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MOBILE & WIRELESS HEALTH

VLC, OCC, IR and LiFi Reliable Optical Wireless Technologies to be Embedded in Medical Facilities and Medical Devices

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Abstract

New, emerging technologies, transform every day our life and have direct consequence on our health and well-being. More and more wearable medical devices (MD) with wireless communication technologies embedded are being developed by innovative academic community and companies. Optical wireless communication (OWC) consisting of Visible Light Communication (VLC), infrared (IR), Optical Camera Communication (OCC) and Light Fidelity (LiFi) along with the conventional Radio Frequency (RF) wireless communication are suitable technologies to be used for hybrid Wireless Integrated Medical Assistance Systems (WIMAS). The WIMAS addressed in this paper consists of two Wireless Medical Body Area Networks (WMBAN) (an insulin wearable kit and an ECG test device with VLC/OCC are considered) and an Emergency Remote Medical Assistance (ERMA) with LiFi technology embedded. Using RF in medical facilities is subject of strict regulations due to interferences with other RF medical devices, negative effects on human health and lack of security. VLC and OCC are suitable to be embedded in MDs in order to be used by the patients with wearable WMBAN. Research on IR transdermal communication for implantable MDs has also been demonstrated as feasible and both VLC and OCC have promising future, as well. On the other hand, LiFi technology, recently deployed on the market, is mature enough to be integrated in the ERMA system addressed here.

Keywords LiFi · VLC · OCC · Optical BAN · Health-monitoring · Transdermal communication

Introduction

Smart and versatile wearable medical devices (WMDs) replace faster than ever the traditional MDs able to collect data and analyse it and ever more advanced to make diagnosis and take actions. Driven by the desire to improve quality of live and support people with chronic illness, researchers and companies together develop advanced WMDs bringing the IoT (Internet of things) revolutions one step further to IoMT (Internet of Medical Things). The connection of the device to the user in a sophisticated way leads into new and emerging applications in the wearable technology for WMDs. New technologies shift towards personalized medicine and out-of-hospital care. Diabetes patients can monitor and control their glucose levels anytime and everywhere with devices for smart infusion and cardiac diseases can be monitored remotely and efficiently. WMDs such as drug delivery infusion pumps, ECG and vital signs monitoring, diagnostic devices, nerve stimulation, self-testing, post-operational rehabilitation devices and many others require a reliable interface to the skin that has recently been termed as 'Skin-to-Thing' (S2T) solution [1].

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Many scenarios of a Wireless Integrated Medical Assistance System (WIMAS) have been already presented, discussed and implemented as reliable systems, most of them based on the RF communication [2–4]. The WIMAS we propose (Fig. 1.) based on optical wireless communication, consists of a WMBAN and an ERMA.

WMBAN refers to, for example, an insulin device with wireless transmission between sensor, glucose monitor and insulin pump and/or an electrocardiogram (ECG) test system.

All data acquired are sent wireless to a Smart Processing Unit (SPU) (smart phone, laptop, tablet, desktop) being then remotely forwarded to a dedicated server, an emergency room or a physician for emergency medical assistance. The SPU collects all data gathered by the sensors, stores and/or remotely sends data acquired to the "outside world" via an external gateway.

Present WIMAS based on RF transmission

General considerations on WMBAN

Body Area Network (BAN) technology use tiny, low-power smart devices that can be carried on or embedded inside the human body. The main two activities where BAN are currently used target to monitor general or specific human health condition or wellness.

Wireless BAN (WBAN) consists in ultra-low power, self-sustained, intelligent and light weight body-borne sensors, designed to work on/in or around the human body and mainly operates in the license-free industrial, scientific, and medical overcrowded radio band centred at 2.45 GHz (IEEE 802.15.6) [5]. WMBAN technology (IEEE 802.15.4j, 2360–2490 MHz) allow early detection, diagnosis, prevention, monitoring, treatment or alleviation of disease or injury and fast aid in the medical field, thus offering a reliable monitoring of different human diseases and fast interventions in case of emergency situations [6]. Wireless communication technologies based on RF enable WIMASs are short-range, such as WLAN aka Wi-Fi, Bluetooth, and Bluetooth Low Energy, ZigBee or ultra-wideband [7].

Reliable wireless technologies for a real-time health monitoring that support short range communication within the surrounding area of the human body (BLE and VLC), indoor communication based on both RF (BLE, Wi-Fi, Bluetooth) and optical transmission (VLC, IR, OCC or LiFi), as well as remote transmission (Wi-Fi, WLAN, GSM, UMTS - Universal Mobile Telecommunications system) are presented in Fig. 2.

Weaknesses of wireless data communication based on RF

The most important issues regarding WMBAN refers to monitoring and sensing, power efficient protocols, system architectures, routing, and security [8].

RF negative effects on human health

Potential health effects of exposure to electromagnetic fields (EMF) has constantly been under evaluation by the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) that deals with queries related to emerging or newly identified health and environmental risks [9]. The most restrictive limits on RF exposure are in the frequency range of 30–300 MHz where the human body absorbs RF energy most efficiently. The limit for human exposure to RF emission is between 1.6 and 2 (W/kg) averaged over 10 g of tissue [10]. SCENIHR concluded that, using cell phones, exposure to RF and EM radiation do not indicate an increased risk of brain tumours or other cancers of the neck region and head or childhood cancer [11].

RF interference issue

According to U.S. FDA regulation, manufacturers of electronic implantable MD (such as pacemakers) have to test their products for susceptibility to electromagnetic interference

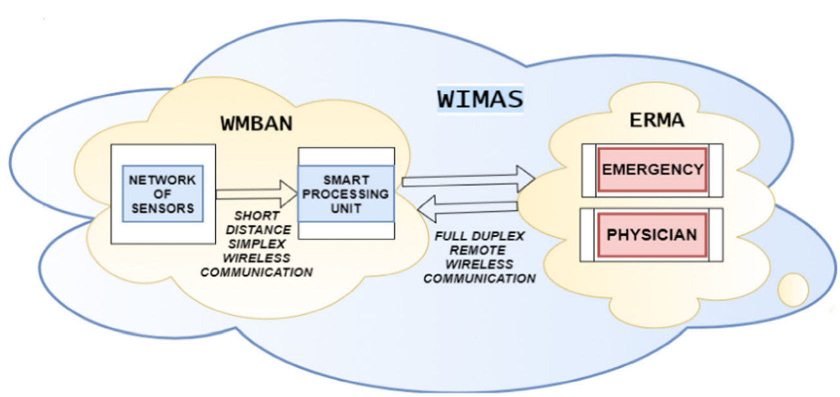

Fig. 1 A general view of a Wireless Integrated Medical Assistance System (WIMAS)

Fig. 2 Different wireless communication technologies to be used for a reliable WIMAS

(EMI) over a wide range of frequencies. Cell phones, have adverse effects on the MD used in critical care setup [12] and therefore they are usually limited or forbidden to be used in some specific places of the healthcare facilities. EMI causes power flows and spikes with undesirable effect on data collected by medical equipment. To avoid this kind of problems, insulation transformers can be used to allow most Class I equipment to pass the electrical side of the EN60601 regulation to become safe for use in hospitals [13].

Both EN 60601 (European) and IEC 60601 (U.S.) standards provide requirements for EM compatibility for MDs (as external pacemaker, nerve and muscle stimulators, ECG, EMG, hearing aids, alarm systems, patient monitoring) [14]. New regulation has entered into force since May 26th 2017 replacing the current EU's Directive for MDs (93/42/EEC) and active implantable MD (90/385/EEC) [15].

RF security issue

The medical wireless data communication must be strictly private and confidential and therefore encrypted. On the other hand, the medical staff should receive non altered data (data integrity requirement) due to high secure management of authentication and authorization processes. Furthermore, the network should be accessible in case of emergency, e.g. trauma situations when the user is not capable to give the password. RF communication implemented in MD has proved to be easily accessible by unauthorized persons [16].

Hybrid WIMAS based on both OWC and RF

OWC consist of VLC, IR, OCC and LiFi transmission technologies.

VLC (defined by standard IEEE 802.15.7:2011 Short Range Optical Wireless Communications) uses wavelengths in visible light (visible for human-eye) that spreads from 380 nm to 780 nm on EM spectrum in a simplex communication scenario. It can be used as the OWC in the system proposed, between sensors (placed on body) and the ECG station.

Currently, the most appropriate IR part (near IR – NIR with wavelengths from 780 nm to 950 nm) used for OWC applications, has most of the physical properties of the visible light, do not pass through opaque/solid obstacles, reflect off the walls, ceiling and other objects indoor but invisible to the human-eye. IR communication has been proved as viable OWC between IMD and SPU, therefore possible to be used as part of the insulin MD.

The OCC technique is a practical version of VLC that uses an image sensor (array of photodiode pixels) and/or a camera as an optical receiver (oRx) that demodulates the optical signal modulated by optical transmitter (oTx) according to On Off Keying (OOK) [17]. The use of OCC in four different scenarios for channel modelling have been addressed: open office, office room with secondary light; living room and manufacturing cell and relevant channel parameters were discussed [18]. IEEE 802.15.7r1, the revision of 802.15.7, targets the commercial usage of VLC systems. Technical consideration document of Task Group 7r1 that defines the PHY mode supported in standard, stipulates the compatibility between a variety of cameras with different image sensing sampling rates (read-out time), constant/varying frame rates or resolutions [19]. The most important advantages of OCC refer to the stability over different changes of communication distance, high quality of signal to noise ratio (SNR) and there is no need of complex signal processing. Due to its main advantages over VLC (low complex oRx and wide already available device, the smartphone) OCC can be used, in the system proposed, as OWC between insulin MD and smart phone, avoiding any spoofing attack, hence providing high security.

LiFi enables full duplex (one way VLC and the other IR, for example), multiple-in multiple-out (MIMO) high speed optical data wireless communication between mobile devices and other networked devices via LED lights fixtures used to carry data [20]. LiFi can be used as local OWC between any SPU and lighting fixture in medical facilities, especially in places where RF interference jeopardise human health (emergency room or rooms with diagnostic instruments such as MRI, CT Scan or surgical equipment), providing data security, as well.

The three RF's weaknesses presented above show that alternative wireless technologies have to be searched. OWC has advantages over RF communication: there are no interference with other MDs, no negative effects on human health (except some particular setups) and there are only some minor security issues. Therefore, indoor communication should rely on OWC and remote transmission can be done using RF technologies.

Both VL and IR wavelengths cannot penetrate solid objects, and therefore data piggybacked by light is inherent secure into the room, even though light interception, hence data eavesdropping has been already investigated and proved to be possible [21, 22].

The EN 62471:2008 standard (concerning the photobiological safety of lamps and lamp systems), states that incoherent diffuse continuous-wave-modulated LEDs don't bring any photobiological hazard for the human-eye in case that the irradiance does not exceed 100 W/m^2 at a distance of 0.2 m from the optical source in the direction of maximal directivity within 1000 s [23]. On the other hand, since human-eye is sensitive to IR, the communication intensity has to be limited and therefore IR is subject of strict regulations according to European Directive 2002/95/EC. Long exposer at high heat loads can interfere with the temperature balance of the body and can cause tissue damage or accelerate skin aging. Also, excessive exposure to IR can cause damage to the cornea and the retina leading to eye disease (as cataract) [24].

The hybrid wireless medical assistance system proposal (Fig. 3) with optical WMBAN for ECG test (S1, S2, S3 - sensors for ECG) and insulin MD (IP – insulin pump, GM - glucose monitor, S – sensor) has optical wireless communication technology embedded for local data communication and rely on current RF wireless technologies for data remote transmission. This is a particular proposed system, but the idea can be generalised, embedded in other MDs.

VLC System description, topologies and optical channel evaluation

VLC uses the light intensity of a light emitting diode (LED) that is modulated by a message signal to send data from an optical Transmitter (oTx) to an optical Receiver (oRx). The light signal send by oTx propagates through the optical wireless channel and is detected by a photodiode (PD) integrated into the oRx. The PD converts the optical signal into an electrical signal that is further processed by the electronic board of the oRx. The most important characteristics of the oTx and oRx refer to the electrical modulation bandwidth, optical spectral response, patterns of both radiation and detection, LED optical power, the PDs active area, the PDs sum of noises and so on [25].

The optical channel modelling depends on the impulse response of a finite duration and the light' path loss. Path loss (dB) is linear over logarithmic distance, from 27 dB to 80 dB in case of both line-of-sight (LoS) and non-LoS communication setups [23].

The indoor light distribution for a specific setup can be determined either using geometry based deterministic models (GBDM) (recursive [26], iterative [27], ceiling bounce [28], DUSTIN [29] and ray tracing GBDM [30, 31]) or stochastic model (spherical model [32], Monte Carlo Algorithm (MCA) or modified MCA) [33, 34].

CIR describes the optical delay spread (Mean Excess Delay Spread and Root Mean Squared Delay Spread - RMS DS) in a dispersive optical wireless channel [35]. RMS DS for a LoS setup is between 1.3 ns and 12 ns and in case of a non-LoS setup, RMS DS' values are between 7 and 13 ns [23].

The value of channel RMS DS is used to compare the CIR's width and its effect on the transmission system for different configurations, therefore both h(t) and RMS DS are fixed for a certain VLC setup configuration. Measurements showed that the RMS DS's value has significant importance in the power penalty due to Inter Symbol Interference ISI [36].

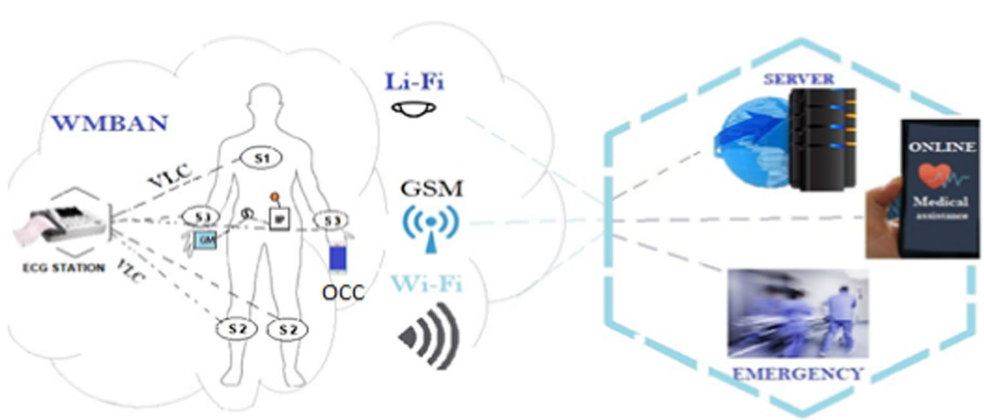

Fig. 3 Hybrid Wireless Integrated Medical Assistance System

The single-carrier pulse modulated signals such as, OOK, multi-level Pulse Position Modulation (M-PPM) and multi-level Pulse Amplitude Modulation (M-PAM) are typically applied in a VLC system, but at high speed modulation, ISI appears due to the frequency selective optical wireless channel [37]. Modified Orthogonal Frequency Division Multiplexing (OFDM) method, suitable for VLC and LiFi (purely unipolar - in frequency and time domain also) can be used with a single-tap equalizer in the frequency domain. Some appropriate solutions are: Asymmetrically Clipped Optical OFDM (ACO-OFDM) [38], DC biased optical OFDM (DCO-OFDM) [39], PAM discrete multi-tone (PAM-DMT) [40], flip-OFDM [41], unipolar OFDM (U-OFDM) [42] and so on.

Two of the most investigated light propagation setups between the oTx and oRx are LoS (Fig. 4) and NLoS (Fig. 5). In the direct LoS link, oTx and oRx are straight aligned to each other, thus this is the ideal choice topology for a point-to-point communication suitable for oTx and oRx close to each other. When a solid object is placed on the light transmission path, data communication is possible to be seriously affected or even blocked. In case that the object indoor are highly reflective, even in the non-LOS situation, some of the reflected (delayed) photons hit the active area of the PD.

The path loss of an optical wireless channel has been modelled for the first time by Bapst and Gfeller [43]. They presented an analytical model of the received optical power both for LoS (Fig. 3) and one reflection NLoS (Fig. 4) and also took into consideration, the orientation of oTx and oRx as well as orientation in the direction of the reflecting surface of a solid object.

Most of the researchers so far, investigated the VLC model with the oTx modelled according to a Lambertian radiation pattern and the oRx a Lambertian detection pattern with a specific Field of View (FOV) (Table 1).

The general form of an optical power received on the PD active area, in a diffuse single path LoS topology, is defined as a sum of the optical power received from LoS direct path (P_{LoS_dp}) and optical power received from a single reflection coming from one reflecting surface (solid object) (P_{NLoSsr}):

$$P_{LoS_{dp}} = P_{LED}\frac{m_1+1}{2\pi}cos^{m_1}(\varphi_o)\frac{A_{PD}}{d^2}\cos(\omega_i)r_{FOV}(\omega_i) \quad (1)$$

$$P_{NLoS_{sr}} = P_{LED}\frac{m_1+1}{2\pi}\int_\varphi\int_\omega cos^{m_1}(\varphi_t)\frac{\rho R(\theta_i)}{d_1^2}\frac{A_{PD}}{d_2^2}\cos(\omega_r)r_{FOV}(\varphi_t)d\varphi d\omega \quad (2)$$

where:

P_{LED} total optical power of LED;
m_1 Lambertian number of LED's radiation lobe related to LED directivity;
φ_{obs} observation angle of oTx on the direct path;
ω_{inc} incident angle of the oRx;
A_{PD} active area of the PD;
d distance between oTx and oRx on the direct path;
ρ reflexion coefficient of the reflecting object indoor according to its material's surface;
d_1 distance between oTx and the reflecting object;
d_2 distance between the reflecting object and oRx.

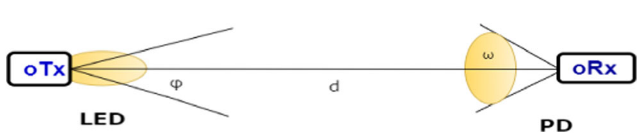

Fig. 4 A direct alignment of oTx and oRx in a LoS scenario

An ideal non-imaging concentrator (NIC) has the optical gain $g(\omega)$.

There is an inverse proportional relation between the FOV and the concentrator gain (CG): when the FOV is reduced, CG has to be increased. The DC gain of oRx in LoS scenario, a band-pass filter (Ts (ω)) and a NIC is:

$$H_{LoS} = \begin{cases} \frac{A_{PD}(m_1+1)}{2\pi d^2}\cos^{m_1}(\varphi)T_s(\omega)g(\omega)\cos\omega, & 0\le\omega\le\omega_c \\ 0, & \text{elsewhere} \end{cases} \quad (3)$$

where:

A_{PD} active area of the PD;
d distance between oTx and oRx on the direct path;
m_1 Lambertian number of LED's radiation lobe related to LED directivity (LEDs without any beam-shaping component are Lambertian sources with spatial distribution function depending on m);
Ts(ω) optical transmission of the band-pass filter;
$g(\omega)$ optical gain of the non-imaging concentrator.

CIR simulation [44, 45] for a LoS scenario, although in ideal conditions (ideal Lambertian sources and purely diffuse reflections), in a room with white walls (high reflective plaster with 0.8 reflectivity index), with a NIC and an optical band-pass filter, is presented in Fig. 6.

Following simulation, the prototype developed allows to prove the VLC technology concept and test the optical communication between oTx and oRx in conditions simulated before. Testing the prototypes (Fig. 7) with low cost off-the-shelf optical devices (PCB with 1 W cold white LED at the oTx and the PCB with VTB8440BH PD, IR filtered and optics at the oRx). Both the signals sent (up) and received at the PD (down) are shown in Fig. 8. Tests, simulation as well as analyses (though not in real conditions with many specular and mixed specular-diffuse reflections) proved to meet the quality requirements for MDs and therefore have ubiquitous availability in medical environments for fast data communication in a short range LoS topology [46].

However, two of the most important challenges regarding the optimal use of light as wireless data communication conveyor inside the medical facilities refers to the high reflectivity

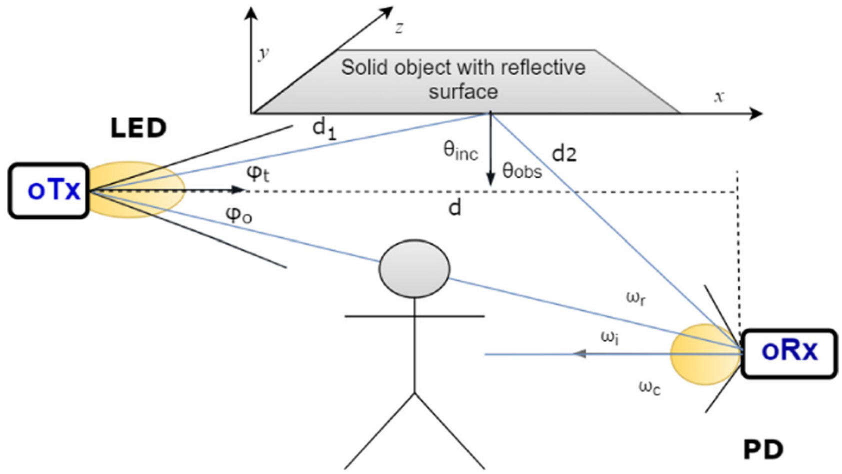

Fig. 5 A diffuse non-LoS scenario with one reflected ray considered between oTx and oRx

of objects indoor depending on their materials as well as high level of Additive White Gaussian Noises (AWGNs).

Due to interaction of photons with object made of different materials, beams of lights suffer from light absorption (when photons give energy to materials), reflection (photons of identical energy are immediately emitted by the material), transmission (photons do not interact with the material) or refraction (during transmission photons velocity is changed). Depending on the light behavior when hit the objects, materials indoor can be translucent (light is transmitted diffusely), transparent (low amount of light is absorbed and reflected) or opaque (materials absorb all the energy from the light photons). Materials into the medical facilities have predominant reflective characteristics. Most of the metallic materials, for example, are opaque but layers thinner than 0.1 μm can transmit the light. In metals, the refractive index is of 0.90–0.95, for glasses it is close to 0.05, polyethylene (plastic) is 1.52, polystyrene (plaster) is 1.60 and white paint is 2,1 [47].

As for the AWGN, it increases with the number of additional light sources (such as different illumination devices) as well as natural light. These two drawbacks result in multipath propagation, time delay, optical signal fading and path loss (PL) in medical facilities [48].

Therefore, a very complex and careful evaluation of both the objects indoor and additional light sources has to be done when different LoS or NLoS topologies for OWC setups are considered in medical facilities. In this regard, valuable contribution to LiFi reference channel models (Channel DC Gain and Mean Excess Delay Spread) for a hospital room were proposed by Uysal and Miramirkhani [49].

IR, VLC and OCC technologies embedded in WMBAN

The wireless technology mainly avoids the risk of infection or disconnection that arises from wired connections.

Conventional ECG tests can be done using 3, 4, 5 or 10 sensors, in order to provide increased detailed information of the electrical activity of the heart.

Operating in the 2.4–2.4835 GHz band, RF wireless communication platforms for ECG, maintains reliable performance but reduces sensor transmission power when data are captured and monitored by a wearable board [50].

An ECG monitoring using VLC has been tested with maximum 3% error in received signal at a distance of 2 m [51]. At the beginning of this year, a demonstration for ECG transmission using OCC has been proved as viable [52]. Also, a VLC/

Table 1 VLC System Parameters for CIR simulation

Nr.	Parameters	Symbol	M.U.	Value
1	Semi-angle of half power (see Figs. 4 and 5)	φ	0	30^0
3	Transmitted optical power by LED	Ptot	lm	80
4	Active area of PD	A_{PD}	mm^2	3,2 5.15
5	Refractive index of lens in front of PD	Index	–	1.7
6	FOV of the PD	FOV	degrees	30
7	Dimensions of space considered	L x l x h	m	3 × 4 × 2,8
8	Distance between LED and PD	d	m	1.470
9	Direct position of PD related to LED	X_T, Y_T	m	1

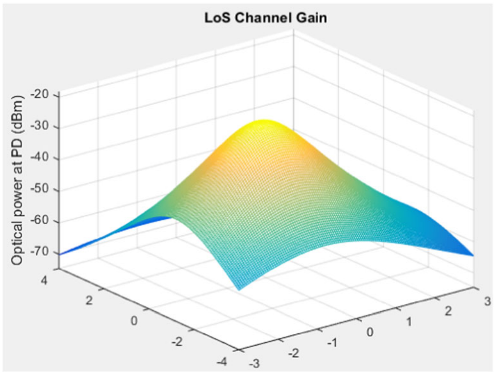

Fig. 6 Optical Power Distribution

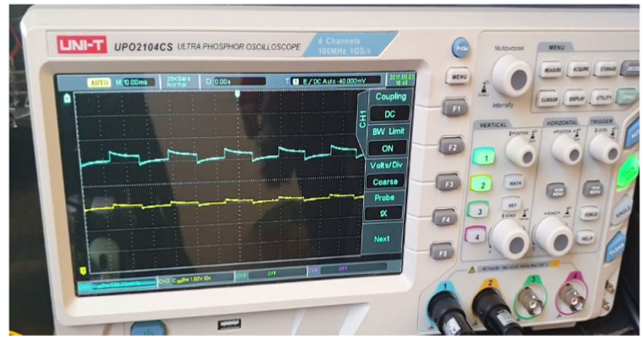

Fig. 8 Signal sent (oTx –up/blue) and received (oRx – down/yellow) at the PD

OCC hybrid optical wireless systems for versatile indoor applications are simulated and experimental results are presented and discussed in [53].

Therefore, the proposed WMBAN for the ECG system with VLC embedded, consists of optical transmission between sensors and the ECG equipment. Effectiveness of LED index modulation and non-DC biased OFDM for OWC with and array of LEDs and PDs have been demonstrated as optically power efficient [54].

Implantable medical devices (IMDs) have been subject of simulation and extended research, too. Near IR based on the spectroscopy concept refers to the IR waves penetration depth (usually 1–100 mm), therefore the glucose can be measured when the finger is pressed on the sensor button [55]. Using hybrid technologies, like optical pulses (near IR) and vibrational signals, a new technique (termed vibrational optical coherence tomography - VOCT) has been developed in order to do virtual biopsies of skin lesions by combining images made using optical coherence tomography with stiffness measurements made simultaneously using vibrational analysis [56].

Youngseok et.al propose a new type of sensor spoofing attack based on saturation using two medical infusion pumps equipped with IR drop sensors to control precisely the amount of medicine injected into a patients' body [57].

Early studies regarding transdermal optical links have been done since 1991 (neuromuscular stimulators) [58], artificial hearts as well as implanted cardiac assist devices [59]. The first duplex transdermal optical transmission system for monitoring and control an artificial heart at data rate of 9600 bps was demonstrated in 2005 [60].

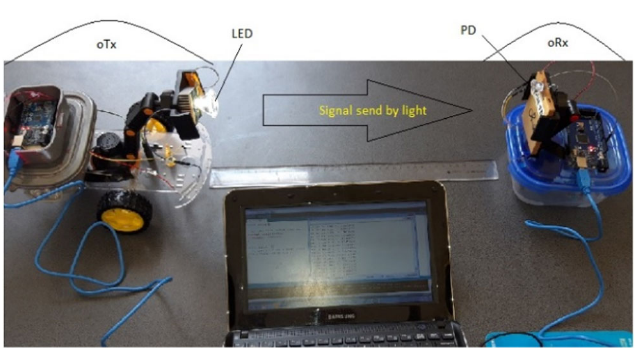

Fig. 7 VLC Prototype Developed

The optical transdermal channel model considers attenuation of the skin, the misalignment between the oTx and oRx, and the background noise. Three types of misalignment (longitudinal, lateral, and angular) have direct effect on the power level at the PD active area.

When oTx and oRx are perfectly aligned, the power at the PD on the radial direction (P_{oRx} (rd)) is defined by expression:

$$P_{oRx}(rd) = P_{oTx}(rd)\left(1 - e^{\frac{-2d}{w^2(t)}}\right) \tag{4}$$

where P_{oTx} is power of the LED, d is diameter of the PD's active area and $w(t)$ is the optical beam radius [61].

Transdermal simulations with oTx outside the body and the oRx inside, immediately under the skin showed that solar lighting as well as artificial lights highly affect the quality of the data signal and the quality of communication is acceptable for an ideal emission wavelength of 1100 nm and a skin thickness of 4 mm. Different optical communication measurements through the porcine skin, tissue and bone were made. Although the transmission intensity through bone is ≈75% less than the tissue in between, there is more than sufficient signal to obtain threshold conditions for accurate 115 Kbps optical communication with an oTx LED (880 nm, 80°) and infrared IR sensor (PIN diode with 850 nm peak sensitivity, 140°) as oRx [62].

Even though, transdermal IR communication has been demonstrated as a reliable transmission, the optical VLC is not in this moment an efficient way of collecting data for IMDs. However, due to fast technical developments, as well as intensive research on the area, the VLC short range transdermal transmission has promising future.

LiFi fast indoor data wireless communication

LiFi technology (coined by Haas in 2011 during a TED conference [63]) is a cellular wireless network that uses light from LEDs and supports multiuser access and handover in order to enable mobile services. LiFi data wireless communication is a suitable partner and in some situations viable alternative of the present RF wireless technologies indoor, such as medical facilities, taking into account that some video streaming available prototypes are ready to be launched on the market [64–66].

Conclusions

The hybrid WIMAS proposed consists of a WMBAN and a remote emergency medical assistance based on both optical and RF transmission. As has been already demonstrated, RF has adverse effects on MDs dedicated to life support, resulting in negative effects on human health, RF interference and security issues, making OWC technologies suitable alternative.

A comprehensive description of VLC, IR, OCC and LiFi optical wireless communication technologies has been done along with their advantages (lack of RF interference, safe for human and secure data communication), and drawbacks (materials with high reflectivity indoor and high AWGN) when are used in medical facilities.

LiFi is a suitable solution and reliable alternative to RF communications wireless indoor data transmission technology for WMBAN. Two different WMBAN are considered here as examples (an insulin wearable kit and an ECG test device based on VLC or OCC technologies).

VLC channel model simulation followed by a prototype designed, manufacture and tested in laboratory conditions, proved the viability of the technology and its quality requirements to be embedded into the MDs.

One potential implementation considered here refers to ECG test, consisting in VLC communication between sensors (placed on human body) and the ECG equipment with oRx embedded. The other WMBAN intended to replace the RF transmission with simplex optical transmission (IR as transdermal communication set in into insulin MD and VLC / OCC communication between insulin MD and SMU) embedded in the MD worn by patients with type 1 diabetes.

Optical transdermal communication for IMDs is addressed with practical tests made by different researchers. In order to be embedded in IMDs, the channel model (the skin optical properties) has been considered in both LoS and non LoS scenarios with longitudinal, lateral and angular misalignment and skin attenuation with additive noise have been evaluated.

All optical wireless communication technologies with already several simulations, prototypes developed, tests in different scenarios for reliable implementation in both MDs and medical facilities, have encouraging perspective into the close future.

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Compliance with Ethical Standards

Conflict of Interest Author Simona Riurean declares that she has no conflict of interest. Author Tatiana Antipova declares that she has no conflict of interest. Author Alvaro Rocha declares that he has no conflict of interest. Author Monica Leba declares that she has no conflict of interest. Author Andreea Ionica declares that she has no conflict of interest.

Ethical approval This article does not contain any studies with human participants and animals performed by any of the authors.

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