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Body Area Network

Standardization, Analysis and Application

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Bachelor's Thesis

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Valitse kohde.

SAVONIA UNIVERSITY OF APPLIED SCIENCES **THESIS**
Abstract

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Abstract

The advancement in technology coupled with the increasing use of wireless networks has brought to light the development of Body Area Networks. Body Area Network is designed to provide a platform for continuous health monitoring of patients and sometimes application of medication. Although BAN standards are been designed for medical purposes, its usefulness covers a range of applications.

This thesis offers a general overview of wireless networks. Firstly it focused on BAN positioning and requirements. Then, followed by BAN standardization and communication. A further detailed analysis of frame processing of Media Access Control specified by IEEE 802.15.6 and the physical layer is discussed.

Finally, the current and future applications of BAN are summarized, providing a comprehensive review of BAN.

Keywords
Body Area Network, IEEE 802.15.6, Media Access Control (MAC), Physical Layer (PHY)

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I will like to say a big thank you to my family and my very good friends, home and abroad for their immersed encouragement in putting this work together.

Finally, "I count not myself to have apprehended: but this one thing I do, forgetting those things which are behind, and reaching forth unto those which are before, I press towards the mark of the prize of the high calling of God in Christ Jesus".

Philippians 3:13 & 14

Diamond Asare
Kuopio, 18th February, 2014.

Abbreviations

BAN	Body Area Network
BSN	Body Sensor Network
CAN	Car Area Network
CDMA	Code Division Multiple Access
CDPD	Cellular Digital Packet Data
ECG	Electrocardiogram
EEG	Electroencephalography
ESTI	European Telecommunication Standards Institute
FDMA	Frequency Division Multiple Access
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
GTK	Group Temporal Key
HBC	Human Body Communication
HCS	Header Check Sequence
HME	Hub Management Entity
IEEE	Institute of Electrical and Electonics Engineers
LAN	Local Area Network
LTE	Long-Term Evolution
MAC	Media Access Control
MICS	Medical Implant Communication Service
MK	Master Key
MSDU	Media Access Control Service Data Unit
NB	Narrow Band
NIC	Network Interface Card
NME	Node Management Entity
OFDMA	Orthogonal Frequency Division Multiple Access
OS	Operating System
PAN	Personal Area Network
PD	Personal Device
PDA	Personal Digital Assisstant
PHY	Physical
PLCP	Physical Layer Convergence Protocol

PPDU	Physical – layer Protocol Data Unit
PSDU	Physical Layer Service Data Unit
PTK	Pairwise Temporal Key
QoS	Quality of Service
RF	Radio Frequency
SAP	Service Access Point
SFD	Start Frame Delimiter
TTA	Telecommunications Technology Association
UMTS	Universal Mobile Telecommunications System
UWB	Ultra – Wide Band
WAN	Wide Area Network
WiBro	Wireless Broadband
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network
WSN	Wireless Sensor Network
WWAN	Wireless Wide Area Network

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1 INTRODUCTION

Technology has advance in recent years and has revolutionized human daily activities. The development of Nano and micro devices for monitoring activities in and around the human body has increased significantly, given rise to the development of standards to provide guidelines for such devices and their development.

Wireless body area networks also sometimes referred to as body sensor network (BSN) or IEEE 802 Task Group 6 (IEEE 802 an international group specialized in the developing of standards) was formed to develop standards for Wireless Body Area Networks (WBAN).

The sensitivity of the human body requires the use of frequencies that are in compliance with communication standards and the safety of the tissues and organs. Such devices must, have long battery life and transmit at very low power to enhance their use within proximity of the body in order to obtain a measurement or to apply medication.

Body Area Network is designed to provide a platform for continuous health monitoring of patients and sometimes application of medication. Although BAN standards are been designed for medical purposes, its usefulness covers a range of applications such as gaming, control and automation, logistic and transportation, education and training, sports and entertainment and military.
This thesis would evaluate and analyze the development and standardization of BAN and its applications thereof.

2 EVOLUTION OF WIRELESS NETWORKS

2.1 Overview

The development of wireless networks has enjoyed tremendous growth over the past decades. Wireless network communication can be said to be the communication of nodes of elements of a communication system without any form of wire. This communication could be between the elements of the same network or to larger networks or to even the Internet.

The drive for wireless networks arises as the result of:

- Ease of deployment and comparatively low cost.
- Ease of upgrading and low maintenance cost relatively to cabled networks.
- Its superior mobility and flexibility features.

Although wireless networks seems to have a slight edge over cabled networks in terms of mobility, flexibility, cost and convenience it poses its own bottlenecks. These challenges such as:

- Interference from other electronic and electrical equipment operating on the same or similar frequency can posses a great deal to communication between a transmitter and a receiver.
- Privacy and security
  Security is of a major concern when it comes to wireless communication. This is because the medium for communication is radio waves and hence anyone within the coverage area of a wireless network can attempt to access the network.
- Health risk
  Although the RF emitted by wireless devices have not been proven to pose a serious danger, there is always health concern about the level of radiations.
- Frequency regulations
  The available frequencies are almost occupied and therefore there is a need for effective coordination and a more prudent use of the available spectrum (Becta 2004, 3- 5.)

2.2 Types of wireless networks

Wireless networks can be grouped either by coverage area or when they were developed, referred to as generation. Grouping enable the identification of specific needs and hence the development of standards to meet these needs. Wireless networks can be classified into four major groups, namely:

- Wireless LANs
- Wireless MANs
- Wireless WANs
- Wireless PANs

These groups are sub-divided into other smaller groups to meet specific applications.

2.2.1 Wireless LANs

A wireless LAN provides the exchange of data and information locally between computers and devices through a radio wave medium. Basically, most wireless LANs consists of transmitters/receivers known as transceivers and referred to as access point and a wireless NIC. The access point provides the bridging between the wired network and wireless network. The access point does the receiving, buffering and transmission of data between the wireless and wired network. Wireless LANs are short-range wireless networks that may span a few meters. Wireless LANs can however be extended by mean of two or more access points and this is referred to as Extended Service Set (Becta, 2004).

The architecture of wireless LAN could be star (where the access point is placed as a hub) or a peer-to-peer connecting many access points to form a network (Goldsmith, 2005).

Wireless LANs standardization and interoperability vary depending on the application area of the WLAN. IEEE 802.11-1997 describes wireless LANs and it comes in various versions described in alphabets as amendments to IEEE 802.11 except 802.11F and 802.11T that are practiced recommended (Lammle 2012, 340).

A comprehensive summary of IEEE 802.11 standards and their purposes are represented in table 1.

Standards	Purpose and year
IEEE 802.11a	54 Mb/s 5 GHz standard, 1999
IEEE 802.11b	Supports 5.5 and 11 Mb/s, 1999
IEEE 802.11c	Bridge operation procedure, 2001
IEEE 802.11d	International roaming extensions, 2001
IEEE 802.11e	Quality of Service (QoS), 2005
IEEE 802.11F	Inter-Access Point protocol, 2003
IEEE 802.11g	54 Mb/s, backwards compatible with b, 2003
IEEE 802.11h	DFS and TPC, 2004
IEEE 802.11i	Enhance security, 2004
IEEE 802.11j	Extensions for Japan and US, 2004
IEEE 802.11k	Radio resource management, 2008
IEEE 802.11m	Maintenance of the standard: odds and ends
IEEE 802.11n	High throughput improvement with MIMO, 2009
IEEE 802.11p	Wireless Access for Vehicular Environment (WAVE), 2010
IEEE 802.11r	Fast BSS transition, 2008
IEEE 802.11s	Mesh Network, ESS, 2011
IEEE 802.11T	Wireless Performance Prediction (WPP)
IEEE 802.11u	Internetworking with non-802 networks, 2011
IEEE 802.11v	Wireless network management, 2011
IEEE 802.11w	Protected Management frame, 2009
IEEE 802.11y	3650-3700 MHz operation in US, 2008
IEEE 802.11z	Extension to Direct Link setup, 2010
IEEE 802.11aa	Robust streaming of Audio Video Transport Stream, 2012
IEEE 802.11ac	Very high throughput 6 GHz, 2014
IEEE 802.11ad	Very high throughput 60 GHz, 2012
IEEE 802.11ae	Prioritization of management frames, 2012

Table 1. IEEE 802.11 Standard and amendments (Banerji & Chowdhury. 3-4.)

2.2.2 Wireless MANs

Wireless Metropolitan Area Networks (WMANs) are point – to – point or point – to – multipoint networks that can span over a metropolitan city providing wireless connectivity to users at different locations. These networks are larger than the WLANs but smaller than WWANs.

Wireless MANs can be categorized into two types depending on the setup infrastructure, namely:

- Wireless last mile
- Back haul

The last mile is based on wired network infrastructure; here base stations are connected to the backed end of a wired network.

The back haul however is a purely wireless network providing options for enterprises that cannot afford the lease or the installation of fiber optic.

Wireless MAN has seen the development of standards such as:

- IEEE 802.16
- ETSI HIPERMAN
- TTA WiBro

These standards provide a benchmark for Wireless MAN implementation (Rackly, 2007.)

Table two describes IEEE 802.16 standards and area of implementation (Wikipedia, 2012).

Standards	**Description**	**Status**
IEEE 802.16	Fixed broadband wireless	Superseded
IEEE 802.16.2	Recommended for coexistence	Superseded
IEEE 802.16c	System profile for 10-66 GHz	Superseded
IEEE 802.16a	Physical Layer and MAC definitions for 2 – 11 GHz	Superseded
IEEE 802.16b	License-exempt frequencies	Withdrawn
IEEE 802.16d	Maintenance and system profiles for 2 – 11 GHz	Merged
IEEE 802.16	Air Interface for Fixed Broadband Wireless Access System (2004).	Superseded
IEEE 802.16.2a	Coexistence with 2 – 11 & 23.5 – 43.5 GHz (2004)	Merged
IEEE 802.16.2	Recommended practice for coexistence (2004)	Current
IEEE 802.16f	Management information based for 802.16 - 2004	Superseded
IEEE 802.16e	Mobile Broadband Wireless Access System (2005)	Superseded
IEEE 802.16k	Bridging of 802.16	Current
IEEE 802.16g	Management plane Procedures and Serves (2007)	Superseded
IEEE 802.16i	Mobile management information based (2007)	Merged
IEEE 802.16	Air Interface for Fixed and Mobile Broadband Wireless Access System (2009)	Current
IEEE 802.16j	Multi-hop relay	Current
IEEE 802.16h	Improved Coexistence Mechanisms for License-Exempt Operation (2010)	Current
IEEE 802.16m	Advanced Air Interface with data rates of 100 Mbit/s mobile and 1 Gbit/s fixed (WiMAX) - 2011	Current
IEEE 802.16n	Higher reliability networks	In progress
IEEE 802.16p	Enhancement to support machine – to – machine operation.	In progress

Table 2. IEEE 802.16 standards

Table two has shown tremendous advancement of Wireless MANs standards indicating a rapid growth in the usage of Wireless MANs.

The ETSI HIPERMAN is a proposed standard from European Telecommunication Standard Institute. This standard was developed in close collaboration with IEEE 802.16 to use unlicensed spectrum for the provision of fixed wireless access to small and medium scale businesses based on point – to – multipoint or mesh network (Rackly, 2007.) Table three summarizes the parameters of ETSI HIPERMAN.

Parameter	**HIPERMAN (standard)**
RF band	5.725 – 5.875 GHz
EIRP	< 30 dB (1 watt)
Data rate	Peak data rate > 2 Mbps
Modulation	OFDM
Channelisation	5 MHz, 10 MHz or 20 MHz channel width
Duplex method	TDD and FDD are supported

Table 3. HIPERMAN parameters (Rackly, 2007.)

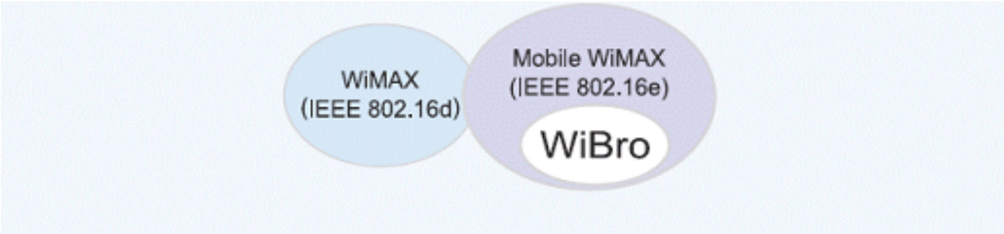
The TTA WiBro is a standard for wireless MAN developed by TTA of South Korea to provide mobile broadband wireless access. The WiBro, which is an abbreviation of wireless broadband, was designed to provide low cost and high data rate, providing wireless broadband anytime, and in anywhere (WiBro, 2007).

Table four is a comprehensive summary of the key physical layer parameters of TTA WiBro.

Parameter	**HIPERMAN (standard)**
RF band	2.300 – 2.400 GHz
Network topology	Cellular structure
Maximum data rate; user	Downlink; 6 Mbps, uplink 1 Mbps
Maximum data rate; cell	Downlink; 18.4 Mbps, uplink 6.1 Mbps
Multiple access	OFDM
Modulation	QPSK, 16-QAM, 64QAM
Channelisation	9 MHz channel widths
Duplex method	TDD

Table 4. TTA WiBro Parameters (Rackly, 2007)

WiBro employs access technology and mobility support as in Mobile WiMAX (IEEE 802.16e). The position of WiBro between WiMAX is illustrated in figure one (WiBro 2007.)



Items	WiMAX(Fixed) (802.16d)	Mobile WiMAX (802.16e)	
			WiBro
Frequency(GHz)	3.5, 5.8	2.3, 2.5, 3.5, etc	2.3
Bandwidth(MHz)	3.5, 7, 10	3.5, 5, 7, 8.75, 10, 15, 20	8.75
Duplex Method	TDD/FDD	TDD	TDD
Multiple Access	TDMA	OFDMA	OFDMA

Figure 1. WiBro position with WiMAX (WiBro 2007.)

2.2.3 Wireless WANs

Wireless WANs are computer data networks that may receive and transmit data using radio signals over a large geographical area. This type of wireless network employs cellular networks such as GSM, GPRS, CDPD, CDMA, UMTS, LTE and satellite communication to transmit data (Benmammar & Amraoui, 2013.)

2.2.4 Wireless PANs

A wireless PAN is a short-range wireless network designed to support mobile computing and portable devices for communication. It provides an infrastructure for home appliances to interconnect, enabling them to access the Internet in some cases. Examples of such technologies are Bluetooth (IEEE 802.15.1), ZigBee (IEEE 802.15.3a) and UWB (IEEE 802.15.4) (Garg 2013, 654.)
The insertion of WPANs has seen development of standards to address the industrial need and somehow put into harmony technologies from different industrial manufacturers. The IEEE 802 has formed a task group 15 to oversee the development of standards for WPAN and its family.

A summary of the developed standards by Group 15 is shown in table five below.

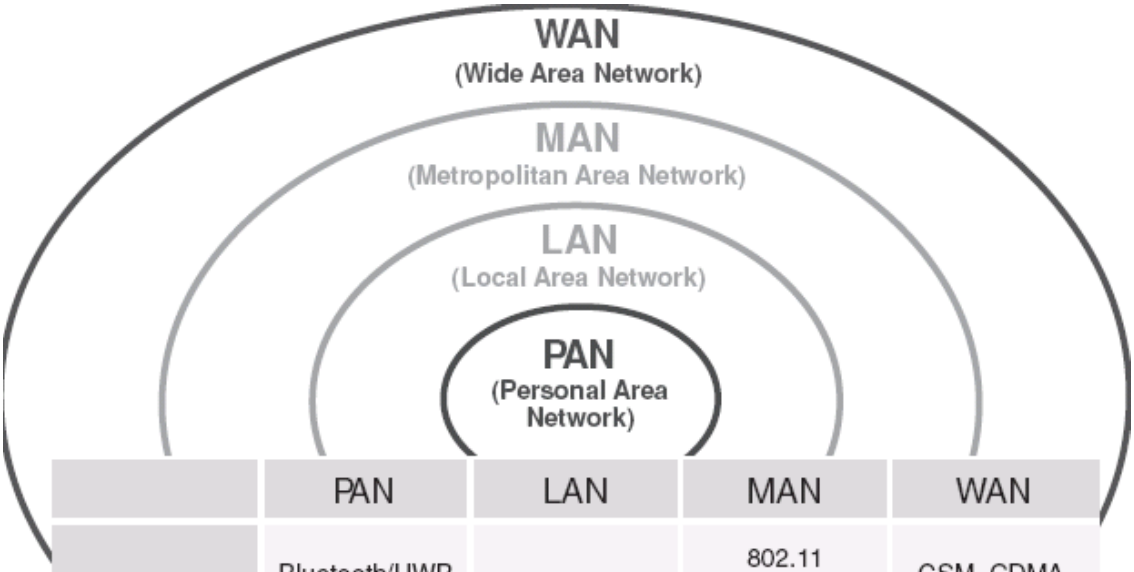
Standard	Description	Status
IEEE 802.15.1	Specification based on Bluetooth System v1.1 & 1.2 (2002 & 2005)	Withdrawn
IEEE 802.15.2	Recommended for coexistence	Hibernation
IEEE 802.15.3	PHY and MAC high-rate WPAN standard	Complete
IEEE 802.15.4	Low-rate PHY and MAC WPAN standard	Superseded
IEEE 802.15.4a	Low-rate alternative WPAN	Approved
IEEE 802.15.4b	Revision and enhancements to 802.15.4	Approved
IEEE 802.15.4f	PHY and MAC amendments for active RFID	
IEEE 802.15.4g	PHY amendment for the Smart Utility Network (SUN)	
IEEE 802.15.5	Mesh networking	Approved
IEEE 802.15.6	Body Area Networks	Draft approved
IEEE 802.15.7	Visible light communication	Ongoing

Table 5. IEEE 802.15 standards (Graton, 2013.)

2.3 Wireless Network Technologies

Wireless network technologies have enjoy a tremendous growth over the past two decades. Technologies operate in the fourth and to the sixth order magnitude, from few centimeters to thousands of kilometers. Industries offer a wide range of wireless network technologies to satisfy the growing need of data and information (Rackley 2007, 3.)

Figure two compares some of the wireless network standards and technologies (Han, Li & Yin., 2013.)



	PAN	LAN	MAN	WAN
Standards	Bluetooth/UWB 802.15.3	802.11	802.11 802.16 802.20	GSM, CDMA, Satellite
Speed	<1 Mbps or <480 Mbps	11–54 Mbps	10–100+ Mbps	10 Kbps– 2 Mbps
Range	Short	Medium	Medium–Long	Long
Applications	Peer-to-Peer Device-to-Device	Enterprise Networks	Last Mile Access	Mobile Data Devices

Figure 2. Wireless networks, standards and technologies

3 BODY AREA NETWORKS

BANs evolved from generic networks referred to as wireless sensor networks (WSNs), which belongs to a big network family known as PAN. BAN however may be described as a set of nodes that can be used to sense, actuate, compute and communicate in a multi-hub wireless channel with each other. BAN’s operation around the human body allows it to be used to collect, process and store physiological, activity and environmental parameters from the host’s body and it’s immediate surroundings. The operation of BAN is not limited to only the outside of the human body. It can be used to implant in order to perform specific tasks (Gupta, Mukherjee & Venkatasubramanian, 2013.)

The development of BAN became necessary since the existing low power and short-range standards such as PAN could not fulfill some of the requirements for medical applications. BAN standards are to support a combination of reliability, QoS, low power, data rate and must be noninterference. The proposed data rate for BAN is up to 10Mbps and it is to use existing industrial scientific medical bands or any frequency band approved by national medical and regulatory authority (IEEE SA. 2012, 15.)
In order to emphasize the need and requirement for standards like BAN, a comparison of some of the existing short range, low power standards are illustrated in Table six.

Standard		Frequency	Data Rate	Scope	Type
802.11	has	5 GHz	54 Mbps	120m	LAN
	b	2.4 GHz	11 Mbps	140m	LAN
	g	2.4 GHz	54Mbps	140m	LAN
	n	2.4/5 GHz	248 Mbps	250m	LAN
802.15.1		2.4 GHz	3 Mbps	100m	PAN
802.15.4		868/915 MHz	40 Kbps	75m	PAN
		2.4 GHz	250 Kbps		
802.15.6		NB	> 1 Gbps	10m	BAN
		(UWB)			
		21 MHz (HBC)			

Table 6. Comparison of IEEE 802.15.6 to other short-range standards (Wikipedia Foundation 2013.)

3.1 BAN Positioning

BAN is described as a short-range, low-powered device that operates around the human body (not limited to humans) providing a variety of applications. These applications may include medical, personal entertainment and consumer electronics. BANs can be described as special WSNs that have lesser nodes and much reliable with special importance placed on QoS as compared to the tradition WSN. BAN in some cases is referred to as BSN.

The positioning of BAN in relation with other wireless networks is shown in figure three.

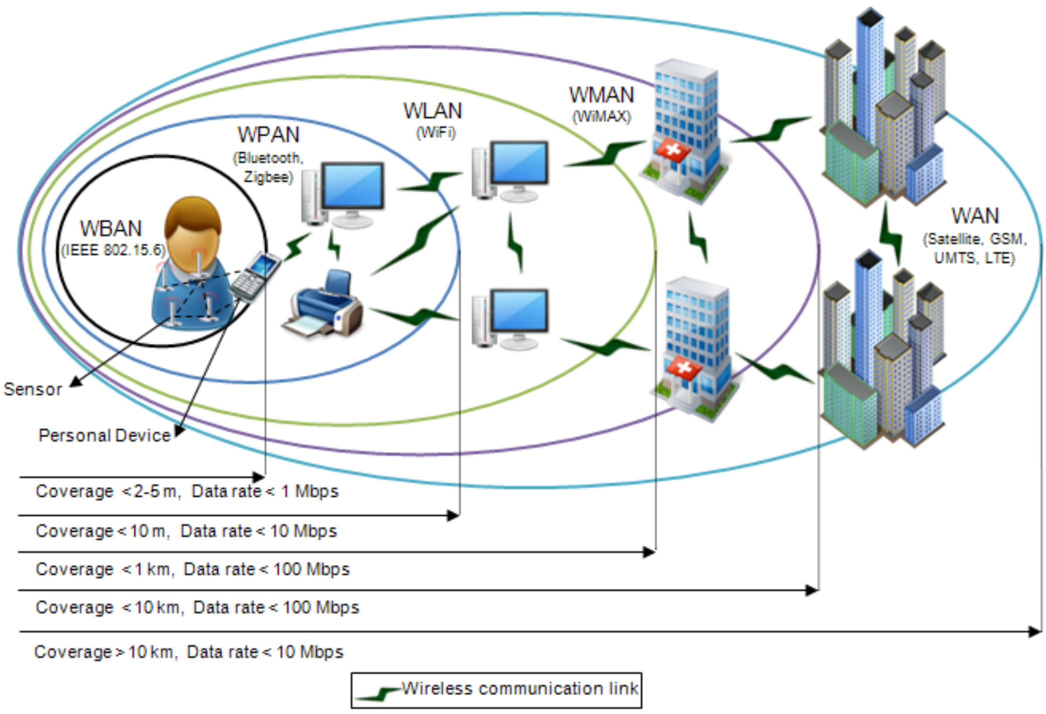


Figure 3. Comparison of BAN with other wireless networks (Movassaghi et. al)

3.2 Architecture of BAN

The architectures of BAN can be summarized in the following categories:

- Hardware
- Network topology
- Communication technology
- Software
- Deployment
- Physical environment
- Energy source

BAN is a network of computing nodes that are used to perform operations to aid monitoring and actuation application in healthcare. BAN is not only applicable in healthcare but also in performance monitoring in sports and providing feedback in military and leisure applications.

3.2.1 The Hardware

The IEEE TG6 recommended and approved hardware components for BAN are as follows:

- A general purpose sensor (humidity, temperature and light)
- A medical device (pulse-oximeter)
- A data collector or aggregator (image collector)
- A controller or tuner (infusion-pump) and
- An access point or a gateway (smart phone)

A lot of platforms for sensing and processing specific signals have been developed (Gupta, et al 2013.)

3.2.2 Network Topology

The IEEE 802 TG6 recommended and approved a one-hub network topology with zero to mMaxBANSize of nodes. A simple one-hub network topology is represented in figure three (IEEE Computer Society 2012.)

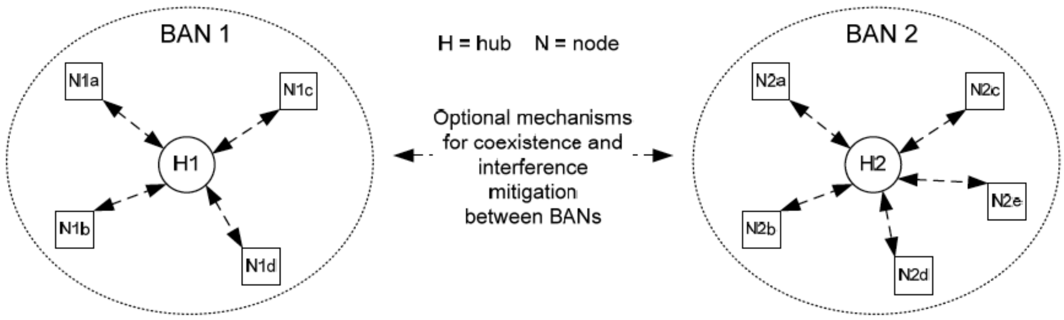


Figure 3. One-hub star network topology

The Task Group also recommended mesh and hybrid network topology as shown figure four (Gupta et al 2013).

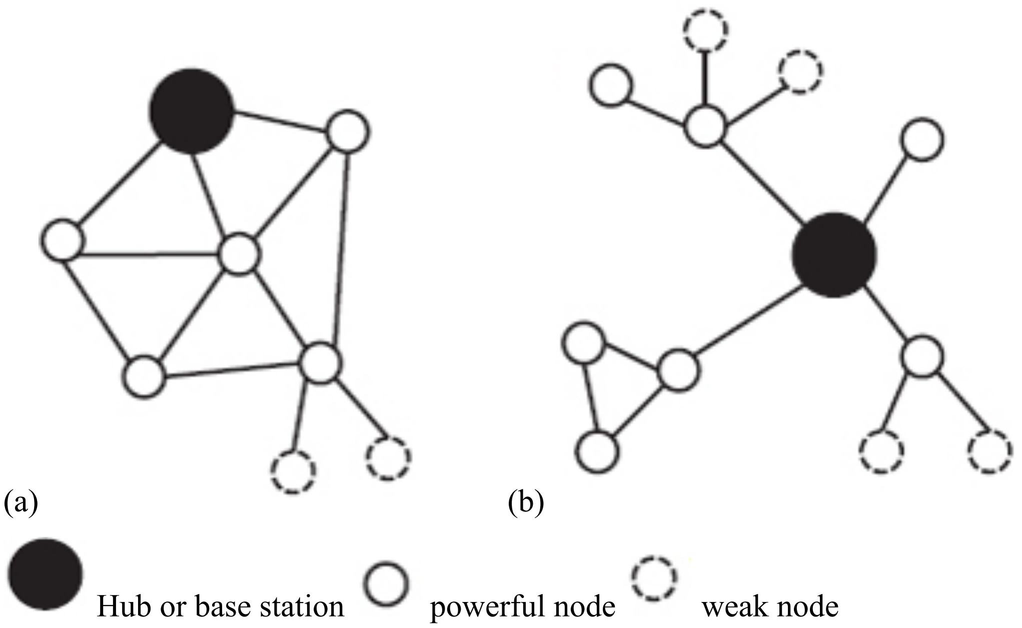


Figure 4. Recommended (a) mesh and (b) hybrid network topology for BAN.

In BANs nodes and hubs are time synchronized based on packet arrival time. Communication is through a wireless channel with assumable reliability. A node in

BAN has neighboring nodes to perform communication through a one-hub wireless link.

Figure five provides an insight to network topology for BAN (Gupta et al).

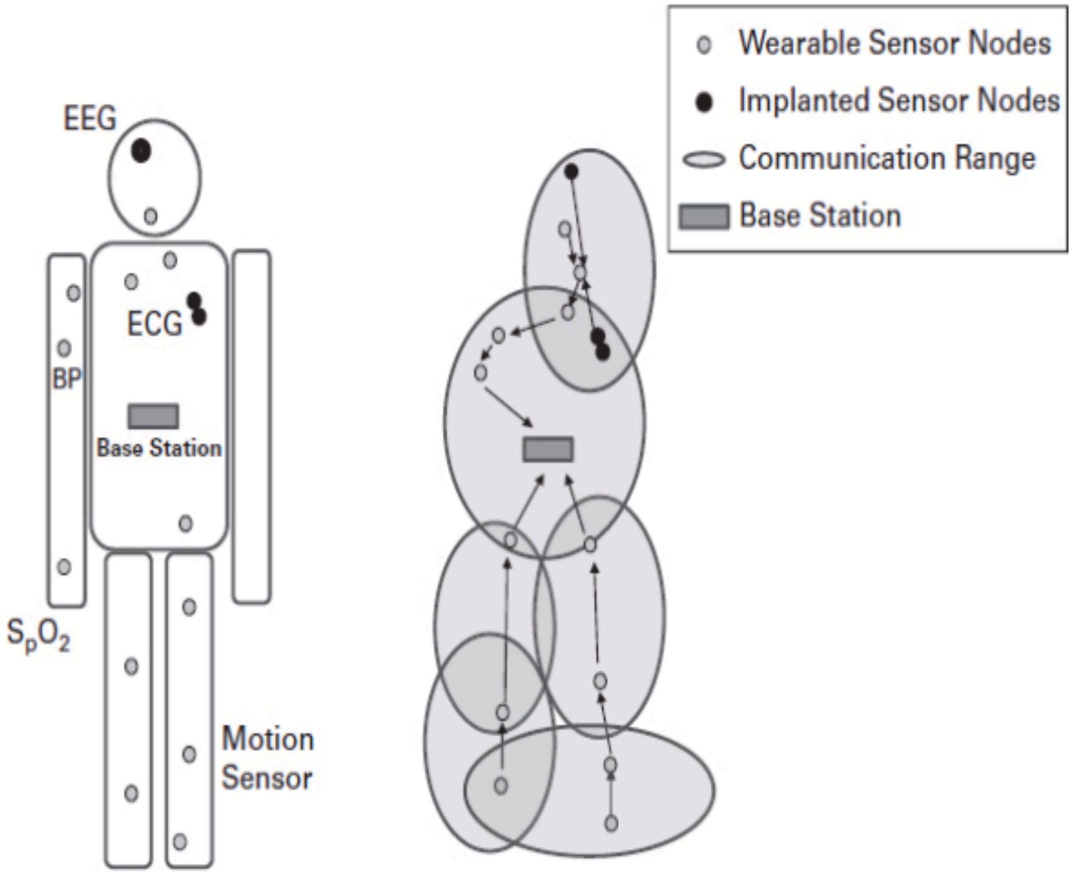


Figure 5. Body Area Network

3.2.3 Communication Technology

Researchers have put forward a lot of communication technologies for BAN. These technologies vary in frequency of transmission, range and power consumption. Although BAN operates heavily in PHY and MAC layer, it has five layers in its protocol stack. These layers perform specific tasks to ensure smooth communication between node – node and node – hub.

- The PHY layer; deals with radio hardware and antenna specifications.
- MAC layer; handles channel access and contention management.

- Network layer; provides a structure reliable data transfer and routing management.
- Application-support sub layer; deals with applications that secure the communication infrastructure.
- Application framework; provides abstraction functionalities of the radio to the application (Gupta et al, 2013.)

Several factors influence the choice of technology for communication, however standards provide basic requirements. Available technologies that work along side BAN are; Zibee, 6lowPAN and Bluetooth low power.

3.2.4 Software

BANs are made up of the sensor type of devices and the base station devices that require different software to function. Sensors or nodes use event-driven software in order to optimize power usage. Computation is event-driven which is based on occurrence of an-event. The most commonly used OS is TinyOS, however there are other OS such as LiteOS, Contiki, RIOT and ERIKA Enterprise. The base stations are normally smart phones with OS such as Android, iOS, and Windows Silverlight.

3.2.5 Deployment

Deployment of sensors in BAN depends on the application and the desired function it has to perform. Sensors could be worn or implanted within the human body for specific applications. For example, medical sensors could be deployed to monitor or deliver medications to patients. BAN has also been networked with car sensors (CAN) to enhanced safety of the driver by providing feedbacks of fatigue. Researchers are exploring a lot of areas where BAN can be deployed to enhance the quality of life and increase safety.

3.2.6 Physical Environment

The human body is mainly the physical environment, although BAN is not limited to only humans.

The environmental influences on the sensor nodes are crucial and the same way deployment can cause side effects on the environment.

3.2.7 Energy Source

To ensure mobility without any obstruction of movement, BAN devices have to be connected wirelessly. Thus the communication between sensing nodes and hubs should basically be wireless. For this purpose to be achieved, nodes and hubs energy sources should be independent. Batteries are the most primary source of energy for BAN and these could be re-chargeable or un-rechargeable. Depending of the BAN application one of the energy source above or both can be selected.

3.3 Requirements of BAN

BAN identification as a special type of sensor network due to its specific needs and requirements. The requirements of BAN are tailed to meet the needs in the applications. BANs are deployed over a loose time varying channel and due to their small scale and proximity to tissues and organs, safety standards must be adhered to. The following are to be considered when designing BAN.

3.3.1 Device types and operating system

Mobility is a key issue in device selection. BANs are designed to support free mobility and hence the choices of devices should not obstruct movement. As discussed earlier in this work, BAN devices include sensor nodes, actuator nodes and personal devices (PD) or BS.

Sensor nodes serves as interface for the acquisition of data from the host (human body) and may consist of a transceiver, power unit, processor and memory, while actuator nodes however received data from the sensor node and act accordingly or act upon the interaction with BAN user and may deliver medication. Actuator nodes consist of similar component as the sensor nodes in addition to actuator hardware.

The PD (smart phone, PDA) provides the user interface and display the necessary result for the user. PDs are of large processors and memory, providing the necessary computation for the interpreting of the results.

3.3.2 Power and Energy

Power consumption is of a most concern in BANs. The longevity of the BAN network depends heavily on the battery life cycle of the sensor and actuator nodes. To obtain miniature size of sensors, battery sizes must be kept small since their size affect the over all size of the nodes. Energy scavenging is one of the most efficient ways of ensuring that the BAN network runs years without any interactions. In order to achieve energy efficient BAN, power consumption level must be restricted and communication should only be done periodically or as at when needed.

3.3.3 Data rate

Data requirement in BAN may vary from application to application and this could range from few kilobit/s to several Mbits/s. Data generated from nodes are low in packet size, however aggregating data from BAN could result to Mbps, a size above the existing low power radios. Death threatening packets are to have much priority and low latency than sensor data. Table seven gives a brief description of data in BAN.

Application	Target Data rate	Latency	BER
Drug delivery	< 16 Kbps	< 250 ms	$< 10^{-10}$
Deep brain stimulation	<320 Kbps	< 250 ms	$< 10^{-10}$
Capsule endoscope	> 1 Mbps		$< 10^{-10}$
ECG	192 Kbps	< 250 ms	$< 10^{-10}$
EEG	86.4 Kbps	< 250 ms	$< 10^{-10}$
EMG	1536 Mbps	< 250 ms	$< 10^{-10}$
Glucose level monitor	1 Kbps	< 250 ms	$< 10^{-10}$
Audio	1 Mbps	< 20 ms	$< 10^{-5}$
Video/Medical imaging	< 20 Mbps	< 100 ms	$< 10^{-3}$
Voice	50-100 Kbps per flow	< 10 ms	$< 10^{-3}$

Table 7. BAN application and targeted data rate (Cordeiro 2007.)

3.3.4 Quality of Service

BAN is expected to support different classes QoS in order to ensure packets delivery. QoS in BAN can be a challenge but this can be addressed from different layers in the network protocol suite. QoS parameters may vary from application to application in terms of level of criticality. Packets must be reliable and priority should be given to life threatening situations (Thapa & Shin, 2012.)

3.3.5 Privacy and Security

Security of data and its privacy is of major concern in the implementation of BAN. BAN was primarily developed for health application and monitoring. Such communication must be secured due to the confidentiality of data. To ensure safety, reliability, data integrity and data confidentiality, encryption and authentication is required. The authentication and encryption should not pose too much overhead on the energy consumption of BAN. Hence lightweight authentication and encryption is required.

3.3.6 Usability

BANs should be easily setup by medical personnel and BAN users who might not have any ICT training. This implies that BANs should be capable of auto-configuring and self-maintaining. BAN nodes should be able to set up whenever they are placed in a BAN network and turned on without any intervention. Placements of nodes are application based; for example, a peacemaker could be implanted into the brain to stimulate different region of the brain with electrical signals.

4 BAN Standardization

Increasing research and interest developed by academic researcher and industry has motivated the standardization of BAN. BAN standards are to provide a basic requirement for developers and industry. This is to ensure interoperability of BAN products from vendors. The need for this standard became necessary since the current IEEE 802.15 (PAN) does not support certain requirements that are important in the implementation of BAN. BAN requirements as stated is the preceding section call for a new standard.

The IEEE 802.15 Task Group 6 was formed to provide guidelines for BAN and has published standard 802.15.6 in February 2012. PHY layer and MAC layer specifications are defined in this standard. Although IEEE 802.15.6 supports mostly medical and health applications, it provides support for other application areas as well. This is a key feature of flexibility of standard 802.15.6. Requirements are design specific and device manufacturers provide devices tailed for each application.

Furthermore the standard provides information on MAC frame formats and MAC functions. It also defines three PHY layer specifications namely, a narrow band PHY (NB-PHY), ultra-wide band PHY (UWB-PHY) and human body communication (HBC-PHY).

4.1 Communication of BAN

Communication between a node and hub as specified by IEEE 802.15.6 is to take place at the PHY layer and MAC sub layer. An operation channel is to be used by a hub or node at a given time. Security key generation is to occur inside and /or outside the MAC sub layer. The MAC service access point SAP provides MAC services to upper layers in a hub or a node. Also the PHY service access point provides the MAC sub layer with the PHY layer services. Both node and hub may have management entity to manage the exchange of management information between layers and these are the node management entity (NME) and the hub management entity (HME) respectively (EEE Computer Society 2012.)

A reference model for the communication is shown in figure six.

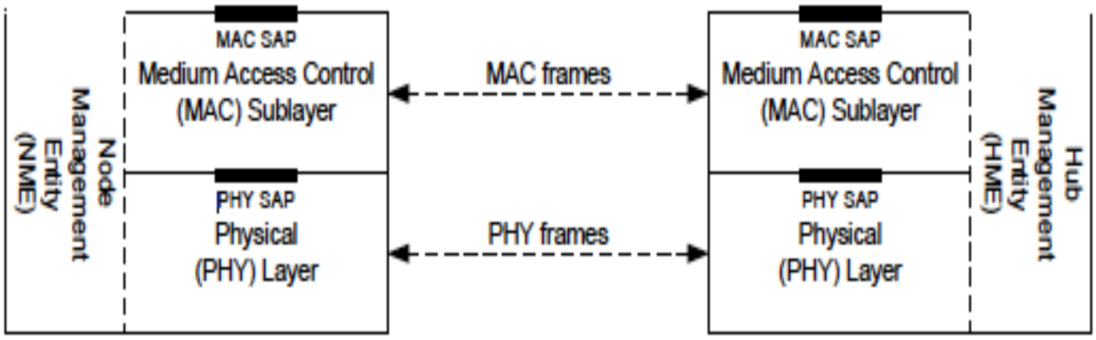


Figure 6. Reference model of PHY and MAC layer (EEE Computer Society 2012)

4.2 Secured and Unsecured Communication of BAN

The IEEE 802.15.6 describes two states and three levels with regards to security in BAN. Whereas state could be secured or unsecured, level are defined from zero to two.

4.2.1 Secured Communication

A secured communication can be established between a node and a hub for secured frames exchange if the process adheres to following states:

- **Orphan State**

  There is no association at this state and hence no exchange of frame except security association and control unsecured frames. This security association activates a pre-shared master key (MK) or generation of a new MK. If the activation and establishment of MK fails, the node and hub cannot communicate and hence cannot proceed to the next state (IEEE Computer society).

- **Associated State**

  The node holds a shared MK with the hub at this state. A creation of pairwise temporal key (PTK) is done. Only security disassociation, PTK unsecured frame and control unsecured frame are allowed at this state. A successful shared MK and the creation of PTK transit the association to secured state otherwise the node and the hub is returned to the orphan state (IEEE Computer society).

- **Secured State**

  A node holds PTK with the hub at this state, making way for secured frame exchange. Security disassociation, connection request, connection assignment and control secured or control unsecured frames can be transmitted. Any other frames are not allowed. A successful connection request and assignment frames transit the state to connected state. A failure will cause them to move back to association state or orphan state if either requested for security disassociation (IEEE Computer society).

- **Connected State**

  Connection is established and the node holds an assigned connected NID. A wakeup arrangement and one or more scheduled and unscheduled allocation is made with the hub for node addressing, desired wakeup, and scheduled and unscheduled access. Transmission of secured frames can now take place with the exception of security association secured frames. The state is moved back to orphan state if MK is invalid during PTK recreation. A missing or invalid PTK will send the connection back to associated state (IEEE Computer society).

4.2.2 Unsecured communication

There are only two states for unsecured frame exchange between a node and a hub. These are as follows:

- **Orphan State**

  There is no relation between the node and the hub for unsecured communication. The node can however send a connection assignment and control unsecured frames to the hub. A connected state is entered if the connection request and association assignment is successful. A failure will cause the connection not to advance to the next state (IEEE Computer society).

- **Connected State**

  A connected NID is assigned to the node since it is connected. A wakeup arrangement and one or more scheduled and unscheduled allocation is made with the hub for node addressing, desired wakeup, and scheduled and unscheduled access. The node and hub can now transmit unsecured frames to each other. They cannot transmit any secured frames either than Security association, security disassociation and PTK frames. They can however disassociate and return to an orphan state to start a secured association (IEEE Computer society).

4.3 Security

The IEEE 802.15.6 standards approved three security levels. The levels are described as security pattern for node and hub association.

These levels are; level 0 (unsecured communication), level 1 (authentication but no encryption), and level 2 (authentication and encryption), (IEEE Computer society).

4.3.1 Level 0 (Unsecured communication)

At this level frames are transmitted unsecured and hence there are no measures of message integrity validation, authentication, and replay defense, privacy and confidentiality.

4.3.2 Level 1 (authentication but no encryption)

This level provides data transmission in authenticated but unsecured way. There is no privacy and confidentiality. Integrity, authenticity and reply defense are taken care of in this level.

4.3.3 Level 2 (authentication and encryption)

Measures are provided for integrity, validation, authenticity and replay defense, privacy protection and confidentiality. The highest level of security is set at this level.

Security level is determined at the point of association. A PTK is established and used per section after a pre-shared MK or the creation of a new MK. Figure seven illustrates the security levels described above (Somasundaram & Sivakumar, 2011.)

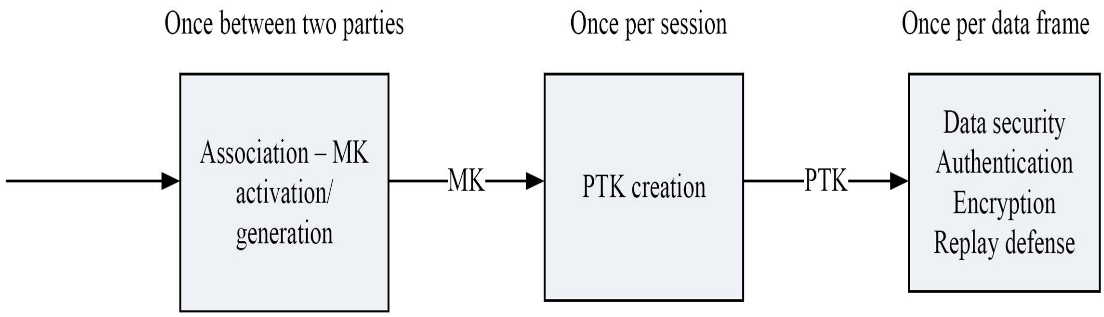


Figure 7. Security levels of IEEE 802.15.6

5 The Media Access Control (MAC) - Frame Processing

The MAC performs several functions to ensure that frames are delivered to their destination. Among these functions are; frame processing, access classification and division, BAN creation, random access, improvised access and unscheduled access, scheduled access and scheduled-polling access, access continuation, termination and timeout, MICS band communication, clock synchronization and guard time provisioning, power management and, coexistence and interference mitigation.

5.1 Abbreviated Addressing

The MAC frame header sent to or from a hub contains a body area network identifier (BAN ID) selected by the hub. The BAN ID is one octet integer from 0x00 to 0xFF. Also in the MAC frame header is a hub identifier (HID) and a node identifier (NID). The HID is selected from a subset of connected_NID, which is not being used, by any neighboring hub while the NID is selected and used as an abbreviated address sent from or to a node or group of nodes (IEEE Computer Society 2012, 79.)

5.2 Full Addressing

A sender or recipient hub will be addressed using extended unique identifier-48 (EUI-48) whose value will be included in the payload, specifying the type of management frame. Received management frame type addresses are to be checked by the recipient to ensure that the frames were addressed to it from unexpected sender (IEEE Computer Society 2012, 80.)

5.3 Priority Mapping

BANs was designed basically for medical application and some of these application can be critical. Prioritization is therefore necessary to differentiate these (medical) application form other BAN application. The designation of frame payloads determines user priority (UP).

Table eight illustrates the payload type and user priority (IEEE Computer Society 2012, 81) (Zhang & Dolmans 2010).

Priority	**User priority**	**Traffic destination**	**Frame type**
Lowest	0	Background (BK)	Data
	1	Best effort (BE)	Data
	2	Excellent effort (EE)	Data
	3	Video (VI)	Data
	4	Voice (VO)	Data
	5	Medical data or network control	Data or management
	6	High-priority Medical data or network control	Data or management
Highest	7	Emergency or medical implant event report	Data

Table 8. User Priority (IEEE Computer Society 2012, 81.)

5.4 Frame Reception

IEEE 802.15.6 specify modalities by which hubs and nodes can receive frames for processing. These modalities are:

- The NID or HID for node and hub of the recipient ID field of the MAC header frame is set respectively.
- The ID field for sender is set to NID for hubs and HID for nodes respectively.
- Expected value is set for the BAN ID field.
- Both parties taking part in the frame exchange support the protocol versions.
- A valid FCS of the frame (IEEE Computer Society 2012, 82.)

5.5 Frame sequencing

The IEEE 802.15.6 has identified two types of frames; these are management type frames and data type frames, hence provided specification for their sequencing. Management type frames are considered received by the sending node or hub, when sender received an I-ACK from the recipient. Any frame received apart from I-ACK from the recipient is considered as an acknowledgement and the sending node or hub will act or process the received frame.

However for data type frames, MSDUs are transmitted in the octet at the order in which they arrived at the local MSC service access point. MSDU are extracted and transmitted in the same order of fragmentation. The transmitted MSDUs are to be released to the MSC client, which is contained in the same frame subtype (IEEE Computer Society 2012, 82.)

5.6 Frame retry and frame timeout

Frames can be retransmitted to the same recipient if a hub or node, which assumes the recipient, does not receive the frames. Before retry the hub or node may consider the reliability, channel conditions, fairness policy and delay requirements of the network. Frame timeout however, is described as a situation where a node or hub treats expected frame not arriving if timeout after the end of a PHY preamble frame, it has not receive a PHY preamble frame (IEEE Computer Society 2012, 82).

5.7 Frame Separation

The IEEE 802.15.6 identifies two types of frame separation. These separations are based on sender and recipient role. Frames are separated and sent sequentially by a node or hub and likewise the receiving node or hub performs separation based on sender's request. The start and end of the frame are determined by the underlining PHY layer. A recipient must not exit the receiving state until mTimeOut, stating the end of PHY preamble of the expected frame (IEEE Computer Society 2012, 83.)

5.8 Frame Acknowledgement

Frame acknowledgement policy field is set by the sending node or hub in the MAC header frame. However, to ensure smooth exchange of frames the recipient must support the acknowledgement policy of the sending node or hub. Standards 802.15.6 has identified the following acknowledgement policies for frame exchange and these are no acknowledgement (N-Ack), immediate acknowledgement (I-Ack), group acknowledgement (G-Ack), block acknowledgement (B-Ack) and block acknowledgement later (L-Ack). A summary of acknowledgement policies and frame type is illustrated in table nine (IEEE Computer Society 2012, 83 & 84.)

Frame type name	**Frame subtype name**	**Ack Policy field**
Management	Beacon	N-Ack
	Security association	I-Ack
	Security disassociation	I-Ack
	PTK	I-Ack
	GTK	I-Ack
	Connection request	I-Ack
	Connection assignment	I-Ack
	Disconnection	I-Ack
	Command	I-Ack
Control	I-Ack	N-Ack
	B-Ack	N-Ack
	I-Ack + Poll	N-Ack
	B-Ack + Poll	N-Ack
	Poll	N-Ack
	T-Poll	N-Ack
	Wakeup	N-Ack
	B2	N-Ack
Data	Data subtype set to mG-AckDataSubtype	G-Ack
Data	User-defined data subtype other than mG-AckDataSubtype	N-Ack, I-Ack, B-Ack or L-Ack

Table 9: Acknowledgement policy with frame type.

6 Physical Layer (PHY)

Standard 802.15.6 of the IEEE identified the PHY to support three different layers namely; narrow band (NB) PHY, human body communication (HBC) PHY and ultra-wideband (UWB) PHY. While NB PHY is optional, UWB and HBC PHYs are mandatory.

6.1 Narrowband (NB) PHY Specification

The NB PHY is an optional layer specified by IEEE standard 802.15.6 but provides the following functionalities:

- Activation and deactivation of radio transceiver
- Clear channel assessment within the current channel
- Data transmission and reception.

The PSDU is transformed into PPDU, which is made up of Physical Layer Convergence Procedure (PLCP) preamble, a PLCP header and PHY Service Data Unit (PSDU) (IEEE Computer Society 2012, 172) (Movassaghi, et. al.). A diagrammatical representation of the PPDU is shown in figure eight.

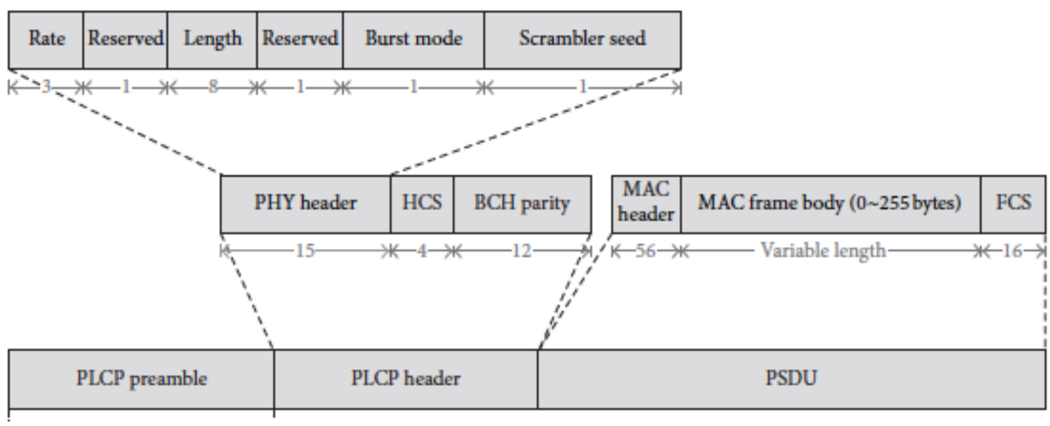


Figure 8. PPDU structure (Ullah et. al).

Packets are transmitted with the PLCP preamble transmitted first, followed by the PLCP header and then the PSDU in that order. The NB PHY provides various bit rates, channels and modulation schemes by employing the use of seven different frequency bands (Ullah et al 2013) (Movassaghi et al).

The PLCP preamble of the PPDU consist of two sequences, which aid in timing synchronization, packet detection and carrier offset recovery. The PLCP header however conveys information about PHY parameters that is required for the decoding of PSDU. The PLCP header consists of the PHY header, HCS and BCH parity (IEEE Computer Society) (Movassaghi et al) (Ullah et al, 2013.)

6.2 Ultra Wideband (UWB) PHY Specification

UWB PHY specification is aimed at achieving low power consumption, low complexity and high performance. This specification meets the MICS power limits for human body exposure. The UWB can be operated with two types of technics. These are, impulse radio (IR-UWB) and wideband frequency modulation (FM-UWB) (Ullah et al, 2013) (IEEE Computer Society 2012).

Standard 802.15.6 of the IEEE specified three levels of functionality for UWB PHY. These functions are:

- Radio transceiver activation and deactivation
- Providing clear channel assessment indication to the MAC for wireless medium activity verification.
- Constructs the PPDU, whose bits are converted into RF signals for transmission (IEEE Computer Society 2012)

The UWB PHY is made up of two frequency bands with three low band and eight high band channels divided with bandwidth of 499.2 MHz. One of which is mandatory in each band. The PPDU of UWB PHY consists of a synchronization header (SHR), physical layer header (PHR) and physical layer service data unit (PSDU). The order of transmission is from SHR to PHR to PSDU.

The PPDU frame structure of UWB PHY is represented in figure nine (Ullah et al. 2013.)

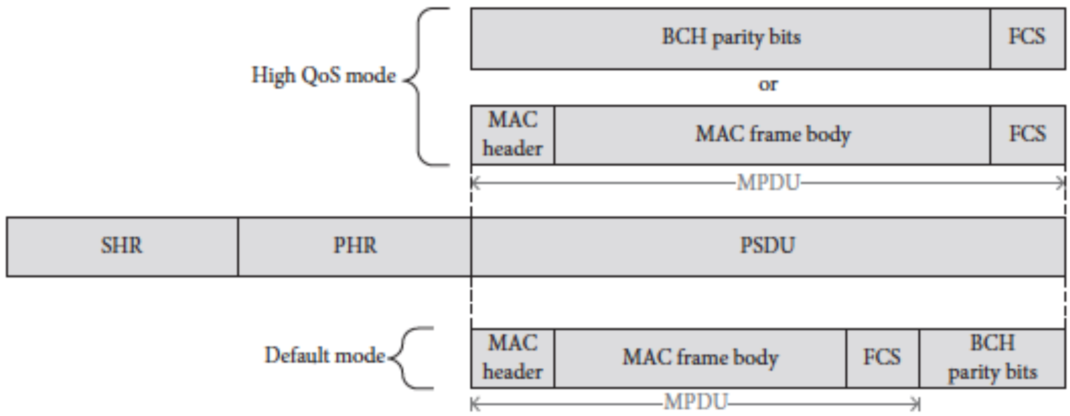


Figure 9. The UWB PHY PPDU frame structure

The SHR is made up of a preamble and SFD. Information such as length of payload, data rate and scramble seed about the PSDU is carried in the physical header while the SHR provides repetitions of Kasami sequence of 63 in length (Kwak, Ullah, Ullah 2010).

6.3 Human Body Communication (HBC) PHY Specification

HBC presents a form of technic that uses the human body as medium of communication (electrical wire). This is referred to as Electrostatic Field Communication. The HBC PHY PPDU consists of a preamble, a SFD, a PHY header and PSDU. Data patterns are specified by the preamble and SFD, which are pre-generated and sent before the payload and packet header. The preamble is sent four times to ensure packets synchronization. Figure ten illustrate the structure of the PPDU for HBC PHY (Ullah et al 2013) (Movassaghi et al) (Otgonchimeg & Kwon 2011).

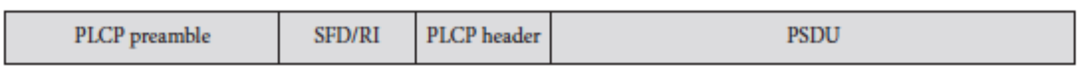


Figure 10. HBC PHY PPDU structure

7 Application of BAN

Body area networks (BANs) have been designed to confine the coverage area to the human body. The coverage area is limited to a region around the subsidiary waveguide, to which the wireless device is electromagnetically coupled. The wireless body area network (WBAN) is a key technology to realize convenient continuous monitoring by removing cumbersome wires. BAN is applied in four basic ways to enhance the human body alignment and to keep feet and rendered good physics. BAN application areas can be divided into two main groups namely, medical applications and non-medical applications. The following are applications in these groups; Medicals (medical healthcare, artificial organs and implants control and monitoring), monitoring of persons operating in harsh environment (fire and military personnel), Sports (personal fitness monitoring), Entertainment and gaming (personal audio system, mobile communication devices, video communications and peripheral devices) (Reichman 2009) (Somasundaram & Sivakumar 2011).

7.1 Medical

In recent, the level of information provided and energy resources capable of powering the sensors are advancing. Technology has moved from its primitive stage as such, wide researches have led to breakthrough innovations in healthcare, leading to concepts such as telemedicine and mHealth becoming real. Primarily applications of BANs were expected to appear mainly in the healthcare domain, especially for continuous monitoring and logging vital parameters of patients suffering from chronic diseases such as diabetes, asthma, and heart attacks. Usually a BAN network is placed on a patient to alert the hospital, even before they have a heart attack, through measuring changes in their vital signs. BAN network placed on a diabetic patient could auto inject insulin through a pump, as soon as their insulin level declines. Other medical applications include, body rehabilitation (tissue and marcels, hip rehabilitation monitoring, blind support, disability support, hearing aid) (Somasundaram et al) (Soini, Nummela, Oksa, Ukkonen & Sydänheimo 2008).

Figure eleven represents a medical application of BAN

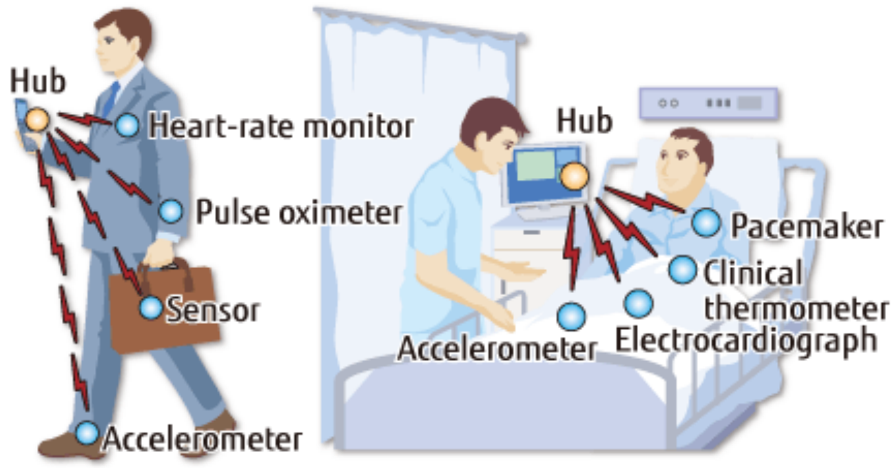


Figure 11. Medical application of BAN

7.2 Sports

BAN is not limited to the medical industry but has extended to the sports field. In recent times sports wares are incorporated with wearable muscle monitor, which analyzed the capacity of the muscles. In sports BANs a set of wireless sensors are used to take certain readings of athletes as well as normal people. These sensors can measure the distance traveled, speed, fats and calories burnt, weights, heart rate, blood pressure and motion. Below is schematic diagram of the proposed sport BAN.

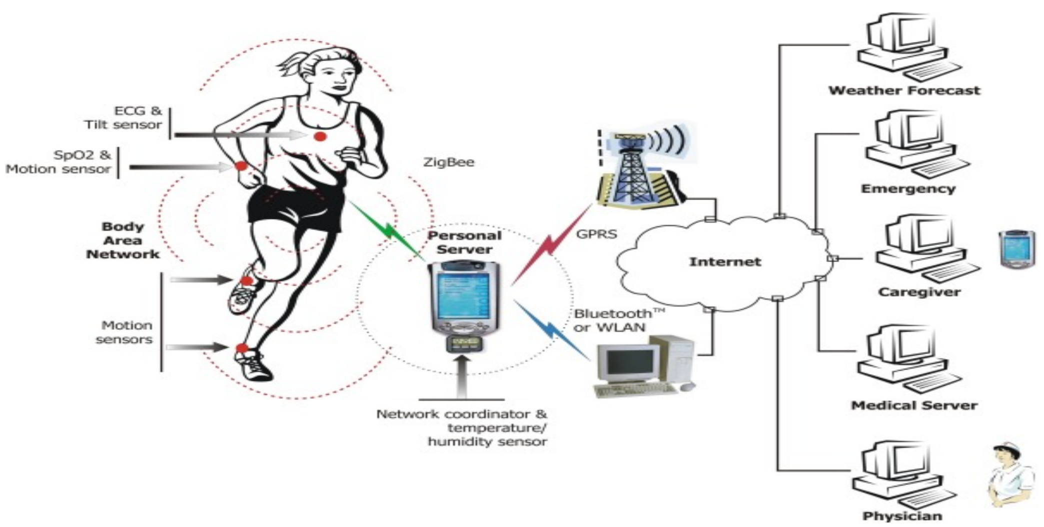


Figure 12. Sport application of BAN

BAN assist to rehabilitate athletes as well as other people, with the help of BAN muscles loaded correctly.

7.3 Entertainment and Gaming

Entertainment applications are made up of gaming applications and social networking. It uses appliances such as microphones, MP3-players, cameras, head-mounted displays and advanced computer appliances. BAN entertainment applications can be used in game control with hand gesture, mobile body motion game and virtual world game, recently BAN is used in entertainment programs such as multimedia and gaming applications, video streaming, data file transfer, sports, and 3D videos. BANs enable new services and functions for wireless body-centric networks including wearable entertainment system like music entertainment.

8 Conclusion

In conclusion, wireless networks provide a medium of mobility and flexibility thereby increasing efficiency in daily life activity. This has given birth to a lot of technologies with various application and standards providing solution from global communication to personal communication to personal safety and in of recent times, application of medicine.

Developed purposely for medical applications although not limited for only medical application, body area network have shown a positive sign of reducing deficit in patient doctor / nurse ratio. BAN provides hope for life saving situation and hence will have an immerse contribution towards the provision of total health.

BAN standardization provides a baseline for technology takeoff in the implementation on mobile health (MobiHealth) as explained in section 4 of this thesis. The technology is very refined and robust, providing various forms of technics in MAC frame processing as explained in section 5. Section 6 and 7 provide a comprehensive summary of the IEEE 802.15.6 physical layer specification and application of BAN respectively.

BAN applications in medical health and other areas are unlimited. Its market shows huge potential and integrating BAN into health delivery will increase wellness and total health.

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