna izloženost učenika u različitim laboratorijama srednje škole „Nikola Tesla”, u zavisnosti od vrste rutera koji su u njima postavljeni i da se neki od dobijenih rezultata provere odgovarajućim softverskim programom visokih frekvencija (engl. *High Frequency Simulation Software* - HFSS) za simulaciju elektromagnetnog zračenja kroz različite sredine.
Metode: Merenja jačine elekrtičnog i magnetnog polja, kao i elektromagnetno izlaganje, su realizovana, korišćenjem mernog instrumenta Spectran HF 60105, na četiri različita tipa rutera instaliranih u četiri laboratorije Elektrotehničke srednje škole „Nikola Tesla“ u Nišu. Merenja su realizovna na svakom ruteru, kroz pet položaja po horizontali i po vertikali, sa razmakom od 45^0 u odnosu na horizontalnu i normalnu osu rutera, a u razmacima od 1 cm, što daje ukupan broj od hiljadu merenja.
Rezultati: Ostvareni mereni rezultati na četiri različita rutera koji su radili na frekvenciji od 2,4 GHz za jačinu električnog polja (reda milivolta po metru), jačinu magnetnog polja (reda mikroampera po metru) i elektromagnetnu izloženost (reda mikrovati po kvadratnom centimetru) bili su ispod graničnih vrednosti definisanih standardima. Provera ostvarenih rezultata je realizovana samo za ruter TL-WR841HP pomoću HFSS za simulaciju elektromagnetnog zračenja kroz različite sredine. Rezultat provere simulacijom praktično potvrđuje verodostojnost izmerenih rezultata za ruter TL-WR841HP.
Zaključak: Merenje i praćenje elektromagnetnog zračenja predstavlja veoma važan zadatak u cilju očuvanja i unapređenja kvaliteta radne i životne sredine i kvaliteta života i zdravlja ljudi i dece. Softverski programi za simulciju elektromagnetnog zračenja mogu da se koriste ukoliko zbog tehničkih problema nije moguće sprovesti eksperimentalno merenje zbog otežanog pristupa uređaju, opasnosti od prevelikog zračenja ili nekog drugog razloga.

Ključne reči: ruter, elektromagnetno zračenje, učenici

Uvod

Savremeno društvo i savremeni način života podrazumevaju intenzivnu komunikaciju i stalni pristup velikoj grupi elektronskih podataka u realnom vremenu. Promet i promena elektronskih informacija ušli su u svaku poru savremenog društva. Ova činjenica govori o upotrebi savremenih uređaja kao što su računari, laptopovi, mobilni telefoni, tableti, itd. Tehnologija je omogućila da se prenos elektronskih informacija između uređaja i korisnika može realizovati odgovarajućim kablovskim (žičnim, optičkim, itd.) i bežičnim putem (1). Bežična komunikacija predstavlja jedan od najčešćih vidova saobraćaja (1). Ona služi za prenos informacija između dva ili više korisnika bez direktne fizičke veze. Primeri bežičnog prenosa informacija su različiti: ruteri, *bluetooth* uređaji, mobilni uređaji, uređaji koji koriste satelitski sistem za precizno određivanje bilo koje geografske pozicije na zemlji - GPS (globalni položajni sistem; engl. *Global Positioning System*) uređaji, bežični miševi, bežične

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EXPOSURE OF THE STUDENTS OF THE SECONDARY SCHOOL OF ELECTRICAL ENGINEERING "NIKOLA TESLA" TO WIRELESS ELECTROMAGNETIC RADIATION

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SUMMARY

Introduction/Aim: Wireless electromagnetic radiation from routers is an everyday occurrence in the life and work of modern man. They are widely used in many professional, public and domestic facilities, which means that people of all ages can be constantly exposed to electromagnetic radiation from these devices. The aim of this study was to determine the electric field strength, the magnetic field strength, and the electromagnetic exposure of students in different laboratories of the Secondary School "Nikola Tesla", depending on the type of routers installed in them, as well as to check some of the obtained results with the help of the appropriate software program of high-frequency (High-Frequency Simulation Software – HFFSS) for the simulation of electromagnetic radiation through different environments.
Methods: Measurements of electric and magnetic field strength, as well as electromagnetic exposure, were carried out using the measuring instrument Spectran HF 60105, on four different types of routers installed in four laboratories of the Secondary School of Electrical Engineering "Nikola Tesla" in Niš. Measurements were realized on each router, through five horizontal and five vertical positions, with a distance of 45° in relation to the horizontal and normal axis of the router, and with spaces of 1 cm, which gives a total number of one thousand measurements.
Results: The measured results obtained on four different routers that operated at a frequency of 2.4 GHz for the electric field strength (measured in millivolts per meter), magnetic field strength (measured in microampere per meter) and electromagnetic exposure (in microWatts per square centimeter) were below the limit values defined by standards. The achieved results were verified only for the router TL-WR841HP with the help of HFSS for the simulation of electromagnetic radiation through different environments. The result of the simulation check practically confirms the reliability of the measured results for TL-WR841HP router.
Conclusion: Measuring and monitoring electromagnetic radiation is a very important task aimed at preserving and improving the quality of the working and living environment, as well as the quality of life and health of people and children. Software programs for the simulation of electromagnetic radiation can be used when it is not possible to carry out experimental measurements due to technical problems, hindered access to the device, danger of excessive radiation or some other reasons.

Keywords: router, electromagnetic radiation, students

Introduction

Modern society and the modern way of life imply intensive communication and constant access to a large group of electronic data in real time. The circulation and change of electronic information have entered every pore of modern society. This fact speaks of the use of modern devices such as computers, laptops, mobile phones, tablets, etc. Technology has enabled the transmission of electronic information between the device and the user to be realized via appropriate cables (wired, optical, etc.) and wirelessly (1). Wireless communication is one of the most common types of traffic (1). It serves to transfer information between two or more users without a direct physical connection. Examples of wireless transmission of information are various:

tastature, uređaji za daljinsko upravljanje, saobraćajni sistemi, računarske mreže i mnogi drugi (1). Udaljenost između bežičnih uređaja može biti od nekoliko metara do nekoliko hiljada kilometara. Potreba za bežičnom komunikacijom ima logične i praktične razloge: fizička ograničenja kada se koriste kablovi, povezivanje mobilnih urađaja, finansijske prednosti povezane sa žičnim i kablovskim prenosom, i drugo (1).

Ruter je jedan od najkorisnijih bežičnih uređaja (1). On omogućava povezivanje računarskih mreža na različitim frekvencijama, najčešće od nekoliko gigaherca. Generalno, ruteri mogu biti hardverski i softverski (1). Svaki hardverski ruter predstavlja računar sa softverom, dok softverski ruter predstavlja softver instaliran na serverima sa operativnim sistemima.

Zbog mnogih potencijala i učestalosti upotrebe, javljaju se logična pitanja o bezbednosti bežične tehnologije za zdravlje ljudi. Ovo se posebno odnosi na upotrebu bežičnih uređaja u objektima sa puno ljudi i dece, gde više korisnika može istovremeno da koristi jednu mrežu, kao što je Internet. Korisnici su stalno izloženi elektromagnetnom zračenju rutera (2). Jedan od tipičnih objekata gde se ruteri veoma često koriste za bežično povezivanje je škola u kojoj deca tj. đaci provode mnogo vremena u toku dana pa je samim tim njihova izloženost elektromagnetnom zračenju velika i skoro kontinuirana. Dakle, za ugradnju rutera u školama u kojima će ovi ruteri biti instalirani, veoma je važna njihova snaga i minimalno rastojanje između rutera i korisnika-učenika (3).

Elektromagnetno zračenje različitih uređaja može biti štetno po decu i odrasle. Brojna istraživanja pokazuju i dokazuju da štete koje mogu nastati mogu biti trenutnog i dugotrajnog karaktera (4-8). Trenutne smetnje se ogledaju u nedostatku koncentracije, povećanoj anksioznosti, peckanju i svrabu kože, problemima sa vidom, dok trajne mogu biti veoma teške u vidu pojave određenih maligniteta (4-8). Neki naučnici smatraju da je elektromagnetno zračenje štetno, ali ima i onih koji tvrde i dokazuju da štetnosti nema. Posebno interesantnu grupu predstavljaju deca školskog uzrasta, čija je izloženost elektromagnetnom zračenju različitih uređaja, prvenstveno mobilnog telefona, rutera i drugih uređaja, znatno povećana. Iako postoje i uputstva i pravila o bezbednosti upotrebe mobilnih telefona, ona se veoma malo ili skoro uopšte ne poštuju od strane korisnika (4-8).

Postoji nekoliko standarda (Internacionalna komisija za zaštitu od nejonizujućeg zračenja, engl. *International Commission on Non-ionizing Radiation Protection – ICNIRP*; Institut elektronskih i elektrotehničkih inženjera, engl. *Institute of Electrical and Electronics Engineers - IEEEE*, jugoslovenski univerzalni standard - JUS) koji se bave elektromagnetnim zračenjem (9). Ovi standardi se koriste za merenje utvrđenih vrednosti koje karakterišu elektromagnetno zračenje i određivanje graničnih vrednosti. Karakteristične elektromagnetne vrednosti su električno polje [V/m], magnetno polje [A/m] i elektromagnetna izloženost izražena kao [mW/cm^2] ili [W/m^2]. Izloženost elektromagnetnom zračenju se obično određuje za vreme od 6 minuta, u slučaju kontrolisanog izlaganja, odnosno 30 minuta, u slučaju nekontrolisanog izlaganja (9). Dozvoljene vrednosti izlaganja električnom i magnetnom polju za različite frekvencije, za neprofesionalnu i profesionalnu izloženost u vezi sa ICNIRP-om prikazane se u Tabeli 1, dok su dozvoljene vrednosti za elektromagnetnu izloženost u odnosu na IEEE C95.1 prikazane u Tabeli 2 (9).

Elektromagnetno zračenje se može podeliti na nisko i visokofrekventno. Realna je činjenica da savremeni čovek živi u elektromagnetnom smogu koji se sastoji iz mnogo različitih frekvencija iz mnogo različitih izvora. Ova podela elektomag-

Tabela 1. Dozvoljene vrednosti izlaganja električnom i magnetnom polju za različite frekvencije za neprofesionalnu i profesionalnu izloženost u odnosu na ICNIRP (9)

f [MHz]	E [V/m]	H [A/m]
10-400	28 61	0,0173 0,160
400-2000	$1.375\sqrt{f}$ $3.000\sqrt{f}$	$0.0037\sqrt{f}$ $0.0080\sqrt{f}$
2000-300000	61 137	0,160 0,360

routers, Bluetooth devices, mobile devices, devices that use a satellite system to accurately determine any geographic position on earth – GPS (Global Positioning System) devices, wireless mice, wireless keyboards, remote control devices, traffic systems, computer networks and many others (1). The distance between wireless devices can be from a few meters to several thousand kilometers. The need for wireless communication has logical and practical reasons: physical limitations when cables are used, connecting mobile devices, financial advantages connected with wired and cable transmission, etc. (1).

A router is one of the most useful wireless devices (1). It enables the connection of computer networks at different frequencies, usually of several gigahertz. In general, routers can be hardware and software. Each hardware router represents a computer with software, while a software router represents software installed on servers with operating systems.

Due to its many potentials and frequency of use, logical questions arise about the safety of wireless technology for human health. This especially applies to the use f wireless devices in facilities with a lot of people and children, where multiple users can simultaneously use a single network, such as the Internet. Users are constantly exposed to the electromagnetic radiation from the router (2). One of the very characteristic facilities where routers are frequently used for wireless connection is a school, where children, that is, students spend a lot of time during the day, and therefore, their exposure to electromagnetic radiation is high and almost continuous. Thus, for the installation of routers in schools, where these routers will be installed, their strength and minimal distance between the router and the user-student are very important (3).

Electromagnetic radiation from various devices can be harmful to children and adults. Numerous studies show and prove that the damage that can occur can be of an immediate or long-term nature (4-8). Instantaneous disturbances are reflected in the lack of concentration, increased anxiety, burning and itching of skin, problems with eyesight, while permanent ones can be very severe in the form of the appearance of some malignancies (4-8). Some scientists believe that electromagnetic radiation is harmful, but there are also those who claim and prove that it is not harmful. A particularly interesting group is school children, whose exposure to electromagnetic radiation from various devices, primarily mobile phones, routers and other devices has increased significantly. Although there are instructions and rules about safety of using mobile phones, they are respected by users very little or not at all (4-8).

There are several standards (International Commission on Non-ionizing Radiation Protection – ICNIRP; Institute of Electrical and Electronics Engineers – IEEEE; Yugoslav Universal Standard – YUS) that deal with the electromagnetic radiation (9). These standards are used to measure the established values that characterize the electromagnetic radiation and determine the reference values. The characteristic electromagnetic values are the electric field [V/m], magnetic field [A/m], and electromagnetic exposure expressed as [mW/cm^2] or [W/m^2]. The exposure to electromagnetic radiation is usually determined for the time of six minutes, in the case of controlled exposure, or 30 minutes, in the case of uncontrolled exposure (9). The allowed values of exposure to electric and magnetic fields for different frequencies, for professional and non-professional exposure in relation to ICNIRP are shown in Table 1, while the allowed values for electromagnetic exposure in relation to IEEE C95.1 are shown in Table 2 (9).

Table 1. Allowed values of exposure to electric and magnetic field for different frequencies for non-professional and professional exposure in relation to ICNIRP (9)

f [MHz]	E [V/m]	H [A/m]
10-400	28 61	0.0173 0.160
400-2000	$1.375\sqrt{f}$ $3.000\sqrt{f}$	$0.0037\sqrt{f}$ $0.0080\sqrt{f}$
2000-300000	61 137	0.160 0.360

Tabela 2. Dozvoljene vrednosti za elektromagnetnu izloženost u odnosu na IEEE C95.1 standard (9)

Frekvencija [MHz]	Kontrolisana izloženost [mW/cm²]	Nekontrolisana izloženost [mW/cm²]
30-300	1,0	0,2
300-1500	f/300	f/1500
1500-100000	5	1,0

netnog zračenja je gruba, ali je najčešće korišćena, dok su razlozi za ovu vrstu podele uglavnom bili istorijski. Kada je ova podela u pitanju, niskofrekventno elektromagnetno zračenje podrazumeva širok opseg frekvencija, ali su najdominantnije frekvencije od 50 Hz ili 60 Hz i talasne dužine λ ~ 6000 km (λ=c/v). S druge strane, visokofrekventno elektromagnetno zračenje predstavlja frekvencije reda megaherca i gigaherca. Postoje neke razlike između niske i visoke frekvencije elektromagnetnog zračenja u reakciji, distribuciji, efektima i uticaju na ljudski organizam. Ljudsko telo predstavlja poluprovodni, nehomogen i disperzivni medijum za niskofrekventno elektromagnetno zračenje (9,10). Takođe, za niskofrekventno elektromagnetno zračenje, ljudsko telo se nalazi u tzv. „zoni indukcije" i faktor oštećenja za niske frekvencije se može definisati u vezi sa formiranom gustinom struje, zbog normiranja rizika (9,10). Moguće je izračunati gustinu struje *J* za niske frekvencije povezane sa jednačinom $J = \sigma E$, gde je σ provodnost, a E jačina električnog polja.

Kada je u pitanju faktor oštećenja, moguće je izračunati ograničene vrednosti jačine električnog polja u različitim delovima ljudskog organizma. Važno je napomenuti da loši efekti elektromagnetnih polja industrijskih frekvencija još nisu dovoljno proučeni. Faktor oštećenja, gustina struje i odgovarajući opis reakcija tkiva, organa i organizama prikazani su u Tabeli 3.

Visokofrekventno elektromagnetno zračenje u smislu pomenute podele podrazumeva tzv. RF-radio frekvencijsko zračenje. Ovo zračenje obuhvata širok opseg frekvencija, od frekvencija dugih talasa do frekvencija mikrotalasa. Visokofrekventno elektromagnetno zračenje prodire u okolinu kao što je ljudsko telo tako da za visoke frekvencije mora biti definisana dubina prodora označena kao δ [m], u vezi sa jednačinom 1 (9).

$$\delta = \frac{1}{\omega}\cdot\left(\frac{\varepsilon\mu}{2}\left(\sqrt{1+\frac{\sigma^2}{\omega^2\varepsilon^2}}-1\right)\right)^{-1/2} \qquad (1)$$

Ova vrednost nije ista za različite organe (mozak, jetra, organi za varenje itd.). Ona, naravno, nije dovoljna da detaljno opiše elektromagnetna polja koja su prodrla u ljudsko telo. Poznato je da lokalna distribucija visokofrekventnih elektromagnetnih polja u živim tkivima dovodi do termičkih i netermičkih efekata. Netermički efekti još nisu detaljno i dovoljno proučeni. To je činjenica jer se najčešće govori o termičkim efektima. Za ove efekte korišćena je posebna veličina. Ova veličina je nazvana specifična stopa apsorpcije (eng. *Specific Absorption Rate* - SAR) i predstavljena je u jednačini 2 (9).

$$SAR = \frac{d}{dt}\left(\frac{dW}{dm}\right)\left[\frac{W}{kg}\right] \qquad (2)$$

Tabela 3. Faktor oštećenja za niske frekvencije (9)

Faktor oštećenja	Gustina struje J [mA/m²]	Opis
A	1-10	Beznačajan biološki odgovor tkiva.
B	10-100	Lakši poremećaji vida i nervnog sistema.
C	100-1000	Stimulansi tkiva koji izazivaju nevoljne pokrete. Poremećaji srčanog ritma i centralnog nervnog sistema.
D	>1000	Termičko oštećenje tkiva. Poremećaji i otkazivanje nervnog sistema. Stanja koja dovode do smrtnog ishoda.

Table 2. Allowed values for electromagnetic exposure in relation to IEEE C95.1 standard (9)

Frequency [MHz]	Controlled exposure [mW/cm²]	Uncontrolled exposure [mW/cm²]
30-300	1.0	0.2
300-1500	f/300	f/1500
1500-100000	5	1.0

Electromagnetic radiation can be divided into low and high frequency electromagnetic radiation. It is a real fact that modern man lives in the electromagnetic smog that consists of many different frequencies from many different sources. This classification of electromagnetic radiation is rough, but it is the most commonly used, while the reasons for this type of classification were mostly historical. When it comes to this classification, low-frequency electromagnetic radiation includes a wide range of frequencies, but the most dominant frequencies are 50 Hz or 60 Hz and wave lengths λ ~ 6000 (λ=c/v). On the other hand, high frequency electromagnetic radiation represents frequencies measured in megahertz and gigahertz. There are some differences between low and high frequency electromagnetic radiation in the reaction, distribution, effects and impact on the human body. The human body is a semiconducting, inhomogeneous and dispersive medium for low frequency electromagnetic radiation (9,10). Also, for low-frequency electromagnetic radiation, the human body is in the so-called "zone of induction" and the damage factor for low frequencies can be defined in connection with the formed current density, due to risk norming (9,10). It is possible to calculate current density J for low frequencies related to the equation $J = \sigma E$, where σ is conductivity, while E is the electric field strength.

When it comes to damage factor, it is possible to calculate the limited values of the electric field strength in different parts of the human body. It is important to note that that the bad effects of electromagnetic fields of industrial frequencies have not yet been sufficiently studied. The damage factor, current density and corresponding description of reactions of tissues, organs, and organisms are shown in Table 3.

High-frequency electromagnetic radiation in the sense of the aforementioned classification implies the so-called RF-radio frequency radiation. This radiation includes a wide range of frequencies, from long-wave frequencies to micro-wave frequencies. High-frequency electromagnetic radiation penetrates the environment such as the human body, and therefore, for high frequencies the penetration depth denoted as δ [m], must be defined in relation to equation 1 (9).

$$\delta = \frac{1}{\omega} \cdot \left(\frac{\varepsilon\mu}{2} \left(\sqrt{1 + \frac{\sigma^2}{\omega^2 \varepsilon^2}} - 1 \right) \right)^{-1/2} \quad (1)$$

This value is not the same for different organs (brain, liver, digestive organs, etc.). This value, of course, is not enough to describe in detail the electromagnetic fields that have penetrated the human body. It is known that the local distribution

Table 3. Damage factor for low frequencies (9)

Damage factor	Current density J [mA/m²]	Description
A	1-10	Insignificant biological tissue response.
B	10-100	Lighter vision and nervous system disorders.
C	100-1000	Tissue stimuli that lead to involuntary movements. Heart rhythm and central nervous system disorders.
D	>1000	Thermal tissue damage. Disorders and failure of the nervous system. Conditions that lead to death.

Ova veličina se može definisati i na druge načine, ali je važno napomenuti da je često nezavisna. Vrednosti za SAR su različite za profesionalne radnike i neprofesionalce (9). Efekti apsorbovane elektromagnetne energije se akumuliraju. Međutim, još uvek nije utvrđeno kada se pojavljuju nepovratni efekti. Ovo je posebno važno za mobilne telefone i rutere, jer ovi uređaji omogućavaju kratko i dugotrajno izlaganje visokofrekventnom elektromagnetnom zračenju. Dakle, neophodno je meriti visokofrekventno elektromagnetno zračenje mobilnih telefona i rutera, posebno kod mlađe populacije, kako bi se pronašla najmanja količina zračenja sa odgovarajućim kvalitetom signala (9,10).

Cilj ovog istraživanja je bio da se utvrdi jačina električnog polja, jačina magnetnog polja i elektromagnetna izloženost dece u različitim laboratorijama srednje škole „Nikola Tesla", u zavisnosti od vrste rutera koji su u njima postavljeni i da se neki od dobijenih rezultata provere odgovarajućim simulacionim programom HFSS.

Metode

U cilju merenja parametara visokofrekventnog elektromagnetnog zračenja u srednjoj elektrotehničkoj školi „Nikola Tesla" korišćena je metoda direktnog merenja u realnom vremenu korišćenjem Spectran HF 60105 instrumenta. Ovaj instrument je namenjen za merenje visokofrekventnog elektromagnetnog zračenja i njegovih parametara na frekvencijama od 1,0 MHz do 9,4 GHz. U cilju višestrukih merenja izloženosti visokofrekventnom elektromagnetnom zračenju korišćen je Spectran HF 60105 sa odgovarajućim softverom instaliranim na laptopu. Instrument Spectran HF 60105 sa kompletnom dodatnom opremom prikazan je na slici 1.

Slika 1. Instrument Spectran HF 60105 za merenje parametara visokofrekventnog elektromagnetnog zračenja

Merenja visokofrekventnog elektromagnetnog zračenja su realizovana u četiri najčešće korišćene laboratorije u Elektrotehničkoj školi „Nikola Tesla" u Nišu: laboratoriji broj 106 i 109 u prizemlju, 110 na prvom spratu, i 2 na drugom spratu. Višestruka merenja u trajanju od minimalno 6 minuta realizovana su horizontalno i vertikalno u odnosu na ose rutera, u opsegu od 0 do 100 cm, u koracima od 1 cm. Elektromagnetno zračenje je mereno na četiri različita tipa rutera u zavisnosti od laboratorije gde je sprovođeno istraživanje. Ruter koji se nalazio u laboratoriji 106 bio je TL-WR841N (slika 2a), u laboratoriji 2 TL-WR841HP (slika 2b), u laboratoriji 109 Mi AIoT AC 2350 (slika 2c), a u laboratoriji 110 TL-WR740N (slika 2d).

Slika 2a. Ruteri u različitim laboratorijama, TL-WR841N u laboratoriji 106

Slika 2b. Ruteri u različitim laboratorijama, WR841HP u laboratoriji 2

of high frequency electromagnetic fields in living tissues leads to thermal and non-thermal effects. Non-thermal effects have not yet been studied in detail and sufficiently. This is a fact because thermal effects are the most common. A special measure was used for these effects. This measure was called the Specific Absorption Rate (SAR) and it is presented in equation 2 (9).

$$SAR = \frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\mathrm{d}W}{\mathrm{d}m}\right)\left[\frac{\mathrm{W}}{\mathrm{kg}}\right] \quad (2)$$

This measure can be defined in other ways, but it is important to note that it is often dependent. The values for SAR are different for professional workers and non-professionals (9). The effects of the absorbed electromagnetic energy accumulate. However, it has not yet been established when irreversible effects appear. This is especially important for mobile phones and routers, because these devices enable short and long-time exposure to high frequency electromagnetic radiation. Thus, high frequency electromagnetic radiation of mobile phones and routers should necessarily be measured, especially in the younger population, in order to find the smallest radiation quantity with the appropriate signal quality (9,10).

The aim of this study was to determine the electric field strength, the magnetic field strength and the electromagnetic exposure of students in different laboratories of the Secondary School "Nikola Tesla", depending on the type of routers installed in them, as well as to check some of the obtained results with the help of the appropriate simulation program HFSS.

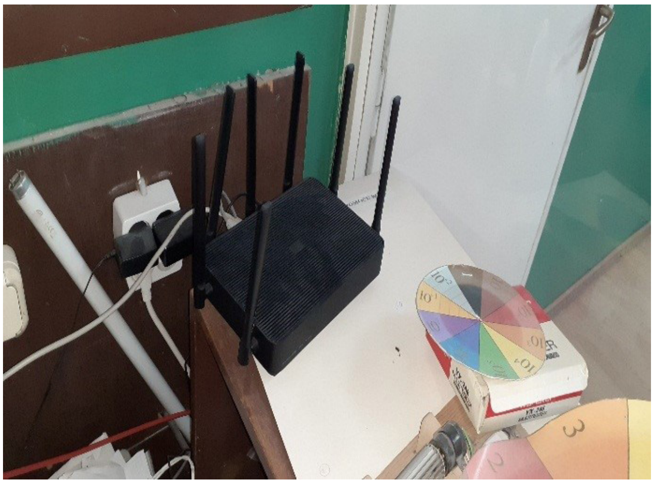
Picture 1. Instrument Spectran HF 60105 for measuring the parameters of high frequency electromagnetic radiation

Method

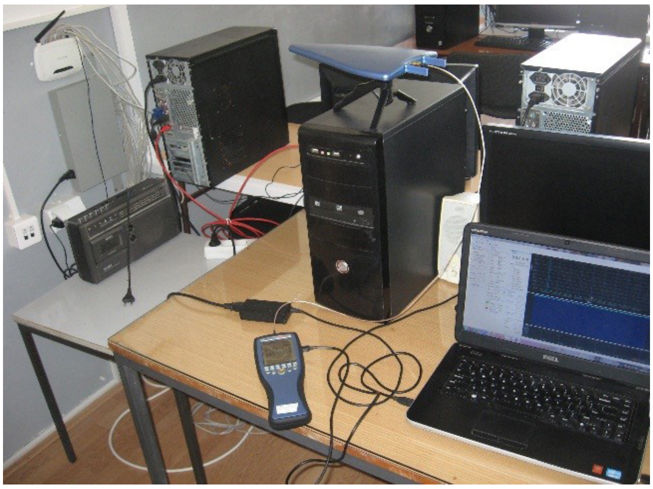
In order to measure the parameters of high frequency electromagnetic radiation in the Secondary School of Electrical Engineering "Nikola Tesla", the method of direct measurement in real time with the help of the Spectran HF 60105 instrument was used. This instrument is intended for measuring high frequency electromagnetic radiation and its parameters at frequencies from 1.0 MHz to 9.4 GHz. For the purpose of multiple measurements of exposure to high frequency electromagnetic radiation, Spectran HF 60105 was used with the appropriate software installed on the laptop. Spectran HF 60105 instrument

Picture 2a. Routers in different laboratories, TL-WR841N in laboratory 106

Picture 2b. Routers in different laboratories, TL-WR841HP in laboratory 2



Slika 2c. Ruteri u različitim laboratorijama, Mi AIoT AC 1350 u laboratoriji 109



Slika 2d. Ruteri u različitim laboratorijama, TL-WR740N u laboratoriji 110

Svi ruteri na kojima su vršena merenja su radili na frekvenciji od 2,4 GHz. Sva merenja su realizovana u periodu od februara do septembra 2022. Minimalno trajanje svakog pojedinačnog merenja je bilo 6 minuta, u skladu sa standardima. Merenja su obuhvatala merenje jačine električnog polja, jačine magnetnog polja i elektromagnetne izloženosti. Ukupan broj realizovanih merenja po svakom ruteru je bio deset, pet po horizontali i pet po vertikali, sa razmakom od 45° u odnosu na horizontalnu i normalnu osu rutera. Merenja jačine električnog polja, jačine magnetnog polja i elektromagnetne izloženosti su realizovana tako što bi se instrument postavio u neki od navedenih položaja, na rastojanjima od po 1 cm, od 0 cm pa sve do 100 cm. Ukupan broj merenja za sve položaje je bio hiljadu. Ovo je urađeno čisto provere radi, iako su rezultai pokazali da su merene vrednosti na različitim rastojanjima vezano za različite položaje bili skoro identični. Sva meranja jačine električnog polja i jačine magnetnog polja uz pomoć instrumenta Spectran HF 60105 prikazani su na slikama 3a i 3b, a realizovana su prema uputstvu za upravljanje i merenje instrumentom, kao i korišćenjem softvera HFSS za proveru rezultata putem simulacije (11-14).

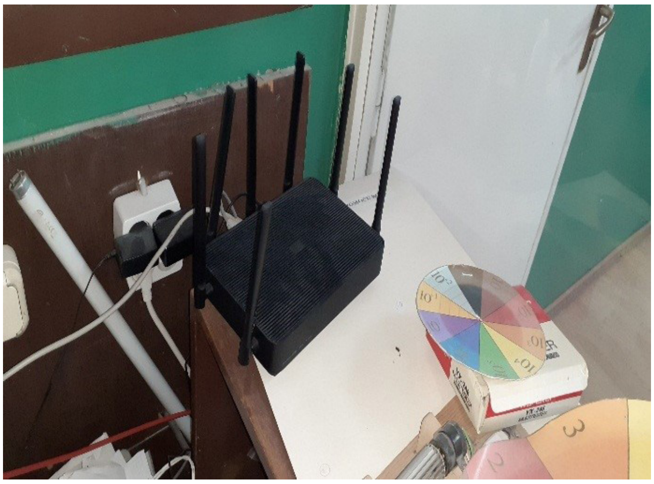
Karakteristična pozicija rutera u Elektrotehničkoj školi „Nikola Tesla" u Nišu prikazana je na slici 4. Generalno, ruteri se postavljaju u prostorijama u tačkama gde će prijem signala biti najbolji ili gde uslovi instaliranja dozvoljavaju, a to su uglavnom lokacije ispod samog plafona ili uglovi plafona.

Rezultati i diskusija

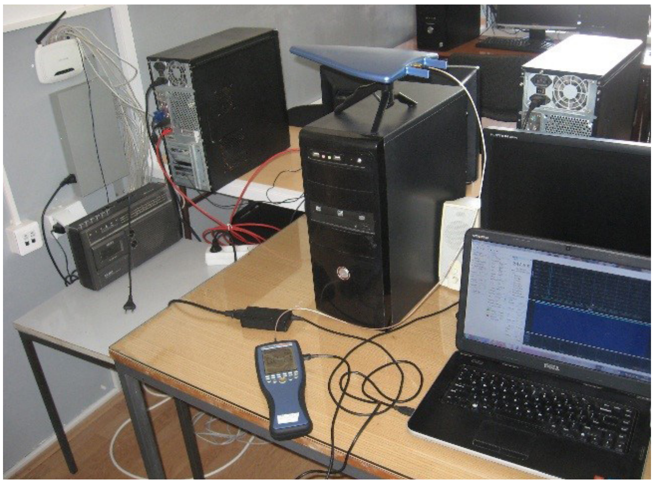
Primeri merenja jačine električnog polja i jačine magnetnog polja uz pomoć instrumenta Spectran HF 60105 prikazani su na slikama 3a i 3b,

Slika 3a. Primer merenja jačine električnog polja uz pomoć instrumenta Spectran HF 60105

Slika 3b. Primer merenja jačine električnog polja uz pomoć instrumenta Spectran HF 60105



Picture 2c. Routers in different laboratories, Mi AloT AC 1350 in laboratory 109



Picture 2d. Routers in different laboratories, TL-WR740N u in laboratory 110

with complete additional equipment is shown in Picture 1.

The measurements of high frequency electromagnetic radiation were carried out in four laboratories that were used most frequently at the Secondary School of Electrical Engineering “Nikola Tesla” in Niš: laboratories number 106 and 109 on the ground floor, laboratory number 110 on the first floor and laboratory number 2 on the second floor. Multiple measurements lasting at least 6 minutes were made horizontally and vertically from the router axis, in the range from 0 to 100 cm, in steps of 1 cm. Electromagnetic radiation was measured on four different types of routers depending on the laboratory where the research was conducted. The router located in laboratory 106 was TL-WR841N (Picture 2a), in laboratory 2 TL-WR841HP (Picture 2b), in laboratory 109 Mi AloT AC 2350 (Picture 2c), and in laboratory 110 TL-WR740N (Picture 2d).

All the routers, on which the measurements were made, operated at a frequency of 2.4 GHz. All measurements were carried out from February to September 2022. The minimum duration of each individual measurement was 6 minutes, in accordance with the standards. The measurements included the measurements of the electric field strength, magnetic field strength and electromagnetic exposure. The total number of realized measurements for each router was ten, five horizontally and five vertically, with a distance of 45° in relation to the horizontal and normal axis of the router. The measurements of the electric field strength, magnetic field strength and electromagnetic exposure were realized by placing the instrument in one of these positions, at

Picture 3a. Example of measuring the electric field strength using the instrument Spectran HF 60105

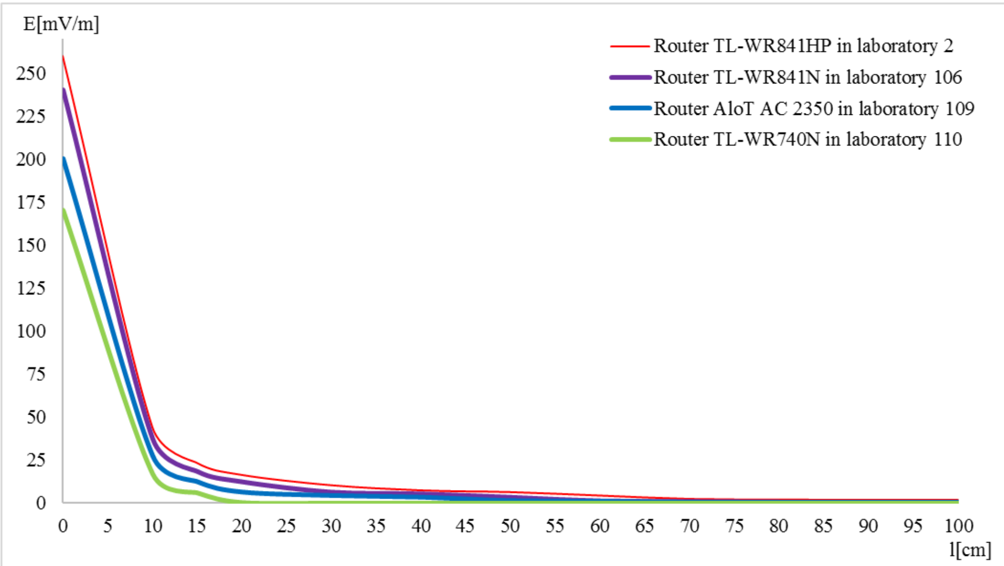
Picture 3b. Example of measuring the electric field strength using the instrument Spectran HF 60105

Slika 4. Karakteristična pozicija rutera (označena strelicom) na prvom spratu Elektrotehničke škole "Nikola Tesla" u Nišu

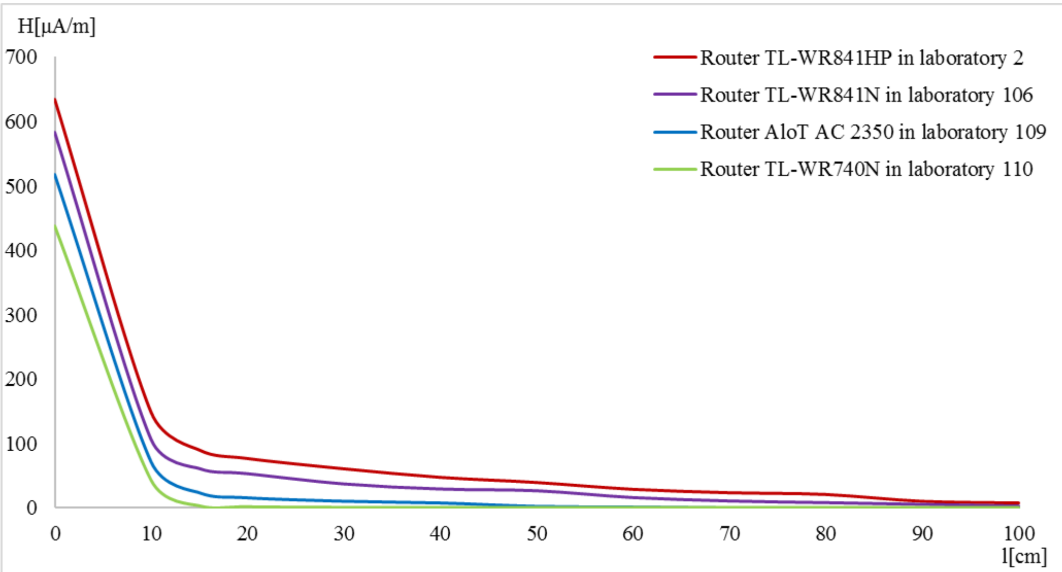
dok su kompletni rezultati jačine električnog polja, jačine magnetnog polja i elektromagnetne izloženosti prikazani na slikama 5-8.

Kada je u pitanju jačina električnog polja, rezultati prikazani na slici 5 su pokazali da su izmerene jačine električnog polja bile daleko ispod granične vrednosti za jačinu električnog polja u skladu sa važećim standardima (E = 61 V/m za frekvencije veće od 2000 MHz, u skladu sa ICNRIP). Važno je napomenuti da je najmanja udaljenost od rutera (za sva četiri rutera) bila 1,2 metra, tako da je izračunata izloženost bila svega nekoliko mV/m, što je više od dvesta puta manja vrednost u odnosu na graničnu vrednost.

Kada je u pitanju jačina magnetnog polja, rezultati prikazani na slici 6 su pokazali da su izmerene



Slika 5. Kompletni rezultati merenja jačine električnog polja za sve rutere

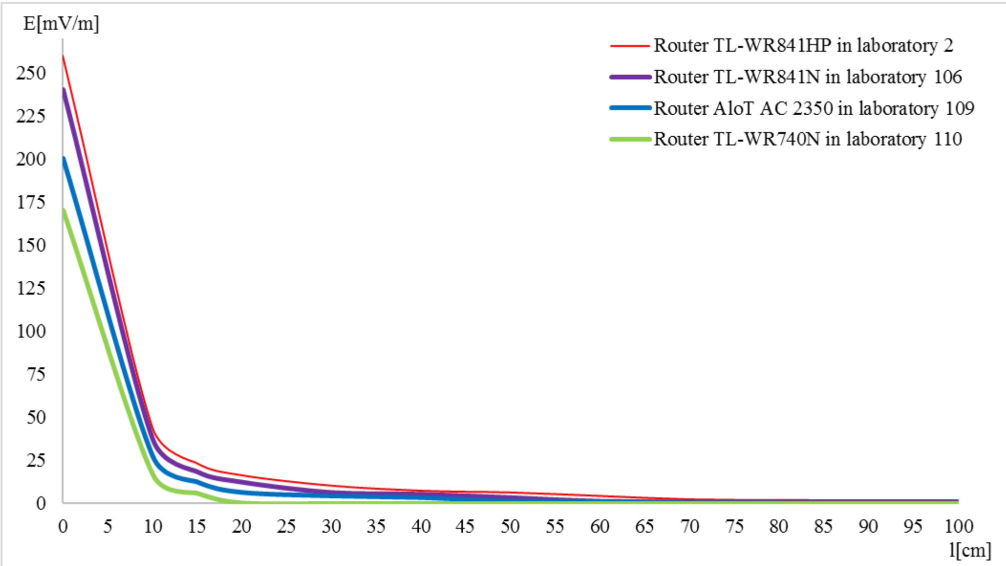


Slika 6. Kompletni rezultati merenja jačine magnetnog polja za sve rutere

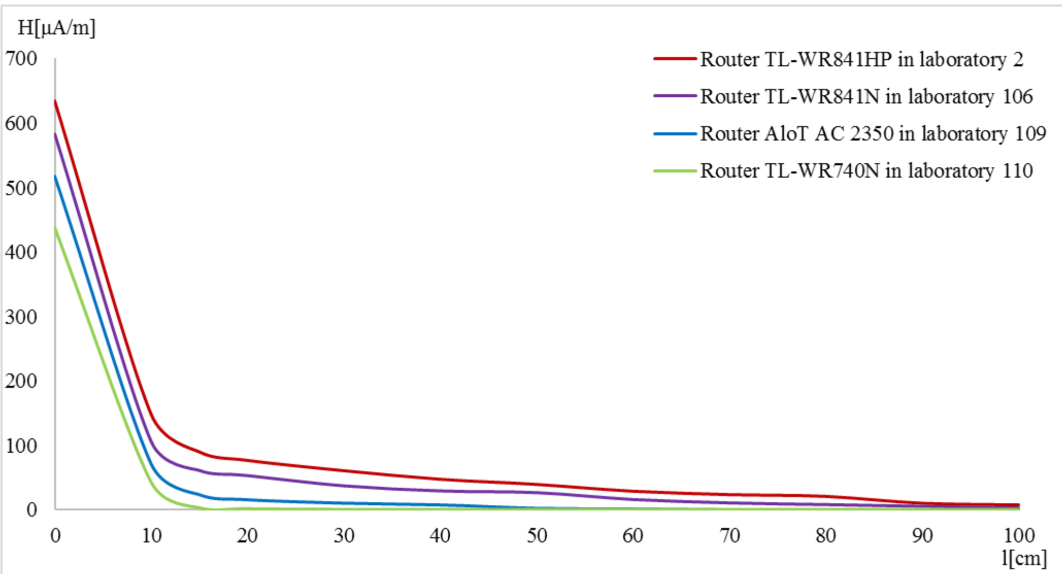
Picture 4. Characteristic position of router (marked with an arrow) on the first floor of the Secondary School of Electrical Engineering "Nikola Tesla" in Niš

distances of 1 cm, from 0 cm to 100 cm. The total number of measurements for all positions was one thousand. This was done purely for verification, although the results showed that the measured results at different distances for different positions were almost identical. All measurements of the electric field strength and magnetic field strength with the help of the Spectran HF 60105 instrument were shown in Pictures 3a and 3b, and they were realized according to the instructions for operating and measuring with the instrument, as well as using the HFSS software for checking the results with the help of simulation (11-14).

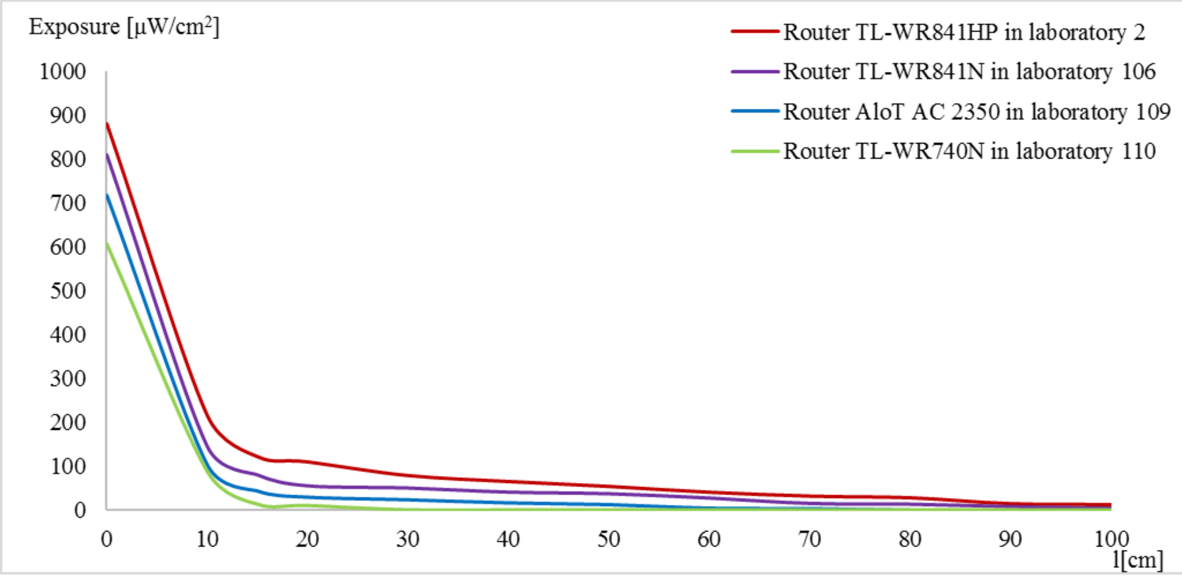
The characteristic position of router at the Secondary School of Electrical Engineering "Nikola Tesla" in Niš was shown in Picture 4. Generally,



Picture 5. Complete results of measurements of the electric field strength for all routers



Picture 6. Complete results of measurements of the magnetic field strength for all routers



Slika 7. Kompletni rezultati merenja elektromagnetne izloženosti za sve rutere

jačine magnetnog polja bile daleko ispod graničnih vrednosti za jačinu električnog polja u skladu sa važećim standardima (H = 0,16 A/m za frekvencije veće od 2000 MHz, u skladu sa ICNRIP). Najveća izmerena vrednost bila je više od dvesta puta manja u odnosu na graničnu vrednost.

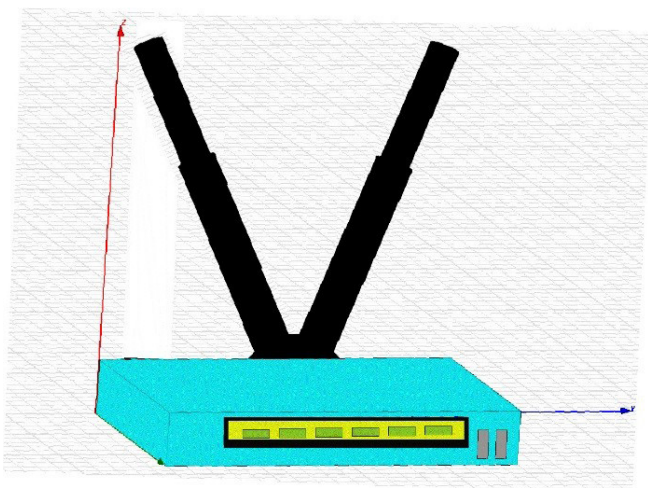
Kada je u pitanju elektromagnetna izloženost, rezultati prikazani na slici 7 su pokazali da su izmerene jačine magnetnog polja bile daleko ispod granične vrednosti za jačinu električnog polja u skladu sa važećim standardima (elektromagnetna izloženost je 5 mW/cm^2 za frekvencije veće od 1500 MHz u skladu sa IEEE C95.1). Najveća izmerena vrednost je bila daleko manja u odnosu na graničnu vrednost za vreme izlaganja od 6 minuta.

U cilju provere ostvarenih rezultata, urađena je simulacija jačine električnog polja i jačine magnetnog polja u softveru HFSS 10 za ruter TL-WR841HP. HFSS 10 je softver koji se koristi za proračun prodora visokofrekventnog elektromagnetnog zračenja kroz višeslojna okruženja. Ovaj softver omogućava simulaciju različitih elektronskih proizvoda, kao što su antene, komponente, konektori itd. Na tržištu je bilo nekoliko verzija ovog softvera. Zbog složenosti softvera za simulaciju i ograničenja papira, samo je simulacioni model rutera TL-WR841HP korišćen kao primer za proveru. Simulacioni model rutera TL-WR841HP u HFSS 10 prikazan je na slici 8, dok su uporedni rezultati za izmerene simulacije jačine električnog polja i jačine magnetnog polja prikazani na slikama 9a i 9b.

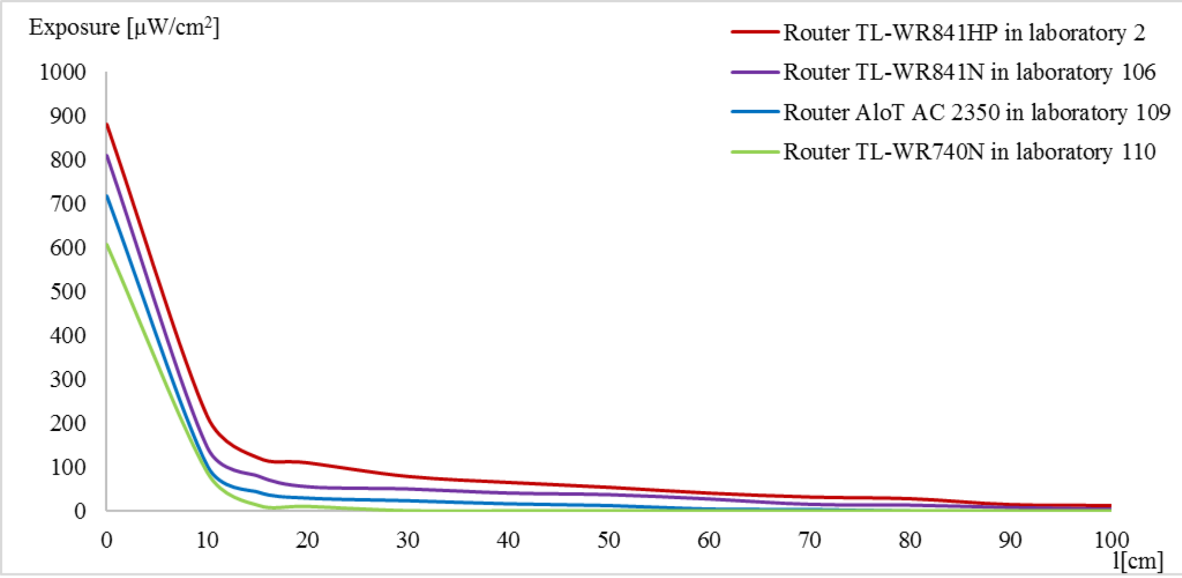
Simulacije su pokazale da su ostvareni rezultati simulacije za jačinu električnog polja i jačinu magnetnog polja nešto niži od rezultata dobijenih direktnim merenjem. Ovo je bilo očekivano zato što simulacija nije podrazumevala dodatno zračenje koje potiče od razvodne kutije, računara u učionici i drugih vrsta zračenja.

Slična ranija merenja realizovana na ruterima u školama su pokazala slične rezultate sa neznatnim razlikama (2,18). To znači da elektromagnetno zračenje rutera u učionicama u kojima su ruteri smešteni ne predstavlja opasnost za učenike kada su u pitanju izmerene vrednosti u poređenju sa odgovarajućim standardima.

Značaj ovakvog merenja je veoma veliki. Zbog činjenice da se nivo zračenja stalno povećava, važno je imati u vidu zračenje u smislu jačine zračenja, njegove učestalosti i izloženosti u radnoj i životnoj



Slika 8. Simulacioni model rutera TL-WR841HP u HFSS softveru



Picture 7. Complete results of measurements of electromagnetic exposure for all routers

routers are placed in rooms at points where the signal reception will be the best and where the installation conditions allow, and these are generally locations under the ceiling or in the corners of the ceiling.

Results and Discussion

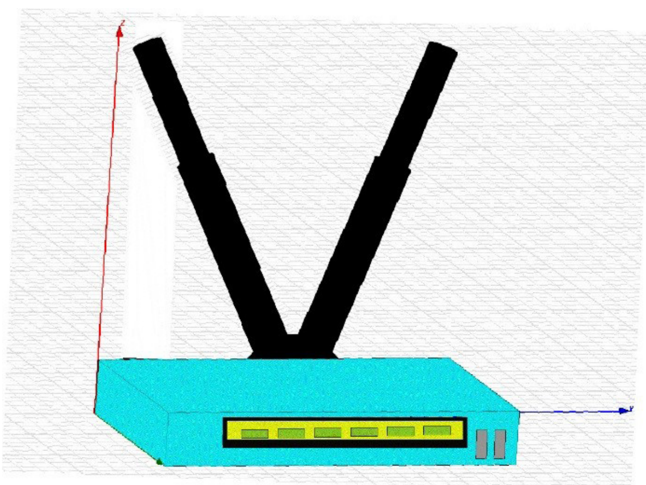
The examples of measurements of the electric field strength and magnetic field strength using the Spectran HF 60105 are shown in Pictures 3a and 3b, while the complete results of electric field strength, magnetic field strength and electromagnetic exposure are shown in Pictures 5-8.

When it comes to the electric field strength, the results shown in Picture 5 showed that the measured electric field strength was far below the limit value for the electric field strength in accordance with current standards (E = 61 V/m for frequencies higher than 2000 MHz, in accordance with the ICNRIP). It is important to note that the smallest distance from the router (for all four routers) was 1.2 meters, so the calculated exposure was only a few mV/m, which is more than two hundred times lower than the limit value.

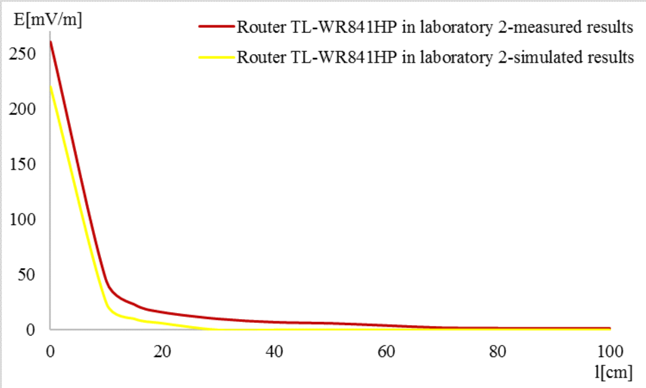
When it comes to the magnetic field strength, the results shown in Picture 6 showed that the measured magnetic field strength was far below the limit values for the electric field strength in accordance with the current standards (H = 0.16 A/m for frequencies higher than 2000 MHz, in accordance with the ICNIRP). The highest measured value was more than two hundred times lower than the limit value.

When it comes to electromagnetic exposure, the results shown in Picture 7 showed that the measured magnetic field strength was far below the limit value for electric field strength in accordance with current standards (electromagnetic exposure is 5 mW/cm^2 for frequencies higher than than 1500 MHz in accordance with IEEE C95.1). The highest measured value was far lower than the limit value for the exposure time of 6 minutes.

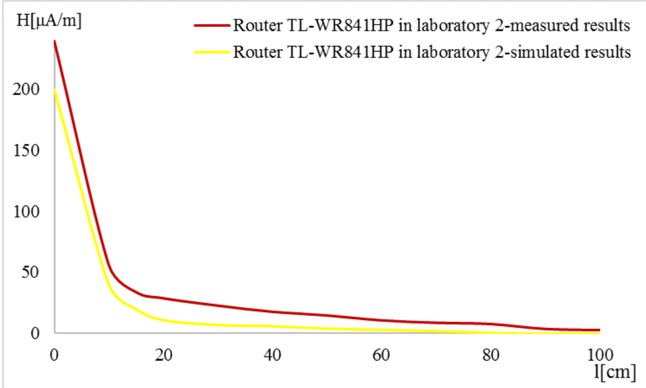
In order to verify the achieved results, the simulation of the electric field strength and magnetic field strength was conducted with the help of the software HFSS 10 for the TL-WR841HP router. HFSS is software used to calculate the penetration of high frequency electromagnetic radiation through multilayered environments.



Picture 8. Simulation model of router TL-WR841HP in HFSS software



Slika 9a. Uporedni rezultati za jačinu električnog polja rutera TL-WR841HP



Slika 9b. Uporedni rezultati za jačinu električnog polja

sredini. Na primer, 5G mreža za mobilne telefone će omogućiti mnogo brži protok informacija na višim frekvencijama, ali će takođe značiti i veće zračenje. Dakle, veoma je važno imati u vidu količinu zračenja i izloženost ljudi, a posebno dece tom zračenju (16-18).

Buduća istraživanja bi trebalo da uključe stalno praćenje i merenje visokofrekventnog elektromagnetnog zračenja u cilju smanjenja zračenja, optimalne lokacije za antene, rutere i druge uređaje koji emituju zračenje. Takođe, trebalo bi da budu usmerena na poređenje elektromagnetnog zračenja na različitim frekvencijama. Na primer, u Elektrotehničkoj školi „Nikola Tesla" u Nišu postavljena je još jedna mreža koja koristi frekvencije na 5 GHz. To podrazumeva korišćenje rutera na frekvencijama od 5 GHz. Postojanje dve mreže na različitim frekvenciijama povećava nivo elektromagnetnog zračenja. Dakle, bilo bi veoma važno izmeriti iste vrednosti elektromagnetnog zračenja i uporediti ih sa izmerenim rezultatima, kao i sa važećim standardima. Takođe, buduća istraživanja bi morala da obuhvate merenje elektromagnetnog zračenja sistema koji koriste 5G tehnologiju.

Zaključak

Sve veće prisustvo elektromagnetnog zračenja u radnoj i životnoj sredini zahteva stalno merenje i praćenje nivoa elektromagnetnog zračenja. Ovo bi moglo značajno poboljšati kvalitet radne i životne sredine, kao i kvalitet života i zdravlja ljudi i dece.

Konflikt interesa

Autori su izjavili da nema konflikta interesa.

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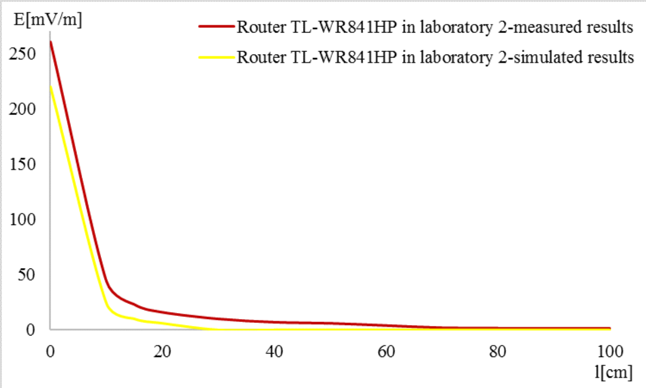
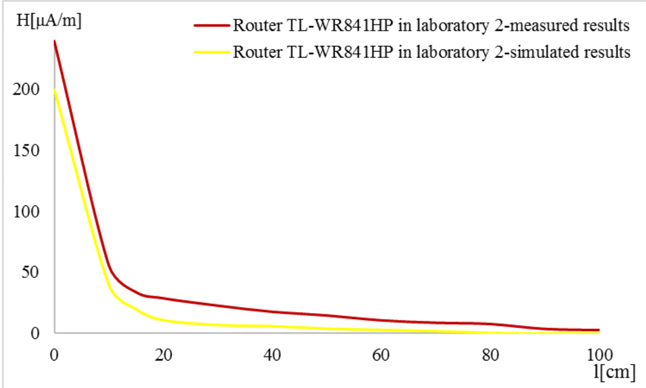


Picture 9a. Comparative results for the electric field strength of router TL-WR841HP



Picture 9b. Comparative results for the electric field strength

This software enables the simulation of various electronic products, such as antennas, components, connectors, etc. There were a few versions of this software on the market. Due to the complexity of the simulation software and paper limitations, only the simulation model of the TL-WR841HP router was used as a verification example. The simulation model of the TL-WR841HP router is shown in Picture 8, while the comparative results for the measured electric field strength and magnetic field strength simulations are shown in Pictures 9a and 9b.

The simulations showed that the simulation results for the electric field strength and magnetic field strength were slightly lower than the results obtained by direct measurement. This was expected because the simulation did not include additional radiation coming from the switch box, computers in the classroom and other types of radiation.

Similar earlier measurements that were carried out on routers in schools showed similar results with insignificant differences (2,18). This means that the electromagnetic radiation of the routers located in the classrooms does not pose a danger to the students when it comes to the measured values in comparison to the corresponding standards.

The significance of this measurement is very great. Due to the fact that the level of radiation is constantly increasing, it is important to consider radiation in terms of radiation strength, its frequency and exposure in the work and living environment. For example, 5G mobile phone network will enable much faster flow of information at higher frequencies, bit it will also mean more radiation. Therefore, it is very important to take into account the amount of radiation and the exposure of people, especially children, to that radiation (16-18).

Future research should include continuous monitoring and measurement of high frequency electromagnetic radiation in order to reduce radiation, as well as the optimal locations for antennas, routers and other radiation-emitting devices. Also, they should be aimed at comparing electromagnetic radiation at different frequencies. For example, at the Secondary School of Electrical Engineering “Nikola Tesla” in Niš, another network using 5 GHz frequencies has been installed. This implies the use of routers at 5 GHz frequencies. The existence of two networks at different frequencies increases the level of electromagnetic radiation. Therefore, it would be very important to measure the same values of electromagnetic radiation and compare them with the measured results, as well as with valid standards. Also, future research should include measuring the electromagnetic radiation of systems using 5G technology.

Conclusion

The increasing presence of electromagnetic radiation in the working and living environment requires the constant measurement and monitoring of the level of electromagnetic radiation. This could significantly improve the quality of the working and living environment, as well as the quality of life and health of people and children.

Competing interests

Authors declare no competing interests.

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