BODY AREA SENSOR NETWORKS: REQUIREMENTS, OPERATIONS, AND CHALLENGES

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A health-care system that promises the continuous and reliable gathering and objective analysis of physiological and behavioral aspects of a patient, and delivers this information to physicians, has been the goal of body area networks (BANs). BANs can tackle health-care monitoring and delivery challenges by wireless technology and mobile and cloud computing through the use of independent sensors and actuators attached to the body. BANs can accomplish what human–computer interaction aims for, i.e., the design of technologies that are flexible to human needs.

In a wireless BAN, the nodes or sensors are placed on the body or on everyday clothing. These sensors that create an interface to humans have ultra-low power connectivity, which allow them to be portable and measure vital signs outside a hospital or other health-care settings. BANs connect several sensors on the body to a central processing system. This information is then transferred to a medical network, where health-care professionals can assess the user's health condition. The data can be further processed to diagnose the medical condition. Allowing the medical data to be sampled, processed, and transmitted while the user is at home or on the move, without restraining the user's activities, is a key attribute of a BAN. Since a BAN is associated with wireless transmission of a user's personal data, it is also known as a wireless personal area network. The employment of telemedicine by BANs has transitioned in-person hospital visits to remote consultation; telemedicine uses mobile communication and information technology to deliver health care in the modern world.

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BANs focus on bringing about radical changes in the health care delivered by ambulances, emergency rooms, operation theaters, clinics, and homes. It aims at detecting any short- or long-term abnormalities in users, the regulation of treatment procedures, alerting the caregiver in case of an emergency, and improving patient comfort. Other potential applications of BANs include the protection of those who are exposed to dangerous environments such as soldiers, responders, and deep-sea and space explorers. Figure 1 shows some of the applications that involve BANs.

Technical requirements of a BASN

Biomedical sensors are interconnected into a system to form a body area sensor network (BASN), which is derived from BANs. The term BASN is used when referring to telemedicine or m-health that involves mobile communication, networking, and computing. A BASN node acts as an interface, helping

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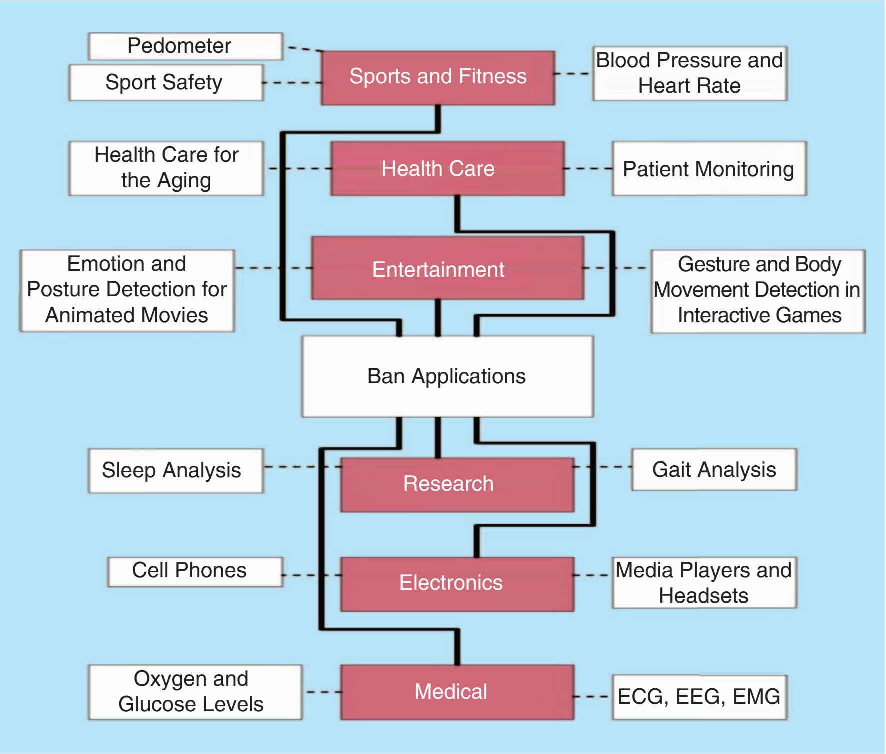

Fig. 1 The potential applications of BANs.

in processing and transmitting data in medical applications. Figure 2 shows the structure of a BASN node.

System architecture of a BASN

This system usually has a three-stage architecture, and each stage has a unique location and function. The three stages, as shown in Fig. 3, are categorized in order as the sensors, the data hub, and the medical network.

Sensors

Sensors, specifically wireless sensors, come in different shapes and sizes. These sensors receive signals from the body and relay them to each other and the data hub.

There are different kinds of sensors. Physiological sensors are used to measure altered blood pressure; blood glucose level; temperature; blood oxygen level; and the signals related to ECG, EEG, and EMG. Biokinetic sensors are used to measure the acceleration and the angular rate of rotation that results from body movements. Ambient sensors are used to measure environmental factors such as temperature, humidity, light, and the sound pressure level. The sensor readings are assessed by physicians to get the medical status of the patient.

The connectivity of sensors with a processing device is achieved using radio frequency technologies. Different wireless technologies such as ANT, Bluetooth classic, Bluetooth low energy, Sensium, Zarlink ZL70101, and Zigbee use different spectrums to operate and have different topologies and on-body operating space.

Data hub

The information received from the sensors can be stored in the data hub. The data hub is a device that allows the sensor data to be stored for immediate or later release of the data to a medical network. The data hub is usually a cell phone or personal digital assistant. It acts as a mediator for the communication between the three tiers as shown in Fig. 3. Information from the data hub can be transferred to a medical network via the Internet or other means.

Medical network

The medical network is the most crucial tier as it receives all of the information about the patient's medical status, which is then assessed by physicians. The medical network is usually operated by a hospital, clinic, or a telemedicine center. This network has to protect all personal data and handle multiple users. Gathered data can be sent to the medical network over a local area network, wide area network, or a cellular network.

As shown in Fig. 3, if a medical condition is detected, biofeedback systems can be formed within a BASN. These systems can trigger a treatment procedure when a medical condition is detected in the user. For example, if the blood glucose level is low or high, an implanted sensor detects the level of sugar and wirelessly triggers an insulin pump to regulate the amount to be injected. These events are insensitive to delays, and the information can be sent later for analysis. A sensor that detects cardiac arrest can trigger a wireless-enabled implantable cardioverter defibrillator to call an ambulance, and a fall detector can send an emergency call to the hospital or caregiver when a fall is detected. These are critical events where, once the signal is processed, the information is sent immediately to emergency services. Feedback control can be used to fix and assist the user with physical functions. In this case, a physiological signal such as the movement of a facial muscle can be used to replace the function of an injured or paralyzed limb(s).

Different applications of BASNs call for specific technical requirements. Applications such as capsule endoscopy, deep brain simulation, ECG, EEG, EMG, monitoring oxygen and carbon dioxide levels, blood pressure, and temperature require different data rates, topologies, bit error rates, duty cycles, and battery lifetimes. There are various issues that have to be

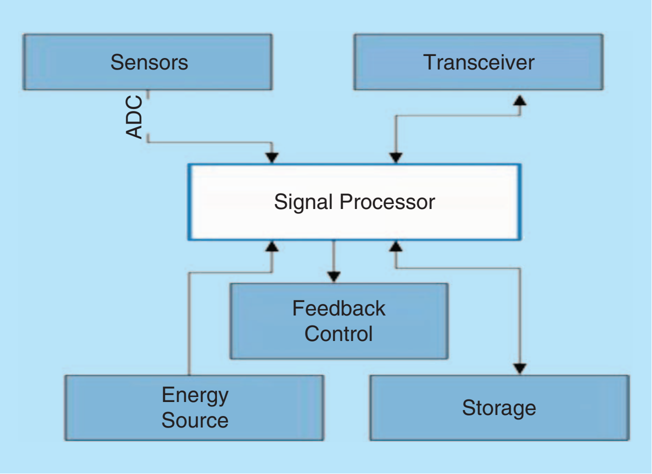

Fig. 2 The architecture of a BASN node.

taken into account while designing wireless systems. The frequency band selection for BASNs is crucial. Some BASN devices are carried globally by users, and this requires the BASN radio to act worldwide. There are various frequency bands that can be used for BASN applications. These include MedRadio; General Telemetry; Wireless Medical Telemetry Service; Industrial, Scientific, and Medical; and Ultrawideband. The operational frequency bands for each, along with the merits and the demerits can be found in the article by Patel et al.

Human body as a communication channel

The study and modeling of a transmission channel is imperative when it comes to the design of wireless devices. Channel models for wireless BASNs are categorized into on-body to on-body, on-body to around-body, in-body to on-body, and in-body to in-body. Efforts have been made into making the human body a communication channel, where the body can act as a carrier of wearable devices. It is crucial that the propagation characteristics of wireless radio waves are looked into while developing a BASN channel model. These characteristics can then be used for the design of suitable BASN transceivers.

Wegmueller et al. attempted to model the human body for intrabody communication. The idea is that the data from the sensors will wirelessly travel to a single node on the body. This node, which can be a monitoring node or a wrist watch, will then be wirelessly connected to the hospital medical network via a wireless technology. Transmission of signals is done through galvanic coupling. The signal is transferred from a transmitter to a receiver by engaging signal currents galvanically into the body. The transmitter forms a regulated magnetic field which the receiver senses. Figure 4 shows the concept of electrical signal transmission in the body.

Energy consumption in a BASN

Energy efficiency in BASNs

BASN nodes have to be extremely energy efficient. The batteries should last for years. The sensor node, shown in Fig. 3, consumes the most energy when it performs communication. Energy consumed at different layers of the communication stack, namely physical (PHY), medium access control (MAC), and network (NWK) layers, can be optimized. Energy expended at the physical layer can be reduced by an ultra-low power radio, for example using the one proposed by Shuo Xiao et al. Sensor data is collected and organized into packets that can be periodically transmitted by a radio. This is a classical approach to the reduction of

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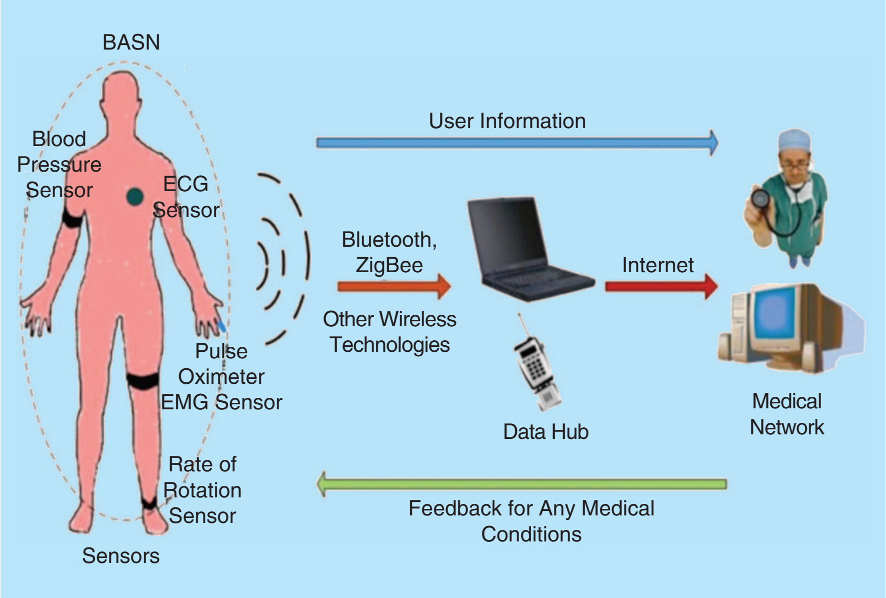

Fig. 3 The architechture of a body area sensor network.

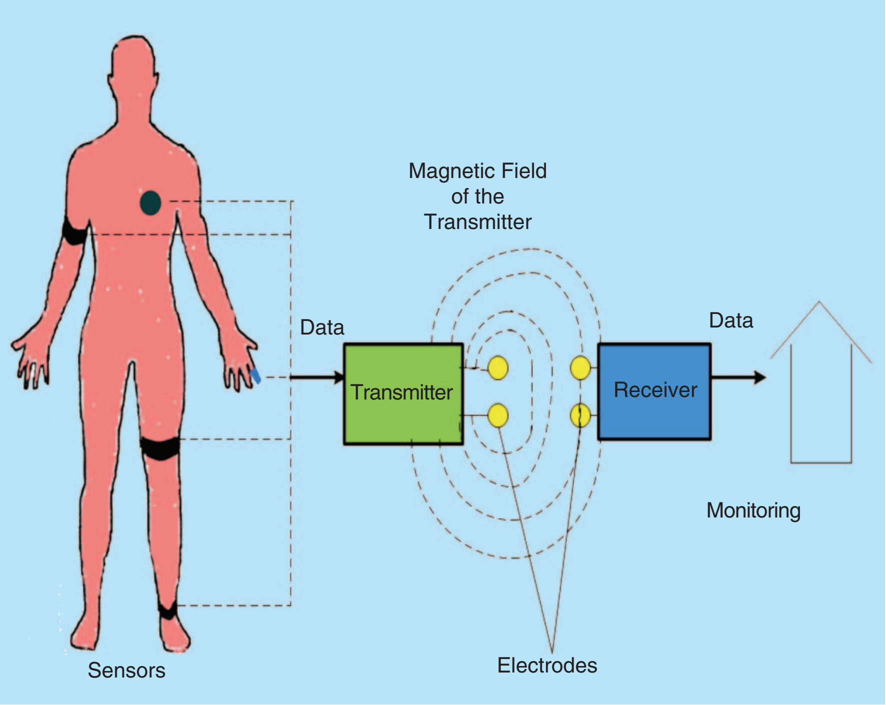

Fig. 4 The electrical transmission of signals in an intrabody BAN channel. The electromagnetic field on or inside the body has to be determined for each position of the transmitter on or inside the body.

power consumption. At the MAC layer, energy can be saved by medium access control protocols that turn off the radio whenever packets do not have to be transmitted or received. The specifications at the MAC layer can greatly affect the power consumption of a sensor network.

Various MAC techniques have been implemented to improve the efficiency of BASNs. Slots can be allocated to reduce major packet losses between the sensor and the hub. When packets are lost, energy and the particular time slot is wasted. Dynamically allotting slots can increase reliability without increasing energy consumption. In the case of a transmission failure, scheduling a retransmission by employing efficient relay nodes can ensure a reliable and efficient BASN. Controlling the transmit power of each node can improve transmission reliability and energy efficiency.

Energy harvesting for self-powering of devices

The human body can produce enough heat to create a power density of 20 mW/cm^2, in comparison to the 15 mW/cm^2 produced by a solar panel exposed to outdoor sunlight. This makes the human body an eligible candidate for energy harvesting. This thermal energy can then be harvested by thermoelectric generators (TEGs), which in turn gets converted to electrical energy. The TEG then continuously charges a battery or super-capacitor that powers electronic modules. These thermal energy harvesters help in the development of autonomous health-care monitoring systems.

Energy can also be harvested from other sources such as vibrations or temperature. Hanson et al. investigated the average power a BASN user can harvest from seven different sources, deployed simultaneously, on an average day. The sources include solar power (from both inside and outside), vibrations, pressure variation, air flow, human power, and temperature. The energy produced is highest during the afternoon (approximately 2.91 mW/cm^2), compared to a blackout period in the morning where the BASN nodes are almost rendered powerless (approximately 0.3 mW/cm^2). Energy harvesting from ambient sources such as sunlight or vibrations is an attractive way to prolong the battery life. However, the research on this area is limited.

Other energy-saving techniques

Using the human body as a communication channel is more energy efficient and reliable. This idea of body-coupled communication is suggested to be an effective way of improving energy efficiency of the PHY layer in BASNs. Research is being done on developing low power protocols for the MAC layer. The concept used in developing these protocols is that the nodes in a BASN alternate between sleep and active modes, thus saving energy. However, hese protocols are more efficient when dealing with RF wireless sensor networks.

On-node storage of data enhances BASN functionality and prolongs battery life, along with archiving data. Information insensitive to delay can be cached, which helps prolong battery life and decreases errors. Data rate and power consumption are important criteria for a system that can be worn on the body for long time data acquisition. The analog signal is converted to the digital domain before the data is stored and transferred. This type of conversion is provided by analog-to-digital converters. Lowering the data rate proportionally lowers the power consumption of the device by slowing down processing and transmission of digital data or the storage stages.

> BASNs EMPLOY A THREE-TIERED ARCHITECTURAL SYSTEM THAT REQUIRES VARIOUS TECHNICAL REQUIREMENTS FOR ITS OPTIMAL AND EFFICIENT OPERATION.

Developing low-power converters to reduce the power consumption of the entire device was the aim of Rieger et al. The data processing in BASNs is hierarchical. This is to preserve the efficiency of the system and utilize the asymmetry of the resources. Data captured by the sensors are processed by microcontrollers to extract valuable information. This is then wirelessly transferred to other devices via the Internet. With each processing level, power consumption increases. This explains the hierarchical nature of BASNs, where hardware and software have to work together through many levels of wireless infrastructure.

Shuo Xiao et al. have shown through various experimental scenarios that fixed transmit power control compromises energy saving and system reliability. However, adaptive transmit power saved nearly 35% of energy during various scenarios, without compromising reliability. Using supercapacitors and carbon nanotube-based stores can potentially improve battery life. The biofuel cell is a potential option, where chemical energy from fuel like glucose is converted into electrical energy in the presence of biocatalysts.

Challenges and future research

BASNs suffer challenges such as eavesdropping and message modification due to short communication range. User-oriented requirements for the adoption of BASNs include value, safety, security, privacy, compatibility, and ease of use. A unique challenge faced by wireless communication in a BASN is the signal attenuation between the sensor and the data hub. The level of attenuation should not be below the receiver's sensitivity. The data quality can be compromised if the sensor is ineffectively placed or displaced due to movement. The location of the sensors on or within the human body, along with its orientation relative to each other and the body, are the main factors that affect the strength of the signal in a BASN.

Another problem to resolve is BASN interference. This can occur when many people wearing BASNs come into a group and are within the range of other BASNs that could lead to packet collision or loss. Researchers have tried to implement methods that allow the sensors or nodes of BASNs to realize that they belong to the same individual. One such method employs biometrics, which usually involves identifying or verifying an individual by physiological parameters. Physiological characteristics with high levels of entropy (such as blood pressure or glucose level) are usually preferred as they are not prone to hacker attacks that can jeopardize the confidentiality of the medical data. Poon et al. used the timing information of the heart beat as a characteristic to secure the BASN. Shu-Di Bao et al. also developed a scheme that uses principles of biometrics to achieve secure access control during the setup of a wireless link. They used heart rate variability as a physiological trait in their design rather than well known biometric traits such as fingerprints, iris patterns, or palmprints.

With one BASN per individual, multiple BASNs that share a limited wireless medium can be present in public locations. The devices in the same BASN do not communicate with the devices in another BASN, and the data sent by two BASNs simultaneously through the same channel will not necessarily reach the destination(s). To avoid packet collision or losses, ideally only one device is allowed to send data through a given channel at a given time. Using multiple channels can reduce the chances of collision. Thus, it is important to allocate channels or wireless mediums appropriately to avoid data collision or interferences. When each BASN has an individual channel for itself, packet delivery is nearly 100%, without any collision or interference. Packet-, link-, or flow-based approaches can be used for channel allocation.

Lower power consumption, increased security measures for a patient's medical data, noninterference, increased data throughput, message latency, and the ability to adapt to various network configurations are still areas where research is currently being done. Researchers are working on improving deep brain simulation, heart regulation, drug delivery, and prosthetic actuation. Efforts are being put into developing power-efficient processors. Research is also being done in the areas of system integration, low-power sensor interface, and optimization of wireless communication channels. Other potential applications include analyzing the activity of patients with Parkinson's disorder, monitoring vital signs in the ear, and estimating the respiration rate with an existing cardiac sensor.

Conclusion

This article provides an overview of BASNs, an application of wireless technology that changed health care to suit the comfort of the population. There are various applications of BASNs and attempts have been made to make the human body a channel for wireless communication. BASNs employ a three-tiered architectural system that requires various technical requirements for its optimal and efficient operation. Energy consumption is one of the major issues that is currently being addressed through self-harvesting and many other techniques. Even with the benefits at hand, there are various issues such as interference and eavesdropping that BASNs have to tackle. Biometrics is a widely used solution. Researchers are also working on various ambitious projects that deal with improving deep brain simulation, heart regulation, drug delivery, and prosthetic actuation to use BASN effectively.

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Read more about it

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