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Editorial

Special Issue on Body Area Networks

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Wireless body area networks (WBANs) are a fascinating research field offering wearable and implantable sensor technology [1–13], communications and platforms [14–21] that are revolutionizing healthcare, quality of life and interactions between physicians and patients. A WBAN is realized through the integration of different nodes (sensors and actuators) relying on different communication technologies (wired, wireless and human body communication [22–30]) to allow interconnection under skin, over skin, when embedded in clothes and in portable devices, to provide both managed and autonomous applications [31–36]. Usually, WBANs are not confined to the human body. Gateways, networks and cloud technology [37] extend the number of applications a WBAN can offer and support. One example of such applications is (remote) healthcare [38–43], where WBANs are considered a key technology to help facing the side effects of an aging population on healthcare systems and society in general.

This special issue is devoted to collecting contributions from researchers on the realization of real-world and reliable wireless body area networks, platforms and applications, addressing the major associated challenges. Nine papers have been selected for this special issue, beginning with a paper [44] that gives the reader a general overview of the WBAN research field and highlights its main features and requirements, sensor types and contributions to healthcare, concluding with the main current challenges. The other eight research papers are segmented into three main application areas: energy harvesting, communications and applications in the research field of wireless body area networks.

Energy harvesting: Under the assumption that a single energy harvester from a human body is not enough to reliably drive an electronic device, Sung-Eun et al. [45] propose energy harvesting by combining multiple energy harvesters in wireless body area network applications. An efficient 0.13-µm TSMC Complementary metal–oxide–semiconductor (CMOS) energy management and distributing circuit is defined that is able to combine up to three sources of harvested energy and is suitable for autonomous WBANs, with a special focus on implantable devices for which it is very difficult to maintain a battery.

Communications: This special issue addresses the three physical layers defined by the Institute of Electrical and Electronics Engineers (IEEE) 802.15.6 standard. Yamamoto et al. [46] focused on the human body communication (HBC) physical layer to better understand its basic signal transmission paths when relying on one-electrode and two-electrode transmitters. In terms of off-body communications, Cwalina, Ambroziak and Rajchowski [47] present a study of system loss for both 868-MHz narrow band

and 6489-MHz ultra-wide band radio channels in a very harsh environment is conducted, as opposed to the majority of currently designed WBANs which are focused in indoor environments. Additionally, Cwalina et al. [48] describe a novel adaptive method for data stream allocation to increase the available time-frequency resource usage in heterogeneous WBANs with dual radio interfaces (narrow band and ultra-wide band). The communications application area ends with the proposal of an enhanced temperature-aware routing protocol, with efficient mobility, that is based on a multi-criteria decision making method. The authors suggest this as a new option to deal with the challenge of rises in node temperatures (hot spot regions) in WBANs [49].

Applications: Chen et al. [50] describe a novel lossless electroencephalography (EEG) compression Very-Large-Scale Integration (VLSI) circuit to increase both efficiency and effectivity of EEG signal transmission over WBANs with very promising results. Park et al. [51] present technology for low-power high data-rate digital capsule endoscopy with human body communication. This special issue ends with the presentation of a novel method based on an ensemble of heterogeneous classifiers that is able to recognize static, dynamic and transitional user activities [52].

In summary, this special issue includes a series of excellent research papers on body area networks, covering three important application areas.

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References

1. Mosenia, A.; Sur-Kolay, S.; Raghunathan, A.; Jha, N. Wearable medical sensor-based system design: A survey. *IEEE Trans. Multi Scale Comput. Syst.* **2017**, *3*, 124–138. [CrossRef]
2. Guanglou, Z.; Shankaran, R.; Yang, W.; Valli, C.; Qiao, L.; Orgun, M.; Mukhopadhyay, S. A critical analysis of ECG-based key distribution for securing wearable and implantable medical devices. *IEEE Sens. J.* **2018**, *19*, 1186–1198. [CrossRef]
3. Majumder, S.; Mondal, T.; Deen, M.J. Wearable sensors for remote health monitoring. *Sensors* **2017**, *17*, 130. [CrossRef] [PubMed]
4. Wang, H.; Wen, Y.; Zhao, D. Location verification algorithm of wearable sensors for wireless body area networks. *Technol. Health Care* **2018**, *26*, 3–18. [CrossRef]
5. Chao, L.; Zhenjiang, Z.; Fei, X.; Qing, L. An efficient and stable route protocol in wearable body networks. In Proceedings of the 2015 First International Conference on Computational Intelligence Theory, Systems and Applications (CCITSA), Yilan, Taiwan, 10–12 December 2015; pp. 104–109. [CrossRef]
6. Leu, F.; Ko, C.; You, I.; Choo, K.; Ho, C. A smartphone-based wearable sensors for monitoring real-time physiological data. *Comput. Electr. Eng.* **2017**, *65*, 376–392. [CrossRef]
7. Gholami, M.; Rezaei, A.; Cuthbert, T.J.; Napier, C.; Menon, C. Lower body kinematics monitoring in running using fabric-based wearable sensors and deep convolutional neural networks. *Sensors* **2019**, *19*, 5325. [CrossRef]
8. Jiang, P.; Winkley, J.; Munnoch, R.; Min, G.; Yang, L. An intelligent information forwarder for healthcare big data systems with distributed wearable sensors. *IEEE Syst. J.* **2014**, *10*, 1147–1159. [CrossRef]
9. Li, J.; Liu, Y.; Nie, Z.; Qin, W.; Pang, Z.; Wang, L. An approach to biometric verification based on human body communication in wearable devices. *Sensors* **2017**, *17*, 125. [CrossRef]
10. Chen, C.-M.; Xiang, B.; Wu, T.-Y.; Wang, K.-H. An anonymous mutual authenticated key agreement scheme for wearable sensors in wireless body area networks. *Appl. Sci.* **2018**, *8*, 1074. [CrossRef]
11. Antolín, D.; Medrano, N.; Calvo, B.; Pérez, F. A wearable wireless sensor network for indoor smart environment monitoring in safety applications. *Sensors* **2017**, *17*, 365. [CrossRef]

12. Belmonte-Fernández, Ó.; Puertas-Cabedo, A.; Torres-Sospedra, J.; Montoliu-Colás, R.; Trilles-Oliver, S. An indoor positioning system based on wearables for ambient-assisted living. *Sensors* **2017**, *17*, 36. [CrossRef] [PubMed]
13. Guo, A.; Ma, J. Context-Aware scheduling in personal data collection from multiple wearable devices. *IEEE Access* **2017**, *5*, 2602–2614. [CrossRef]
14. Song, X.; Wen, T.; Sun, W.; Zhang, D.; Guo, Q.; Zhang, Q. A coverage-aware unequal clustering protocol with load separation for ambient assisted living based on wireless sensor networks. *China Commun.* **2016**, *13*, 47–55. [CrossRef]
15. Poncela, A.; Coslado, F.; García, B. Smart care home system: A platform for eAssistance. *J. Ambient Intell. Hum. Comput.* **2019**, *10*, 3997–4021. [CrossRef]
16. Filho, R.; Neto, R.; Junior, I. A body sensor network simulation platform for medical applications. *IEEE Lat. Am. Trans.* **2016**, *14*, 1835–1841. [CrossRef]
17. Huang, X.; Gao, X.; Yan, Z. Security protocols in body sensor networks using visible light communications. *Int. J. Commun. Syst.* **2015**, *29*, 2349–2363. [CrossRef]
18. Bou Dargham, N.; Makhoul, A.; Bou Abdo, J.; Demerjian, J.; Guyeux, C. Efficient hybrid emergency aware mac protocol for wireless body sensor networks. *Sensors* **2018**, *18*, 3572. [CrossRef]
19. Zhang, C.; Wang, Y.; Liang, Y.; Shu, M.; Chen, C. An energy-efficient mac protocol for medical emergency monitoring body sensor networks. *Sensors* **2016**, *16*, 385. [CrossRef]
20. Magno, M.; Polonelli, T.; Casamassima, F.; Gomez, A.; Farella, E.; Benini, L. Energy-Efficient context aware power management with asynchronous protocol for body sensor network. *Mob. Netw. Appl.* **2016**, *22*, 814–824. [CrossRef]
21. Yu, D.; Kim, N. An efficient low-power MAC protocol for wireless body sensor networks. *Int. J. Future Gener. Commun. Netw.* **2016**, *9*, 257–268. [CrossRef]
22. Di Franco, F.; Ge, Y.; Tinnirello, I. On-Body and off-body transmit power control in IEEE 802.15.6 scheduled access networks. In Proceedings of the IEEE 25th Annual International Symposium on Personal, Indoor, and Mobile Radio Communication (PIMRC), Washington, DC, USA, 2–5 September 2014; pp. 1254–1258. [CrossRef]
23. Fourati, H.; Khssibi, S.; Val, T.; Idoudi, H.; Bossche, A.; Azzouz, L. Comparative Study of IEEE 802.15.4 and IEEE 802.15.6 for WBAN-based CANet. In Proceedings of the 4th Performance Evaluation and Modeling in Wireless Networks, Hammamet, Tunisia, 11–13 November 2015; Available online: https://oatao.univ-toulouse.fr/15422/1/fourati_15422.pdf (accessed on 20 May 2020).
24. Ambigavathi, M.; Sridharan, D. Saturation throughput analysis of IEEE 802.15.6 under ideal transmission channel condition. *Int. J. Comput. Intell. IoT* **2018**, *2*, 4. Available online: https://ssrn.com/abstract=3361546 (accessed on 20 May 2020).
25. Fatehy, M.; Kohno, R. A novel contention probability dynamism for IEEE 802.15.6 standard. *J. Wirel. Commun. Netw.* **2014**, 92. [CrossRef]
26. Jacob, A.; Kishore, G.; Jacob, L. Lifetime and latency analysis of IEEE 802.15.6 WBAN with interrupted sleep mechanism. *Sadhana Acad. Proc. Eng. Sci.* **2017**, *42*, 865–878. [CrossRef]
27. Salehi, S.; Razzaque, M.; Tomeo-Reyes, I.; Hussain, N. IEEE 802.15.6 standard in wireless body area networks from a healthcare point of view. In Proceedings of the 22nd Asia-Pacific Conference on Communications (APCC), Yogyakarta, Indonesia, 25–27 August 2016; pp. 523–528. [CrossRef]
28. Kwak, K.; Ullah, S.; Ullah, N. An overview of IEEE 802.15.6 standard. In Proceedings of the 3rd International Symposium on Applied Sciences in Biomedical and Communication Technologies (ISABEL 2010), Rome, Italy, 7–10 November 2010; pp. 1–6. [CrossRef]
29. Christos, T.; Fabio, D.F.; David, T.; Nick, T.; Jim, M. An energy analysis of IEEE 802.15.6 scheduled access modes for medical applications. In *Ad Hoc Networks Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering*; Springer: Cham, Switzerland, 2012; Volume 89, pp. 209–222. [CrossRef]
30. Ullah, S.; Mohaisen, M.; Alnuem, M.A. A Review of IEEE 802.15.6 MAC, PHY, and security specifications. *Int. J. Distrib. Sens. Netw.* **2013**, *9*, 950704. [CrossRef]
31. Navarro, J.; Vidaña-Vila, E.; Alsina-Pagès, R.M.; Hervás, M. Real-Time distributed architecture for remote acoustic elderly monitoring in residential-scale ambient assisted living scenarios. *Sensors* **2018**, *18*, 2492. [CrossRef]

32. Aguirre, E.; Lopez-Iturri, P.; Azpilicueta, L.; Rivarés, C.; Astrain, J.J.; Villadangos, J.; Falcone, F. Design and performance analysis of wireless body area networks in complex indoor e-Health hospital environments for patient remote monitoring. *Int. J. Distrib. Sens. Netw.* **2016**, *12*. [CrossRef]
33. Domingues, M.F.; Alberto, N.; Leitão, C.S.J.; Tavares, C.; de Lima, E.R.; Radwan, A.; Antunes, P.F. Insole optical fiber sensor architecture for remote gait analysis—An e-health solution. *IEEE Internet Things J.* **2017**, *6*, 207–214. [CrossRef]
34. Vegesna, A.; Tran, M.; Angelaccio, M.; Arcona, S. Remote patient monitoring via non-invasive digital technologies: A systematic review. *Telemed. e Health* **2017**, *23*, 3–17. [CrossRef]
35. Pagan, J.; Fallahzadeh, R.; Pedram, M.; Risco-Martin, J.L.; Moya, J.M.; Ayala, J.L.; Ghasemzadeh, H. Toward ultra-low-power remote health monitoring: An optimal and adaptive compressed sensing framework for activity recognition. *IEEE Trans. Mob. Comput.* **2018**, *18*, 658–673. [CrossRef]
36. Malasinghe, L.P.; Ramzan, N.; Dahal, K. Remote patient monitoring: A comprehensive study. *J. Ambient Intell. Hum. Comput.* **2019**, *10*, 57–76. [CrossRef]
37. Altini, M.; Penders, J.; Roebbers, H. An android-based body area network gateway for mobile health applications. In Proceedings of the Wireless Health, San Diego, CA, USA, 5–7 October 2010; pp. 188–189. [CrossRef]
38. Rahmani, A.; Thanigaivelan, N.; Nguyengia, T.; Granados, J.; Negash, B.; Liljeberg, P.; Tenhunen, H. Smart e-health gateway: Bringing intelligence to internet-of-things based ubiquitous healthcare systems. In Proceedings of the 12th Annual IEEE Consumer Communications and Networking Conference, CCNC 2015, Las Vegas, NV, USA, 9–12 January 2015. [CrossRef]
39. Fortino, G.; Fatta, G.; Pathan, M.; Vasilakos, A. Cloud-Assisted body area networks: State-of-the-art and future challenges. *Wirel. Netw.* **2014**, *20*, 1925–1938. [CrossRef]
40. Wan, J.; Zou, C.; Ullah, S.; Lai, C.-F.; Zhou, M.; Wang, X. Cloud-Enabled wireless body area networks for pervasive healthcare. *Netw. IEEE* **2013**, *27*, 56–61. [CrossRef]
41. Arya, S.P.; Kaushal, C. Cloud-Based wireless body area network for healthcare monitoring system. *Adv. Comput. Sci. Inf. Technol.* **2015**, *2*, 2393–9907.
42. Quwaider, M.; Jararweh, Y. Cloud-Assisted data management in wireless body area networks. *Int. J. Comput. Sci. Eng.* **2017**, *14*, 16. [CrossRef]
43. Li, C.; Lee, C.; Weng, C. A secure cloud-assisted wireless body area network in mobile emergency medical care system. *J. Med. Syst.* **2016**, *40*, 117. [CrossRef]
44. Vera, D.; Costa, N.; Roda-Sanchez, L.; Olivares, T.; Fernández-Caballero, A.; Pereira, A. Body area networks in healthcare: A brief state of the art. *Appl. Sci.* **2019**, *9*, 3248. [CrossRef]
45. Kim, S.-E.; Kang, T.; Oh, K.-I.; Park, M.J.; Park, H.-I.; Lim, I.G.; Lee, J.-J. Energy management integrated circuit for multi-source energy harvesters in WBAN applications. *Appl. Sci.* **2018**, *8*, 1262. [CrossRef]
46. Yamamoto, K.; Nishida, Y.; Sasaki, K.; Muramatsu, D.; Koshiji, F. Electromagnetic field analysis of signal transmission path and electrode contact conditions in human body communication. *Appl. Sci.* **2018**, *8*, 1539. [CrossRef]
47. Cwalina, K.K.; Ambroziak, S.J.; Rajchowski, P. An off-body narrowband and ultra-wide band channel model for body area networks in a ferryboat environment. *Appl. Sci.* **2018**, *8*, 988. [CrossRef]
48. Cwalina, K.K.; Ambroziak, S.J.; Rajchowski, P.; Sadowski, J.; Stefanski, J. A novel bitrate adaptation method for heterogeneous wireless body area networks. *Appl. Sci.* **2018**, *8*, 1209. [CrossRef]
49. Kim, B.-S.; Shah, B.; Al-Obediat, F.; Ullah, S.; Kim, K.H.; Kim, K.-I. An enhanced mobility and temperature aware routing protocol through multi-criteria decision making method in wireless body area networks. *Appl. Sci.* **2018**, *8*, 2245. [CrossRef]
50. Chen, C.-A.; Wu, C.; Abu, P.A.R.; Chen, S.-L. VLSI implementation of an efficient lossless *EEG* compression design for wireless body area network. *Appl. Sci.* **2018**, *8*, 1474. [CrossRef]
51. Park, M.J.; Kang, T.; Lim, I.G.; Oh, K.-I.; Kim, S.-E.; Lee, J.-J.; Park, H.-I. Low-Power, high data-rate digital capsule endoscopy using human body communication. *Appl. Sci.* **2018**, *8*, 1414. [CrossRef]
52. Ni, Q.; Zhang, L.; Li, L. A heterogeneous ensemble approach for activity recognition with integration of change point-based data segmentation. *Appl. Sci.* **2018**, *8*, 1695. [CrossRef]

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