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Research paper

Specific Absorption Rate Computation for Human Body Exposure to Mm Waves Using Fuzzy Systems as Approach

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Abstract

The interaction between the human tissues and the Radiations waves produce a chemical reaction which increase the temperature in human body tissues, thus this chemical reaction may generate a several potential health effects as DNA Damage; Alzheimer and brain cancer, despite the previous studies and several researches, the radiations sources increase daily which drive to expand the spectrum frequency band that will arrived to 300 GHz with 5G and 6G which allow to connect several objects other than smartphones, tablets and computers. With the 5G or 6G the human body organs will also be connected through the radiation sensors attached to the body. According to the previous studies the evaluation of biological effects caused by the existing radiation sources is achieved according to the Specific Absorption Rate of human body to radiations waves, whereas it increase if the distance between the source of radiation and the human body is short, as well with the higher frequency bands and the emitted power sources. The objective of this paper is the interpolation of Specific Absorption Rate simulated values by Fuzzy system that allow to have an overview of the absorbed dose of human body exposed to the 5G Radiation's in an enclosed area.

Keywords: *SAR, Mm waves, wearable devices, Fuzzy System, Sugeno Fuzzy System.*

1. Introduction

Mobiles and wireless networks have made tremendous growth over the last twenty years, whereas in recent years we may notice the appearance of other connected objects other than smart phones or computers. Internet of things, smart cities have the essential purpose to expedite the human life from their smart phone and smart management of energy and resources for Sustainable Development. As figured in the Fig.1 the fifth generation or as a popular IOT (Internet of Things) invade all domains as Energy, environment, health, security, transport then it opt to facilitate the human life by creating a smart home that allow to operate our houses via our smartphones, then we may even be hospitalized and supervise from our houses. Therefore we will need a wide range of frequencies able to accept all connected object.

Fig. 1: General View of Smart city

As the Fig.2 depict the potential of 5G communication architecture [1], it is considered in the macro cells scale that will be equipped with large antenna arrays ,additional small cells and Femto cells that will be distributed over the macro cell network. The buildings located in the macro cell's 5G area will be also equipped with large antenna arrays installed outside of the building, hence each one will be able to communicate with the macro cell's base station directly or with the distributed large antenna arrays of the base station. For the outside installed large antenna arrays will be connected via cable to the wireless access points inside the building which communicate with indoor users [2]. Beside the Macro cell's base stations, Micro cell, Femto cell and users mobiles, with the fifth generation a new wireless propagation environments had developed as V2V (Vehicle-to- Vehicle) [3] almost instantaneous exchange between vehicles or (V2I) [3] Vehicle-to-Infrastructure exchange between vehicles and the base station or network. More than the connected vehicle, the 5G allow to connect any equipment in order to facilitate life, thus to avoid the congestion in the network D2D (Device to Device) [4] the new generations included in the communications system. The access to the network or the transmission data is done via a frequency band, consequently the increase of connected users its needed to increase the spectrum frequency band in order to allow all the usurers to accede to network with level debits then by including a new object connected, for this raison the 5G chose to operate in Mm wave.

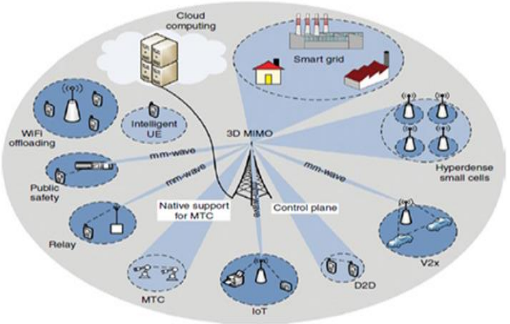


Fig. 2: 5G system architecture

The previous studies [5]have unveiled the harmful effects of the radio equipment's on human health. The evaluation is based on the specific absorbed dose which varies depending on the frequency band as well as the proximity of the source the [6] and [7] have developed the influence of the last parameters. The 5G will conquer the medical domain, Where it allow the best management of the hospital by connecting the human infected organ directly to their doctors without having to move to hospital, in case of hospitalization the patient will be pick up from a hospital ultra-connected from the bed to the plaster. In spite of smart services offered by the 5G, but the problematic is related to its frequency band operation, thus the new communication systems included then we will be face and the several radiations and powerful sources to we will be exposed as satellite which allow the coverage network outside cities and in space, which may increase the SAR. More than communication systems, the severity of the problem is reflected in the wearable sensors that will stick to organs.

In this paper we will interpolate in part 4.1 A by Sugeno System the simulated SAR values of part body closed to wearable devices, thus as an interpolation of the same values for the whole body is treated in the part 4.2, in order to estimate the Level exposure approach to 5G Radiation sources especially with wearable devices and the Radio Access Point installed in enclosed Area.

2. Specific Absorption Rate analyze for Radiation's 5G

2.1. 5G Operation Frequency Band

Since the 5G pledge an ultra-connected word that will allow humans to manage their life via smart phones, the services offered by this network they will require a large frequency band that range all the way from 600 MHz to 71 GHz that the different countries have proposed and are working on as presented in Table 1 [8].

Zigbee, Wifi, WiGig, Lifi, Bluetooth and others, with the heterogeneous networks (HetNets) will play an important role in integrating a diverse spectrum to provide a high quality-of service (QoS), especially in indoor environments where there is localized infrastructure supporting short-range directional wireless access. Device to device communication is the technique used in modern wireless transmission technology like Internet of Things and 5G. Device to device communication is the technique used in modern wireless transmission technology like Internet of Things and 5G. ZigBee Bluetooth 2.1+ED and Bluetooth4.0+LE are adequate to device to device communication in a smart home application which operate in 2.4 GHz (home automation), 784 MHz, 868 MHz and 915 MHz (country specific) with the range of 10 to 100 meters [9]. Wi-Fi protocols are not robust enough to support the higher traffic demands of 5G.Wi-Fi has evolved into WiGig [10], the WiGig tri-band enabled products are commercially available in the frequency band of 2.4, 5 and 60 GHz. There is also far more spectrum available to use with Li-Fi [11]than Wi-Fi, as the visible light spectrum is 10,000 times larger than the entire radio frequency spectrum 300 GHz.

Table 1: Frequency Band of 5G

Font Size	Spectrum frequency	
	the lower spectrum frequency	the higher spectrum frequency
United States	3100 - 3550 MHz 3700 - 4200 MHz	27.5 – 28.35 GHz 37 – 40 GHz 64 - 71 GHz
Europe	3400 - 3800 MHz	24.25 - 27.5 GHz
China	3300 - 3600 MHz 4400 – 4500 MHz 4800 – 4990 MHz	24.25 – 27.5 GHz 37 – 43.5 GHz
Japan	3600 - 4200 MHz 4400 - 4900 MHz	27.5 – 28.28 GHz
Korea		26.5 – 29.5 GHz

2.2. Specific Absorption Rate Dosimetry of Mm wave

With regard to the antenna proximate to the human body, part of the energy stored around the antenna might couple into the tissue and human exposure can be affected by the presence of reactive energy, it is presented in Reflection Coefficient into human tissues. In order to evaluate this factor in the targeted frequency range, the field generated by the source is noted $E_{inc}(x, y,\ z)$ of plane waves, the transmitted plane E_{tx} on the human surface body is according to E_{inc} and $\Pi_0(k)$ the spectral transmission operator for the planar interface (z=z_0) corresponding to the tissue model surface [12]:

$$\widehat{E_{tx}}(k) = \Pi_0(k)\widehat{E_{inc}}(k) \tag{1}$$

The PWS of the magnetic field, determined solving Maxwell's equations, is [12]:

$$\widehat{H_{tx}} = \frac{1}{\omega\mu}(k_z\hat{z} + k) * (\widehat{E_{tx}}) \tag{2}$$

Where ω and μ are respectively the angular frequency and the permeability inside the human tissue media. The absorbed power within the tissue at $z = z_0$ was therefore determined as [13]:

$$P = \frac{1}{2}\iint(E_{tx} * H_{tx}^*)\hat{z}\ dxdy \tag{3}$$

2.2.1 Analyzed Dosimetry of Near-field

A plane-wave equivalent incidence on Skin-equivalent is due to Specific Absorption Rate (SAR) the power density P_0 in $(\frac{W}{m^2})$ is defined by equation (4) [14] :

$$P_0 = \frac{\rho.\delta.SAR(0)}{2(1-|\Gamma|^2)} \tag{4}$$

Where P_0 is the input power delivered to the antenna,ρ mass density, δ is the penetration depth, and SAR (0) is the SAR at point $z = 0$ and Γ reflection coefficient between skin/antenna.

2.2.2 Analyzed Dosimetry of far-field

The most exposed body parts are hands because most of time we use our mobiles and head in case of communication and with 5G the Radio Access point will installed usually above the head, the mobile terminal is generally located at a distance ranging from 15 to 30 cm, then the power density P_0 in $(\frac{W}{m^2})$ is approximated by [15]:

$$P_0 = \frac{P_tG_t}{4\pi d^n} \tag{5}$$

Where P_t the power radiated by the antenna, G_t is the transmitter antenna gain, d is the distance between the human body and mobile terminal, n is the attenuation coefficient (n = 2 in free space).

2.2.3 SAR distribution on surface and the Whole body

The evaluation of SAR distribution on a surface skin closed to wearable sensors, it was modelled by using a Gaussian function over a surface (x, y) by the equation (6) [16] follow:

$$SAR(x,y) = SAR_0 e^{-y/\delta} e^{-(x/R)^2} \qquad (6)$$

Where SAR_0 the peak of SAR at the closed surface to the wearable antenna, δ and R are the depth and lateral distance at which the SAR has fallen to $1/e$ of its peak value at the surface. Concerning the 5G equipment's which concerned as a Far fields as Radio Access point that installed in an enclosed surface, we have chosen to evaluate the SAR of whole human body exposed to this fields by equation (7) depending on the total volume of whole skin human body [17], which will allow us to model SAR value for whole body exposed to 5G devices in different frequency band.

$$SAR_{wb} = \frac{1}{V_{tot}} * \frac{2}{\delta} * SAR(0) \iint dxdy \qquad (7)$$

3. Perspective of Radiation Exhibitions to Mm wave

3.1. Illustration of the Studied Indoor Radiation System

The impact of radio radiation on health is one of the interest areas of many researchers have managed to prove this harmful effects on the human body [18]. The proximity, the number of radiation sources, the frequency band operation and the duration of exhibition are the influencer parameters on the specific absorption Rate values.

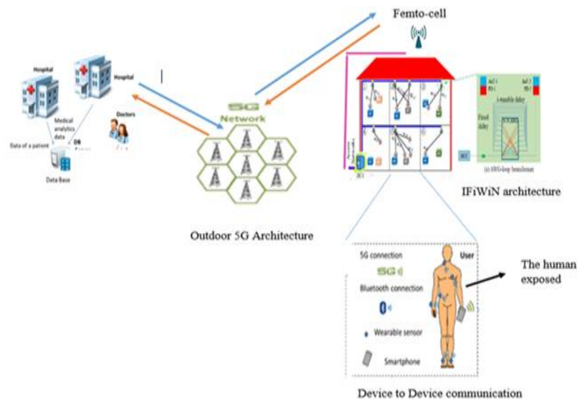


Fig. 3: Illustration of the studied Radiation system on Human body in an enclosed area

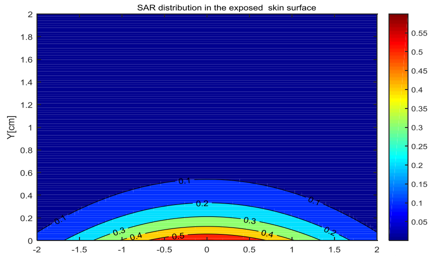
Since the Millimeter waves using by 5G are sensitive to oxygen and the path loss propagations which increased greatly when multiple materials were penetrated such as clear glass [19], for this reason in our illustration of studied we have neglected the outdoor coverage. The Fig.3 present the context of the indoor network coverage will focus on the fiber wireless systems [20] and a multiple simplified remote antenna sites are attractive to avoid the indoor coverage problem caused by the high wall penetration loss of mm-wave signals. We suppose that the human inside the room he is clothed the ECG sensor [21] that operate in ZigBee frequency band, the head phone that operate in WiGig band [22] and the connected bracelet in 5GHz [23], all this wearable's devices are connected to the 5G smart phone which is simultaneously connected to Radio Access point that connected to the optical fiber, the radiation parameters concerning the last radiations sources are presented in the Table 2.

Table 2: The Perspective of Radiation of Each 5G Equipment Radio

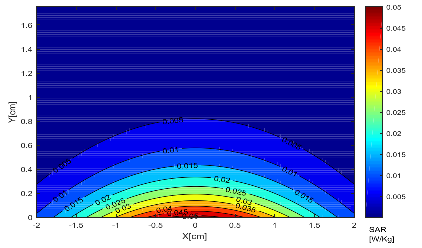
Indoor Radiation sources				
Wearable Wireless Devices				
Equipment	Frequency band (GHz)	The Output power	σ (S/m)	δ (mm)
ECG	2.4	3.38 W	1.44	3
The connected Bracelet	5	100 mW	3.06	3.5
Head phone	60	500 mW	38	0.48
Millimetre Wave Mobile Communications for 5G Indoor Cellular				
Smart-phone	28	10W/m^2	26.19	1.5
Radio Access Point	28	31.66 W/m^2	26.19	1.5

3.2. Simulation and results

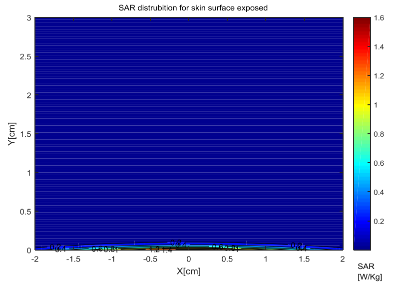
Using the simulator and relying to radiation parameters on the Table II, we have simulate the SAR values on the Skin surface closed the wearable sensors and SAR of whole body exposed to smartphone and the Radio Access point antennas. The Fig.4 illustrate the Specific Absorption Rate on Surface Skin closed to (a) ECG sensor radiate with 500 (mW) input power and Reflection coefficient into skin surface equal 0.0031, the Peak SAR is arrived to 0.6 (W/Kg), for (b) the connected bracelet the peak SAR is 0.05 (W/Kg) and 1.6 (W/Kg) for (c) the head phone.



(a) ECG 2.4 GHz



(b) The connected Bracelet 5 GHz



(c) Head Phone 60 GHz

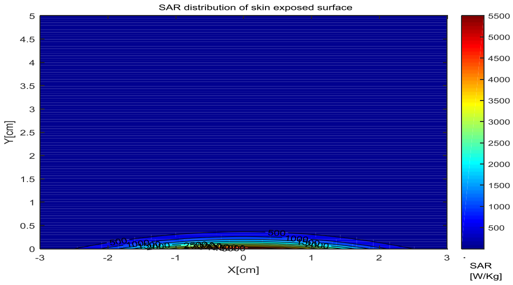
Fig. 4: SAR distribution in Skin surface closed to wearable devices

According to the Maximum; median and minimum SAR values in the skin figured in Table 3, the ECG that operate in 2.4 GHz and the head phone that operate in 60 GHz with the same output power which is 500 (mW), we notice that the largest values emerged for the 60 GHz high frequency band state to wearable sensors.

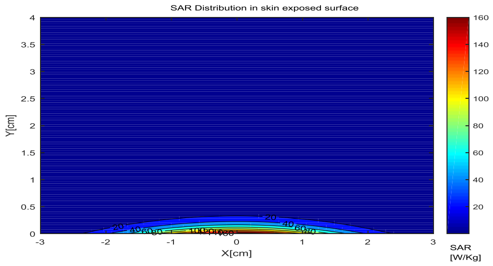
Table 3: The SAR values of surface Skin closed to wearable devices

Equipment	Frequency Band	Output Power	SAR Values (W/Kg)		
			min	mean	Max
ECG	2.4 GHz	500 mW	0.05	0.3	0.5
Connected Bracelet	5 GHz	100 mW	0.05	0.275	0.5
Head Phone	60 GHz	500 mW	0.2	0.9	1.6

With 5G generation that using the method of Multiple Input Multiple Output all Smart phones and the Radio Access Point equipped by more than one antenna [24]with a powerful output power. Since our smart phones are bonded to our hands, thus the Fig.5 show the peak SAR of 5G Smartphone closed to a local surface closed to hand (a), the peak SAR of a head which is near to Radio Access point (b) installed in the Room.



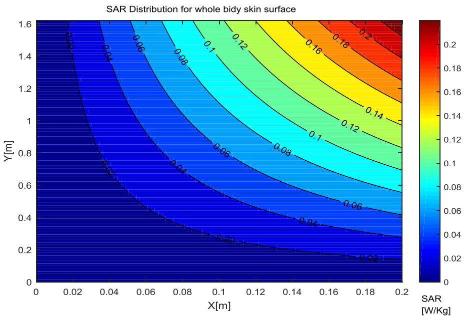
(a) SAR for Smart Phone



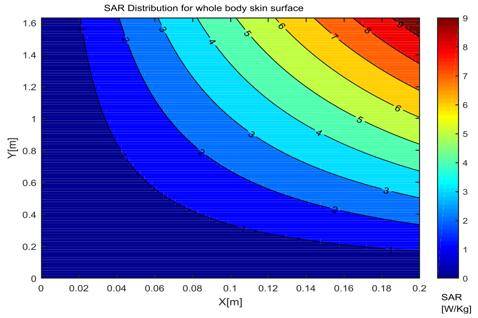
(b) SAR for IFiWiN

Fig. 5: SAR distribution in Skin surface closed to smartphone and the Network

The above figure may be offensive where the peak SAR is increased to 5500 (W/Kg) in the point of the finger closed to Smartphone and the peak one for a part of human head wich is directly under the antennas of IFiWiN that installed for each room is arrived to 160 (W/Kg).



(a) Smart phone 28 GHz



(b) IFiWiN 28 GHz

Fig. 6: SAR distribution in whole body exposed to (a) smartphone and (b) Radio Access point.

The Fig.6 show the distribution SAR for whole body exposed to Smartphone where the peak SAR value is 0.3 (W/Kg) for the exposure to IFiWiN antenna's the peak SAR arrived to 9 (W/Kg). According the results we conclude that the absorbed dose of radiation emitted by antennas equipment's in 5G Network that may increase to 5500 (W/Kg) for the skin surface closed to the equipment that operate in 28 GHz frequency band, the wearable equipment operating in 2.4 GHz, 5GHz and 60 GHz the Maximum SAR values is 1.6 (W/Kg) for 60 GHz. we notice that the SAR values change according the frequency band, the transmitter power and the distance between radiation source and the surface exposed.

4. Specific Absorption Rate Modeled by fuzzy system

The simulate results substantiate that the human tissue absorb more with the high frequency bands and also show that SAR values for each frequencies overlap in some spaces. Because of variation of SAR values for each frequency band, we present the simulate SAR values by membership functions (8) using the minimal median and maximal simulated values for each frequency band as an example the SAR values for wearable devices as figured in the Table 4. For each wearable device, a fuzzy sequence in different frequency band [25] as presented in the Fig.7.

Equipment	Frequency	SAR Min	SAR Median	SAR Max
Smart phone	28 GHz	0.02 W/Kg	0.3 W/Kg	0.5 W/Kg
IFiWiN	28 GHz	1 W/Kg	5 W/Kg	9 W/Kg

In correspondence with the simulated values in Table III and Table IV the modeling of the fuzzy systems[26], that set 2.4 GHz: the fuzzy subset of SAR in frequency band 2.4 GHz [0.05;0.55], 5GHz: the fuzzy subset of SAR in frequency band 5 GHz [0.05; 0.5],60 GHz :the fuzzy subset of SAR in frequency band [0.2;1.6],28 GHz-S: the fuzzy subset of SAR in frequency of Smartphone [0.02;0.32], 28 GHz-N: the fuzzy subset of SAR in frequency of Network [1,9]. Where the interpolation of SAR values of the connected wearable devices is by applying respectively the membership functions: **$\mu_{2.4}$: SAR ϵ 2.4 GHz→[0;1], μ_5: SARϵ 5GHz→[0;1], μ_{60}:SARϵ60 GHz→[0;1], μ_{28-S}:SARϵ28 GHz-S →[0;1], μ_{28-N}:SARϵ 28 GHz-N→[0;1].**

$$\text{SAR} = \begin{cases} \dfrac{SAR-SAR_{Min}}{SAR_{Median}-SAR_{Min}} & \text{for } SAR_{Min} \leq SAR < SAR_{Median} \\ 1-\dfrac{SAR-SAR_{Median}}{SAR_{Max}-SAR_{Media}} & \text{for } SAR_{Median} \leq SAR < SAR_{Max} \\ 0 & \text{else} \end{cases} \tag{8}$$

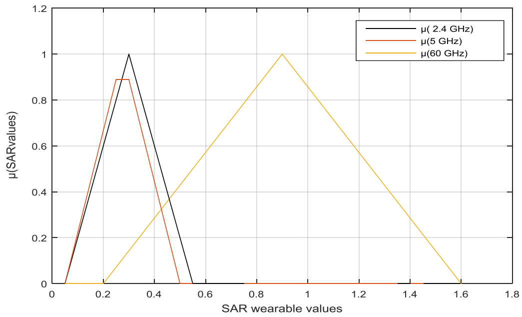


Fig. 7: SAR Fuzzy dynamic model of the connected wearable devices

4.1. The Specific Absorption Rate for Wearable Devices by Sugeno System

A SISO zero-order Sugeno fuzzy system [27] is a construction comprising:

i) A set of input membership functions: $\mu_k: S \to [0,1], k = 1, \dots, m$
ii) a set of output singletons, $\{\beta_h\}$
iii) an application i(.) : {1, a,m} → {1, … ,Q}, that associates to any $k \in 1, \dots \dots, m$ a value $i(k) \in \{1, \dots, Q\}$, each such individual association, that is a value for a specified, is named rule.
iv) an application : S R defined by

$$x \to y = \frac{\sum_k \beta_{i(k)}\, \mu_k(x)}{\sum_k \mu_k\,(x)} \qquad , \beta_{i(k)} \in R$$

The part (iii) in the construction is equivalent to saying that there is a set of m rules,

R (k): If input is μ_k, then output is $\beta_{i(k)}$, that is, one singleton is assigned to each input membership function.

The interpolation of the specific absorption Rate in surface closed to three wearable devices by fuzzy system, we extend this interpolation for the part of body closed to the three devices by calculating the center of gravity of the intersection of the membership functions denoted μ_{center} of three wearable devices as shown in Fig.8, this center of gravity equal 0,373 W/Kg which will be the input of the Sugeno system.

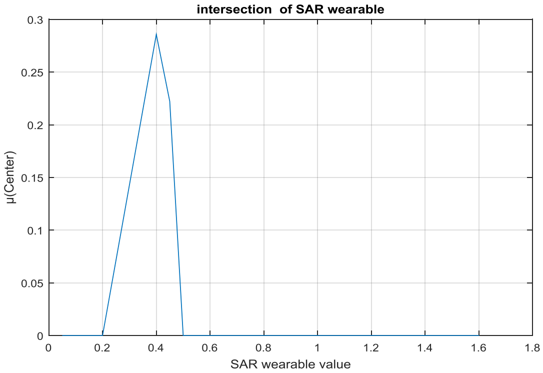


Fig. 8: The center's membership functions of the connected wearable Devices

The weighted SAR values of wearable devices in the part of body closed to the three devices, we will be modified by triangulating the $SAR_{wearable}$ as presented in the Fig.9, as specified the vertices of this triangle will be the inputs membership functions of Sugeno System.

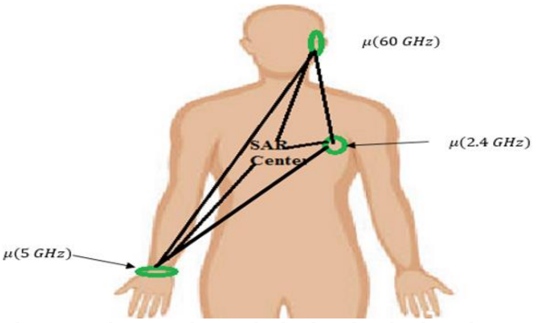


Fig. 9: The Triangulation in the part body closed to the three devices

The three point of triangle by$\mu_{2.4}$;μ_5; μ_{60} as a correspondence with the definition of the Sugeno system we set the rules of the system as follows:
Rule: if input x

i) x is $\widehat{2.4}$ GHz then output is the center of gravity of wearable device 2.4 GHz frequency band noted GOC ($\mu_{2.4}$)
OR
ii) x is $\hat{5}$ GHz then output is the center of gravity of wearable device 5 GHz frequency band noted GOC (μ_5)
OR
iii) x is 60 GHz then output is the center of gravity of wearable device 60 GHz frequency band noted GOC (μ_5)

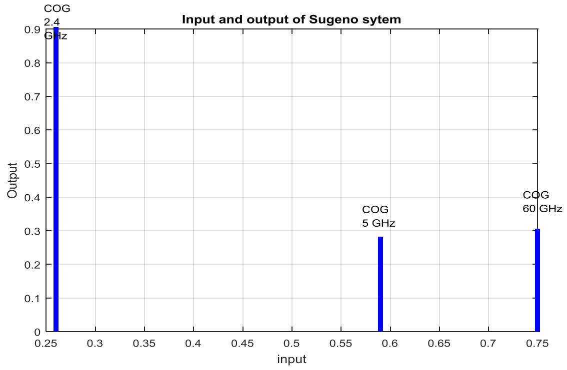


Fig. 10: The input and output of the Sugeno System

The Fig.10 Present the input $\mu_{2.4}(SAR_{center})$, $\mu_5(SAR_{center})$, $\mu_{60}(SAR_{center})$ and the Sugeno system outputs according to the rules cited. The weighted SAR in Skin of the human body part closed to wearable devices, then the interpolation of the Specific Absorption Rate is done by using the Sugeno System according to the equation (9):

$$y(SAR_{center}) = \frac{\sum_k \beta_{i(k)} \mu_k(SAR_{center})}{\sum_k \mu_k(SAR_{center})} = 0.388 \frac{W}{Kg} \tag{9}$$

The weighted SAR value of the skin part of the human body closed to wearable devices operating in the 2.4 GHz; 5GHz and 60 GHz it is 0.388 W/Kg.

4.2. Specific Absorption Rate for Whole Body Molded By Fuzzy

As an evaluation of variability of SAR for Whole body exposed to several frequency band of 5G, using the variation of the degree of overlapping between the successive memberships functions of wearable devices, the smartphone and the Network IFiWIN, that is tested by their intersection [28], the intersection of the membership functions for whole bodyμ_{28-S}, μ_{28-N} and the membership functions of wearable devices that figured in Fig.11, it is almost null.

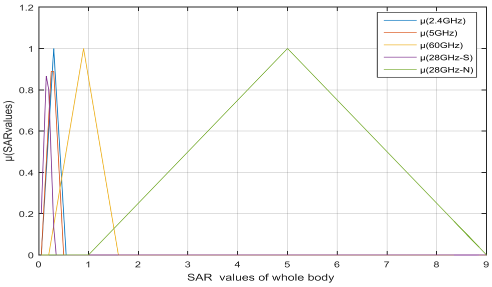


Fig. 11: The SAR Fuzzy dynamic model of Skin Whole body

Consequently to be capable to concretize the SAR for whole body is the Union of the membership functions of all radiations sources of 5G equipment 2.4 GHz ∪5 GHz ∪ 60 GHz which is the Maximum of the membership functions as defined blow $\mu_{2.4\ GHz\ \cup 5\ GHz\ \cup\ 60\ GHz} = Max\ (\mu_{2.4}; \mu_5; \mu_{60})$ as plotted in the Figure 12.

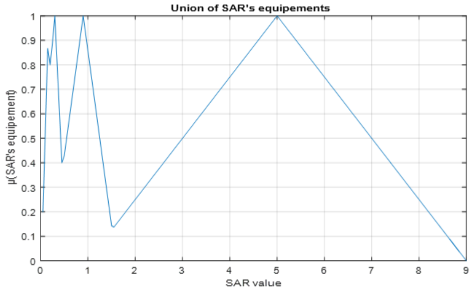


Fig. 12: The union of membership functions of SAR on human body exposed to equipment's 5G

As an interpolations of the Specific Absorption Rate for whole body exposed to equipment's 5G, the weighted SAR value using the method of center of gravity as shown in equation (10) [29]:

$$SAR_0 = \frac{\int_{0.05}^{9} SAR * \mu_{2.4\ GHz \cup 5GHz \cup 60GHz \cup 28GHz-S \cup 28GHz-S}(SAR)dSAR}{\int_{0.05}^{9} \mu_{2.4\ GHz \cup 5GHz \cup 60GHz \cup 28GHz-S \cup 28GHz-S}(SAR)\ dSAR} = 4.303\ \text{W/Kg} \qquad (10)$$

The Specific Absorption Rate weighted in skin of whole human body exposed to several radiations sources specified to 5G, it is equal 4.303(W/Kg), which is exceed the ICNIRP exigencies limits of 0.08 (W/Kg) for whole body.

5. Conclusion

In From the simulated results the SAR peak in the skin surface that closed to smartphone for 5G it is arrived to 5500 W/Kg as well as the results of [30]substantiate that the Peak SAR of a hand closed with 15 mm to the equipment's 5G, it increased to 3010W/kg. Concerning the wearable sensors operating in Mm wave that are close to skin surface the Peak SAR value reached 1.66 W/kg in the search paper [31]however after modeling our Simulated SAR values for 2.4 GHz,5 GHz and 60 GHz by Sugeno Fuzzy System the Peak SAR for the wearable sensor zone reached 0.38 W/Kg. The Weighted Specific Absorption Rate is 4.303W/Kg for the human body that put a wearable sensors with different frequency band and in the same time it is exposed to radiations emitted by the Smart phone in 28 GHz and by the Radio Access point in 28 GHz installed in the enclosed space. As summarize of our paper, with 5 Generation and the smart cities the Specific Absorption Rate will be exceed ICNIRP the exigencies limit. More than SAR increases more than body temperature increases [32] which will have a negative biological effect. .

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