5G and wireless body area networks

Conference Paper · April 2018

DOI: 10.1109/WCNCW.2018.8369035

2 authors:

Richard W. Jones
ZJU-UIUC International Institute, Zhejiang University, Haining, China

Konstantinos Katzis
European University Cyprus

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Richard W. Jones
ZJU-UIUC International Institute
Zhejiang University
Haining, Zhejiang Province, China

Konstantinos Katzis
Department of Computer Science and Engineering.
European University Cyprus,
Nicosia, Cyprus

Abstract—**5G wireless is the next step in the evolution of mobile communications with the aim being to provide connectivity for any kind of device and any kind of application. Wireless Body Area Networks (WBANs) constitute just one component of connected healthcare utilising small intelligent physiological sensors either on or implanted in the human body. This contribution examines the 5G technologies that will make a significant contribution to providing secure healthcare-orientated WBANs with improved energy efficiency, interference mitigation and wireless power transfer capability.**

Keywords- WBANs; Interference Mitigation; Energy Efficency; Millimeter wavelength; Network Coding; Security.

I. INTRODUCTION

Fifth generation (5G) wireless access is the next step in the evolution of mobile communications with goals that include; providing connectivity for any kind of device, an order of magnitude increase in data rate, higher energy efficiency as well as compatibility with previous technologies - the ultimate aim being successful management of future mobile device requirements. To be able to achieve these goals a variety of 5G enabling technologies are being developed. These include extending wireless communication to higher frequency bands, the development of advanced multi-antenna systems, and the use of wireless power transmission. In addition to be able to evolve beyond 4G, intelligence, communication capabilities, and processing power will need to be diffused across networks and mobile devices, empowering even the smallest of connected devices. The European 5G Public Private Partnership (5GPPP) have, for example, funded projects in areas ranging from physical layer to overall architecture, network management and software networks [1].

To achieve all of the above, most likely new paradigms and enablers such as Software Defined Networking (SDN) and Network Function Virtualisation (NFV) need to be supported. In such an ultra-flexible environment, it is necessary to consider new solutions, such as the separation of user and control planes, and possibly, re-definition of the boundaries between the network domains (e.g. radio access network and core network) [1].

The recent advances made towards 'Totally connected healthcare', due to advances in wireless and electronics technology, promises to increase not only the quality of healthcare but also patient accessibility while achieving all this at a lower cost per patient. Wireless Body Area Networks (WBANs) have great potential for continuous patient monitoring in ambulatory settings as well as the early detection of abnormal conditions, and supervised rehabilitation [2]. A typical Wireless Body Area Network (WBAN) consists of a number of inexpensive, lightweight, and miniature sensor platforms, each featuring one or more physiological sensors, such as electrocardiograms (ECG), blood pressure, electro-encephalograms (EEG), and blood glucose sensors. The sensors could be located on the body as intelligent patches, integrated into clothing, or implanted in the body. The trend is towards integrating implanted miniaturized devices into WBANs, for example, Deep Brain Stimulation for the control of Parkinson's disease is becoming viable. WBANs are generally characterized by a three-tier architecture composed of: (1) body-worn or implanted sensors, (2) a hospital information system for storage and management of health data and (3) a mobile device that acts as a personal gateway between (1) and (2), see Figure 1. The continuing advances in WBANs are driven by developments in wireless communications, as well as pervasive, and wearable computing.

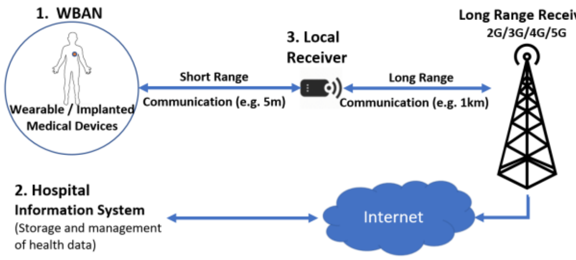

Figure 1. A Typical 3-Tier WBAN Architecture.

This contribution provides a brief overview of G5 enabling technologies and the ways in which they can make a significant contribution towards realizing the full potential of healthcare orientated WBANs, with regard to energy efficiency, interference mitigation, wireless power transfer and security.

II. 5G TECHNOLOGIES

In 5G networks, spectrum availability is one of the key challenges to supporting the projected future mobile traffic demand. It will be necessary to go higher in frequency and use larger portions of free spectrum bands, especially in dense deployments to overcome overcrowding currently used bands. Thus 5G networks will operate in a wide spectrum range with a diverse range of characteristics, allowing spectrum to be managed (more efficiently) by enabling sharing strategies in mobile networks. For example, multi-RAT resource allocation could exploit spectrum in licensed, unlicensed and/or lightly-licensed bands allowing the prioritization and allocation of traffic in a dynamic way. Moreover, 5G networks will have to address the complexity of advanced communication and different antenna types with different beam-forming capabilities. Examples of this are multi-antenna schemes with large antenna arrays, massive multiple-input multiple output (MIMO) and clustering of millimeter-wave (mmWave) access points addressing the coverage and mobility needs by using beam-steered antenna patterns. Software network technologies are also fundamental 5G enablers needed to realize the requirements of programmability, flexibility (e.g., re-configurability, and infrastructure sharing), adaptability (e.g., self-configuration, self-healing and self-optimization) and capabilities (e.g., mobile edge computing, network slicing, autonomic network management) expected to be inherent in 5G networks [1].

A selection of G5 technologies, that have direct impact on WBAN capability, are now addressed, namely mmWaves, Network coding, Radio Access Networks and Game Theory.

A. Millimeter Wave (mmWave) Bands

The main reason attracting scientists and engineers for research and development of communication systems in the millimeter wave (mmWave) bands, which range from 30 to 300 GHz, is the availability of huge and continuous bandwidth within this part of the spectrum. While mmWave has historically been used for backhaul links and satellite communications, it was not considered suitable for cellular communications due to much higher path-loss characteristics. Advances in RF and semiconductor technologies have made the use of mmWave bands more suitable for cellular communications [3] with antenna arrays now small enough so they can be practically accommodated inside mobile devices. Beam-forming – basically steerable antennas - is considered an essential enabling technology for mmWave communication [4], see Figure 2.

Figure 2. Beam-forming antenna enabling signals and nulls to be precisely directed from a base station [5].

The IEEE 802.11ad standard focuses on the 60 GHz frequency though for outdoor use the maximum rain drop related attenuation occurs at this frequency. Rappaport and co-workers have investigated radio channel measurements at 28, 38 and 73 GHz [6] while Samsung already has its own 5G prototype network based on mmWave technology, at 28 GHz, which can reach 200 m without LoS and 256 Mbps error-free messages [7].

B. Network Coding

Network coding (NC) can offer significant gains in terms of network throughput [8], robustness and security [9] if/when thousands of devices interact. In NC the classical store-and-forward paradigm of managing packets is changed to a code-and forward paradigm. This is recognized as ‘the’ enabling technology of 5G [10]. Random linear network coding (RLNC), involving random linear combinations of the original data, is extremely flexible and can operate in a decentralised way, making it particularly useful for a variety of applications, including mesh networks, peer-to-peer (P2P) file distribution P2P streaming [11] as well as cloud storage. The concept has been extended, to create more reliable WBAN’s, by combining NC (more precisely RLNC) with Cluster-based Cooperative Communications [12] to create Cooperative Network Coding (CNC) [13]. CNC increases reliability by transmitting information through spatially separate paths, see Figure 2, where the solid lines represent logical wireless channels.

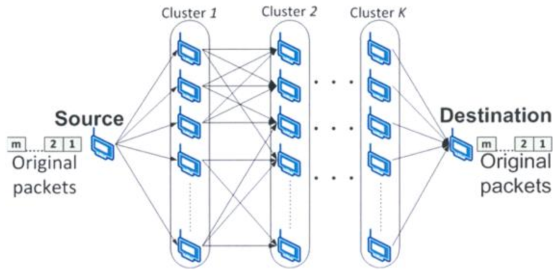

Figure 3. Cooperative Network Coding Model. [13].

Cooperation provides increased reliability while NC provides increased throughput by using spatial and time diversity. Additionally, latency, which is an important metric in WBANs applications, is decreased because of the feed-forward nature of these approaches.

C. Radio Access Networks

The integration of a number of new radio technologies with existing technologies is anticipated in 5G. Both the availability (and characteristics) mmWaves are expected to be exploited which will make cells even smaller and denser than in current setups. Also, the adoption of massive MIMO systems will necessitate more efficient interference management schemes, e.g., by coordinated multi-point (CoMP) techniques [14]. Thus interference coordination has to be realised across systems (e.g., across both macro and small cells).

D. Game Theory

Game theory has been widely used in wireless networking for a range of problems such as flow control, power control, routing, and resource sharing can be modeled using game theoretical methods [15]. A non-cooperative game - Figure 4 provides an overview of an ‘energy efficiency game’ - is a game with competition between individual players. When other players' strategies are fixed, the strategy that produces the most favorable outcome for a player is called the best response (BR). If all the players play at their BR's then the Nash bargaining game has the capability to deal with the problem effectively and achieve a desirable solution with a good balance between efficiency and fairness with Pareto optimality being used to check the solution. Since the players are only concerned with their own payoffs this tends to be inefficient from the whole system viewpoint.

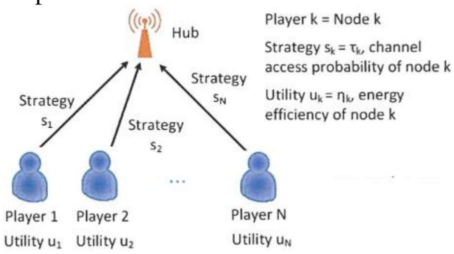

Figure 4. Energy Efficiency game in IEEE 802.15.6 UWB WBANs

However, the inefficiency of the Nash equilibrium, which stems from selfish behavior, has been solved by adopting usage-based pricing mechanisms - both linear [16] and nonlinear [17] solutions, with regard to the allocated resource, have been determined.

III. Wireless Body Area Networks

WBANs face several design challenges – its requirements relate to reliability, quality of service (QoS), low power, data rate, and non-interference. Both IEEE 802.15.6 [18] and the ETSI SmartBAN standard [19] were established to help meet these requirements, especially the dual requirements of energy efficiency and quality of service (QoS), as well as supporting high data rates up to 10 Mbps in the vicinity of living tissues [18].

In WBANs, the nodes are partitioned into a physical (PHY) layer and a medium access control (MAC) layer. An integral part of WBAN operation is the energy efficiency of the devices and enabling their transmissions with the optimal choice of Physical layer (PHY) and Medium Access Control (MAC) parameters. Both IEEE 802.15.6 and SmartBAN describe MAC and PHY layers to provide a certain level of quality for low power devices in communications surrounding the human body in order to support a variety of WBAN applications. SmartBAN provides increased channel utilization in both layers, for example, enabling the transmission of emergency (high-priority) packets in every time slot [19].

A. Existing Frequency Bands for WBAN's

WBANs have to comply with applicable medical and communication regulatory authorities. Medical Implant Communications Service (MICS), Wireless Medical Telemetry Services (WMTS), Industrial, Scientific and Medical (ISM) and ultra-wideband (UWB) are some of the frequency bands used worldwide for medical purposes, see Figure 5. IEEE 802.15.6 does support different frequency bands such as UWB, narrowband (NB), and human body communication (HBC) with three levels of security (levels 0, 1 and 2) in terms of authentication and encryption. The specific type of WBAN healthcare application determines which of these technologies is most suitable.

Currently the most widely used WBAN technologies include Bluetooth and ZigBee. Bluetooth is already integrated in cell phones while Wibree is a low power version of Bluetooth that is well suited to personal monitoring applications. ZigBee is an emerging wireless standard for low data rate, very low-power applications, with potential applications in personal healthcare. UWB is currently considered the best candidate technology for WBANs, leading to standardization within, for example, the IEEE 802.15.6 or 802.15.4a. UWBs intrinsic characteristics include good material penetration properties, low power emissions, low-interference, robustness against multi-path, radar-like operation and high temporal resolution, enabling accurate sub-centimetres localizations [21].

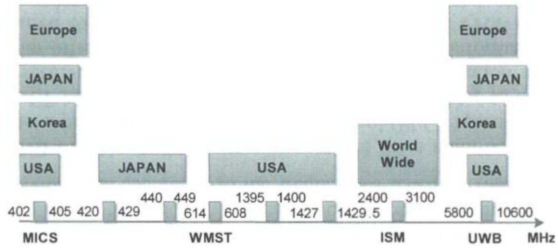

Figure 5. Standard Designated Frequency Bands for WBANs. [20].

Implanted sensors – standalone or as part of an implanted medical device - provide important information on internal organs and/or the implanted medical devices themselves. Such *in vivo* communication requires effective wireless solutions for WBAN implementation with UWB contributing to a possible solution. UWB provides tools to measure the spatial movement or trajectory of an implant after installation which potentially allows the human healing process to be monitored.

IV. 5G Enabled WBANs

This section discusses the utilization of 5G related technologies (plus channel estimation and link adaptation), to enhance the performance of WBAN's. Game theory is used primarily within two areas of extreme importance to a WBAN; Energy Efficiency and Interference Mitigation.

A. Energy Effciency

Energy efficiency is essential for WBAN application because of the battery-operated sensor nodes. Application requirements, such as average application data bandwidth, maximum required data bandwidth and latency, as well as alert requirements, need to be considered.

Methods to increase the energy efficiency of wireless sensor networks include [22]:

- Link adaptation methods, which jointly optimize the PHY and MAC layer parameters, provide a means to adapt the transmissions to the channel characteristics. Different ways of implementing link adaptation in WBANs are outlined in [23].
- The use of sleeping patterns and duty cycling [24] offers significant energy savings by periodically turning

off energy-hungry components or even the whole device. IEEE 802.15.6 addresses this through the m-periodic scheduled allocation mode, where devices can enter into sleep modes between superframes [18].

- The third method includes joint low duty cycle MAC and routing protocols that trade off latency, reliability, and energy efficiency [25] such that nodes only wake up if they have data to transmit. WBAN MAC protocols typically have dynamic transmission power control (TPC) – in [26] a protocol based on link-state estimation, where Wireless sensors adjust the transmission power, based on short and long-term link state estimations. The dynamic TPC achieved a PDR of 97% using 26.6mW.

An energy efficiency maximization problem for the IEEE 802.15.6 IR-UWB PHY has recently been formulated - a cross-layer optimization algorithm being used to determine the optimal payload size in MAC layer and number of pulses per burst in the physical layer [22].

B. Interference Mitigation

A WBAN may suffer interference not only because of the presence of other WBANs, see Figure 6, but also from wireless devices simultaneously operating on the same channel. It has been stated in [27] that even with one active transmitting device per user, supporting multiple uncoordinated wearable communication networks become unfeasible at high user densities, 1−2 users/m^{-2}, due to resource scarcity.

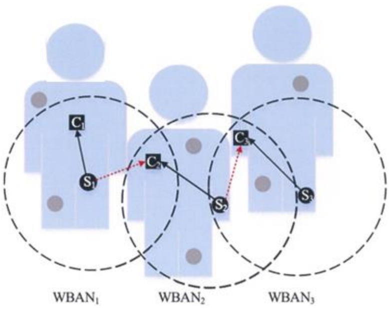

Figure 6. Interference model for co-located WBANs

IEEE 802.15.6 designated the Medical Implant Communication Service (MICS) band to provide reliable communication with low power consumption for in-body communication. Unfortunately the MICS band suffers from interference problems, which causes significant performance degradation in WBANs - coexistence mitigation schemes in IEEE 802.15.6 completely, ignore the MICS band.

Avoidance and mitigation of channel interference have been extensively researched in the wireless communication literature. So far not many techniques in the area of IoT have been published but those that have can be categorized as either resource sharing and allocation [28, 29] or power control and scheduling. In [29] a dynamic frequency allocation method is proposed to mitigate bi-link interferences, that affect the WBAN's, and hence impose them to switch to the same frequency.

Game theory-based power control schemes for interference mitigation among WBANs are proposed in [30], in which players maximize their individual utilities selfishly by adapting their transmission power, see Figure 4. In addition, channel allocation approaches using game theory have also been adopted to alleviate inter- and intra-WBAN interference in body-to-body networks [31]. As mentioned previously non-cooperative game models, always result in non-Pareto optimal solutions due to player selfishness though a data-rate tuning mechanism, based on the Nash bargaining game model, attempts to improve network performance amongst multiple heterogeneous sensors with different priorities though it does not consider inter-WBAN interference [15]. In [32] a QoS-based adaptive power control (QPC) scheme for co-located WBANs from a cooperative bargaining game theoretic perspective is proposed. It improves both network reliability and energy efficiency by dynamic power adjustment with friendly adaption to different QoS requirements. Perhaps the most important contribution of this work is the incorporation of both the urgency of the sensed data into the utility function, especially the former. The index used to quantify the urgency of the sensed data grows with the measured increasing fluctuation of the signal.

C. Body Shadowing

Propagation paths in WBANs can experience fading due to different reasons, such as energy absorption, reflection, diffraction, shadowing by the body, and body postures. All these unique features lead to high packet losses. Relay nodes, if deployed outside of the human body, might possess better channels and less stringent energy limitations. Therefore, cooperative communication has received considerable interest in recent years [18, 33].

D. Data Rate

'Faster Data Rates' is perhaps the most prominent stated advantage of 5G though for a WBAN, depending on the characteristics of the individual elements, a range of data rates will likely result, especially with the need to address energy efficiency. There have been a variety of studies that specifically address faster data rates and the advantages they might bring. These include *In vivo* wireless networks, as part of a WBAN [34]. To overcome the highly dispersive nature of the *in vivo* environment Chao and co-authors [35] have investigated, with some success, the use of MIMO communications to achieve enhanced data rates. This work is currently being applied to Laparoscope-Endoscopy surgery at Tampa General Hospital [36] to provide low-delay high definition video.

A number of 5G-based WBAN architectures have also been proposed and studies performed to specifically address the effect faster data rates can have on performance. These architectures specifically consider emergency healthcare situations where continuous monitoring, at fast data rates, far outweighs energy efficiency considerations. In [37] the emergency healthcare system, basically a WBAN configured to address emergency situations, is based on both mobile cloud computation and 5G to provide low-delay continuous patient monitoring and location detection. In a more recent proposal [38] the architecture elements include wearable devices, a smartphone to process the patient data and an intelligent decision support system to generate an alarm when an anomalous event is detected, see Figure 7. Simulated 4G and 5G performance was very similar up to about 300 users but increasing 4G packet loss above this number showed that only 5G can deliver both low delay and bandwidth availability if a high number (≈1000) need to be continuously monitored.

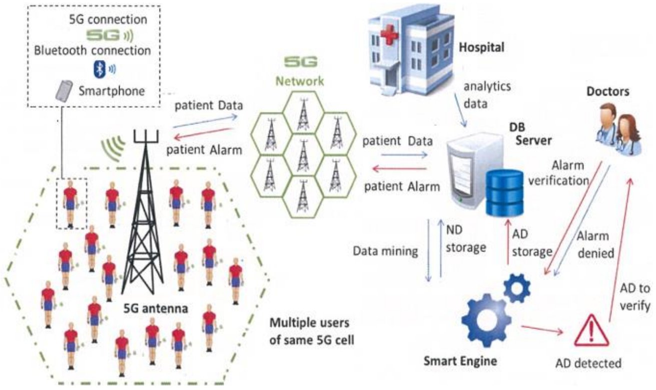

Figure 7. 5G-based Continuous mHealth Monitoring. [38]

E. Communication: Millimeter Waves

A number of researchers are now looking at the use of mmWave based communication, to examine if it provides distinct advantages with regard to interference mitigation, signal security, technology miniaturization and fast data rates in WBANs [27, 39, 40]. Multi-gigabit data rate, Line-of-Sight (LoS) and Non-line-of-Sight (NLoS) indoor communication, high level frequency reuse are extremely advantageous plus at the exposure levels to which humans will be subjected to mmWaves in the future there are no real safety concerns, though more work needs to be done on eye exposure [41].

MmWave communication drastically reduces the inter-network interference among coexisting WBANs due to its short-range which also has important implications for improving signal security However, being unlicensed will pose a significant challenge for mmWave-based WBANs to coexist with other unlicensed mmWave networks

MmWaves are mostly reflected by the human body therefore can only be used to connect wearable devices, not implantable or endoscopic devices which indicates that at least a dual-band solution is required for WBANs with implanted devices. A recent mmWave-based study revisits interference mitigation of co-existing WBANs using a game theory-based power control scheme [42]. 60 GHz mmWave communication between WBANs is used and a pair of pricing factors is introduced into the game to penalize greedy players.

V. WIRELESS POWER, SECURITY AND PRIVACY

This section briefly considers two areas that though perhaps not obviously 5G enabling technologies nevertheless will have a substantial impact on 5G as well as the future design, development and operation of WBAN's namely wireless power transfer (WPT) and security.

WPT to both on-body and in-body sensors/devices provides a way of (a) lengthening the life of the device and (b) overcoming the low power design requirements subject to safety operating limits. With the trend towards miniaturized body implants, WPT becomes pretty much a necessity [43]. The two practical WPT approaches relating to WBANs are:

- Ultrasonic based WPT [43].
- Energy Harvesting (EH) [44].

Ultrasonic WPT provides many advantages, especially for implanted devices such as small propagation losses and high allowable intensity. EH-based WPT currently has a greater amount of research effort applied to it. Not only conventional EH but energy harvested from the Radio Frequency-based communication is being investigated.

Most of the recent work seems to be addressing simultaneous wireless power transfer and information transfer. [43] mainly examines ultrasonic-based power transfer efficiency relating to the depth of a miniaturized body implant as well as examining simultaneous power and data transfer performance while [44] considers the information throughput from the sensor to the uplink by examining the trade-off between the time used for the EH phase and the information transfer phase.

Finally some brief remarks relating to security. Security considerations for WBAN off-body communication match those for any other mobile device as a smartphone is generally accepted as an appropriate on-body receiver. Security challenges such as reliability and data privacy must be addressed with eavesdropping, evil twin access point and man-in-the-middle being typical types of attacks that can challenge the confidentiality of the system.

The IEEE 802.15.6 standard [18] defines three levels of security: Level 0 represents the lowest level of security where data is transmitted via unsecured frames. Level 1 represents the medium level of security where data is transmitted with secured authentication but without being encrypted. Level 3 provides the highest level of security where data is transmitted in securely authenticated and encrypted frames. This low-overhead but relatively strong security solution includes a master-key generation pre-shared association, unauthenticated association, public key hidden association, password authenticated association and displace-authenticated association. It also features a simple two-way handshake for MK pre-shared association, elliptic curve cryptography (ECC) based for key agreement and temporal key creation / distribution, pairwise temporal key (PTK) creation for unicast protection, group temporal key (GTK) distribution for multi-case / broadcast protection. Also, it supports data authentication / encryption based on AES-128 as well as reply prevention.

VI. DISCUSSION AND CONCLUSIONS

This work provides some indication about how the technologies required to realise evolving and improved mobile communications, in the guise of 5G, can generally enable the Internet of Things and specifically, WBANs. A snapshot of both the most recent and most applicable, to WBAN's developments are outlined.

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