Comparative Analysis of Short-range Wireless Technologies for m-Health: Newborn Monitoring Case Study

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Keywords: Short-range, Wireless, Healthcare, mHealth, Internet of Things, WBAN, Newborn.

Abstract: The Healthcare and the Internet of Things (IoT) are being integrated to improve the people life quality in many aspects, as for example, through the increasing of the patients wellness and also optimizing Hospitals activities. One of the main actors in this integration is the communication link that connects the people to the systems, which is made in most of the cases through wireless devices. There are many available wireless technologies to be applied in a great diversity of healthcare scenarios, in which would stands out specific technologies advantages for each one. Therefore, among the great number of information about it, in this work it is detailed the physical layer characteristics of 9 most used technologies in short-range wireless applications for healthcare. Also, it is made a technology selection for one specific application scenario of newborn babies monitoring.

1 INTRODUCTION

The information and communication evolution of healthcare, as a consequence of the globalization, quick technological developments or even unexpected reality of pandemic scenarios, is called e-health. It represents a mean of improving health services access, efficiency and quality, having one of its branches called m-Health, which is basically the practice of medicine and public health supported by mobile smart healthcare wireless devices (European mHealth Hub, 2020; Watson et al., 2020; Maksimović and Vujović, 2017).

In this context, the Internet of Things (IoT) plays a key role by enabling, for example, constant medical supervision through patients remote healthcare monitoring, instead of staying in hospital for monitoring of vital signals. However, despite the IoT-based healthcare advances, there are some research challenges to be addressed in short-range wireless communications, being energy efficiency considered as one of the key concerns about it. From this energy point of view, usually the communication module draws more power than sensing or even data processing. Although the transmission power increasing eventually can improve the communication reliability, this approach does not contribute to the energy efficiency nor to the effects of radiation on human body, what is also an important factor for wireless sensors networks placed in, on or around the human body (Roy and Chowdhury, 2021).

This wireless communication in the vicinity or inside the human body are called Wireless Body Area Network (WBAN) and uses existing industrial scientific medical (ISM) bands as well as frequency bands approved by national regulatory authorities (IEEE Std 802.15.6, 2012).

A comprehensive understanding of WBAN architecture is its division into tiers. The Tier-1 which covers the intra-WBAN communication, that is, the network interaction of small-sized, low-power sensor nodes and their respective transmission ranges. The body signals are forwarded to a hub device that can act as a network coordinator of a star or mesh topology and transmit the concentrated data to the Tier-2. The Tier-2 covers the inter-WBAN communication, which is the communication between the hub in Tier-1 with a gateway at Tier-2. Here are also included eventually more patients Tier-1 communications handled by the same or others Tier-2 gateways. Finally, the Tier-3 is application-specific and essentially used to bridge the connection from Tier-2 to a database, for example, for knowledge discovery and decision-making (Movassaghi et al., 2014). The Fig-

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Crivellaro, F., Costa, A. and Vieira, P.
Comparative Analysis of Short-range Wireless Technologies for m-Health: Newborn Monitoring Case Study.
DOI: 10.5220/0010611700990106
In *Proceedings of the 18th International Conference on Wireless Networks and Mobile Systems (WINSYS 2021)*, pages 99-106
ISBN: 978-989-758-529-6

ure 1 presents this Tier approach applied to the newborn monitoring case study.

Therefore, the objective of this work is to contribute with technical discussions around the use of WBANs in healthcare through the comparison of most used Tier-1 radio technologies, and also enlightening some requirements, challenges and possible solutions for an exemplified application scenario.

1.1 Related Work

A survey on emerging IoT-based healthcare communication standards and technologies was made by (Gardašević et al., 2020), with the comparison of low-power wireless technologies. However, it is not considered the different network topologies and it is not clear about the energy efficiency analysis performed.

The short-range wireless comparative study made by (Vidakis et al., 2020) considering Bluetooth, BLE, Near Field Communication (NFC) and Wi-Fi Direct concluded that Bluetooth is the ideal candidate for the healthcare domain, when considered the transference of large medical files.

In terms of power consumption, the study made by (Thomas et al., 2016) conclude that Wi-Fi can consume less power than Bluetooth Low Energy (BLE) due to the capacity of retaining the network connections in sleep mode. However, it is not specified important configurations of the communication modules, as for example the transmission power, which has a huge impact on energy consumption.

In the study made by (Čuljak et al., 2020), the ultra-wideband (UWB) technology has not been yet adapted in everyday use and commercial devices because the relevant standards that regulate their use have appeared only recently. Also there are still being developed intensive research to overcome obstacles in the influence of random body movements and UWB antenna, for example.

The work developed by (Seferagić et al., 2020) remarks that the absence of random backoff in Bluetooth Low Energy (BLE) would increase the collision probability, decreasing the reliability and scalability of BLE mesh networks.

The review made by (Abugabah et al., 2020) identified challenging factors related to radio-frequency identification (RFID) efficient implementation, for example, the cost effectiveness, troubles with metals and liquids, difficulty in training, ethical issues related to breach of privacy and narrow channel bandwidth.

About the electromagnetic field (EMF) related to wearable devices, (Zradziński et al., 2020) suggest that emissions below 3 mW of equivalent isotropically radiated power (EIRP) from wireless communications modules may be considered environmentally insignificant EMF sources.

2 APPLICATION SCENARIO

The scenario that is being considered in this short-range wireless technology analysis comprehend the operation of multiple non-invasive sensors distributed through a WBAN, more specifically (but not exclusively), in newborns, as presented in Figure 1.

When compared to adults, newborns cannot articulate pain and uneasiness, therefore, the continuous monitoring of vital signs of newborns are very important, specially in cases of pre term or critically ill newborn (Memon et al., 2020).

So, the concept is to perform non-invasive measurements of oxygen saturation, heart rate, respiratory rate, temperature and transcutaneous bilirubin from the baby birth until at least the second day of life, or even a week in more critical cases. For hospital cases, the newborn can be monitored until discharge or even in post-discharge if necessary.

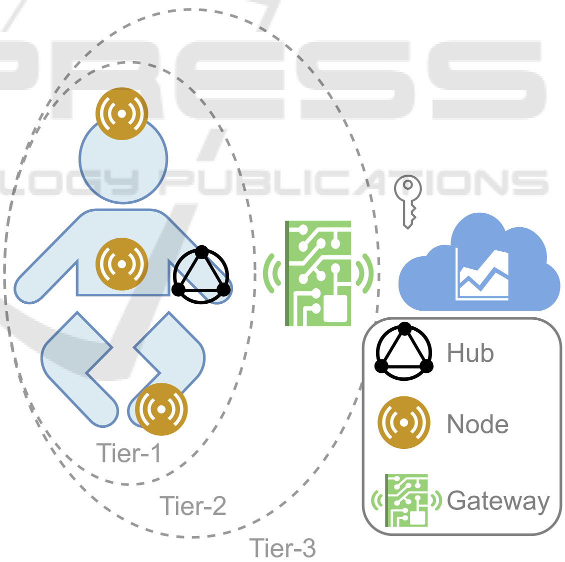

Figure 1: Example of application scenario.

The measure data is gathered by one of the sensors with the hub network role in Tier-1, which performs the interconnection with a Tier-2 gateway. In Tier-3, the network technology is highly dependent on the local of application deploy (hospital or remote monitoring at home, for example) and it is out the focus of this study. Also, it is considered in this article that security concerns are more relevant in the Tier-3 and should be addressed in a specific study applied to it.

Among the sensors measurements mentioned above, there are signals monitored in common routine procedures (respiratory rate, bilirubin) and also signals (oxygen saturation, heart rate, respiratory rate, temperature) that are normally continuously evaluated in more critically situations/environments, like pre terms in intensive care units (Chen et al., 2010).

In relation to data rate, it is estimated that the list of the above measurements could be transmitted with a period of about 2 seconds. Also, the measured data could be first evaluated in the node and then be transmitted only when significant deviations occurs. (Philip et al., 2021).

Another important point to be considered in this application is the electromagnetic risk of using wireless communication in sensors placed on the patient skin. As pointed by (Calvente et al., 2017), the fact that the newborns are at a vulnerable stage of development and the electromagnetic exposure impact on premature newborns is unknown, the use of wireless equipments in neonatal care unit environments should have a prudent avoidance strategy (Magiera and Solecka, 2020).

According to the recommendation (Ziegelberger et al., 2020) of the European Union and the International Commission on Non-ionizing Radiation Protection (ICNIRP), it is used the Specific Absorption Rate (SAR, W/Kg) measure to evaluate the human body exposition to radio frequencies. For frequencies from 10 MHz to 10 GHz, the average permissible SAR for the entire human body is 0.08 W/Kg, with specific values of 2 W/Kg for head and torso, while for limbs this value is 4 W/Kg.

3 TECHNOLOGIES COMPARISON

The objective of this comparison is to decide which short-range wireless technology best fit the more important requirements for the exemplified application scenario of healthcare.

3.1 Requirements

The requirements were summarized into 3 main concerns: patient safety, network reliability and network performance, which are detailed below.

3.1.1 Patient Safety

Considering the patient safety as the first requirement, the radio transmission power in WBANs should be the lowest power possible in order to minimize the heating of patient body tissues, while also reduces the chances of interference of signals and preserves energy. According to the study made by (Yu-nan et al., 2006), considering a body-worn Bluetooth device, the peak SAR for an antenna output of 100 mW is 2.54 W/Kg (above the 2 W/Kg required by ICNIRP). The study also suggest that the SAR levels will be lower than the safety limits for an antenna output power below 80 mW, which is considered as the limit required for this case study.

However, lowering power during transmissions can result in a poor link performance, especially for non-line-of-sight (NOL) between the communication nodes. In order to overcome this kind of issues, routing techniques as relay-based routing have been proposed in (IEEE Std 802.15.6, 2012).

3.1.2 Network Reliability

The second relevant requirement is the capacity of the network to handle the nodes distributed around the patient body. Also, the body position is of substantial importance for the WBAN network because baby sleep posture, for example, can lead to a long duration of link disconnection compared to other human postures. Therefore, the network topology should allow dynamic adaptation to keep the necessary data flowing (Vyas et al., 2021).

The number nodes depends on the hardware integration of the sensors and the satisfactory measurement locations on the body, but an estimative of around 4 nodes is considered sufficient for the above mentioned monitored signals.

In relation to the number of patients, it depends on the physical space as well as the type of patient, being considered a maximum estimative of around 8 newborn patients in the Tier-2 for this case.

3.1.3 Network Performance

Another requirement is the capacity of handle the measurement data generated by the sensors.

For the considered sensors nodes, it was firstly estimated to reach a maximum data rate of around 100 kb/s per node, which is considered a low bandwidth in comparison to a 25 lead ECG at 500 Hz being transmitted in real time, for example (Philip et al., 2021).

However, tt has to be noted that the integration of more than one measurement in the same node will need more throughput for it as well as the overall number of measurements will directly impact the Tier-1/Tier-2 link data rate. Therefore, for this case study and considering the network topology dynamic adaptation, the Tier-1 node data rate requirement is stipulated for at least 500 kb/s.

3.2 Technologies

About the technologies selection, it was found 9 main technologies that are related to WBAN and which are evaluated in this comparison. The Bluetooth/Bluetooth Low Energy (BLE) and Wi-Fi are the most used wireless technologies found in literature for smart healthcare applications, followed by ZigBee, and RFID. There are studies mentioning/comparing the use of Wi-Fi Direct, Z-Wave, Thread and UWB, which are also included in the analysis (Albahri et al., 2021; Vidakis et al., 2020; Ahad et al., 2020). Each technology features are detailed below, with special attention to the physical layer, which is the main focus of this study.

In Table 1 there is a summary of the technologies comparison for a quick evaluation of each network technology characteristics.

3.2.1 Bluetooth

The Bluetooth operation is based on its actual specification, Core v5.2, which spans from physical to application layers. Bluetooth devices operate in the unlicensed 2.4 GHz Industrial Scientific Medical (ISM) band using Adaptive Frequency Hopping (AFH) through 79 radio frequency (RF) channels of 1 MHz in order to stablish robust communications with less interference. The modulation technique is Gaussian Frequency Shift Keying (GFSK) with a mode called Basic Rate, that has a data rate of 1 Mb/s, and another called Enhanced Data Rate, with a data rate of 2 Mb/s or 3 Mb/s. The devices are classified into three power classes based on the maximum transmitter output power: class 1 (1 mW - 100 mW), class 2 (0.25 mW - 2.5 mW) and class 3 (1 µW - 1 mW) (Bluetooth SIG, 2019).

3.2.2 BLE

The BLE operation is similar to Bluetooth (ISM frequency band, AFH) and it is also based on Core v5.2 specification. However, BLE has only 40 RF channels, which are spaced by 2 MHz each other, being 3 of them used for advertising, while the other 37 are available for use during connected communication. BLE also uses GFSK modulation technique and define two modulation schemes. The 1 Msym/s modulation scheme supports a data rate of 1 Mb/s with uncoded data or 125 kb/s - 500 kb/s for coded payload. The 2 Msym/s modulation scheme supports a data rate of 2 Mb/s with uncoded data. About the transmission power, it is divided into 4 classes: class 1 (10 mW - 100 mW), class 1.5 (10 µW - 10 mW), class 2 (10 µW - 2.5 mW) and class 3 (10 µW - 1 mW) (Bluetooth SIG, 2019).

3.2.3 Wi-Fi

The Wi-Fi 6 label in a device implies that its operation is certified by the Wi-Fi CERTIFIED 6™ program, which is based on the IEEE 802.11ax standard. The Wi-Fi network operates over the 2.4 GHz, 5 GHz and also 6 GHz bands in United States (other countries worldwide regulatory bodies are taking steps to expand Wi-Fi access to the 6 GHz band). Counting with the 6 GHz band, the Wi-Fi operates over up to 59 channels of 20 MHz or 29 channels of 40 MHz or 14 channels of 80 MHz or even 3 channels of 160 MHz. The IEEE 802.11ax mandatory use of Low-Density Parity Check (LDPC) and Binary Convolutional Encoding (BCC) coding techniques, as well as Dual Carrier Modulation (DCM), contribute to the robustness enhancing of radio transmissions. With 1024-QAM as the highest modulation together , the data rate can theoretically reach up to 9.6 Gb/s considering the channel bandwidth of 160 MHz and 8 spatial stream. Considering the transmission power in Europe, the limits are 0.1 W for 2.45 GHz band and 0.2 or 1 W for devices in the 5.2 and 5.5 GHz bands respectively. On the other side, there are devices that allows decrease the transmission power until around 1 mW (Qu et al., 2018; Foster and Moulder, 2013).

3.2.4 Wi-Fi Direct

The Wi-Fi Direct, specified in Wi-Fi Direct 1.8, operates over IEEE 802.11 and has the approach of Peer-to-Peer (Pr-to-Pr) devices interconnection, without joining a traditional Wi-Fi home, office or public network. The idea is to simplify the data sharing between devices, therefore, multiple connections is an optional feature that is not supported by all Wi-Fi Direct devices. The frequency bands are 2.4 GHz and 5 GHz, not being mandatory the support for both frequency bands. (Vidakis et al., 2020; Alliance, 2020).

3.2.5 ZigBee

The ZigBee specification, ZigBee 2015, assumes the use of the physical layer defined in the IEEE 802.15.4. A compliant ZigBee device shall support one of the following options: offset quadrature shift-keying (O-QPSK) at 2.4 GHz frequency band (16 channels) or binary phase shift-keying (BPSK) at both 868 MHz (1 channel) and 915 MHz (10 channels) bands. The theoretical network size, limited by the destination address frame field, is 65535, while the network topology can be organized as star and mesh. About the

Table 1: Technologies comparative table.

Technology	Last Specification	Physical Layer	Frequency	Network Size	Topology	Data Rate	TX Power
Bluetooth	Core 5.2	Core 5.2	2.4 GHz	8	Star Pt-to-Pt	1 Mb/s to 3 Mb/s	1 µW to 100 mW
BLE	Core 5.2	Core 5.2	2.4 GHz	32000	Star Pt-to-Pt Mesh	125 Kb/s to 2 Mb/s	10 µW to 100 mW
Wi-Fi	Wi-Fi CERTIFIED 6™	IEEE 802.11ax	2.4 GHz 5 GHz 6 GHz	250	Star Pr-to-Pr	up to 9.6 Gb/s	1 mW to 1 W
Wi-Fi Direct	Wi-Fi Direct 1.8	IEEE 802.11	2.4 GHz 5 GHz	2	Star Pr-to-Pr	up to 250 Mb/s	1 mW to 100 mW
ZigBee	ZigBee 2015	IEEE 802.15.4	868 MHz 915 MHz 2.4 GHz	65535	Star Mesh	20 Kb/s to 250 Kb/s	0.5 mW to CRL*
Thread	Thread 1.2	IEEE 802.15.4	2.4 GHz	16352	Star Mesh	20 Kb/s to 250 Kb/s	0.5 mW to CRL*
UWB	WiMedia UWB Alliance FiRa	IEEE 802.15.6 802.15.4z ISO/IEC 26907	3.1 GHz to 10.6 GHz	8	Pr-to-Pr	53.3 Mb/s to 1024 Mb/s	74 nW to 15 mW
Z-Wave	Z-Wave Plus v2	ITU-T G-9959	865 MHz to 923 MHz	232	Mesh	9.6 Kb/s to 100 Kb/s	CRL-20 dB to CRL
RFID	ISO/IEC 18000	ISO/IEC 18000	120 kHz to 5.8 GHz	2	Pt-to-Pt	4 Kb/s to 848 Kb/s	1 mW to 1 W

transmission power, the maximum value shall conform with each country regulated limit (CRL) and the minimum value can reach the 0.5 mW. The standard provide a raw data rate high enough (250 kb/s) to satisfy a set of applications but is also scalable down to the needs of sensor and automation needs (20 kb/s) for wireless communications (IEEE Std 802.15.4, 2020; Zigbee Alliance, 2008).

3.2.6 Thread

Thread is a technology based on Internet Protocol (IPv6) communication, with the last specification Thread 1.2.

It also uses the IEEE 802.15.4 Physical layer specifications, operating at 250 kb/s in the 2.4 GHz. Thread devices use 6LoWPAN standard for transmission of IPv6 packets over IEEE 802.15.4 networks. The network topology can be star (only one device of type Router, which provide routing services to Thread Devices in the network) or mesh (more than one Router device). The theoretical limit in number of addressable devices in a thread network is 16352 (32 routers + 511 end devices per router). The supported channels of the 2.4 GHz frequency band are 11-26 (the same as ZigBee), with O-QPSK, while the transmission power follow the values presented for ZigBee. (Lammle, 2020).

3.2.7 UWB

The ultra-wideband (UWB) is a technology with the physical and media access control layers described in the IEEE 802.15.4 and 802.15.6 standards, defined as an antenna transmission for which emitted signal bandwidth exceeds the lesser of 500 MHz or 20 % of the arithmetic center frequency. In this scenario, the UWB Alliance and FiRa organizations are active players in the UWB operation, promotion and certification. Also, WiMedia works towards the use of UWB for wireless USB and streaming video applications. According to IEEE 802.15.6-

2012, the UWB operates through 11 channels of 500 MHz in the corresponding frequency bands of 3.25 to 4.74 GHz and 6.24 to 10.23 GHz. The UWB physical specification defines two radio operation technologies. The Impulse Radio UWB (IR-UWB), which supports the On-off keying (OOK), Differential-BPSK (DBPSK) and Differential-QPSK (DQPSK) modulation schemes. The Frequency Modulation UWB (FM-UWB), which uses Continuous Phase Binary FSK (CP-BFSK) modulation over another wideband FM modulation. The transmit power levels are in the range of about 74 nW to 1 mW, with time restrictions for the TX pulses. The wireless USB and streaming video applications runs over the UWB branch called high-rate ultra-wideband, which is specified by ISO/IEC 26907 and WiMedia 1.5. The high-rate UWB utilizes the 3.1 to 10.6 GHz spectrum divided into 14 channels of 528 MHz, uses the MultiBand Orthogonal Frequency Division Modulation (MB-OFDM) scheme to transmit information with data rates from 53.3 Mb/s until 1024 Mb/s. The transmit power range in this case is 1 to 15 mW (IEEE Std 802.15.4, 2020; Niemelä et al., 2017; Ullah et al., 2013; WiMedia Alliance, 2009).

3.2.8 Z-Wave

Extensive used in residential systems, Z-Wave operates over ITU-T G-9959 standard and Z-Wave Plus v2 specification for the upper layers. The transmit power level as well as the frequency operation in sub-1GHz is country dependent, ranging from 865 MHz to 923 MHz through one, two or three channels. The Z-Wave network operates in mesh and with a maximum of 232 nodes. The data rate is specified to a range of 9.6 kb/s to 100 kb/s, being the frequency shift keying (FSK) modulation scheme used for lower data rates, while Gaussian frequency shift keying (GFSK) is used for the 100 kb/s (ITU, 2015).

3.2.9 RFID

The radio-frequency identification RFID has 4 basic point-to-point wireless technology types, low frequency (LF) and high frequency (HF) passive, which use magnetic coupling to transfer power and data, while ultra high frequency (UHF) passive and active are based on e-field coupling. The devices specification are present along the ISO/IEC 18000 series, being the LF passive operation frequency below 135 kHz, the HF at 13.56 MHz, the UHF passive in 868 and 950 MHz and UHF active in 433 MHz and 5.8 GHz. The RFID data rates are related to the carrier frequency, ranging from 4 kb/s to 848 kb/s, while the transmit power level is between 1 mW and 1 W (Landaluce et al., 2020; Pardal and Marques, 2010).

4 DISCUSSION

Every short-range wireless technology has its own advantages and disadvantages depending on the application scenario and consequently on the requirements. Below is detailed all the requirements fulfilment and in Table 2 is presented a summary of what requirements each technology is able to achieve.

Considering the presented application scenario and the respective requirements, all the analysed technologies can reach the required level of transmitted power of 80 mW, with some of them reaching the nW or µW scale, UWB, Bluetooth and BLE, which reinforce the prudent EMF exposure strategy suggested by (Magiera and Solecka, 2020).

The network reliability, in contrast to industry scenario evaluated by (Seferagić et al., 2020), for this application scenario is highly based on the network topology, since the transmitted power is bounded by the safety constraint. Therefore, the link issues can be addressed by the two-hop extension suggested in (IEEE Std 802.15.6, 2012), by turning the terminal and intermediate nodes into the relayed and relaying nodes, while the hub into the target hub of the relayed node.

In the study made by (Di Franco et al., 2014) with ZigBee in a mesh topology, the experiments showed that the use of off-body relay scheme offers the best data reliability and network lifetime at all power levels.

The multi-hop communication is intrinsic for mesh networks, while for others topologies, like star, it is not clear. The technologies that fulfil this requirement are BLE, ZigBee, Thread and Z-Wave.

The network performance in healthcare is related to the measurements temporal dynamics and their impact on the patient wellness. For the considered application scenario, it was estimated the requirement of 500 kb/s, which is supported by Bluetooth, BLE, Wi-Fi, Wi-Fi direct, UWB and RFID.

However, if it is only sent an alarm when some measurement deviation occurs, all the technologies probably would support the demanded data rate.

Therefore, considering the overall requirements (Table 2), the BLE stands out as the best fitted short-range wireless technology for the newborn monitoring application scenario exemplified in this work.

Table 2: Fulfilment of requirements.

	Safety	Reliability	Performance
Bluetooth	✓		✓
BLE	✓	✓	✓
Wi-Fi	✓		✓
Wi-Fi Direct	✓		✓
ZigBee	✓	✓	
Thread	✓	✓	
UWB	✓		✓
Z-Wave	✓	✓	
RFID	✓		✓

5 CONCLUSIONS

The wireless technologies analysis are relevant summarized knowledge that needs to be updated periodically due to the continuous evolution of the specifications and radio devices.

In this way, this work brings physical layer details of the 9 most used short-range wireless technologies in healthcare, with the idea to contribute to the short-range wireless technology selection not only for the application scenario presented in this work, but also contribute as a reference for other application scenarios in the future.

Based on standards and scientific research, the application scenario requirements were established. These requirements were only fulfilled by the BLE technology.

Obviously that layers other than the physical one should be evaluated and it will be done in future works. Also, it has to be remembered that different protocols can be operated over the same physical layer, therefore, a detailed understanding of the physical layer needs contributes to match the right upper layers protocols for the development solution.

The next steps for this study are the layer expansion in the comparative analysis and also the implementation of the BLE network of Tier-1 with the use of multi-hoping and low transmitted power, in order to validate the best node distribution for the WBAN network of this case study.

ACKNOWLEDGEMENTS

This research leading to this result has received funding from Fundação para a Ciência e a Tecnologia (FCT) under grant PD/BDE/142935/2018.

REFERENCES

Abugabah, A., Nizamuddin, N., and Abuqabbeh, A. (2020). A review of challenges and barriers implementing RFID technology in the Healthcare sector. *Procedia Computer Science*, 170:1003–1010.

Ahad, A., Tahir, M., Sheikh, M. A., Ahmed, K. I., Mughees, A., and Numani, A. (2020). Technologies trend towards 5g network for smart health-care using iot: A review. *Sensors (Switzerland)*, 20(14):1–22.

Albahri, A. S., Alwan, J. K., Taha, Z. K., Ismail, S. F., Hamid, R. A., Zaidan, A. A., Albahri, O. S., Zaidan, B. B., Alamoodi, A. H., and Alsalem, M. A. (2021). IoT-based telemedicine for disease prevention and health promotion: State-of-the-Art. *Journal of Network and Computer Applications*, 173(July 2020):102873.

Alliance, W.-f. (2020). Wi-Fi Direct ® Specification.

Bluetooth SIG (2019). Bluetooth Core Specification v5.2. page 3256.

Calvente, I., Vázquez-Pérez, A., Fernández, M. F., Núñez, M. I., and Múñoz-Hoyos, A. (2017). Radiofrequency exposure in the Neonatal Medium Care Unit. *Environmental Research*, 152(3):66–72.

Chen, W., Oetomo, S. B., Feijs, L., Bouwstra, S., Ayoola, I., and Dols, S. (2010). Design of an integrated sensor platform for vital sign monitoring of newborn infants at Neonatal Intensive Care Units. *Journal of Healthcare Engineering*, 1(4):535–554.

Čuljak, I., Vasić, Ž. L., Mihaldinec, H., and Džapo, H. (2020). Wireless body sensor communication systems based on UWB and IBC technologies: State-of-theart and open challenges. *Sensors (Switzerland)*, 20(12):1–32.

Di Franco, F., Tinnirello, I., and Ge, Y. (2014). 1 Hop or 2 hops: Topology analysis in Body Area Network. In *2014 European Conference on Networks and Communications (EuCNC)*, pages 1–5. IEEE.

European mHealth Hub (2020). Case Study: Overview of mHealth Policies in Portugal. *WP5 – Policy and Innovation*, 1(September):1–19.

Foster, K. R. and Moulder, J. E. (2013). Wi-Fi and health: Review of current status of research. *Health Physics*, 105(6):561–575.

Gardašević, G., Katzis, K., Bajić, D., and Berbakov, L. (2020). Emerging wireless sensor networks and internet of things technologies—foundations of smart healthcare. *Sensors (Switzerland)*, 20(13):1–30.

IEEE Std 802.15.4 (2020). IEEE Standard for Low-Rate Wireless Networks. *IEEE Std 802.15.4-2020 (Revision of IEEE Std 802.15.4-2015)*, 2020:1–800.

IEEE Std 802.15.6 (2012). IEEE Standard for Local and metropolitan area networks - Part 15.6: Wireless Body Area Networks. *IEEE Std 802.15.6-2012*, pages 1–271.

ITU (2015). G.9959 : Short range narrow-band digital radiocommunication transceivers - PHY, MAC, SAR and LLC layer specifications. *ITU Recommendation*.

Lammle, T. (2020). Network Fundamentals. *CCNA Certification Study Guide*, (May):1–28.

Landaluce, H., Arjona, L., Perallos, A., Falcone, F., Angulo, I., and Muralter, F. (2020). A review of iot sensing applications and challenges using RFID and wireless sensor networks. *Sensors (Switzerland)*, 20(9):1–18.

Magiera, A. and Solecka, J. (2020). Radiofrequency electromagnetic radiation from Wi-fi and its effects on human health, in particular children and adolescents. Review. *Roczniki Panstwowego Zakladu Higieny*, 71(3):251–259.

Maksimović, M. and Vujović, V. (2017). *Internet of Things Based E-health Systems: Ideas, Expectations and Concerns*.

Memon, S. F., Memon, M., and Bhatti, S. (2020). Wearable technology for infant health monitoring: A survey. *IET Circuits, Devices and Systems*, 14(2):115–129.

Movassaghi, S., Abolhasan, M., Lipman, J., Smith, D., and Jamalipour, A. (2014). Wireless Body Area Networks: A Survey. *IEEE Communications Surveys & Tutorials*, 16(3):1658–1686.

Niemelä, V., Haapola, J., Hämäläinen, M., and Iinatti, J. (2017). An Ultra Wideband Survey: Global Regulations and Impulse Radio Research Based on Standards. *IEEE Communications Surveys and Tutorials*, 19(2):874–890.

Pardal, M. L. and Marques, J. A. (2010). Towards the internet of things: An introduction to RFID technology. *Proceedings of the 4th International Workshop on RFID Technology - Concepts, Applications, Challenges, IWRT 2010, in Conjunction with ICEIS 2010*, pages 69–78.

Philip, N. Y., Rodrigues, J. J., Wang, H., Fong, S. J., and Chen, J. (2021). Internet of Things for In-Home Health Monitoring Systems: Current Advances, Challenges and Future Directions. *IEEE Journal on Selected Areas in Communications*, 39(2):300–310.

Qu, Q., Li, B., Yang, M., Yan, Z., Yang, A., Yu, J., Gan, M., Li, Y., Yang, X., Aboul-Magd, O., Au, E., Deng, D. J., and Chen, K. C. (2018). Survey and performance evaluation of the upcoming next generation WLAN standard - IEEE 802.11ax. *arXiv*, 1:1461–1474.

Roy, S. and Chowdhury, C. (2021). Remote health monitoring protocols for IoT-enabled healthcare infrastructure. In *Healthcare Paradigms in the Internet of Things Ecosystem*, pages 163–188. Elsevier.

Seferagić, A., Famaey, J., De Poorter, E., and Hoebeke, J. (2020). Survey on wireless technology trade-offs for the industrial internet of things. *Sensors (Switzerland)*, 20(2):1–22.

Thomas, D., Wilkie, E., and Irvine, J. (2016). Comparison of Power Consumption of WiFi Inbuilt Internet of Things Device with Bluetooth Low Energy. 10(10):1693–1696.

Ullah, S., Mohaisen, M., and Alnuem, M. A. (2013). A review of IEEE 802.15.6 MAC, PHY, and security specifications.

Vidakis, K., Mavrogiorgou, A., Kiourtis, A., and Kyriazis, D. (2020). A Comparative Study of Short-Range Wireless Communication Technologies for Health Information Exchange. *2nd International Conference on Electrical, Communication and Computer Engineering, ICECCE 2020*, (June).

Vyas, A., Pal, S., and Saha, B. K. (2021). Relay-based Communications in WBANs. *ACM Computing Surveys*, 54(1):1–34.

Watson, A. R., Wah, R., and Thamman, R. (2020). The value of remote monitoring for the COVID-19 pandemic. *Telemedicine and e-Health*, 26(9):1110–1112.

WiMedia Alliance (2009). Multiband Ofdm Physical Layer Specification. (1.5):204.

Yu-nan, H., Ying-hua, L., Jin-ling, Z., and Xiao-lu, Z. (2006). The Interaction between PIFA for Bluetooth applications and a High-Fidelity Human Body Model. In *The 2006 4th Asia-Pacific Conference on Environmental Electromagnetics*, pages 331–335. IEEE.

Ziegelberger, G., Croft, R., Feychting, M., Green, A. C., Hirata, A., D'Inzeo, G., Jokela, K., Loughran, S., Marino, C., Miller, S., Oftedal, G., Okuno, T., van Rongen, E., Röösli, M., Sienkiewicz, Z., Tattersall, J., and Watanabe, S. (2020). Guidelines for Limiting Exposure to Electromagnetic Fields (100 kHz to 300 GHz). *Health Physics*, 118(5):483–524.

Zigbee Alliance (2008). Zigbee Specification. *Zigbee Alliance website*, pages 1–604.

Zradziński, P., Karpowicz, J., Gryz, K., Morzyński, L., Młyński, R., Swidziński, A., Godziszewski, K., and Ramos, V. (2020). Modelling the influence of electromagnetic field on the user of a wearable iot device used in a WSN for monitoring and reducing hazards in the work environment. *Sensors (Switzerland)*, 20(24):1–15.