APPLICATIONS, CHALLENGES, AND PROSPECTIVE IN EMERGING BODY AREA NETWORKING TECHNOLOGIES

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Advances in wireless technology and supporting infrastructure provide unprecedented opportunity for ubiquitous real-time healthcare and fitness monitoring without constraining the activities of the user.

ABSTRACT

Advances in wireless technology and supporting infrastructure provide unprecedented opportunity for ubiquitous real-time healthcare and fitness monitoring without constraining the activities of the user. Wirelessly connected miniaturized sensors and actuators placed in, on, and around the body form a body area network for continuous, automated, and unobtrusive monitoring of physiological signs to support medical, lifestyle and entertainment applications. BAN technology is in the early stage of development, and several research challenges have to be overcome for it to be widely accepted. In this article we study the core set of application, functional, and technical requirements of the BAN. We also discuss fundamental research challenges such as scalability (in terms of data rate, power consumption, and duty cycle), antenna design, interference mitigation, coexistence, QoS, reliability, security, privacy, and energy efficiency. Several candidate technologies poised to address the emerging BAN market are evaluated, and their merits and demerits are highlighted. A brief overview of standardization activities relevant to BANs is also presented.

INTRODUCTION

An aging population and sedentary lifestyle are fueling the prevalence of chronic diseases such as cardiovascular diseases, hypertension, and diabetes. According to the World Health Organization, cardiovascular disease causes 30 percent of all deaths in the world (about 17.5 million people in 2005). Diabetes currently affects 180 million people worldwide and is expected to affect around 360 million by 2030. More than 2.3 billion people will be overweight by 2015. A rapid rise in debilitating neuro-degenerative diseases such as Parkinson's and Alzheimer's is threatening millions more.

Burgeoning healthcare needs are exerting enormous strain on the fragile healthcare delivery system. Moreover, a shortage of skilled staff, overload, and tightening of healthcare budgets have aggravated the impending healthcare crisis. These economical, social, and demographic trends highlight the need to exploit technological breakthroughs to bring affordable and efficient healthcare solutions to people that will improve their quality of life.

The advent of miniaturized sensors and actuators for monitoring, diagnostic, and therapeutic functions, and advances in wireless technology have opened up new frontiers in the race to conquer healthcare challenges. Ultra-low-power wireless connectivity among devices placed in, on, and around the human body is seen as a key technology enabling unprecedented portability for monitoring physiological signs in the hospital, at home, and on the move.

Strategically placed wearable or implanted (in the body) wireless sensor nodes sample, process, and transmit vital signs (e.g., heart rate, blood pressure, temperature, pH, respiration, oxygen saturation) without constraining the activities of the wearer. The gathered data can be forwarded in real time to a hospital, clinic, or central repository over a local area network (LAN), wide area network (WAN), cellular network, and the like. Physicians and caregivers can remotely access this data to assess the state of the health of the patient. Additionally, the patient can be alerted using SMS, alarm, or reminder messages.

The measured vital signs can be processed locally for diagnosis of medical conditions, which in turn could trigger a treatment procedure in a close-loop bio-feedback system. For example, upon detecting high blood sugar level, an implanted blood glucose level sensing device can wirelessly trigger an insulin pump to inject a required dose of insulin, thereby acting as an artificial pancreas.

Body area networking (BAN) technology has the potential to revolutionize healthcare delivery in ambulances, emergency rooms, operation theaters, postoperative recovery rooms, clinics, and homes. The benefits of untethered, unobtrusive, and continuous monitoring/treatment include long-term trend analysis, detection of transient abnormalities, prompt alerting of a caregiver to
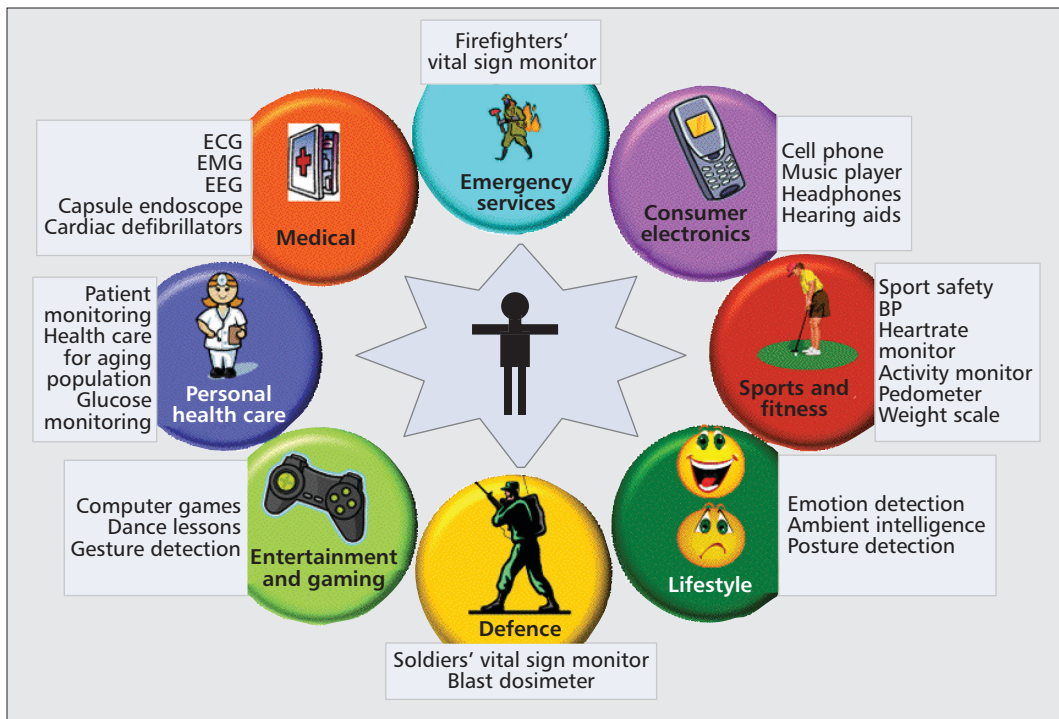
Figure 1. *BAN applications.*

intervene in case of an emergency, regulation of treatment regimes, reduction of errors, reduction of hospital stays, extending independent living for seniors, and improved patient comfort. BAN offers a paradigm shift from managing illness to proactively managing wellness by focusing on prevention and early detection/treatment of diseases. A recent report by ON World titled "WSN for Healthcare" estimates that wireless sensor networks can reduce annual healthcare costs by US$25 billion by 2012.

APPLICATIONS

BAN is envisaged to unleash a wave of innovative, personalized, and integrated medical, lifestyle, fitness, gaming, entertainment, and consumer electronics applications. BAN can enable wireless connectivity to implanted cardioverter defibrillators (ICDs), implanted drug delivery, swallowed camera pills, wearable ECG/EMG/EEG/BP/S_pO_2/temp monitoring, high risk pregnancy monitoring, sleep analysis, gait analysis, emotion detection, media players, and headsets. Figure 1 illustrates some of the applications BAN technology is intended to support.

TECHNICAL REQUIREMENTS

Table 1 shows the technical requirements of a few typical BAN applications. Notice the wide variation in data rate, bit error rate (BER), delay tolerance, duty cycle, and lifetime, which requires scalable solutions with quality of service (QoS) provisions.

Despite significant technological advances in wireless technology, BAN poses unique technical challenges primarily due to the diversity of applications and their stringent requirements, as can be seen from Table 2.

KEY RESEARCH CHALLENGES

BAN brings forward several research issues that need to be taken into account in the design of radio frequency (RF) wireless systems.

FREQUENCY BAND SELECTION

Table 3 shows the characteristics of the frequency bands that could potentially be used for a BAN radio. Many BAN devices such as ICDs and hearing aids are expected to be carried globally by their users. Hence, it is desirable that BAN radio can operate legally worldwide.

The MedRadio core (402–405 MHz) band's superior propagation characteristics for implants, quiet channel properties, and worldwide availability are primary reasons for its popularity for implant applications.

The industrial, scientific, and medical (ISM), wireless medical telemetry service (WMTS), ultra-wideband (UWB), or MedRadio wing bands (401–402 MHz and 405–406 MHz) can be exploited to support on-body communications. Low-power BAN devices would suffer from severe performance degradation in the presence of high-power technologies in crowded ISM bands thus making them less appealing for high-fidelity medical applications. WMTS bands are also heavily used, and their use is restricted to healthcare facilities in the United States. Exploiting UWB for wearable applications brings forward the issue of coexistence with high-data-rate multimedia applications. MedRadio wing band rules are very stringent and restrictive.

These factors have prompted the FCC to consider opening up 2360–2400 MHz spectrum for medical BANs. (See the FCC notice of proposed rulemaking 09-57, June 2009). The FCC is also considering allocating up to 24 MHz of spectrum in the 413-457 MHz range for a "Med-

Application	Target data rate	No. of nodes	Topology	Setup time	P2P latency	BER	Duty cycle	Desired battery lifetime
Deep brain stimulation	1 Mb/s	2	P2P	< 3 s	< 250 ms	< 10^{-3}	< 50%	>3 years
Hearing aid	200 kb/s	3	Star	< 3 s	< 250 ms	< 10^{-10}	< 10%	>40 hours
Capsule endoscope	1 Mb/s	2	P2P	< 3 s	< 250 ms	< 10^{-10}	< 50%	>24 hours
Drug dosage	< 1 kb/s	2	P2P	< 3 s	< 250 ms	< 10^{-10}	< 1%	>24 hours
ECG	72 kb/s (500 Hz sample, 12-bit ADC, 12 channels)	< 6	Star	< 3 s	< 250 ms	< 10^{-10}	< 10%	>1 week
EEG	86.4 kb/s (300 Hz sample, 12-bit ADC, 24 channels)	< 6	Star	< 3 s	< 250 ms	< 10^{-10}	< 10%	>1 week
EMG	1.536 Mb/s (8 kHz sample, 16-bit ADC, 12 channels)	< 6	Star	< 3 s	< 250 ms	< 10^{-10}	< 10%	>1 week
O2/CO2/BP/ temp/respiration/ glucose monitoring, accelerometer	< 10 kb/s	< 12	Star	< 3 s	< 250 ms	< 10^{-10}	< 1%	>1 week
Audio	1 Mb/s	3	Star	< 3 s	< 100 ms	< 10^{-5}	< 50%	>24 hours
Video/med imaging	< 10 Mb/s	2	P2P	< 3 s	< 100 ms	< 10^{-3}	< 50%	>12 hours

Table 1. *Technical requirements of selected BAN applications [1].*

ical Micropower Network" service. (See the FCC notice of proposed rulemaking, 09-20, March 2009.) This is intended to support wideband implanted microstimulator devices that can serve as an artificial nervous system to restore sensation, mobility, and function to paralyzed/impaired limbs and organs.

CHANNEL MODELING

The channel model plays a crucial role in the design of PHY technologies. Experimental channel modeling for implants and wearable devices is difficult due to involvement of human subjects and healthcare facilities, both governed by regulations. The dynamic environment due to twisting, running, multipath, and mobility further complicates the empirical validation of channel models. Some channel models and relevant references can be found in [2].

ANTENNA DESIGN

Antenna design for BAN applications is also a challenging problem due to restrictions on the size, material, and shape of the antenna and hostile RF environment. The RF environment changes with the wearer's age, weight gain or loss, and posture changes [3]. Only non-corrosive and biocompatible material such as platinum or titanium can be used for implants, which results

in poorer performance when compared to a copper antenna. The shape and size of an implant antenna depends on its location and organ, which further limits the freedom of the designer.

PHY PROTOCOL DESIGN

Physical layer protocol design requires minimizing power consumption without compromising the fidelity. Ideally, power consumption should scale linearly as the data rate is increased from a few kilobits per second to 10 Mb/s, thereby attaining constant energy per bit of information. Operation of BAN devices in the presence of other high-power devices over unlicensed bands requires robust interference-agile protocols. Seamless connectivity should be maintained in dynamic environments with the least possible performance degradation in terms of latency, data loss, and throughput. Quick turnaround time from transmit to receive and fast wakeup from sleep mode would contribute significant power savings.

ENERGY-EFFICIENT HARDWARE

Existing wireless technologies draw relatively high peak current and mainly rely on duty cycling the radio between sleep (standby) and active modes to minimize the average current drawn. Innovations in integrated circuits, radio hard-

Characteristic	Requirement	Desired Range
Operating space	In, on or around the body	Typically 0–3 m and extendable up to 5 m
Network siz	Modest	< 64 Devices per BAN
Data rate	Scalable	From sub kb/s up to 10 Mb/s
Target Lifetime	Ultra-long for implants Long for wearable	Up to 5 year for implants Up to 1 week for wearable
Target frequency bands	Global Unlicensed and Medical bands	MedRadio, ISM, WMTS, UWB
Peak Power consumption	Scalable	e.g., Between 0.001–0.1mW in stand-by mode up to 30mW in fully active mode
MAC	Scalable, reliable, versatile, self-forming	Low power listening, wake up, turn-around and synchronization
Topology	Star, Mesh or Tree	Self-forming, distributed with multi-hop support
Device duty cycle	Adaptive, Scalable	From 0.001% up to 100%
Coexistence	Coexistence with legacy devices and self-coexistence	Simultaneous co-located operation of up to 10 independent BANs
QoS support and differentiation	Real-time waveform data, periodic parametric data, episodic data and emergency alarms	• BER: from 10^{-10} to 10^{-3} • P2P latency: from 10ms – 250ms • Reservation and prioritization
Fault tolerance	No single point of failure	Ability to isolate and recover from failures. Self-healing capability
Dynamic Environment	Body shadowing (twisting, turning, running), attenuation	Seamless operation of multiple nodes moving in and out of range of each other
Security	Many levels, long term, short term, light weight	Authentication, Authorization, Privacy, Confidentiality, Encryption, Message integrity
Safety/Biocompatibility	No harmful effects of long term continuous use	Meet regulatory requirements. e.g., FDA, SAR and HIPPA
Setup time and procedure	Not to be perceived as a slow or tedious	Up to 3 sec
Ergonomic consideration	Size, shape, weight and form factor restricted by location and organ	Non-invasive, unobtrusive, small size, weight and form-factor
Reprogramming, Calibration, Customization	Personalized, integrated, configurable and context aware services	Ability to reprogram, recalibrate, tune and configure devices wirelessly

Table 2. *Technical requirements for BAN technology [1].*

ware, sensing technologies, and miniaturization are expected to dramatically lower the peak current drawn [4]. Hence, devices can operate on low peak pulse-discharge current supplied by thin film (paper) batteries thereby enabling new markets of disposable sensor patch type applications.

Researchers are exploring several promising techniques such as low-power listening [5] and wake-up radios [6], which are intended to minimize power consumed by idle listening. Since crystal is one of the most expensive, bulky, power hungry, and fragile components, developing a crystal-less radio [7] could further reduce the cost, size, and power requirements.

MAC Protocol Design

BANs are intended to support lifesaving medical applications. Hence, safety, security, QoS, and reliability are important metrics besides energy efficiency. Harmonized coexistence of multiple collocated BANs in crowded places such as hospital elevators and wards needs a robust MAC protocol. Efficient duty cycling methods have to be developed to minimize power consumption without compromising QoS. The MAC protocol should be able to cope with topology and density changes induced by nodes moving in and out of range due to body movements.

Message prioritization for real-time vital sign

Frequency (MHz)	Acronym	Suitability to BAN applications	
		Merits	Demerits
401~406	MedRadio	Worldwide availability, good propagation characteristics, quiet channel, medical only	Secondary usage, body-worn applications not allowed in 402–405 MHz core band, large antenna size, limited bandwidth, stringent rules
433.05~434.79	General Telemetry	Good propagation characteristics	EU/AU/NZ/SA only, crowded spectrum, large antenna, limited bandwidth
608~614 1395~1400 1427~1432	WMTS	Good propagation characteristics, medical only	Licensed secondary use limited to healthcare providers inside healthcare facilities in US, limited spectrum, heavily used
868~870	General Telemetry	Good propagation characteristics	EU only, limited spectrum, heavily used
902~928	ISM	Good propagation characteristics	US/Canada only, crowded spectrum
2400~2483.5 (2400~2500)	ISM	Worldwide availability, small antenna, large bandwidth	Crowded spectrum, many standards and technologies
5725~5850	ISM	Worldwide availability, small antenna, large bandwidth	Existing standards and technologies, severe attenuation
4200~4800 7250~8500	UWB	Worldwide availability, short range, low power, huge bandwidth	Coexistence with high data rate multimedia applications, severe attenuation

Table 3. *Properties of potential frequency bands for BAN.*

monitoring and guaranteed delivery of alarm messages in emergency situations need to be supported [1]. Adaptive frequency agility and channel migration protocols have to be developed in order to migrate to a quiet channel when heavy interference is detected. A simple network setup procedure, self-organizing, and self-healing are essential for the convenience of unskilled users [8].

QoS AND RELIABILITY

QoS and reliability of wireless BAN technology should be at par (if not better) with current wireline technologies to be adopted in clinical settings. The QoS framework should be flexible so that it can be dynamically configured to suit application requirements without unduly increasing complexity or decreasing system performance. Real-time life-critical applications of BANs are not only delay-sensitive but also loss-sensitive. Lost or corrupt alarm/alert packets due to unreliable wireless networks have serious consequences. Fair bandwidth sharing among collocated BANs and graceful degradation of service are highly desirable. BAN devices have limited memory, which means there is little room to store and retry unacknowledged data. Therefore, strong error detection and correction schemes, and efficient acknowledgment and retransmission mechanisms have to be defined [1].

REAL-TIME CONNECTIVITY OVER HETEROGENEOUS NETWORKS

The full potential of BAN technologies can only be realized if the promise of anytime, anywhere, automatic, and continuous connectivity to infrastructure networks is fulfilled. Connectivity of a BAN to infrastructure networks can be realized using a gateway device (e.g., a cell phone or PDA) that transfers data between the BAN and infrastructure networks such as WLAN, WPAN, or cellular networks. Low-cost limited-range high-capacity WLAN and WPAN infrastructures can be leveraged for indoor connectivity (e.g., inside a hospital or at home), whereas lower-capacity longer-range cellular infrastructure can be leveraged for outdoor connectivity. This brings forward the issues of integration of heterogeneous wireless networking technologies to support seamless roaming and end-to-end QoS.

In non-real-time applications the gateway may store data locally and upload it when the gateway is connected to the Internet. Real-time wireless connectivity to infrastructure enables location freedom and universal mobility while being monitored. A wireless-enabled ICD can automatically call an ambulance through a cell phone when it detects cardiac arrest. Similarly, a fall detector can automatically send an alarm or call an emergency center/caregiver upon detecting a fall. However, precise location determination technologies are needed to be able to provide quick assistance to the person in case of an emergency.

SECURITY AND PRIVACY

BAN applications have significant legal, financial, privacy, and safety implications. Hence, privacy, confidentiality, authentication, authorization, and integrity are fundamental requirements. Conventional security and privacy mechanisms are not suitable for BANs due to

Technology	Spectrum	Modulation	Channels	Data rate	Operating space	Peak power	nJ/b	Topology	Join time
Bluetooth classic	2.4 GHz	GFSK	79	1–3 Mb/s	1–10 m on-body only	~45mA @3.3V	50	Scatternet	~3 s
Bluetooth Low Energy	2.4 GHz	GFSK	3	1 Mb/s	1–10 m on-body only	~28mA @3.3V	92	Piconet Star	<100 ms
ZigBee	2.4 GHz	O-QPSK	16	250 kb/s	10–100 m on-body only	~16.5mA@1.8V	119	Star, Mesh	30 ms
ANT	2.4 GHz	GFSK	125	1 Mb/s	10–30 m on-body only	~22mA @3.3V	73	Star, tree, or Mesh	
Sensium	868 MHz 915 MHz	BFSK	16	50 kb/s	1–5 m on-body only	~3mA @1.2V	72	Star	< 3 s
Zarlink ZL70101	402–405 MHz 433–434 MHz	2FSK/4FSK	10 MedRadio, 2 ISM	200–800 kb/s	2 m in-body only	~5mA @3.3V	21	P2P	< 2 s

Table 4. *Characteristics of candidate technologies for BAN.*

limited processing power, memory, and energy, lack of user interface, unskilled users, longevity of devices, and global roaming. Hence, novel lightweight and resource-efficient methods have to be developed for BANs [8].

There are inherent trade-offs among security, availability, and utility goals [9]. A highly secure system (say an ICD) may prevent medics/paramedics from accessing critical physiological information in case of an emergency (cardiac arrest), thereby endangering the life of the person. On the other hand, any vulnerability in an ICD could be exploited by an adversary to induce heart failure. Striking the right balance among these conflicting goals is very challenging. Global roaming over heterogeneous infrastructure networks further complicates the end-to-end security provisions.

REGULATORY COMPLIANCE

Medical devices are subject to stringent regulations to promote the safety and well being of users. Compliance to applicable regulations set forth by the FCC, U.S. Food and Drug Administration (FDA), European Telecommunications Standards Institute (ETSI), and other regulatory agencies is essential [10]. For example, in the United States the FDA regulates real-time connectivity requirements for patient monitoring. Similarly, HIPPA governs the privacy, integrity, and access control requirements for patient data in the United States. The FCC and other authorities impose limit on specific absorption rate (RF energy absorbed into human tissue) [11]. Regulatory compliance is complicated by the fact that the device wearer is free to roam globally across different jurisdictions.

CANDIDATE WIRELESS TECHNOLOGIES

In this section we review several candidate wireless technologies that are leading contenders in the emerging market of BANs.

Table 4 summarizes mainly the PHY characteristics of these technologies, and Table 5 high-lights their merits and demerits. Note that end-to-end performance is determined by the complete protocol stack (i.e., including PHY and upper protocol layers).

BLUETOOTH CLASSIC

Bluetooth (http://www.bluetooth.com) is a short-range wireless communication standard that defines the link and application layers to support data and voice applications. Bluetooth is depoloyed in more than 2 billion devices, including cell phones and laptops. Bluetooth's link layer employs adaptive frequency hopping spread spectrum full-duplex signal at a nominal rate of 1600 hops/s to reduce interference between wireless technologies sharing the 2.4 GHz spectrum. Up to eight Bluetooth devices form a short-range network called a piconet.

Bluetooth SIG has developed the Bluetooth Health Device Profile (HDP) that defines the requirements for qualified Bluetooth healthcare and fitness device implementations. This profile is used for connecting application data source devices such as blood pressure monitors, weight scales, glucose meters, thermometers, and pulse oximeters to application data sink devices such as mobile phones, laptops, desktop computers and health appliances without the need for cables.

BLUETOOTH LOW ENERGY

Bluetooth Low Energy (BTLE) is an upcoming standard that provides ultra-low-power idle mode operation, simple device discovery, and reliable point-to-multipoint data transfer with power save and encryption functionalities. BTLE will have two implementation alternatives: stand-alone and dual mode. Small devices like watches and sports sensors will be based on a standalone BTLE implementation. Dual-mode implementations will use parts of the Bluetooth classic hardware, sharing one physical radio and antenna. While connected to a standalone BTLE device (without utilization of classic Bluetooth), the device will enjoy the low power consumption

| Technology | Suitability for BAN | |
	Merits	Demerits
Bluetooth classic	Established standard, widespread adoption in cell phones and laptops, health device profile defined, sufficient data rate, low cost	Higher power, limited scalability, limited QoS, coexistence with ISM band technologies, limited security, on-body only
Bluetooth Low Energy	Interoperable with Bluetooth, lower power than Bluetooth, leverage Bluetooth brand	Compatibility requirements limit design freedom, limited scalability, limited QoS, coexistence with ISM band technologies, on-body only
ZigBee	Emerging standard, healthcare profile defined, lower power than Bluetooth, scalable, smaller memory footprint	Low data rate, limited QoS, coexistence with ISM band technologies, on-body only
ANT	Simple protocol, low power, healthcare device profiles defined, smaller footprint	Proprietary, limited throughput, limited QoS, coexistence with ISM band technologies, general-purpose design, on-body only
Sensium	Ultra-low-power, custom designed for BANs	Proprietary, low data rate, limited QoS, coexistence with ISM band technologies
Zarlink ZL70101	Ultra-low power, MedRadio compliant, custom designed for implants	Proprietary, implants only

Table 5. *Merits and demerits of candidate technologies for BAN.*

advantages. The key advantages of BTLE are the strength of the Bluetooth brand and the promise of interoperability with Bluetooth radios in mobile phones.

ZigBee

ZigBee (http://www.zigbee.org) defines a network, security, and application layer protocol suite on top of the PHY and MAC layers defined by the IEEE 802.15.4 WPAN standard. The PHY exploits the direct sequence spread spectrum technique for interference tolerance and MAC exploits carrier sense multiple access with collision avoidance (CSMA/CA) for channel access. Zigbee supports flexible network formation. For example, full-function ZigBee devices form a mesh network to which low-duty-cycle reduced-function ZigBee devices connect as leaf nodes to form a hybrid topology.

Also, ZigBee is highly optimized for low-duty cycle operation of sensing devices (i.e., a sensor can shut off the radio most of the time). This is in contrast to Bluetooth, where a slave needs to keep synchronization to the master, resulting in much longer *radio on* time, and hence much higher average power consumption.

The Zigbee Alliance has developed the Personal Health and Hospital Care (PHHC) profile for interoperable wireless devices enabling secure and reliable monitoring of non-critical, low-acuity healthcare services targeted at chronic disease management, obesity, and aging. It provides full support for IEEE 11073 devices including glucometers, pulse oximeters, electrocardiographs, weight scales, thermometers, blood pressure monitors, and respirometers.

ANT

ANT (http://www.thisisant.com) is a proprietary technology designed for general-purpose wireless sensor network applications. ANT features simple design, low latency, the ability to trade off data rate against power consumption, and a net data rate of 20 kb/s (over-the-air data rate is 1 Mb/s). ANT addresses interference issues in the 2.4 GHz ISM band by employing a time-division multiple access (TDMA)-like adaptive isochronous scheme. ANT incorporates low-level security features.

ANT+ is an open alliance of over 100 member companies that defines health and fitness device profiles and manages network keys. Current ANT+ device profiles include Heart Rate Monitor, Stride-Based Speed and Distance Monitor (footpod), Bicycle Speed and Cadence, and Bicycle Power. Some pending ANT+ device profiles are Weight Scale, Music Player Controls, Multi Sport Speed and Distance, and Environment Sensor.

Sensium

Sensium (http://www.toumaz.com) is a proprietary ultra-low-power transceiver platform custom designed for healthcare and lifestyle management applications. The network adopts a master-slave architecture, where a body-worn slave node periodically sends sensor readings to a central master node. Joining a network is centrally managed, and all communications are single-hop. To reduce energy consumption, all sensor nodes are in standby or sleep mode until the centrally assigned time slot. Sensium features the leading ultra-low power solution (3 mA @ 1.2 V) for low-data-rate on-body applications.

Zarlink

Zarlink (http://www.zarlink.com) has developed an ultra-low-power RF transceiver, ZL70101, for medical implantable applications. It uses a Reed-Solomon coding scheme together with cyclic redundancy check (CRC) error detection to achieve an extremely reliable link. For data

blocks, a maximum BER of less than 1.5×10^{-10} is provided assuming a raw radio channel quality of 10^{-3} BER.

When a ZL70101 transceiver is configured as an implantable medical device (IMD), the transceiver is usually asleep and in a very low current state. The IMD transceiver can be woken up by a specially coded 2.45 GHz wakeup message or an IMD processor to send an emergency message.

The key features of Zarlink ZL70101 are extremely low power consumption (5 mA, continuous TX/RX, 1 mA low power mode), ultra-low-power wakeup circuit (250 nA), and MedRadio compliance.

OTHER TECHNOLOGIES

Proprietary RF technologies such as BodyLAN (www.fitlinxx.com) and Z-Wave (www.z-wave.com) are also emerging on the horizon. Inductive coupling (IC) and body coupled communications (BCC) technologies are also promising. In IC an external coil, held close to the body, powers an implanted coil by a coupled magnetic field. Data transfer takes place by altering the impedance of the implanted loop, which is detected by the external device. The data rate of IC is limited, and it cannot initiate communication from inside the body.

BCC transceivers are capacitively coupled to the skin and use the human body as a channel to exchange data. BCC is energy efficient, and mitigates interference and coexistence issues. BCC can also be used for user identification and automatic formation of BANs, as explained in [8].

STANDARDIZATION

The success of many wireless technologies such as Wi-Fi and Bluetooth is driven by standardization. Standardization enables interoperability and seamless user experience, and drives down the cost by exploiting economies of scale. Standardization frees the consumer from vendor dependence and empowers them to buy what best suits their needs rather than what works.

Interoperability, low cost, and user convenience are key enablers for the mass market, which is why there has been growing interest in standardizing healthcare technologies. The IEEE 802.15.6 Task Group [1] is developing the first industrial standard encompassing PHY and MAC layers for BAN. This standard is expected to fill the critical gap in the peak power vs. data rate graph shown in Fig. 2. Advances in low-power RF technology are likely to lower peak power consumption significantly, thereby making low-cost small disposable sensor patches a reality. It remains to be seen whether the upcoming IEEE 802.15.6 standard outperforms other standardized technologies such as ZigBee and Bluetooth, and succeeds in penetrating the market.

To enable true plug-and-play interoperability, all layers of the protocol stack, application profiles, and data exchange formats have to be standardized, which is currently underway in the following groups.

The ISO/IEEE 11073 Personal Health Data Working Group defines standards and protocols that facilitate exchange of health information
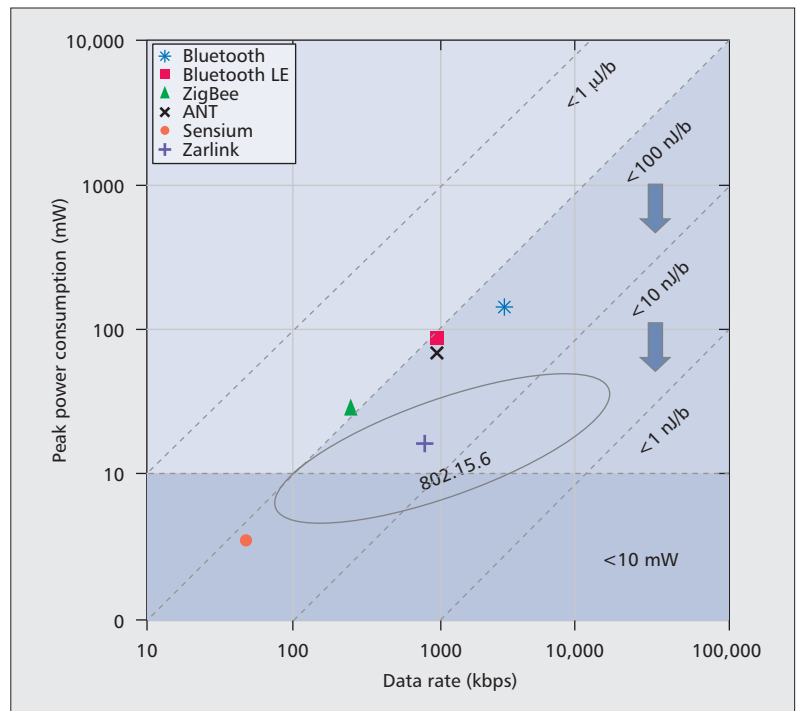

Figure 2. *Target position of emerging BAN technology.*

between peripheral area network devices and application hosting devices such as cell phones, personal computers, and gateways. The group defines transport-independent applications and information profiles including data formats, exchanges, and terminology.

The Continua Health Alliance has been developing interoperability guideline, testing, and certification program for the emerging personal telehealth ecosystem targeting disease management, aging independently, health, and fitness. Continua's interoperability guideline defines profiles over existing or upcoming standards. Continua defines interoperability goals around four network interfaces [12]. The Peripheral Area Network Interface connects body area sensors and actuators to application hosting devices. For instance, Bluetooth is a candidate technology for lower-layer connectivity, and IEEE 11073 protocols are candidates for higher layers. Similarly, a LAN or WAN interface connects application hosting devices to LAN or WAN devices, respectively. The Alliance has endorsed ZigBee healthcare as Continua's low-power LAN standard.

SUMMARY

BAN is a promising technology that can revolutionize next-generation healthcare and entertainment applications. BAN brings out a new set of challenges in terms of scalability, energy efficiency, antenna design, QoS, coexistence, interference mitigation, security, and privacy to name a few, which are highlighted in this article. We also discuss the state-of-the-art technologies and standards relevant to BANs, and their merits and demerits. Developing a unifying BAN standard that addresses the core set of technical requirements is the quintessential step to unleash the full potential of BAN, and is currently under

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discussion in the IEEE 802.15.6 Task Group.

In the end several non-technical factors will also play crucial roles in the success of BAN technology in the mass market such as affordability; legal, regulatory, and ethical issues; and user friendliness, comfort, convenience, and acceptance. BAN technology needs the blessing of key stakeholders in the healthcare domain including the medical electronics industry, patients, physicians, caregivers, policy makers, patient advocacy groups, and payers (insurance companies) for it to become the pervasive technology. We, engineers, researchers, and practitioners from multiple disciplines, must come together and strive hard to overcome technical roadblocks in order to bring the vision of a ubiquitous healthcare network to reality.

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