Research Trends in Multi-standard Device-to-Device Communication in Wearable Wireless Networks

Muhammad Mahtab Alam[1](✉), Dhafer Ben Arbia[1,2], and Elyes Ben Hamida[1]

[1] Qatar Mobility Innovations Center (QMIC), Qatar Science and Technology Park (QSTP), PO. Box. 210531, Doha, Qatar
{mahtaba,dhafera,elyesb}@qmic.com

[2] Polytecnic School of Tunisia, SERCOM Laboratory, University of Carthage, B.P. 743, 2078 La Marsa Tunisie, La Marsa, Tunisia

Abstract. Wearable Wireless Networks (WWN) aim to provide attractive alternate for conventional medical care system. It is an effective way of monitoring patients within clinics, hospitals and remotely from home, offices etc. In this paper we extend the classical envisioned applications from medical health-care to rescue and critical applications for disaster and emergency management using WWN. There are number of challenges to effectively realize this application and several of those are presented in this paper along with various opportunities. We review multi-standard and multiple technologies based wearable wireless cognitive system for Device-to-Device (D2D) communication. Coexistence and inter-operability is one of the important challenges which are discussed along with utilization of possible technologies for on-body, body-to-body and off-body communications.

Keywords: Wearable wireless networks · Heterogeneous networks · Coexistence · Interoperability · Device to device communication · Cognitive radio

1 Introduction

With the revolution and emergence of tremendous amount of growth in various technologies, it is predicted that in the next five years there will be about fifty billion devices world-wide, which means on-an-average every person on the planet will be equipped with about six to seven devices. This massive influx of devices will deluge with huge amount of data which has to deal with disruptive technologies and powerful but smart computing. Further these devices are 'heterogeneous' which are based on multiple technologies and standards to achieve specific applications data rates, reliability and quality-of-service and so on.

In cellular networks Device-to-Device (D2D) communication exploit direct communication between nearby mobile devices to improve the spectrum utilization, overall throughput, and energy consumption, while enabling new peer-to-peer and location-based applications and services. D2D-enabled LTE devices can

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also become competitive for fallback public safety networks, which must function when cellular networks are not available or fail [1]. In additions to that, the efficient usage of frequency spectrum is very vital and therefore the role of software defined cognitive radios in the future technologies is very important [2].

In this paper we focus on one of the emerging technology called wearable to provide an additional ad-hoc network to support public safety networks for emergency management. Typically wearable body sensor networks (WBSN) consists of tiny, smart, low-power, and self-organized sensors to observe physiological signals of a human body. However in our research we extend the communication from on-body to body-to-body and off-body networks to effectively realize the applications such as rescue and critical for disaster and emergency management [3].

We address several challenges as well as opportunities for such heterogeneous wearable wireless networks (WWN). This includes standardization and compliance, effective coexistence and interoperability among multiple technologies, and how to ensure end-to-end network routing and connectivity especially in heterogeneous networks. First several WBSN applications and their requirements are discussed followed by the suitable architecture to realize wide range of applications. Second, with regards to number of different standards which are currently used for WWN, a comparative analysis and utilization of these standards are discussed. Third, several coexistence schemes are explored to ensure effective coexist among multiple technologies and the issues related to interoperability are discussed. Further, the impact of multiple technologies and standards-based applications on network, medium access control (MAC) and physical (PHY) layers are presented. Followed by the software-defined cognitive radio to coordinate and control multiple standards. Finally we present a conclusion and future research directions.

2 Applications and Architecture

Wearable technology is one of the most upcoming and emerging technology which can be seen in many dimension of daily-life as explain below. The wearable computer is defined as a mean of personal empowerment through human-computer interaction of smart devices [4]. The key characteristics of these devices are that they are always on and always available or ready for the users interaction. Unlike portable or other smart devices, wearable devices do not need to turn on and we can augment the reality of the physical world instantly and more powerfully from our surroundings as a result the intelligence can be significantly enhanced.

Wearable wireless network is an enabling ubiquitous monitoring and communication system. Typical envisioned applications range from the medical field (e.g., vital sign monitoring, automated drug delivery, etc.), to sports and fitness, entertainment and augmented reality, gaming and ambient intelligence and so on. However, with regards to applications such as disaster, rescue and critical missions, workers safety in harsh environments (e.g., oil and gas fields, refineries, petro chemical and mining industries) as well as roadside and building workers, wearable WBSN technology can also play a vital role to not only save human

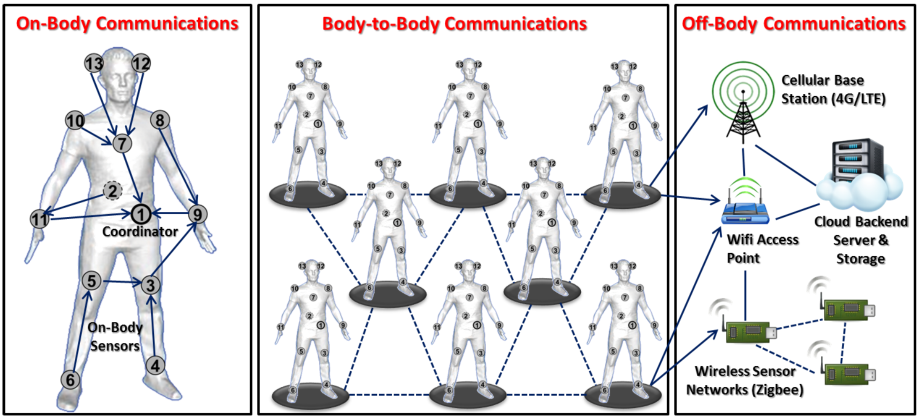


Fig. 1. A Generic Architecture for Wearable Wireless Networks.

lives but also to protect critical and valuable assets [5]. In this paper, we will emphasize on these applications as most of the other applications and their corresponding requirement can be inclusive as well.

The specific application characteristics can help to specify and confined many requirements, however, in general, there are number of parameters which can impact. For example, the devices can be only coordinators, or it can be based on the combinations of both sensors and coordinator, further, actuators can also be included. For our applications context we require all these devices, further we require various types of these devices such as source, sink, gateways and multi-standard nodes. Traffic patterns can be periodic, event driven as well as burst, which includes audio, video and data. The network can be centralized for the on-body communication and distributed for the body-to-body networks.

The generic architecture of wearable wireless networks (WWN) consists of in-body, On-Body, Body-to-Body, and off-Body communication networks as shown in Fig. 1. In-body networks is mainly based on implant devices inside the human body such as heart, kidney, ear, birth control and back pain, etc. On body often called as Wireless Body Sensor Networks (WBSN) typically contains multiple sensors (to sense the physiological signals), actuators (to react according to the perceived signal) and a coordinator which control and coordinate the other sensors (or nodes) within WBSN. Often a coordinator is much more powerful in terms of out-reach, resources and control, which can interconnect the WBSN to remote/external network infrastructures using beyond-WBSN communications (e.g., 4G/LTE/5G, Wi-Fi etc.). Therefore, we require multi-standard based D2D communication which is necessary for emergency management especially in the context where either existing infrastructure is either completely damaged or over saturated to improve end-to-end network connectivity and latency. In order to achieve this vision there are many challenges that are discussed in the following section, including coexistence and interoperability, multi-standards, cross-layer etc.

3 Key Enabling Standards and Compliance

Over the last decade, various low power standards have been used in WWN research as well as for commercial applications, where most of them partly satisfying the requirements for typical health-care related applications. These standards includes Personal Area Network (PAN) technologies, such as Bluetooth (IEEE 802.15.1) [6] and Bluetooth Low Energy (BLE) [7], Wireless Sensors Network (WSN) technologies, such as Zigbee (IEEE 802.15.4) [8], Ultra Wide Band (IEEE 802.15.4a) [9], an alternate physical layer extension to support medical body area networks (IEEE 802.15.4j) [10], and Wireless Local Area Network (WLAN) technologies, such as Wi-Fi (IEEE 802.11a/b/g/n) [11]. More recently, a specific BAN standard, i.e. IEEE 802.15.6 [12], was proposed to meet the increasing demand for WWN applications. With reference to many new and emerging applications of WWN, there is a growing need of compatibility and compliance among multiple standards.

Tab. 1 presents number of different standards and their compliance against various parameters and constraints. In particular with reference to rescue and critical applications for emergency management multiple-standards are required. For example, for on-body communication, low-power WPAN standards such as IEEE 802.15.6 is more suitable, however, it is not designed for body-to-body communication, for that matter, using IEEE 802.15.4, IEEE 802.11, 4G/LTE D2D are required which can extend the networks connectivity in an effective manner. Whereas, for off-body, one of the end-device of BBN should be able to communicate through cellular networks or infrastructure-based networks such as 4G/LTE. To conclude, existing devices, such as smartphones already supports many standards, but existing protocol stack are not smart enough to provide connectivity or routing between different network technologies and this is one of the important challenge for the future wireless networks.

4 Coexistence and Interoperability

Most of the WWN related standards and technologies operate on the same frequency ISM bands which results in significant interruption to each other. In this regard, the initial research studies on WWN interference mainly concentrate on the impact from other technologies (aka., adjacent channel interference) such as IEEE 802.11, IEEE 802.15.1, etc. It is clear from the previous research works that there is a dominant interference from other networks in WBSN [13–16]. Therefore, to coexist in harmony, certain information needs to be shared, hence interoperability is very important. In this context, coexistence strategies can be used which are often categorized as collaborative and non-collaborative. Several non-collaborative schemes are proposed in IEEE 802.15.6 standard such as beacon shifting, channel hopping and active superframe interleaving. However, the performance of all these schemes is yet to be evaluated especially in the context of heterogeneous networks. Moreover, these approaches of interference analysis are only enough for intra-BSN communication; where each node is synchronized

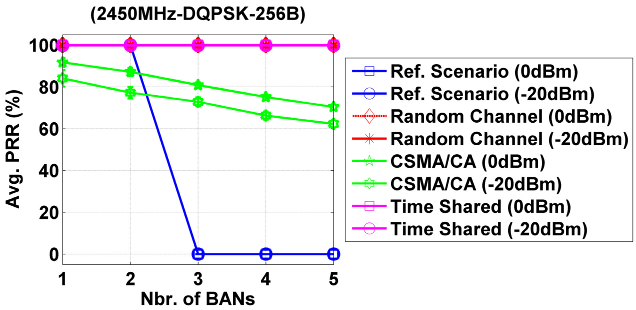
Table 1. Comparison of the Key enabling Standards for Wearable Wireless Sensor Networks.

Parameters	IEEE 802.11 a/b/g/n (Wi-Fi)	IEEE 802.15.1 (Bluetooth)	IEEE 802.15.1 (BLE)	IEEE 802.15.4 (Zigbee)	3GPP LTE/4G	IEEE 802.15.4j (MBAN)	IEEE 802.15.6 (WBAN)
Modes of Operation	Adhoc, Infrastucture	Adhoc	Adhoc	Adhoc	Infrastucture	Adhoc	Adhoc
Physical (PHY) Layers *	NB	NB	NB	NB	NB	NB	NB, UWB, HBC
Radio Frequencies (MHz)	2400, 5000	2400	2400	868/915/2400	700, 750, 800, 850, 900,1900, 1700/2100	2360-2390/2390-2400	402-405, 420-450, 863-870, 902-928, 950-956, 2360-2400, 2400-2483.5
Power Consumption	High (∼ 800mW)	Medium(∼ 100mW)	Low (∼ 10mW)	Low(∼ 60mW)	NA	Low(∼ 50mW)	Ultralow Power (∼ 1mW at 1m distance)
Maximal Signal Rate	Up to 150 Mb/s	Up to 3 Mb/s	Up to 1 Mb/s	Up to 250 Kb/s	Up to 300 Mb/s	Up to 250 Kb/s	10 Kb/s to 10 Mb/s
Communication Range	Up to 250 m (802.11n)	100 m (class 1 device)	> 100 m	Up to 75 m	Up to 100 Km	Up to 75 m	Up to 10 m
Networking Topology	Infrastructure-based	Adhoc very small networks	Adhoc very small networks	Infrastructure-based	Adhoc, Peer-to-Peer, Star, Mesh	Adhoc, Peer-to-Peer, Star	Intra-WBAN: 1 or 2-hop star. Inter-WBAN: non-standardized
Topology Size	2007 devices for structured Wi-Fi BSS	Up to 8 devices per Piconet	Up to 8 devices per Piconet	Up to 65536 devices per network	NA	Up to 65536 devices per network	Up to 256 devices per body, and up to 10 WBANs in $6m^3$
Target Applications	Data Networks	Voice Links	Healthcare, Fitness, beacon, security, etc.	Sensor Networks, home automation, etc.	Data Networks and Voice Links	Short range Medical Body Area Networks	Body Centric applications
Target BAN Architectures	Off-body	On-body	On-body	Body-to-Body, Off-Body	Body-to-Body, Off-Body	On-Body	On-Body

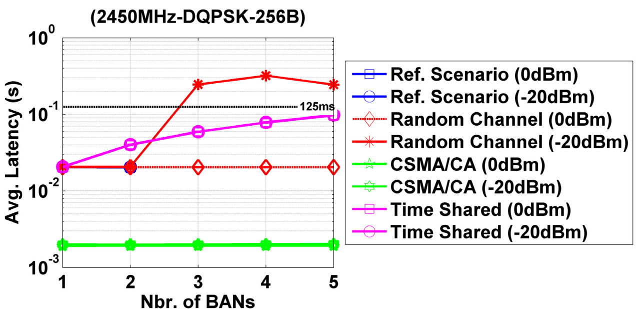
∗ NB: Narrowband, UWB: ultra Wide Band, HBC: Human Body Communication

with its coordinator and are configured at the same transmit power. However, with an advent of body-to-body communications, inter-BSN interference and its mitigation is a new problem. On the other hand, collaborative strategies are necessary for viable inter-operability (i.e., to share key information between other standards), furthermore, they can also help for inter-BSN interference. A little effort has been done so far and there are many opportunities for research in this area.

In one of our recent work [17], several coexistence (both including collaborative and non-collaborative) strategies were evaluated for body-to-body communication. IEEE 802.15.6 standard has proposed beacon shifting, channel hopping and superframe interleaving as coexistence schemes which are all considered as non-collaborative. We have considered scheduled access MAC protocol of IEEE 802.15.6 standard as a reference case (i.e., without any coexistence), then a time shared approach and channel hopping are used for comparisons. In addition to that, we also considered CSMA/CA (carrier sense multiple access/collision avoidance), which can be considered as implicitly collaborative scheme in which multiple nodes sense the channel to avoid collisions and interference. In this



(a)



(b)

Fig. 2. (a): Average packet reception ratio for multiple BANs in various coexistence schemes. (b): Average packet delay for multiple BANs under coexistence schemes.

section due to shortage of space we only presents part of our findings, though some more details can be found in [17]. As an example, we analyze the performance of average packet reception ratio (PRR) and average delay as performance metrics under varying transmission power for three coexistence schemes and one reference scenario and only one of the configurations (i.e., 2450 MHz with highest data rates or in other words differential quadrature phase shift keying modulation (DQPSK) and maximum payload size of 256 bytes) is shown in Fig. 2. These results are conducted in a packet oriented network simulator and all the detail regarding setup and configurations can be found in [17].

From the presented results, it is found that the PRR for reference scenario for 1 BSN is 94.24%, however, as the BSN increases from 2 to 3 the PRR reduces sharply to 0% and since the packets are not received at all therefore we don't have any delay values in Fig. 2-b. Whereas, it can be noticed that, both channel hopping and time-shared perform much better with PRR being above 95% even under -20 dBm, though their delay performance is not as good as PRR and especially as the number of BANs reaches 3 or more channel hopping with -20dBm does not satisfy the upper bound of latency requirements of IEEE 802.15.6 standard. The time-shared scheme is almost independent of the transmit power as far as the PRR and delay is concerned it is only dependent on the number of BANs in which latency increases linearly with increase in number of BANs. For the case of CSMA/CA, the PRR reaches to almost 80% just with 2 BANs and it continuously degrade with increase in number of BANs. With reference to its delay requirements, it fully satisfy all the constraints of IEEE 802.15.6 standard. To sum up, all coexistence schemes have pros and cons depending upon the specific configurations which can satisfy the applications requirements such as latency, PRR, energy efficiency etc., and the best scheme can be selected based on the specific constraints.

5 Cross Layer Networking Protocols

The interoperability of communication technologies in critical and public safety context is important to analyze and the impact on the upper layers in particular the routing layer needs to be investigated. A mechanism between the MAC/PHY and the routing should be in charge of reacting, switching and coexisting with multiple and simultaneous technologies. Below we will present an overview on existing investigations of heterogeneous networks with specific interest on the MAC/PHY and routing layers.

Issued in 2012, the IEEE 802.15.6 norm document details requirements for WBSN [12]. This norm covered many points in particular the communication range of the WBSN nodes, the ability to reconnect dynamically the disconnected nodes. The WWNs are supposed to gather body physical measurements and forward it to a distant monitoring system. Referring to the possible network tactical architecture [18], a BSN may interface with various network technologies mentioned in Section 4. In order to have effective BSN deployment there are several issues and challenges ranging from the hardware to the application layer. Below we will highlight some of the most important aspects for cross layers.

Physical layer must deal with unpredictable topology and network changes. Body sensors must be able to operate with wireless networks and low power [18] in such conditions. The media access control (MAC) layer needs to minimize the packets collisions and allow fair channel access. MAC protocols are also mandatory to increase network capacity, energy efficiency and guarantee a better quality-of-service (QoS). The hidden nodes phenomenon [19] for example is highly considerable, due to the NLOS (Non-Line-Of-Sight) between some nodes which can be caused by mobility and unpredictable topology changes. NLOS depends on the selection of the appropriate MAC techniques to adopt: Carrier Sense Multiplexing Access (CSMA) or Time Division Multiplexing Access (TDMA).

In higher layer, routing in WWN has to handle frequent nodes disconnections and reconnections, which will influence on the capabilities required for the routing protocols to adopt and implement. This should be ensured without causing excessive traffic overhead or computational burden on the power constrained devices [20]. To meet requirements detailed in [12], and referring to the effective networking model presented in [5], a variety of Ad hoc networks are compared in [21]. Mobile Adhoc Networks (MANETs) are the classical approach regarding the implementation of public safety networks, broadcasting communications with multi-hop communications based on reactive and proactive routing protocols. A study on the evaluation of MANETs in emergency and rescue scenario is investigated in [22]. The assessment of the MANETs routing protocols referring to the classes proactive, reactive, hybrid and hierarchical routing protocols. We will discuss first whether this class of the routing protocol is appropriate to the application of WWN or not.

Proactive routing protocols, such as Optimized Link State Routing protocol (OLSR) and Destination Sequenced Distance Vector (DSDV), exchange continuously information to keep up-to-date routes to all network nodes, and is important in case of victim's evacuation or rescue missions. However, this may affect negatively the bandwidth utilization. On the other hand, reactive routing protocols such as Ad hoc On-demand Distance Vector (AODV) and Dynamic Source Routing (DSR) are characterized by their two mechanism components: route discovery and route maintenance. The latency to initiate the communication and the delay to detect network changes exclude reactive routing protocols from tactical and rescue context. Besides these flat routing protocols are not appropriate to critical and rescue context. The hybrid and hierarchical protocols combine two or more proactive and reactive routing protocols and divide the network into zones or clusters. This leads to manage environment sectors through a cluster head which reduce the power consumption and increase network performance, e.g. Cluster Based Routing Protocol (CBRP).

For public safety networks, an ad-hoc congnitive radio (CR) based spectrum-aware routing protocol is proposed in [23]. This routing protocol comes up with the use of the white spaces spectrum resources in TVWS (Television White Space). It presents a specific adoption of ADOV routing protocol due to the unpredictable availability of the TVWS which requires a hop-by-hop routing. The contribution lies in the fact that during the route request (RREQ), the proposed routing protocol includes the TVWS availability of nodes. Each RREQ will inform about the source nodes and TVWS availability. It evaluates the performance in a specific scenario, and validate the adoption of AODV under the controlled simulation conditions [23].

Delay Tolerant Network (DTN) is a network based on nodes encountering. Where a node waits until it encounters another node to deliver the packets. Characterized by its latency, DTN is suitable for low density networks [21], but not in critical and rescue missions. All forwarding mechanisms of DTN are based on opportunistic communications where routes are built dynamically through any encountered nodes (e.g. Epidemic forwarding, PRoPHET forwarding, MaxProp and TTR) [24].

The future routing protocols, are required to consider latency, reliability, mobility, thermal-effects and energy consumption [25]. These challenges leads to the need of a cross-layer networking solution which will be in charge of selecting and calling the communication technology needed in each connection.

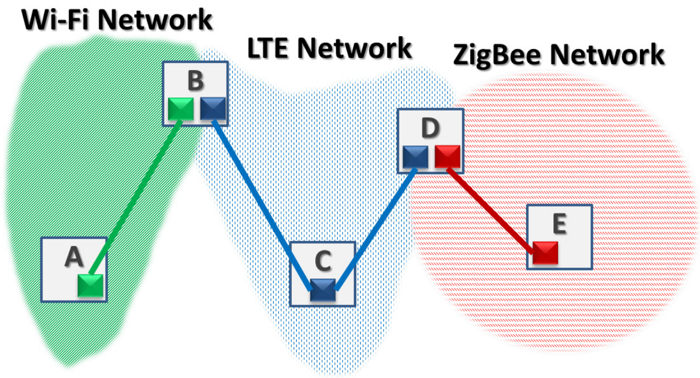


Fig. 3. Multi-Standards Compliant Heterogeneous Wearable Wireless Networks.

6 Software Defined-Based Multi-standard Cognitive Radio

The specific selection among the above presented networking protocols depends upon the specific application. An appropriate routing protocol for the WWN under the given application case, will consequently affect the selection of suitable MAC/PHY layers. Therefore, the heterogeneous technologies adoption in the communication layer is inevitable. Cognitive Radio thus is a promising technology that may fulfill the requirements, imposed by the environment of the WWN (healthcare, emergency and rescue, military, etc.) applications and then by the routing layer. Looking into the heterogeneity aspect in the communication layer, regarding the existing multiple standards (Wi-Fi 802.11, LTE/5G 802.16, ZigBee 802.15.4, Bluetooth 802.15.1, WSN 802.15.4, UWB 802.15.3a), there are many issues to investigate. For example, power consumption, which differ from one technology to another and influence the communication interface. Storage capabilities regarding the packet size and the buffering capacity that has an important role to reduce the processing overload in multiple layers. The various technologies radio range and the bandwidth support are also critical parameters that should be considered for a suitable selection of technology.

A multi-standard node uses more than one technology in communication layer and has the ability to operate with different routing protocols. This node could switch from a communication technology to another (i.e., to keep using different MAC/PHY interfaces), in some prospective conditions. For example the parameters such as, the remaining battery power, the signal strength, the unreachable destinations, the bandwidth specified by the standard may induce the node to be complemented by another available technology interface to get over these issues. In addition, several nodes may also have the ability to communicate with more than one node using different radio technologies as shown

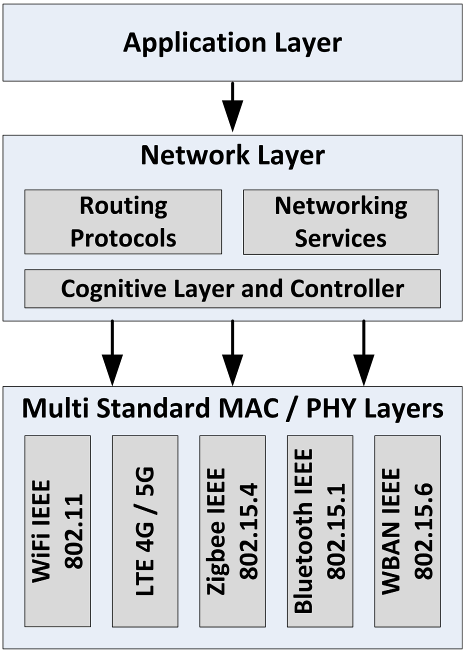


Fig. 4. Cross layer-based Cognitive Protocol Stack for WWN.

in Fig. 3 (e.g. connected to a distant node over LTE/5G interface, and with a close node over Wi-Fi interface).

The basic idea shown in Fig. 3, is that a node-A would like to communicate with a node-E, and based on the best available networks, the transmitted messages could be forwarded through the nodes-B, C and D, using different network technologies, until reaching node-E. In this particular example, node-A and node-B are using Wi-Fi connection, and since Node-E is out of reach of the Wi-Fi range of Node-B, so they are connected through LTE network (i.e., node-C and node-D). Consequently, the routing protocol in the up-layer will be adapted with the requirements imposed by the communication layer.

Fig. 4 shows the cross layer based cognitive radio controlled protocol stack for future emerging WWNs. It can be noticed that a cognitive layer is added to select the suitable technologies (i.e., multi-standards) based on the applications requirements, data rates, channel conditions, radio link quality and many other parameters. The appropriate routing and navigation is also selected based on the specific MAC/PHY technologies through cross-layer interaction.

7 Conclusion

To conclude, a wearable wireless networks is an upcoming and emerging technology. It can be applied to number of applications other than classical health-care.

In paper we emphasize in our on-going research work for rescue and critical applications. We have presented several important issues pertaining to effective realization of this specific application. In particular we have highlighted existing standards and the need to have multi-standards compliant devices. Further, coexistence and interoperability challenges and the possible solutions are explored. In this aspect, one of the key limitations (for testing various coexistence strategies), is the lack of IEEE 802.15.6 standard compliant devices. Further, a cross-layer existing state of the art is presented and the importance of cognitive radio is highlighted and how it can influence the future WWN. Finally software-defined based multi-standard cognitive radio is presented which can control, configure, select and switch between multiple technologies based on the specific requirements.

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References

1. Lin, X., Andrews, J.G., Ghosh, A., Ratasuk, R.: An overview on 3g pp. device-to-device proximity services. CoRR, vol. abs/1310.0116 (2013). http://arxiv.org/abs/1310.0116
2. Rusek, F., Persson, D., Lau, B.K., Larsson, E., Marzetta, T., Edfors, O., Tufvesson, F.: Scaling up mimo: Opportunities and challenges with very large arrays. IEEE Signal Processing Magazine **30**(1), 40–60 (2013)
3. Hamida, E.B., Alam, M.M., Maman, M., Denis, B., D'Errico, R.: Wearable body-to-body networks for critical and rescue operations the crow^2: Project. In: IEEE PIMRC 2014 - Workshop on The Convergence of Wireless Technologies for Personalized Healthcare, pp. 2145–2149, September 2014
4. U. of Toronto. Definition of wearable computer (1998). http://wearcomp.org/wearcompdef.html
5. Alam, M.M., Hamida, E.B.: Surveying wearable human assistive technology for life and safety critical applications: Standards, challenges and opportunities. Sensors **14**(5), 9153–9209 (2014)
6. IEEE standard for local and metropolitan area networks - part 15.1:-part 15.1: Wireless medium access control (MAC) and physical layer (PHY)specifications for wireless personal area networks (WPANS) (2005)
7. Bluetooth.org. Sig, bluetooth (2015). http://www.bluetooth.com/Pages/Bluetooth-Smart.aspx
8. IEEE standard for local and metropolitan area networks - part 15.4: Lowrate wireless personal area networks (LR-WPANS), pp. 1–314 (2012)
9. Amendment to 802.15.4-2006: Wireless medium access control(MAC) and physical layer (phy) specifications for low-rate wireless personal area networks (LR-WPANS) (2007)
10. Bluetooth.org. part 15.4: Low-rate wireless personal area networks (LR-WPAN) amendment 4: Alternative physical layer extension to support medical body area network (mban) services operating in the 2360 mhz 2400 mhzband (2013). http://standards.ieee.org/finndstds/standard/802.15.4j-013.html802.15.4j-2013.html

11. Wireless LAN medium access control (mac) and physical layer (phy) specifications (2012)
12. IEEE standard for local and metropolitan area networks - part 15.6: Wireless body area networks, pp. 1–271 (2012)
13. Martelli, F., Verdone, R.: Coexistence issues for wireless body area networks at 2.45 ghz. In: 18th EW Conference, pp. 1–6, April 2012
14. Davenport, D.M., Ross, F., Deb, B.: Coexistence of wban and wlan in medical environments. In: 70th VTC Conference, pp. 1–5, September 2009
15. Hayajneh, T., Almashaqbeh, G., Ullah, S., Vasilakos, A.: A survey of wireless technologies coexistence in wban: analysis and open research issues. Wireless Networks **20**(8), 2165–2199 (2014)
16. Jie, D., Smith, D.: Coexistence and interference mitigation for wireless body area networks: Improvements using on-body opportunistic relaying. CoRR, abs/1305.6992 (2013)
17. Alam, M.M., Hamida, E.B.: Interference mitigation and coexistence strategies in ieee 802.15.6 based wearable body-to-body networks. CROWNCOM 2015, LNICST **156**, pp. 1–13, 2015
18. Chen, M., Gonzalez, S., Vasilakos, A., Cao, H., Leung, V.: Body area networks: A survey. Mobile Networks and Applications **16**(2), 171–193 (2011). doi:10.1007/s11036-010-0260-8
19. Cheung, L.Y., Chia, W.Y.: Designing tactical networks perspectives from a practitioner, DSTA horizons, Tech. Rep., June 2013
20. Hoebeke, J., Moerman, I., Dhoedt, B., Demeester, P.: An overview of mobile ad hoc networks: applications and challenges. Journal of the Communications Networks **3**(3), 60–66 (2004)
21. Reina, D.G., Askalani, M., Len-Coca, J.M., Toral, S.L., Barrero, F.: A survey on ad hoc networks for disaster scenarios. In: 6th INCoS Conference, September 2014
22. Quispe, L.E., Galan, L.M.: Review: Behavior of ad hoc routing protocols, analyzed for emergency and rescue scenarios, on a real urban area. Expert Systems Applications **41**(5), 2565–2573 (2014). doi:10.1016/j.eswa.2013.10.004
23. Bourdena, A., Mastorakis, G., Pallis, E., Arvanitis, A., Kormentzas, G.: A spectrum aware routing protocol for public safety applications over cognitive radio networks. In: 2012 International Conference on Telecommunications and Multimedia (TEMU), pp. 7–12, July 2012
24. Martn-Campillo, A., Crowcroft, J., Yoneki, E., Mart, R.: Evaluating opportunistic networks in disaster scenarios. Journal of Network and Computer Applications 36(2), 870–880 (2013). http://www.sciencedirect.com/science/article/pii/S1084804512002275
25. Bangash, J.I., Abdullah, A.H., Anisi, M.H., Khan, A.W.: A survey of routing protocols in wireless body sensor networks. Sensors 14(1), 1322–1357 (2014). http://www.mdpi.com/1424-8220/14/1/1322