Homogeneous Interference Mitigation Techniques for Wireless Body Area Network Under Coexistence: A Survey

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Abstract— Wireless Body Area Network (WBAN) enables the monitoring of vital human parameters using on and in body sensor devices. IEEE 802.15.6 standard defines the medium access and physical layer characteristics for WBANs. Body area networks use the unlicensed 2.4 GHz frequency band and have very limited communication power. Communication of WBAN is affected severely by interference due to coexistence with WBANs and/or other wireless networks. Different solutions are proposed in existing literature for interference mitigation due to coexistence. To the best of our knowledge, a comprehensive survey of interference mitigation techniques especially compiled for IEEE 802.15.6 is not present. In this paper, we discuss and categorize the existing interference mitigation strategies for WBAN. Furthermore, this paper evaluates the performance of various existing strategies in terms of their mitigation capacity, communication overhead, processing overhead and energy consumption.

Keywords— *Wireless Body Area Network, Coexistence, Homogeneous, Heterogeneous, Superframe*

I. Introduction

WBAN, also known as Body area network (BAN) or Body sensor network (BSN), consists of wearable sensors that are wirelessly connected with a hub/coordinator. WBANs are responsible for intelligent and continuous monitoring of various critical signs of human body like ECG, pulse rate and Blood Pressure. The sensors are placed on and / or inside human body. These wearable sensors have small size, light weight, low power and short communication power. The hub is the network controller and is responsible for establishing and maintaining the network. A hub acts as the gateway node between the remote monitoring team/physician and the WBAN sensors [1].

WBAN has introduced a portable health care system that can remotely monitor and handle emergency situation [2]. The major use of WBAN is in hospitals and health care systems for monitoring health parameters but the use of WBAN is not only limited to e-health care systems, rather it is useful in various fields of life [3] such as entertainment, military, identification system, fitness etc. The initial implementations of WBANs were done using Bluetooth networks (IEEE 802.15.1) and later using wireless personal area network (IEEE 802.15.4). But due to the extremely resource constrained nature of WBAN devices and limited communication range, in 2012 IEEE 802.15.6 standard was released for body area network. In this paper the term WBAN refers to IEEE 802.15.6 based networks.

IEEE 802.15.6 networks can operate in different frequency bands including the unlicensed 2.4 GHz Industrial, Scientific and Medical (ISM) band. Different wireless networks like Wi-Fi and WPANs also operate in the same frequency band. When multiple wireless networks come within the radio range of each other and they interfere in each other's communication then they are said to coexist. Coexistence is defined as the ability of a system to execute the assignment, in the presence of other systems which may or may not use the same set of rules [4]. Interference is a hindrance in the transmission of a system and results in packet drops and or retransmission of packets, which can be either data packet or control packet, consequently, resulting into synchronization problems, connectivity issue of sensors with hub, decrease in throughput, increase in contention and energy wastage. In coexistence the network that is creating interference is called interferer and the network that is being interfered is called the victim network.

The coexistence between similar types of networks is known as homogeneous coexistence. Coexistence in which both the interfering networks are of different nature is heterogeneous coexistence. It is important to mention here that the coexistence of IEEE 802.15.6 based WBAN with IEEE 802.15.4 based WBAN is heterogeneous coexistence.

Interference reduction is the prime research area in WBANs [5]. Different solutions are proposed for mitigating interference in IEEE 802.15.4 based WBANs. But with release of new WBAN standard, research is more focused on solving the coexistence problem in IEEE 802.15.6 based WBAN. To the best of our knowledge no extensive study is being carried out that surveys the interference mitigation schemes of IEEE 802.15.6 based WBAN. In this paper, a comprehensive survey is presented that focuses on rendering categorization of existing coexistence mitigation strategies for IEEE 802.15.6 based WBANs. Also, we analyze each technique for interference mitigation on the basis of various network performance parameters. This research paper is organized as

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follows: Section II outlines issues of coexistence. Interference mitigation techniques are presented in section III. Homogenous coexistence mechanisms of WBAN are presented in section IV. Section V describes the heterogeneous coexistence of WBAN, while section VI concludes this research paper.

II. ISSUES OF COEXISTENCE WBANS

Low power wireless networks including WBANs make use of the license-free ISM frequency band. Among the free ISM bands 2.4 GHz is the mostly used band by different networking technologies. In the 2.4GHz, WLAN (IEEE 802.11) has a total of 13 with 3 non-overlapping channels each of 22MHz, whereas the IEEE 802.15.4 consists of 16 channels each of 2MHz and IEEE 802.15.6 has 79 channels with 1MHz each. WBAN communication suffers from homogenous as well as heterogeneous interference if some other wireless network are using the same frequency band. Table 1 shows the comparison of the wireless network standards on the basis of number of channels, bandwidth of each channel, transmission rage, transmission power and the applications of each standard in 2.4GHz frequency band.

TABLE I. COMPARISON OF THE IEEE STANDARDS [1,6-8]

IEEE Standard	Frequency Band	No. of channels	Transmission Range	Bandwidth of each channel	Transmission Power	Application
802.11b/g/n	2.4GHz	13	100m	22MHz	15 dBm or above	WLAN
802.15.1	2.4GHz	79	20m	1MHz	10 dBm	WPAN/Bluetooth
802.15.4	2.4GHz	16	10m	2MHz	0 dBm	LR-WPAN/WSN
802.15.6	2.4GHz	79	1-5m	1MHz	–10 dBm or below	WBAN

It is important to note that WBANs have the shortest communication range (1-5 meters) compared to WPAN (10 meters), Bluetooth (20 meters) and WLAN (100 meters). As a result, WBAN communication will be highly affected by WPAN and WLAN. But the impact of WBAN communication on other wireless networks is very low [9] because of its low transmission power. WBAN to WBAN interference is another issue of significance. When multiple WBANs come in the radio range of each other, they coexist and interference occurs in the communication of WBAN. For example patients equipped with WBAN come close to each other, their transmission is interfered.

Interference as result of coexistence decreases network performance and affects throughput, energy consumption, and synchronization among network devices. Interference can result in incorrect reception of packets with errors and even complete packet drops. One of the critical control packets in WBANs is beacon frames that are periodically transmitted by the hub to network devices for device association, synchronization and network management. If beacons are not correctly received new devices cannot join network and existing devices may lose network connectivity. Also, interference of data packets can result in packet drops and increased power consumption due to retransmissions.

III. MITIGATING INTERFERENCE

The IEEE 802.15.6 standard has endowed special attention for the coexistence and it has introduced three interference mitigation mechanisms consisting of channel hopping, beacon shifting and active superfarme interleaving. In channel hopping, according to pre-defined hopping sequence, a WBAN sporadically changes its operating channel but, if multiple WBANs switch to same channel, interference occurs. Frequent channel switching of constrained power sensors occur due to high interference which leads high communication overhead. Beacon shifting works in beacon enabled mode of WBAN. Beacon contains significant information such as superframe structure, network ID etc. The beacon shifting avoids collision of beacons. Beacon shifting does not prevent collision of data frame and only partially addresses the beacon collision among WBANs. A collaborative approach based on superframe interleaving for mitigating homogenous interference is also proposed by IEEE 802.15.6. This involves interfering wireless networks to completely adjust their superframe so that only one network is active in a region at a time.

Besides the techniques provided by the IEEE 802.15.6 standard for interference mitigation, a number of research efforts have been made for developing MAC protocols to solve the problem of interference occurring because of coexistence in existing literature. These efforts can broadly be categorized as homogenous and heterogeneous depending upon the nature of coexisting networks. Figure 1 shows the categorization of existing MAC protocols for interference mitigation.

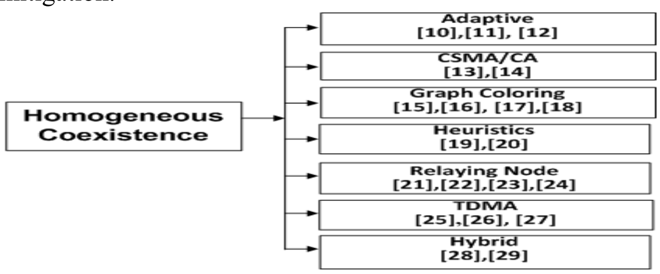

figure. 1. Categorization of interference mitigation techniques for WBAN

Comparatively, less work is done on mitigating heterogeneous interference because heterogeneous mitigation is difficult to predict and mitigate. Another important factor is that in heterogeneous networks, devices are unable to communicate with other network devices because of different physical layer structure. Also it may not be possible for a BAN hub to communicate with WLAN access point because of limited communication range. Therefore, non-collaborative approach is used for interference reduction in which network controllers only detect interference but do not communicate with each other to collectively resolve the interference. This paper focuses on the mitigation of homogeneous interference. When homogeneous networks coexist, network controllers can collaboratively mitigate interference. In collaborative approach both the interfering networks can exchange control information e.g. current channel of communication and superframe format, for better network operations.

The homogenous coexistence mechanisms proposed in existing literature [10-29] are evaluated on the basis of the following parameters:

- **Mitigation capacity**: It is the ability of a mitigation technique to partially or completely resolve interference between coexisting networks.
- **Communication Overhead**: It is an extra burden in terms of control transmissions required to collaborate with the coexisting network.
- **Processing Overhead**: It is the Processing overhead that is incurred while using various scheduling algorithms or channel hopping sequences required for mitigating interference.
- **Energy Consumption**: The battery power required by the scheme.

IV. HOMOGENEOUS COEXISTENCE IN WBAN

In the existing literature besides the coexistence mechanisms provided by IEEE standards, extensive MAC protocols have been used by researchers for mitigation of homogeneous interference. We categorized these MAC protocols for homogeneous interference alleviation of WBAN into adaptive, CSMA/CA based, graph coloring, heuristic, opportunistic relay, TDMA based and hybrid approaches. In remaining of this section the aforementioned techniques are discussed in detail. The summary of homogeneous interference mitigation techniques for WBANs is presented in table 2.

A. Adaptive Techniques

The adaptive techniques strive to reduce interference by simultaneously adjusting different non-CSMA/CA based parameters according to interference level detected within the network. We refer to the techniques [10-12] as adaptive because they attempt to adapt to network conditions. Common parameters used in existing adaptive techniques include transmission power, modulation, communication slots and duty cycle etc.

In [10] the authors propose various adaptive schemes for mitigation of interference. These schemes include adjusting modulation rate, data rate and duty cycle for WBANs according to observed interference level within the network. Although, the suggested schemes [10] are theoretically very effective but are impractical because of the complexity in implementation.

Adaptive Inter-network interference Mitigation (AIM) [11] is proposed for alleviating the homogeneous interference of WBANs. The scheme makes use of the traffic priority of nodes defined by IEEE 802.15.6 standard, the length of packet, signal strength and density of sensors in a WBAN. The proposed scheme using signal strength and density of nodes identifies interference regions that are communicated to neighboring BANs. Traffic scheduling is done to reduce interference by parallel and synchronous transmissions.

In [12] the author proposes a power control scheme that uses SINR to adjust the power level of transmissions. The adaptive power control scheme suggests that by decreasing the power levels of transmissions lesser interference is observed.

As a summary the adaptive techniques dynamically adjust different network parameters to mitigate or avoid homogenous interference. These techniques need collaboration among interfering BANs which can increase communication, energy and processing overheads.

B. CSMA/CA based Techniques

A number of interference avoidance schemes modify and fine tune contention mechanism of CSMA/CA. CSMA/CA parameters such as backoff interval, contention window and/or Clear Channel Assessment (CCA) that are available in IEEE 802.15.6 are used for interference mitigation.

In [13] the authors propose an adaptive CSMA/CA based MAC protocol to mitigate interference. Intra BAN inference is avoided using polling based medium access that is controlled by the hub. To avoid inter BAN interference each hub before polling a device in its network performs CCA followed by a random backoff. Also, the length of the super frame is dynamically adjusted among the interfering BANs for avoidance of beacon collision. The proposed scheme in [13] performs interference mitigation by making use of frequent backoffs but that decreases throughput and increases latency of communication. An approach similar to [13] is presented in [14], that avoids both intra BAN and inter BAN interference using polling and CCA, respectively. In [14] it is the responsibility of the hub to perform carrier sensing prior to polling to ensure that no other BAN is communicating.

As a summary, the CSMA/CA based techniques mitigate the homogenous interference using non-collaborative approach. The interference is partially avoided and cannot be completely evaded. In case of interference, frequent backoffs take place which results in high energy consumption which degrades network performance. The communication and processing overhead of aforementioned schemes is low due to simplicity of these techniques.

C. Graph Coloring Techniques

In graph coloring, the WBANs are represented by nodes and channel resources (e.g. time slot, frequency bands) are presented by the color of the graph. The edge between two nodes of the graph means neighborhood (coexistence) of the WBANs. In this technique, the adjacent WBANs are assigned different colors (different channels) to avoid interference. Graph coloring is focus of researchers for interference mitigation for WBAN because it allocates different communication links to coexisting WBANs.

In [15] the authors suggest Random Incomplete Coloring (RIC) for mobile WBANs to achieve high spatial reuse and low time complexity. Two channels both working on TDMA are used, one for intra-WBAN and the other for inter-WBAN communication. Initially, the WBAN uses graph coloring to calculate the slots and communicate this to neighbor WBANs by using the inter-WBAN channel. The intra-WBAN channel is then used by sensors of the WBAN to transfer critical data in time slots assigned by their respective hubs. The graph coloring is repeated for every beacon period.

In [16] the author mitigates interference of WBANs by combining graph coloring with collaborative scheduling. Each WBAN forms a pair with its coexisting WBAN. When a hub receives communication signal from sensor of other WBAN then that sensor is included in the interference set. Graph coloring algorithm is adapted to allocate time slots to interference free sensors and the interfering sensors are then assigned orthogonal channels.

The WBAN Distributed Coloring algorithm (WBAN-DC) is employed by hub for conflict free scheduling in [17]. Each sensor transmits required number of communication slots to its respective hub. Each WBAN implements the coloring algorithm and informs neighbor WBANs of its total communication slots. Thus, the interference sketch of the interfering nodes is available at each hub among the coexisting WBANs. However, WBAN-DC does not accommodate variations in the interference patterns due to mobility.

In [18] the authors propose a graph coloring to solve the homogeneous coexistence of WBANs, which consists of two phases called initial graph coloring and multi graph coloring. In the first phase, a hub randomly selects channel and priority and informs all its coexisting hubs. In second phase, each WBAN uses free channel that are not being interfered by other WBANS. In case of conflict when two WBANs select the same channel, then the WBAN with low priority change its channel. Thus interference is resolved. Although the protocol is useful in reducing interference among coexisting WBANs, but this technique cannot accommodate topological changes and becomes impracticable. Also the number of colors is limited.

As a summary, the graph coloring techniques perform homogenous interference avoidance and mitigation using collaborative approach. These algorithms are not suitable to dynamically changing network topologies as they consider static networks with less interference. These techniques have high processing overhead as they implement graph coloring algorithms but at the same time can resolve homogenous interference efficiently.

D. Heuristics Techniques

A heuristic is a technique designed to find approximate solution when classic methods fail to find any exact solution for an NP-Complete problem more quickly when classic methods are too slow. Heuristic is applied to solve the interference mitigation problem. Heuristic does not guarantee complete interference mitigation (global solution) but still escort to partial interference mitigation. Heuristic used by various researchers as interference mitigation mechanisms.

In [19] interference among homogeneous WBANs is modeled using non-linear programming and fairness in medium access is provided. Fairness-based Throughput Maximization Heuristic (FTMH) [19] algorithm is proposed that maximizes the throughput under coexistence. The super frame is divided into time slots and one sensor is assigned one time slots for data transmission. The ratio for success of medium access for each sensor is calculated. Also the interference on each time slot is measured. The sensor with highest success medium access ratio is allotted the time slot with highest interference. The author concludes that FTMH improves throughput while keeping fairness among WBANs.

In [20] the author mitigates the interference using a game theory based algorithm. The work proposes a distributed power control algorithm using a non-collaborative approach. The proposed scheme makes efficient use of transmission power and performs partial interference mitigation (Nash Equilibrium) by reducing the radio range. The proposed scheme increases throughput by utilizing minimum radio range.

As a summary the heuristic techniques perform mitigation of homogenous interference. These techniques are non-collaborative and seek for partial interference mitigation (local optimal) therefore can only partially mitigate interference. Also, heuristic techniques are computationally expensive and therefore, have high overhead.

E. *Relaying node Techniques*

These techniques decrease the range of communication in order to avoid interference with neighbor networks. As a result relaying nodes are used to forward information from a device that is at a considerable distance from hub. Therefore, relaying node techniques decrease range of communication below the allowed transmission range in the IEEE 802.15.6 standard.

In [21] the authors investigate the mitigation of high interference of wireless networks on the WBAN. Opportunistic relaying (OR) along with cooperative two-hop relaying node communication scheme, is applied within a mobile WBAN for alleviation of interference. Results render that the Signal-to-Interference-plus-Noise Ratio (SINR) is improved by an outage probability of 10% and level crossing rate (LCR) is significantly reduced at low SINR.

In [22] the authors mitigate the homogeneous interference of WBANs by combining the transmit power control with the two-hop relay selection. The two-hop relay is utilized for cooperative communication. The sensor node before transmission compares the power of the relaying nodes. The power of the sensor is adjusted as required. The results prove improvement in SINR outage probability and power consumption.

Corporative communication using decode-and-forward technique is presented in [23]. The sensors forward packets to relaying nodes which decode and then hand over to hub. The relayed packets are collected at hub by applying selection combining and maximum ratio combining. The selection combining is used to select the strongest signal among all the received signals and maximum ratio combining is used to find the sum of SNR of the received signals. The outage probability and average fade duration are used for performance evaluation and result renders that the performance of BAN is improved.

In [24] the author proposes a model in which node can have direct link as well as a relayed link via some relaying node. Nodes dynamically select the forwarding path based on the SINR of the link. Hence this scheme dynamically selects between direct and relayed communication depending on interference level of previous communication.

As a summary the relaying node techniques require collaboration among network devices for interference mitigation. Also these techniques can partially mitigate interference because reducing communication range does not guarantee mitigation of interference. Another important factor is that overall energy consumption is increased because a single transmission is split into two transmissions due to relaying node.

F. TDMA based Techniques

Some researchers utilize TDMA to alleviate interference. In TDMA the channel is divided into time slots and different interfering WBANs are assigned different time slots so that the WBANs transmissions are interference free.

In [25] a shared and non-conflict scheduling technique for mitigating interference of WBANs using TDMA approach is proposed. The hub of WBAN, continuously observe the inference strength of the received packets and then exchange among the coexisting WBANs. If the value exceeds above a network defined threshold, it assumes the coexistence with other WBANs and then non-conflicting time slots are assigned to interfering WBANs to mitigate interference.

In [26] the hubs of interfering and interfered WBANs coordinate to build up a TDMA schedule to alleviate interference. The work assumes that number of interfering networks is known and they communicate with each other to inform about the interfering nodes. A global TDMA based schedule is generated for all the WBANs in which initial slots are given to nodes facing more interference during their communication. The scheme [26] results in high network performance and low packet drop rate. But it requires prior knowledge of interfering networks and requires strong collaboration among coexisting WBANs.

In [27] an adaptive channel allocation technique is proposed for decreasing homogeneous interference among WBANs. In this technique, each coexisting WBAN creates and broadcast a table of the coexisting nodes to inform its neighbor WBANs, about the interfering nodes in vicinity. These interfering nodes are assigned orthogonal channels, whereas non-interfering nodes are allowed to communicate in the same channel using TDMA. The proposed scheme increases the channel reuse but it does not mitigate interference of hub and only handles interference at sensor.

As a summary the TDMA based techniques are collaborative for mitigate homogenous interference. The interference is completely mitigated as each coexisting WBAN is allocated specific time slots. The energy consumption is low but the communication overhead is high due to allocation of time slots to WBANS, synchronization.

G. Hybrid Techniques

In hybrid, different aforementioned interference mitigation techniques are combined such as CSMA/CA and TDMA based interference mitigation schemes. The jointly use of different schemes improve the process of interference mitigation.

In [28] a novel technique for interference mitigation among coexisting WBANs is proposed. This work accumulates the benefits of both CSMA/CA and TDMA methods. The super frame comprises of beacon, Scheduling Phase (SP) and CAP. TDMA is used in SP and CSMA/CA is used in CAP to use channel. The SP and CAP are dynamically adjusted according to the interference.

In [29], the author proposes a Bayesian game based power control along with heuristic for alleviating the affect of homogeneous interference. The work models the WBANs communication using Bayesian game model. Power control technique is used to calculate the expected low interference. Then make use of a harmonic mean based heuristic to perform partial interference mitigation.

As a summary, the hybrid techniques do not require collaboration among WBANs for mitigation of homogenous interference. But these techniques cannot completely mitigate interference and have high energy consumption and overhead due to use of CSMA/CA in [28] and heuristic in [29].

TABLE II. HOMOGENEOUS INTERFERENCE MITIGATION TECHNIQUES FOR IEEE 802.15.6 WBAN

Technique	Approach	Strategy	Mitigation capacity	Communication Overhead	Processing Overhead	Energy Consumption
Adaptive techniques [10-12]	Non-Collaborative	Mitigation	Partial	High	High	Low
	Collaborative	Avoidance	Complete	High	High	High
	Collaborative	mitigation	Partial	High	Low	Low
CSMA/CA based Techniques [13-14]	Non-Collaborative	Mitigation	Partial	Low	Low	High
	Non-Collaborative	Mitigation	Partial	Low	Low	Low
Graph coloring techniques [15-18]	Collaborative	avoidance	Complete	High	High	High
	Collaborative	mitigation	Complete	High	Low	Low
	Collaborative	Avoidance	partial	High	Low	Low
	Collaborative	mitigation	partial	Low	Low	High
Heuristic techniques [19-20]	Non-Collaborative	Mitigation	partial	High	High	High
	Non-Collaborative	Mitigation	partial	High	High	Low
Relaying node Techniques [21-24]	Collaborative	mitigation	partial	High	High	High
	Collaborative	mitigation	partial	High	High	High
	Collaborative	mitigation	partial	High	High	High
	Collaborative	mitigation	partial	High	High	High
TDMA based techniques [25- 27]	Collaborative	Mitigation	Complete	Low	High	Low
	Collaborative	Mitigation	Complete	High	High	Low
	Collaborative	Avoidance	Complete	High	High	High
Hybrid techniques [28-29]	Non-Collaborative	Mitigation	Partial	High	High	High
	Non-Collaborative	Mitigation	Partial	High	High	Low

V. CONCLUSION

The issue of homogenous coexistence in IEEE 802.15.6 based WBAN is studied in this work. Existing MAC based protocols for mitigating interference due to coexistence are categorized. Merits and demerits of various approaches for interference mitigation are presented. It can be concluded that most of the work focuses on mitigating homogeneous coexistence using both collaborative and non-collaborative approaches. Collaborative approaches can provide better interference mitigation but require extra communication overhead for collaboration. On the other hand, non-collaborative approaches have less communication and processing overhead but can partially mitigate interference. So new approaches are required to mitigate both homogeneous interference of IEEE 802.15.6 based WBAN to yield high throughput with less delay and energy consumption. The heterogeneous coexistence of IEEE 802.15.6 with other wireless networks is an open and challenging research problem that has not yet received due attention of researchers.

REFRENCES

[1] IEEE Std 802.15.6-2012. http://standards.ieee.org/findstds/standard/802.15.6-2012.html (2012).

[2] Jovanov, E., Milenkovic, A., Otto, C., and de Groen, P., A Wireless body area network of intelligent motion sensors for computer assisted physical rehabilitation. JNER 2(6):16–23, 2005.

[3] R. Kohno, K. Hamaguchi, H.-B. Li, and K. Takizawa, “R&D and standardization of body area network (BAN) for medical healthcare,” in Ultra-Wideband, 2008. ICUWB 2008. IEEE International Conference on, vol. 3, Sept 2008, pp. 5–8.

[4] IEEE 802.15.2 definition of coexistence, http://grouper.ieee.org/groups/802/15/pub/2000/Sep00/99134r2P802-15_TG2-CoexistenceInteroperabilityandOtherTerms.ppt.

[5] Hayajneh, Thaier, et al. "A survey of wireless technologies coexistence in WBAN: analysis and open research issues." Wireless Networks 20.8 (2014): 2165-2199.

[6] EEE Std 802.11-1997. http://standards.ieee.org/findstds/standard/802.11-1997.html (1997)

[7] Bluetooth low energy technology. http://www.bluetooth.com/Pages/low-energy-tech-info.aspx..

[8] IEEE Std 802.15.4-2006. http://standards.ieee.org/findstds/standard/802.15.4-2006.html (2006).

[9] Pollin, Sofie, et al. "Harmful coexistence between 802.15. 4 and 802.11: A measurement-based study." Cognitive Radio Oriented Wireless Networks and Communications, 2008.CrownCom 2008. 3rd International Conference on. IEEE, 2008.

[10] Yang, Wen-Bin, and Kamran Sayrafian-Pour. "Interference mitigation using adaptive schemes in body area networks." International Journal of Wireless Information Networks 19.3 (2012): 193-200.

[11] Movassaghi, Samaneh, et al. "AIM: Adaptive Internetwork interference mitigation amongst co-existing wireless body area networks." Global Communications Conference (GLOBECOM), 2014 IEEE. IEEE, 2014

[12] Changbiao Xu, Li Zhang, Yongdan Yang ua, "Centralized Inter-network Power Control Scheme in Wireless Body Area Network." Journal of Information & Computational Science 12:8 (2015) 3311–3318

[13] Chen, Guan-Tsang, Wen-Tsuen Chen, and Shan-Hsiang Shen. "2L-MAC: A MAC protocol with two-layer interference mitigation in wireless body area networks for medical applications." Communications (ICC), 2014 IEEE International Conference on. IEEE, 2014

[14] Huang, Wen, and Tony QS Quek. "Adaptive CSMA/CA MAC protocol to reduce inter-WBAN interference for wireless body area networks." Wearable and Implantable Body Sensor Networks (BSN), 2015 IEEE 12th International Conference on. IEEE, 2015

[15] Cheng, Shih Heng, and Ching Yao Huang. "Coloring-based inter-WBAN scheduling for mobile wireless body area networks." Parallel and Distributed Systems, IEEE Transactions on 24.2 (2013): 250-259

[16] Movassaghi, Samaneh, Mehran Abolhasan, and David Smith. "Cooperative scheduling with graph coloring for interference mitigation in wireless body area networks." Wireless Communications and Networking Conference (WCNC), 2014 IEEE. IEEE, 2014

[17] Huang, Wen, and Tony QS Quek. "On constructing interference free schedule for coexisting wireless body area networks using distributed coloring algorithm." Wearable and Implantable Body Sensor Networks (BSN), 2015 IEEE 12th International Conference on. IEEE, 2015.

[18] Lee, Jieun, BeomSeok Kim, and Jinsung Cho. "A distributed multi-coloring algorithm for coexistence mitigation in WBANs." Proceedings of the 9th International Conference on Ubiquitous Information Management and Communication. ACM, 2015.

[19] Li, Ming, et al. "Throughput optimization with fairness consideration for coexisting WBANs." Communications (ICC), 2015 IEEE International Conference on. IEEE, 2015

[20] Dakun, Du, et al. "A game theoretic approach for inter-network interference mitigation in wireless body area networks." Communications, China 12.9 (2015): 150-161

[21] Dong, Jie, and David Smith. "Opportunistic relaying in wireless body area networks: Coexistence performance." Communications (ICC), 2013 IEEE International Conference on. IEEE, 2013

[22] Dong, Jie, and David Smith. "Joint relay selection and transmit power control for wireless body area networks coexistence." Communications (ICC), 2014 IEEE International Conference on. IEEE, 2014.

[23] Smith, David B., and Dino Miniutti. "Cooperative body-area-communications: First and second-order statistics with decode-and-forward." Wireless Communications and Networking Conference (WCNC), 2012 IEEE. IEEE, 2012.

[24] Dong, Jie, and David Smith. "Coexistence and Interference Mitigation for Wireless Body Area Networks: Improvements using On-Body Opportunistic Relaying." arXiv preprint arXiv:1305.6992 (2013)

[25] Mahapatro, Judhistir, et al. "Interference-aware MAC scheduling and admission control for multiple mobile WBANs used in healthcare monitoring."International Journal of Communication Systems 28.7 (2015): 1352-1366

[26] Jamthe, Anagha, and Dharma P. Agrawal. "Scheduling Transmissions of Coexisting Wireless Body Area Networks Using Minimum Weight Match."Proceedings of Ninth International Conference on Wireless Communication and Sensor Networks. Springer India, 2014

[27] Movassaghi, Samaneh, Mehran Abolhasan, and David Smith. "Smart spectrum allocation for interference mitigation in wireless body area networks. " Communications (ICC), 2014 IEEE International Conference on. IEEE, 2014.

[28] Yuan, Bin, et al. "DIM: A novel decentralized interference mitigation scheme in WBAN." Wireless Communications & Signal Processing (WCSP), 2015 International Conference on. IEEE, 2015

[29] Zou, Lei, et al. "Bayesian game based power control scheme for inter-WBAN interference mitigation." Global Communications Conference (GLOBECOM), 2014 IEEE. IEEE, 2014.