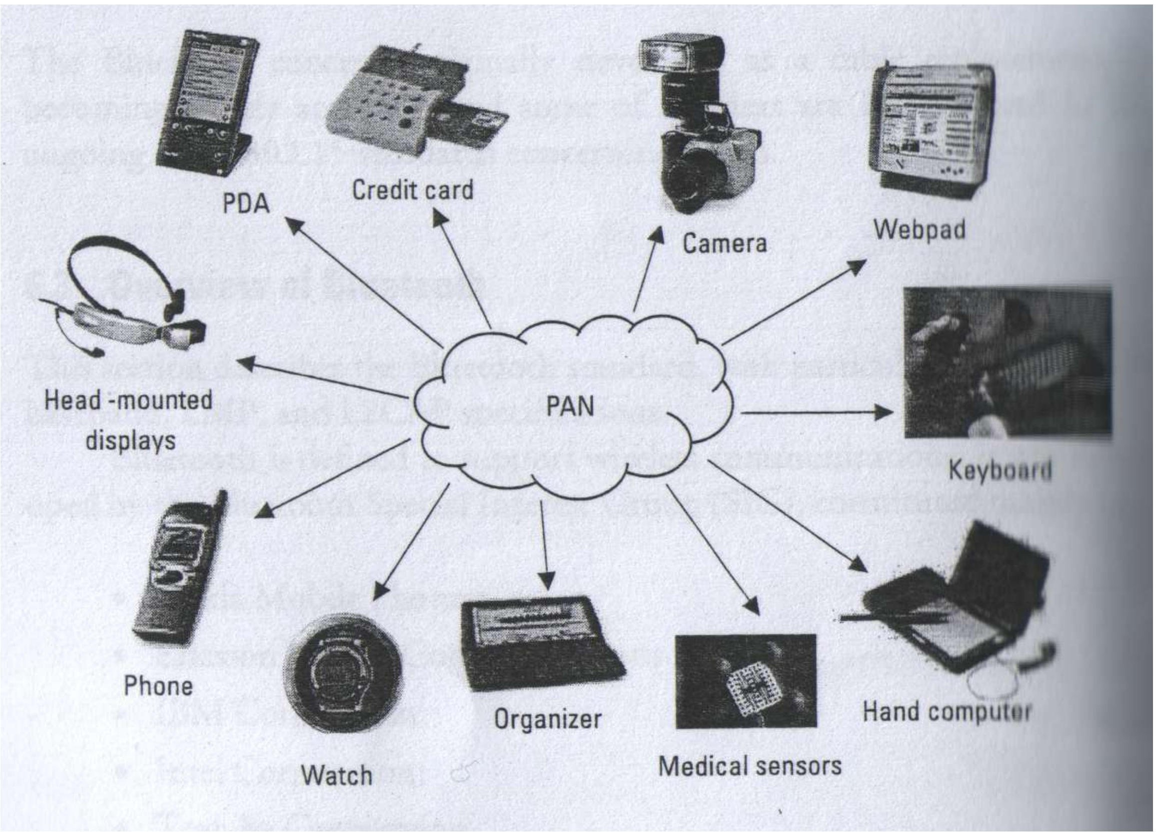
SEMESTER PAPER

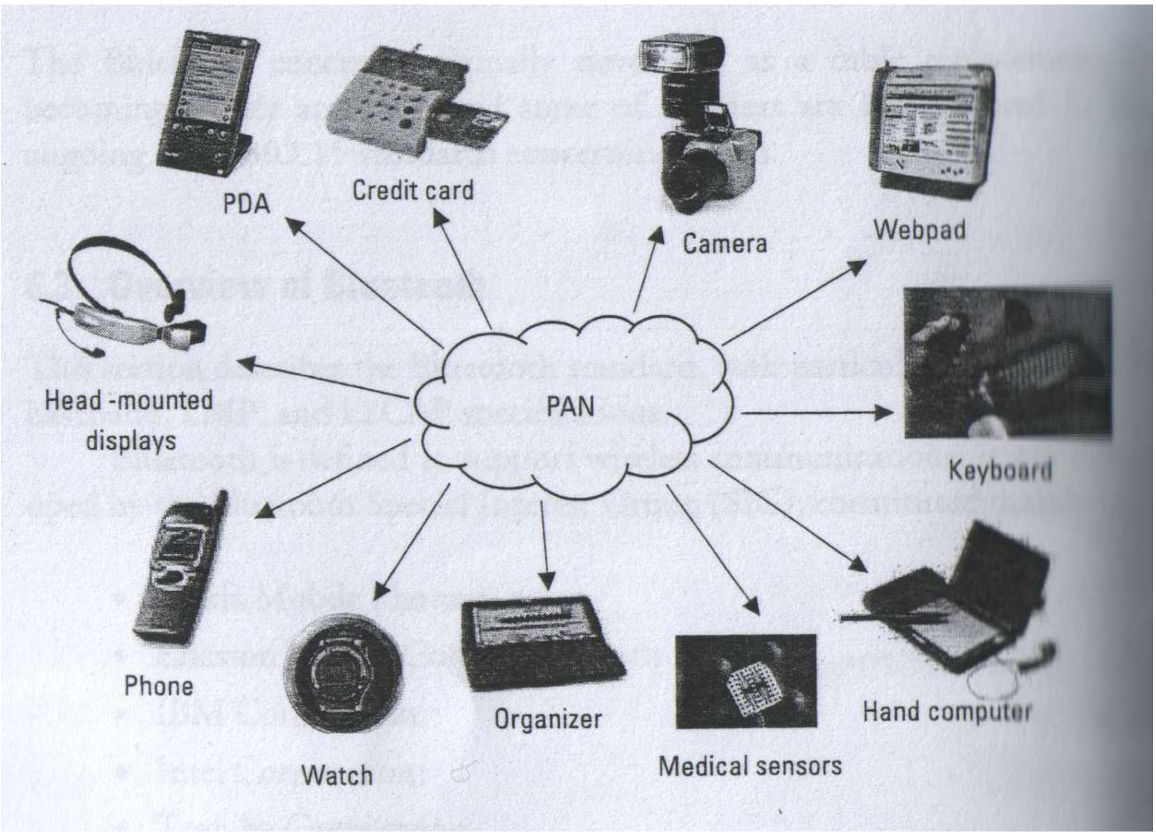
PERSONAL AREA NETWORKS (PANs)



Student: XILOGIANNIS CHRISTOS
Subject: NETWORKING TECHNOLOGIES
Professors: A.A. ECONOMIDIS & A. POMPORTSIS
MSc in INFORMATION SYSTEMS
UNIVERSITY OF MACEDONIA
Date: 05/01/2006

ΕΡΓΑΣΙΑ ΕΞΑΜΗΝΟΥ

ΔΙΚΤΥΑ ΠΡΟΣΩΠΙΚΗΣ ΠΕΡΙΟΧΗΣ PERSONAL AREA NETWORKS (PANs)



ΦΟΙΤΗΤΗΣ: ΞΥΛΟΓΙΑΝΝΗΣ ΧΡΗΣΤΟΣ
ΜΑΘΗΜΑ: ΤΕΧΝΟΛΟΓΙΕΣ ΤΗΛΕΠΙΚΟΙΝΩΝΙΩΝ ΚΑΙ ΔΙΚΤΥΩΝ
Καθηγητές: Α.Α. ΟΙΚΟΝΟΜΙΔΗΣ & Α. ΠΟΜΠΟΡΤΣΗΣ
ΠΜΣ στα ΠΛΗΡΟΦΟΡΙΑΚΑ ΣΥΣΤΗΜΑΤΑ
ΠΑΝΕΠΙΣΤΗΜΙΟ ΜΑΚΔΕΟΝΙΑΣ
Ημερομηνία: 05/01/2006

Summary

This paper discusses what a PAN is, and makes a reference to all the existing concepts on PANs. It introduces the reader to key elements of each existing concept. We see an overview of Bluetooth, its structure, profiles, basic elements and architecture. Later on an overview MIT Oxygen Project is given and its approach and technologies are explained. Continuing, we get a quick look of IrDA and discuss the IEEE 802.15.4 standard making a separate reference to LR-PANs.

In addition certain areas of interest are covered in short such as PAN paradigms, PAN architecture principles and interfaces, as well as their communication via external networks, Ad Hoc networking and their security. Accordingly, we discuss the main PAN applications, possible scenarios and devices as well as PAN challenges and open issues of the future. Finishing this paper makes a separate reference to B-PANs and compares WLANs to PANs and LR-WPANs to WPANs.

Περίληψη

Αυτή η εργασία πραγματεύεται το τι είναι ένα PAN και κάνει μία αναφορά σε όλες τις υπάρχουσες θεωρήσεις για τα PAN. Μας εισάγει στα στοιχεία κλειδιά κάθε υπάρχουσας θεώρησης. Βλέπουμε μία επισκόπηση του Bluetooth, της δομής του, των προφίλ του, των βασικών στοιχείων και της αρχιτεκτονικής του. Εν συνεχεία γίνεται μία επισκόπηση του MIT Oxygen Project και συζητούνται οι προσεγγίσεις του αλλά εξηγούνται και οι τεχνολογίες του. Συνεχίζοντας ρίχνουμε μια γρήγορη ματιά στο IrDA και συζητούμε το πρότυπο IEEE 802.15.4 κάνοντας μία ξεχωριστή αναφορά στα LR-PAN.

Επιπροσθέτως καλύπτονται εν συντομία ορισμένες περιοχές ενδιαφέροντος όπως παραδείγματα PAN, αρχιτεκτονικές αρχές και διεπαφές των PAN, όπως και η επικοινωνία μέσω εξωτερικών δικτύων, η ειδικού σκοπού διαδικτύωση και η ασφάλεια τους. Ακόλουθα συζητούνται οι κύριες εφαρμογές των PAN και πιθανά σενάρια και συσκευές. Επίσης συζητούνται οι πρκλήσεις που θα αντιμετωπίσουν τα PAN καθώ και τα ανοιχτά θέματα που υπάρχουν γύρω από αυτά. Τελειώνοντας αυτή η εργασία κάνει σύγκριση ανάμεσα στα WLAN και στα PAN, όπως και ανάμεσα στα LR-WPAN και τα WPAN.

CONTENTS

Περιεχόμενα

1. Introduction

What does the term PAN mean? The two following aspects pretty match cover the basics of the matter.

The relatively new term Personal Area Network (PAN) is used to describe communications between the devices of one or a few more users within a range of around 10m. There are three different usual application scenarios to mention here:

- The connection of peripheral devices such as printers, mobile telephones, Personal Digital Assistants (PDAs), or digital cameras to a PC to transfer or synchronize data.
- The connection of external user devices with the service platform. A typical example was the early innovation of the Ericsson headset for mobile telephones based on Bluetooth.
- The connection of several PCs for data transfer. This architecture directly borders on the functionality of classic LANs.

Figure 1 Possible PAN Applications **[Book Ref 1 Page 11]**

Taking the application as a starting point we can assume that the communicating devices are usually in the same space or at least close to each other. Most applications will therefore function quite happily with moderate bandwidths.

However, for these PAN applications it is essential that the radio modules can be produced as cheaply as possible because the functionality must also be implemented in relatively simple and inexpensive devices to achieve the required levels of acceptance. **[Book Ref 2 Chapter 3 Pages 51]**

A PAN is a network solution that enhances our personal environment, either work or private, by networking a variety of personal and wearable devices within the space surrounding a person, and providing the communication capabilities within the space and with the outside world.

PAN represents the person-centered network concept (see Figure 2) which will allow a person to communicate with his or her personal devices close to him or her (e.g. personal digital assistants, web pads, organizers, hand-held computers, cameras and head-mounted displays) and to establish the wireless connections with the outside world. [1-5].

Wireless communications experienced dramatic growth within the last decade (GSM, IS-95, GPRS and EDGE, UMTS, and IMT-2000). The siege for higher data bit rates resulted in new wireless systems and network solutions. The advantages of the wireless world and the desire for higher mobility caused the replacement of fixed connections to the communication networks and the development of different PAN solutions, which will change the concept of a terminal to a person and his or her personal place. PAN is a new member of the GIMCV family.

It will cover the personal place surrounding the person within the distance to which voice reaches. It will have a capacity in the range of 10bps to 10Mps (see Figure 3). Existing solutions (i.e. Bluetooth) operate in the unlicensed instrumental, scientific, and medical (ISM) frequency band of 2.4 GHz (see Figure 4). Future PAN systems will operate in the unlicensed bands of 5 GHz and perhaps higher. PAN is a dynamic network concept, which will demand appropriate technical solutions for the architecture, protocols, management and security. **[Book Ref 3 Chapter 6 Pages 183-185]**

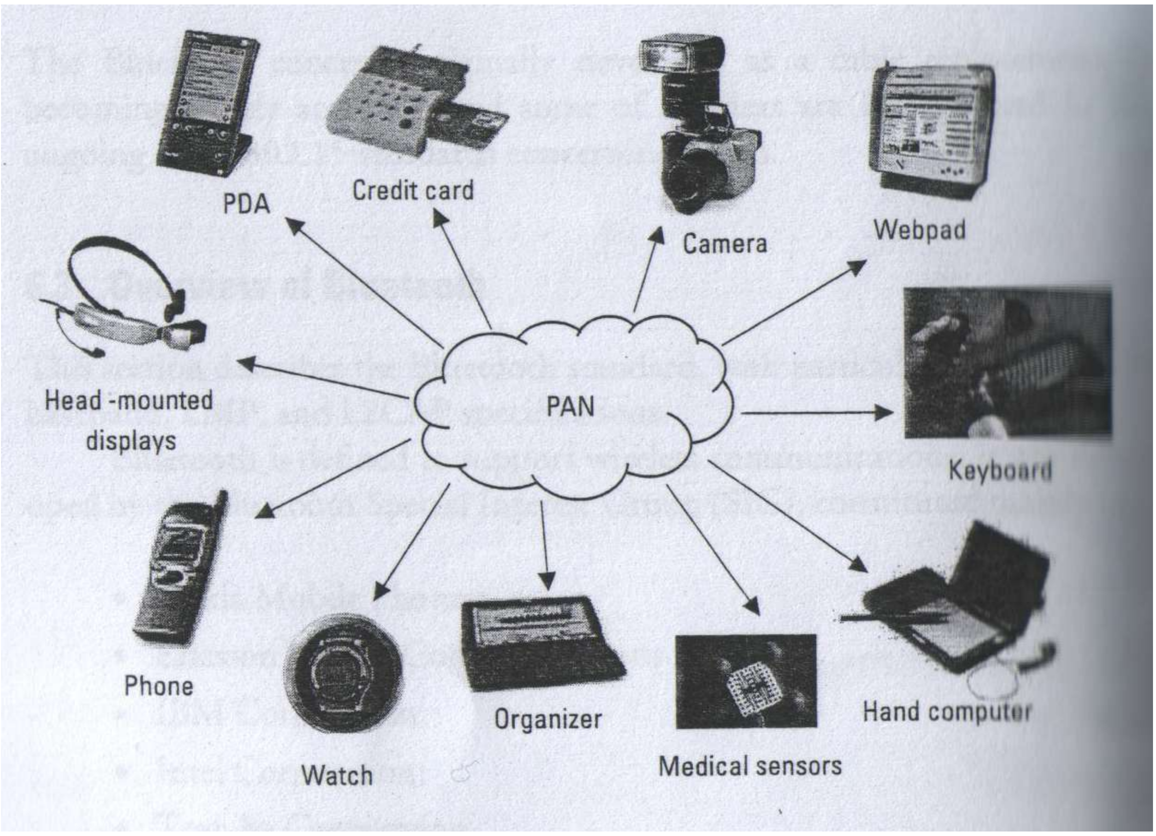


Figure 2 PAN as a network solution **[Book Ref 3 Chapter 6 Page 184]**

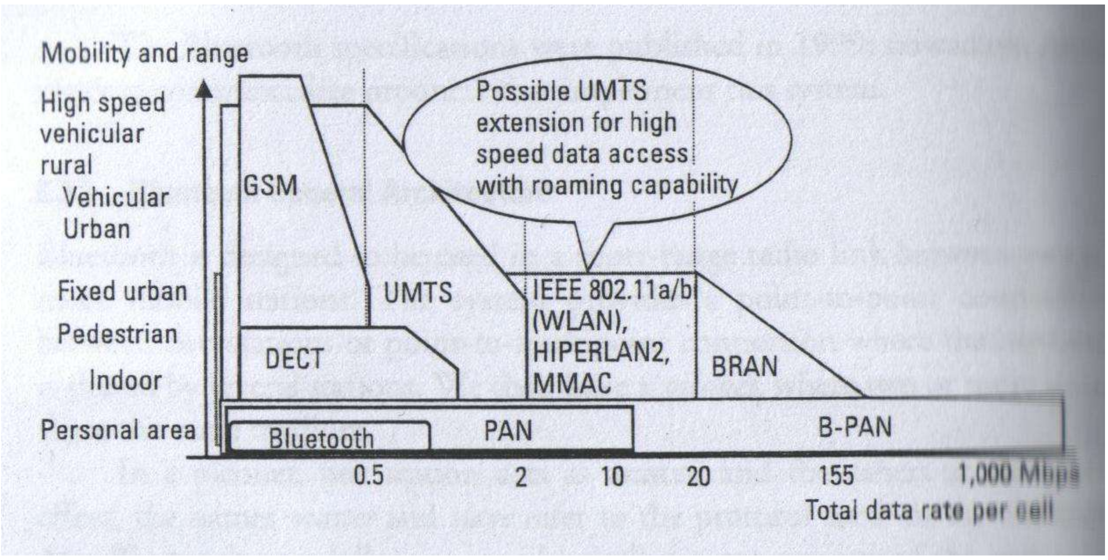


Figure 3 Where PAN belongs **[Book Ref 3 Chapter 6 Page 184]**

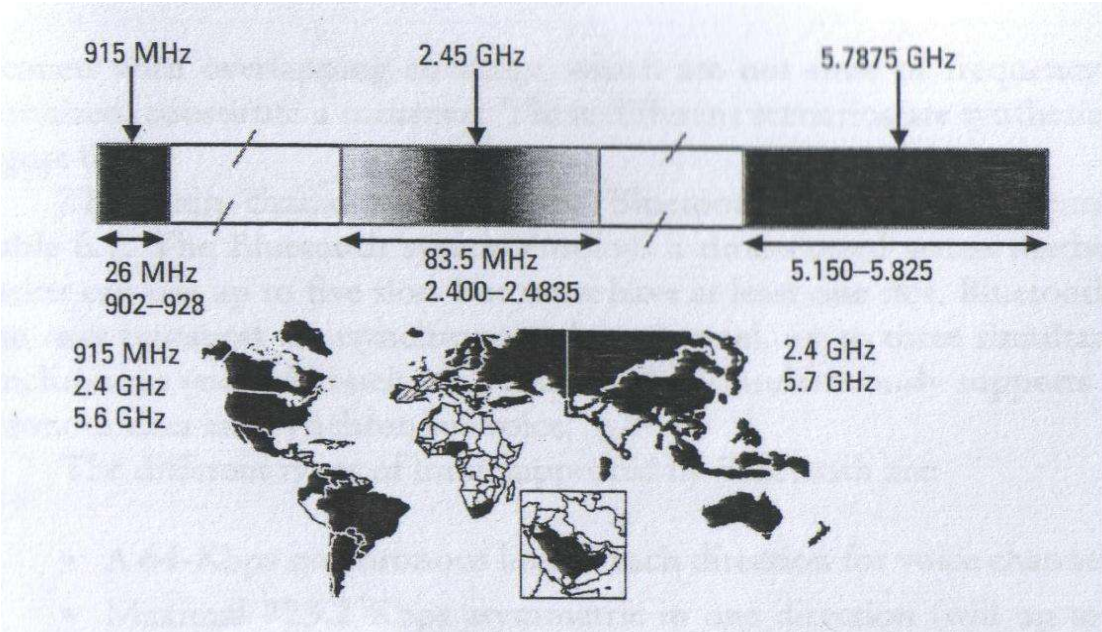


Figure 4 Unlicensed frequency bands **[Book Ref 3 Chapter 6 Page 185]**

As we can see the term PANs mostly refers to Wireless PANs and to fixed cable PANs. There is a major problem with the application of the second category in the modern world of technology.

- **Wires are a problem:** They get broken, get lost, get in the Way, get misconnected .
- **People who carry a watch, pager, cell phone, PDA, and personal stereo have at least** – Four displays, two input devices, four speakers, one microphone, two long range communications links. There is a great degree of complexity in order for fixed cable PANs to cover all the user demands. **[Book Ref 1 Page 8]**
- **Fixed cable PANs don't offer neither user mobility nor user flexibility which by default makes them unwanted and obsolete.**

Therefore this paper will be centered mostly on Wireless Personal Area Networking. Below are shown the basic characteristics of WPANs which mostly can be considered as advantages and their general Positioning Statement with respects to the other network categories (Figures 5 and 6).

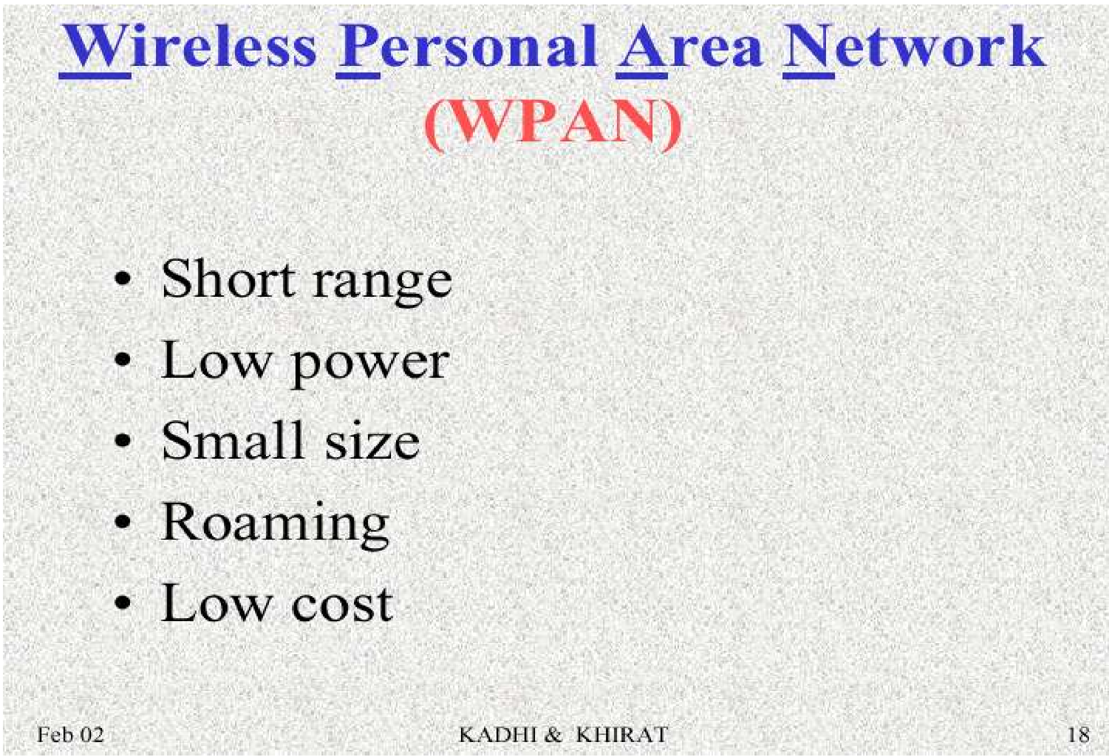


Figure 5 WPAN Characteristics **[Book Ref 1 Page 18]**

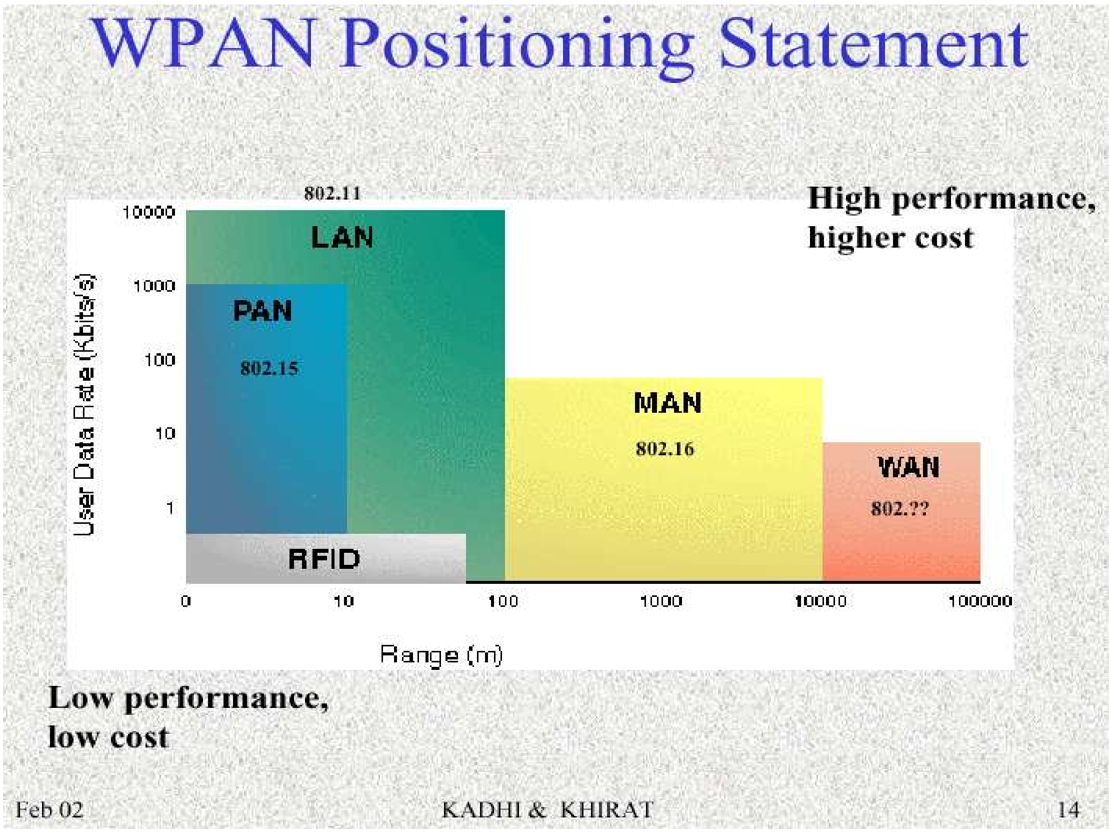


Figure 6 WPAN Positioning Statement **[Book Ref 1 Page 14]**

2. Existing Concepts

Person-centered network concepts developed from a Massachusetts Institute of Technology (MIT) idea from 1995 to use the **intrabody** electrical currents for communication between the devices attached to the human body. It was first accepted by IBM Research and afterwards experienced many variations developed by different research institutions or companies. The different variety of PAN solutions include:

- Bluetooth
- Oxygen project (MIT)
- Pico-radio
- Infrared Data Association (IrDA)
- IEEE 802.15.4

The Bluetooth concept, originally developed as a cable replacement, has become widely accepted the last few years and some of its ideas are incorporated in the on-going IEEE 802.15 standards concerning PANs. **[Book Ref 3 Chapter 6 page 185-186**]

How the intrabody currents would serve for communication between the devices attached to the human body is shown in short below:

- The natural salinity of the human body makes it an excellent conductor of electrical current. PAN technology takes advantage of this conductivity by creating an external electric field that passes an incredibly tiny current through the body, over which data is carried.
- The current used is one-billionth of an amp (one nanoamp), which is lower than the natural currents already in the body. In fact, the electrical field created by running a comb through hair is more than 1,000 times greater than that being used by PAN technology.
- The speed at which the data is transmitted is equivalent to a 2400-baud modem. Theoretically, 400,000 bits per second could be communicated using this method.

[Internet Ref 1 http://www.almaden.ibm.com/cs/user/pan/pan.html]

2.1.1 Overview and Background of Bluetooth

Activities involving Bluetooth began back in 1994 when Ericsson's Mobile Communications Division produced a feasibility study on what could replace the many cable connections between mobile telephones and the various peripheral devices. Following that, the five companies IBM, Toshiba, Intel, Ericsson and Nokia jointly founded the Bluetooth Special Interest Group (BSIG) at the start of 1998 with the task of creating a non-proprietary standard for Personal Area Networks (PAN). At this time the aim was seen as something approaching wireless USB. The first version was finalised in 1999. The first update version 2.0b came out in December 1999. A later version has been available since February 2002 (Version 2.1). It is generally seen as the first solid basis for products that really suit the market, as previous versions contained a range of inaccuracies and errors that resulted in errors in compatibility, in the clean implementation of pico networks and in clear master-slave assignment. Even today, Version 2.1 has a few weak points with regard to interoperability.

The original small group of BSIG founder members has grown with the addition pf a promoter group which first involved the companies 3Com, Lucent, Microsoft and Motorola. The BSIG now has more than 2,500 members.

The technology is named after King Harald II. Blaatand (Bluetooth), who was King of Norway between 940 and 981, and Christianised the country, as well as unifying Norway and Denmark.

The Bluetooth standard is based on three application scenarios which position it at Personal Area Network level:

- Replacing cables
- Data and voice access points
- Personal ad hoc networks.

To provide these applications you don't necessarily need PCs. Often it is case that relatively cheap and simple devices with a wireless connection can be used. For this reason the Bluetooth standard needs to allow the simplest and therefore cheapest solutions available. **[Book Ref 2 Chapter 5 page 95]**.

2.1.2 Structure

Figure 7 shows the main elements of version 2.1 of the Bluetooth standard, the current version.

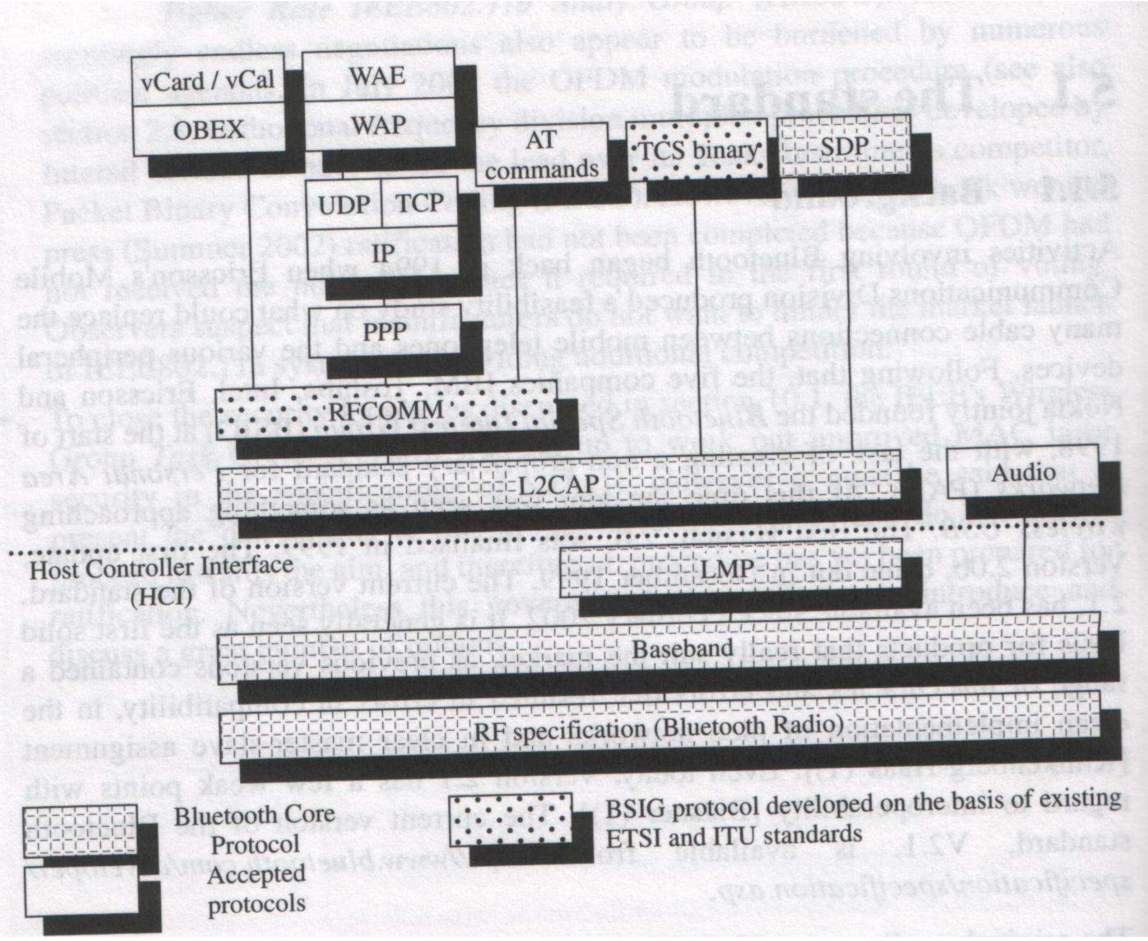


Figure 7 The structure of Bluetooth version 2.1 **[Book Ref 2 Chapter 5 page 96]**

Here it is worth noting the following:

- The description of the Bluetooth communication protocols includes all levels of the protocol layers (OSI reference model). This not only the control protocols for creating ad hoc networks, but also the elements for transferring isochronous data streams, all of which go far beyond the purely transport-specific services of an IEEE802.11 network. Bluetooth provides a complete radio system. Although this is an advantage it must be viewed against the background of interoperability between different device types.
- The complete protocol stack does not only contain Bluetooth-specific protocols: it also uses existing and extended protocols, especially in the higher application

oriented layers. For example it includes the Internet protocols defined in the TCP/IP stack.

- When you consider the large number of protocols shown in Figure 7 it becomes immediately obvious that a Bluetooth station that completely implemented all of them would be so complex that it would be an obstacle to the aim of simple and cheap implementation. For this reason, instead of a complete implementation, the plan is usually to implement only the necessary elements in devices. Each station only needs to contain the core protocols.
- The Bluetooth specification also includes the Host Controller Interface (HCI) which provides a command interface to the baseband controller and link manager, and to the hardware status and command registers. The positioning of the HCI can be modified.
- When the standard was defined no attempt was made to ensure conformity with the layers in the extended reference models (OSI reference model or TCP/IP reference model).

Bluetooth was not defined in an existing standards committee. Efforts have been made, especially by the IEEE, to fit Bluetooth into other standards families, such as the standards defined in IEEE802.x, but as the points above make clear, Bluetooth will need considerable modification before this is possible. The IEEE802.15 attempts to describe the Physical and MAC –portion of the Bluetooth specification. **[Book Ref 2 Chapter 5 pages 96-97]**

2.1.3 Standard Bluetooth elements

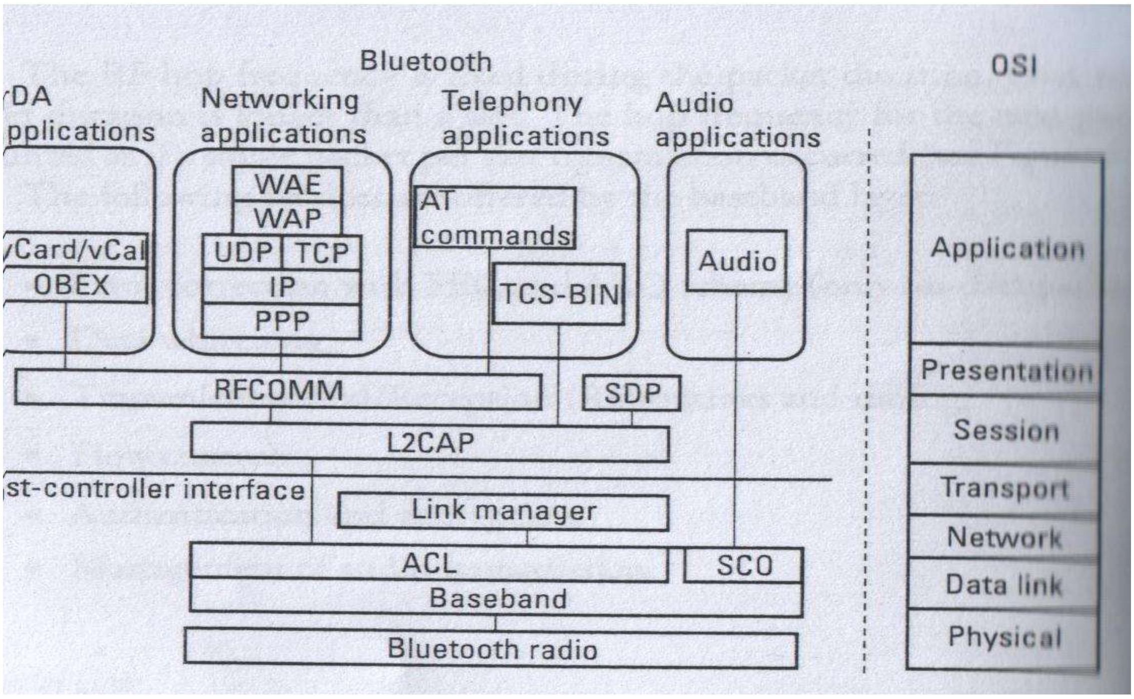


Figure 8 Bluetooth protocol reference model **[Book Ref 3 Chapter 6 page 188]**

Below you will find a brief introduction to the most important elements of the Bluetooth standard (see Figures 7 and 8).

- RF and baseband: these two specifications correspond approximately to the PHY and MAC layers in the IEEE protocol stack.
- Link Manager Protocol (LMP): The LMP is responsible for network management tasks . In particular these include creating connections between stations,

authentication and encryption, controlling power-saving modes and monitoring the status of devices in a pico network.

- Logical Link Control and Adaptation Protocol (L2CAP): L2CAP connects the protocols of the higher layers with the tasks of the baseband.
- Service Discovery Protocol (SDP): The SDP recognises different services and characteristics of each service. It is an essential element of the Bluetooth protocol. With it you can find out which services are available and use that information to create a connection. SDP is the basis for Bluetooth stations to create relatively simple ad hoc networks.
- Wireless Cable (RFCOMM): The RFCOMM standard is part of the ETSI specification TS.07.10. It has been modified to suit the Bluetooth standard, and emulates a serial (RS-232) port. It is essential for many applications and is a clear indication of the intention and range of services of the Bluetooth standard. It primarily describes a point-to-point connection between two devices over the "air serial port". For this reason, for example, LAN connections via TCP/IP are also implemented using the serial Point-to-Point protocol (PPP) via RFCOMM.
- Telephone coupling: Two elements describe how telephone services are to be coupled. Telephony Control Service – Binary (TCS Binary) specifies the signalling for establishing and ending calls. It is based on ITU-T recommendation Q.932. The Bluetooth SIG uses a set of AT commands from the appropriate ITU and ETSI specifications to provide a means of addressing modems and mobile telephones. Fax services are also available.

  Note that only call establishment is carried out using the TCS-Bin protocol and the L2CAP layer. The audio protocol is used to transfer useful data. This protocol directly accesses an SCO link in the baseband.

In addition to this, various application-related protocols have found their way into the Bluetooth standard:

- One is the Object-Exchange (OBEX) protocol, which was adopted from the IrDA standard for infrared connections. It models the representation of objects and the structuring of dialogs between those objects.
- OBEX is used to handle the vCard protocol with which virtual business cards can be exchanged.
- The Wireless Application Protocol (WAP), was developed for transmitting WML resources on mobile telephones. It is also available in the Bluetooth standard, and is implemented via the TCP/IP protocol stack.

[Book Ref 2 Chapter 5 pages 97-98]

[Book Ref 4 Chapter 4 pages 242-245]

[Internet Ref 2: http://www.bluetooth.com/]

[Internet Ref 3: http://www.bluetooth.org]

[Internet Ref 4: http://www.thewirelessdirectory.com/Bluetooth-Software/Bluetooth-Protocol-Stack.htm]

2.1.4 Profiles

The Bluetooth standard also contains details of each protocol stack. In particular you will find definitions called "profiles" that specify the way in which application software can access various layers of the protocol stack. In most cases this involves Application Program Interfaces (APIs). These cover the majority of possible application models and correspond to the service access points in the ISO/OSI reference model. This has the advantage that programs from different manufacturers on different devices can communicate with each other without difficulty as long as they comply with these definitions, which are detailed as possible. However, so much is involved that these definitions are highly complex. As a result these three points need to made:

- Creating complete and consistent definitions is very time-consuming and has been the main aim of revisions to the standard up to the current version, V2.2.
- The standard is becoming very extensive. For example, version V.2.1 includes 13 application-related profiles for activities such as communicating via a serial port, a headset, or a fax-enabled device, for connecting to a LAN, and for data transfer via File Transfer Protocol (FTP).
- Nevertheless, even error-free and efficient use of interfaces is not possible without extensive know-how, which initially makes it more difficult to create new Bluetooth developments **[Book Ref 2 Chapter 5 page 98]**.

2.1.5 Bluetooth Architectures

A Bluetooth network essentially uses a master/slave architecture in which the master controls the traffic flow. In this way relatively simple isochronous traffic streams can be handled, as found, for example in the audio module. All Bluetooth devices have identical hardware properties so that the master is only selected when the network is established.

As Figure 9 shows the following types of Bluetooth network exist:

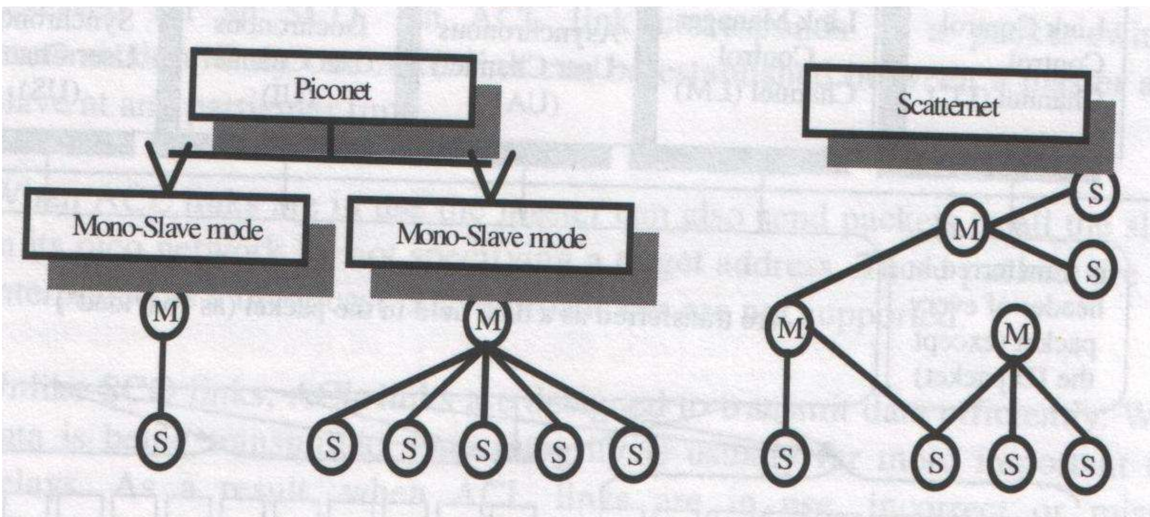


Figure 9 Architectures of Bluetooth Networks **[Book Ref 2 Chapter 5 page 99]**

- If only one master is present in a network then the network is a **pico network**.
    1. If a master only uses a point to point connection to communicate with the slave then the network is operating in mono-slave mode.
    2. However the master can also operate in multi-slave mode, establishing point to multipoint connections to seven active slaves, while additional slaves can participate passively in a "parked" state.
- A **scatternet** consists of several combined or scattered pico networks. As each pico network is managed by its own master this means that there are several masters in scatternet mode. In that mode a station can be logged on as a slave in

several pico networks and then also be active in these networks. At the same time, the master of a pico network can also be a slave in another pico network.

The main characteristics of the Bluetooth system are presented in Figure 10. The Bluetooth system employs a time-slotted access method. A packet can use up to five slots but must have at least one slot. Bluetooth system may transport an asynchronous data channel, up to three simultaneous synchronous voice channels, or a channel that simultaneously supports asynchronous data and synchronous voice.

The different types of links supported by Bluetooth are:

- A 64-Kbps synchronous link in each direction for voice channel.
- Maximal 732 Kbps asymmetric in one direction (still up to 57 Kbps in the return direction) or 433.9 Kbps symmetric for asynchronous link.

Bluetooth System Characteristics

Spectrum	2.4 GHz
Maximum physical rate (symbol rate)	1 Mbps
Access method	TDMA/FDMA-TDD

Figure 10 Bluetooth System Characteristics

[Book Ref 2 Chapter 5 page 99]
[Book Ref 3 Chapter 6 pages 186-187]

2.2.1 Overview of Oxygen Project (Pervasive Human-Centered Computing)

In the future, computation will be human-centered. It will be freely available everywhere, like batteries and power sockets, or oxygen in the air we breathe. It will enter the human world, handling our goals and needs and helping us to do more while doing less. We will not need to carry our own devices around with us. Instead, configurable generic devices, either handheld or embedded in the environment, will bring computation to us, whenever we need it and wherever we might be. As we interact with these "anonymous" devices, they will adopt our information personalities. New systems will boost our productivity. They will help us automate repetitive human tasks, control a wealth of physical devices in the environment, find the information we need (when we need it, without forcing our eyes to examine thousands of search-engine hits), and enable us to work together with other people through space and time.

Networks make it easy to establish *ad hoc* collaborating communities of people and computing devices. They configure and reconfigure themselves automatically, as nodes appear, migrate, and disappear. This makes them easier to maintain than before, when networks were tuned largely for static wired topologies. Local networks connect seamlessly with each other, with satellite and terrestrial networks, and with a large number and variety of physical devices that can be used to monitor and control the physical world.

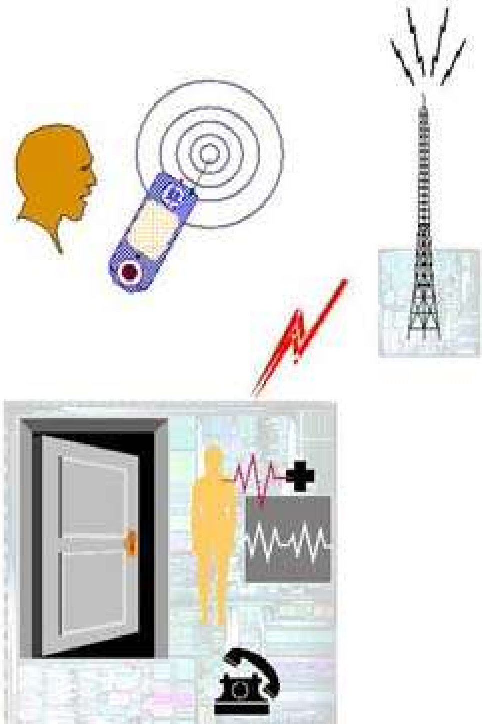


Figure 11 Oxygen network examples

Networks make it easy to locate resources, both nearby and further away, using names that express *what* is needed (e.g., "the nearest available printer"), rather than *where* to find it (e.g., myprinter.mynet.com). This makes them more useful and more resilient to failures, load conditions, and resource mobility.

Networks route heterogeneous traffic efficiently, in response to application demands, through nodes that differ in connectivity, computational power, and resources. They adapt to current channel conditions, no longer treating all channels as "leaky pipes" with fixed and known diameters (peak bandwidths) and loss characteristics. This adaptability is essential for wireless channels, whose peak bandwidth and error characteristics can vary dynamically and unpredictably. RF channels, for example, are affected by terrain, weather, and interference from other transmitters. Networks respond flexibly to such unpredictability. Instead of sending all packets at low data rates or broadcasting at high power, they allow applications to trade data rates off against energy consumption. Instead of always using complex and costly error correction, they use only as much as applications require. Instead of being designed to handle unlikely combinations of worst-case conditions, they are designed more economically to handle current or common conditions.

2.2.2 Approach

Oxygen enables pervasive, human-centered computing through a combination of specific user and system technologies. Oxygen's user technologies directly address human needs. Speech and vision technologies enable us to communicate with Oxygen as if we're interacting with another person, saving much time and effort. Automation, individualized knowledge access, and collaboration technologies help us perform a wide variety of tasks that we want to do in the ways we like to do them.

Oxygen's device, network, and software technologies dramatically extend our range by delivering user technologies to us at home, at work or on the go. Computational devices, called Enviro21s (E21s), embedded in our homes, offices, and cars sense and affect our immediate environment. Handheld devices, called Handy21s (H21s), empower us to communicate and compute no matter where we are. Dynamic, self-configuring networks (N21s) help our machines locate each other as well as the people, services, and resources we want to reach. Software that adapts to changes in the environment or in user requirements (O2S) help us do what we want when we want to do it.

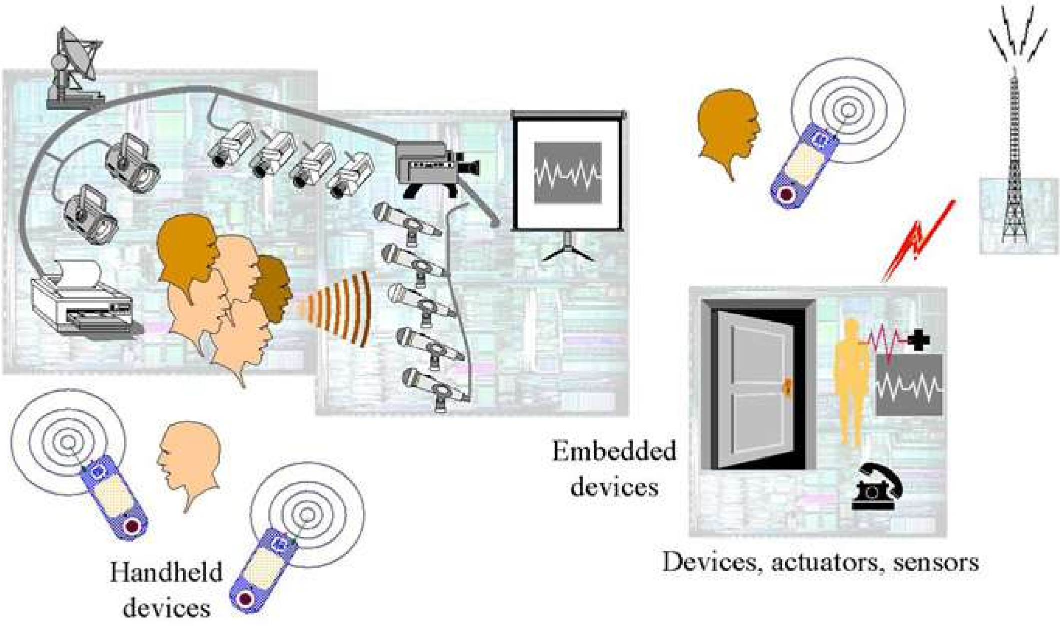


Figure 12 Devices used in Oxygen Networks

Flexible, decentralized networks, called *N21s*, connect dynamically changing configurations of self-identifying mobile and stationary devices. N21s integrate different wireless, terrestrial, and satellite networks into one seamless internet. Through algorithms, protocols, and middleware, they

- configure collaborative regions automatically, creating topologies and adapting them to mobility and change,

- provide automatic resource and location discovery, without manual configuration and administration,

- provide secure, authenticated, and private access to networked resources, and

- adapt to changing network conditions, including congestion, wireless errors, latency variations, and heterogeneous traffic (e.g., audio, video, and data), by balancing bandwidth, latency, energy consumption, and application requirements.

Collaborative regions

Collaborative regions are self-organizing collections of computers and/or devices that share some degree of trust. Computers and devices may belong to several regions at the same time. Membership is dynamic: mobile devices may enter and leave different regions as they move around. Collaborative regions employ different protocols for intra-space and inter-space communication because of the need to maintain trust.

2.2.3 Oxygen Device Technologies

Handheld devices, called H21s, provide mobile access points for users both within and without the intelligent spaces controlled by E21s. H21s accept speech and visual input, and they can reconfigure themselves to support multiple communication protocols

or to perform a wide variety of useful functions (e.g., to serve as cellular phones, beepers, radios, televisions, geographical positioning systems, cameras, or personal digital assistants). H21s can conserve power by offloading communication and computation onto nearby E21s.
Initial prototypes for the Oxygen device technologies are based on commodity hardware. Eventually, the device technologies will use **Raw computational fabrics** to increase performance for streaming computations and to make more efficient use of power.
[Internet Ref 5 http://oxygen.lcs.mit.edu/Overview.html]

[Internet Ref 6 http://oxygen.lcs.mit.edu/Network.html]

2.2.4 Oxygen Network Technologies

Dynamic networks

Grid is a routing protocol for ad-hoc mobile wireless networks. It is self-configuring and does not require any fixed infrastructure such as base stations or access points. Instead, Grid nodes cooperatively forward each other's data. A Grid network can be deployed rapidly, is robust in the face of node failures, and intrinsically supports mobile hosts.

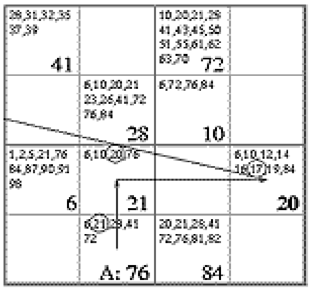


Figure 13 Grid Routing Protocol

Span is a topology maintenance protocol for energy efficient, ad-hoc wireless networks. Since idle receive circuits consume almost as much power listening for packets as do active circuits when receiving packets, Span nodes save power by turning off their radio receivers most of the time. Nonetheless, they forward packets between any source and destination with a delay close to a standard 802.11 ad-hoc network, and the topology formed by awake nodes provides about as much total capacity as the original network.

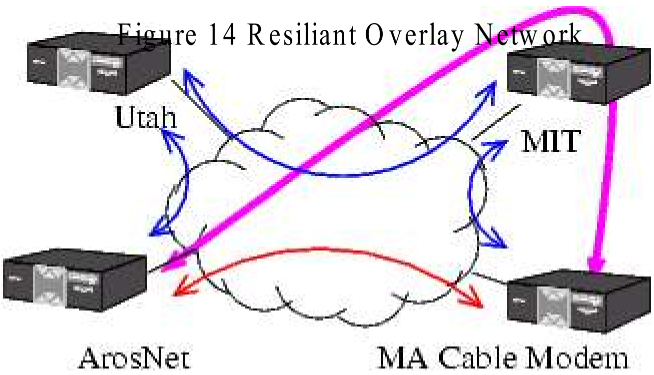


Figure 14 Resiliant Overlay Network

A Resiliant Overlay Network (RON) allows distributed Internet applications to detect and recover from path outages and periods of degraded performance within several seconds, improving over today's wide-area routing protocols that take at least several minutes to recover. RON nodes use active measurements to monitor the functioning and quality of the Internet paths among themselves, and use this information to decide whether to route packets directly over the Internet or by way of other RON nodes, optimizing the path using application-specific routing metrics.

[Internet Ref 7 *(Hari Balakrishnan, Networks and Mobile Systems)* http://nms.csail.mit.edu/]

[Internet Ref 8 (*M. Frans Kaashoek, Robert Morris, Parallel and Distributed Operating Systems)* http://pdos.csail.mit.edu/]

2.3 What is Pico Radio?

A **PicoRadio** is a single-chip implementation of a tiny, very low power, configurable radio. Sometimes, the term **PicoNode** is also used. However, PicoNode is the name of the DARPA contract, while PicoRadio is the title of the research efforts in BWRC on low-end radio and network. To understand what the challenges are in the design of such PicoRadio, we first need some context in which to view the design of the PicoRadio.

Context

The ever-evolving scaling of the semiconductor technology has enabled new opportunities to provide both flexibility and efficiency at a low cost and small size. When reducing the minimum feature sizes into the deep sub-micron realm (0.25 mm and below), it becomes possible to integrate more than one million gates on a single die, enabling the co-integration of, for example, the interfacing, computation, position location and communication functions into a single silicon circuit. This system-on-a-chip approach not only maximally reduces the size of the sensor node, but also allows the use of advanced circuit architectures that provide the optimal trade-off between flexibility and energy-efficiency.

PicoRadio

A PicoRadio is the tight integration of communication and computation functions into a single chip, to obtain the desired functionality at the lowest possible cost and energy. To implement all of these functions with the highest possible energy-efficiency, a single chip nodal architecture is foreseen in the style of Figure 1. It shows the schematic of the key functional blocks. The close integration of these blocks should lead to efficiency improvements that are orders of magnitude better than the solutions that are achieved by combining pre-designed COTS or GFE components, each of which optimized for a single function, on a board or substrate.

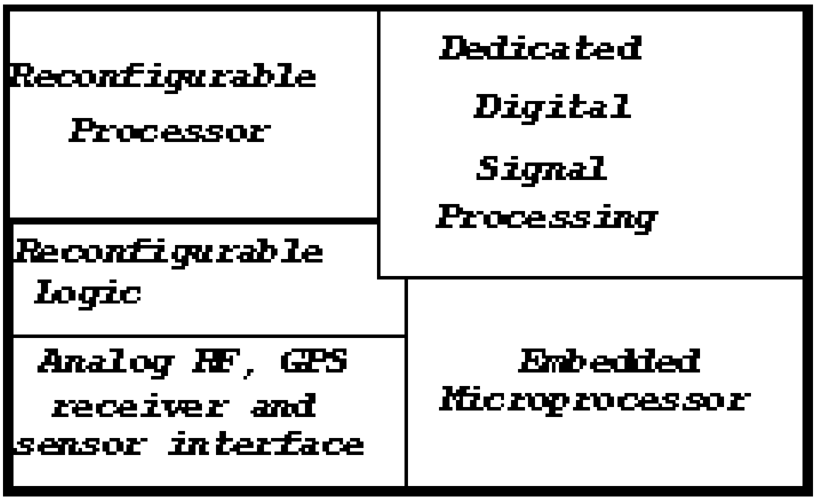


Figure 15 Sub-elements of a PicoRadio microprocessor

Sub-elements of a PicoRadio include an embedded microprocessor, a reconfigurable microprocessor, reconfigurable logic e.g. FPGA, a dedicated (custom) digital signal processing block, and an analog block with RF, sensor interfaces, etc (GPS). These blocks will be interconnected in a potentially different way for each type of PicoNode.

[Internet Ref 9 Information about PicoRadio http://www.gigascale.org/picoradio/]
[Internet Ref 9 DARPA proposal papers for PicoNodes http://www.gigascale.org/picoradio/pdf/IIB_TechRation.pdf]

2.4.1 Infrared Data Association (IrDA)

Since its formation in June 1993 the Infrared Data Association (IrDA) has been working to establish an open standard for short range infrared data communications. At the time of its formation there were a number of vertical, non-interoperable infrared communications technologies. Today IrDA is a strong contender for anyone considering adding infrared data communications to their product. Indeed, whilst supporting their own legacies, vendors who have been offering infrared solutions for years are embarked on the transition to an IrDA based solution.

The key goals for the IrDA are interoperability, low cost, and ease of use. Interoperability is addressed through the creation of an open standard with wide spread, multi-vendor support1.

Low cost refers to the marginal cost of adding an IrDA interface to products in high volume manufacture. For the most part the cost of adding the digital logic required to provide an IrDA interface is regarded as negligible. The few thousand gates that it takes to implement even the recent higher speed proposals are regarded as coming for free in an environment where ASIC functionality is limited largely by pin-count rather than gate utilization. This leaves the marginal cost of adding the optoelectronic transceiver which is estimated as \$2-\$3 and is set to fall further in future with the availability of transceiver modules from optoelectronic suppliers.

Lastly there is ease of use. The IrDA usage model is for short range directed communication link that supports ad-hoc point-and-shoot and place-and-play communications. The nominal operating envelope is a 1m cone with 15 degree half-angles. One of the IrDA frequently asked questions over the past year has been "How do I aim my printer?" The point being that it is all very well to be able to point a PDA at a printer, but it is not really tenable for a printer to sprout legs and point back. Whilst the term "directed" is used to describe an IrDA system, it would be unfair to suggest that it requires highly accurate alignment. Indeed the physical specification allows for more omni-directional behavior at ranges of less than 1m.

The IrDA system design, which is the focus of the bulk of this paper, is also a significant factor in establishing IrDA platforms as easy to use. Users of conventional communications applications have had to deal with having the correct cables to connect a computer or terminal to a peripheral such as a printer or a modem. They have had to do battle with baud rates, and bits per character and parity. They have also had the responsibility of ensuring that the correct software was loaded at opposite ends of the communications channel.

Whilst the IrDA aims to replace the serial cable for ad-hoc peripheral connection, it also aims to add ease of use features that enable applications to identify peer entities with which they can communicate. Thus a printing subsystem; a file sharing client; a calendar management application; a business card exchange utility... can all identify and locate matching peer entities in order to make use of their services.

The IrDA chose to base its initial standards on a 115kbit/s UART based physical layer that had been developed by Hewlett-Packard (HP-SIR), and an HDLC based Link Access Protocol (IrLAP) originally proposed by IBM.

During the course of its first year the need to multiplex multiple application-to-application streams over a single IrLAP connection was identified and with it the need to provide a means for locating and identifying the function of application entities offerings services over an IrDA interface. These needs led to the development of the IrDA Link Management Protocol (IrLMP).

This paper provides an introduction to the services provided by a IrDA platform. These are services upon which new families of Infrared aware applications will be build. End users will not be tied to either applications or platforms from a single vendor.

2.4.2 IrDA System Overview

The IrDA Architecture in Figure 15. There are now three components to the physical IrDA layer2:

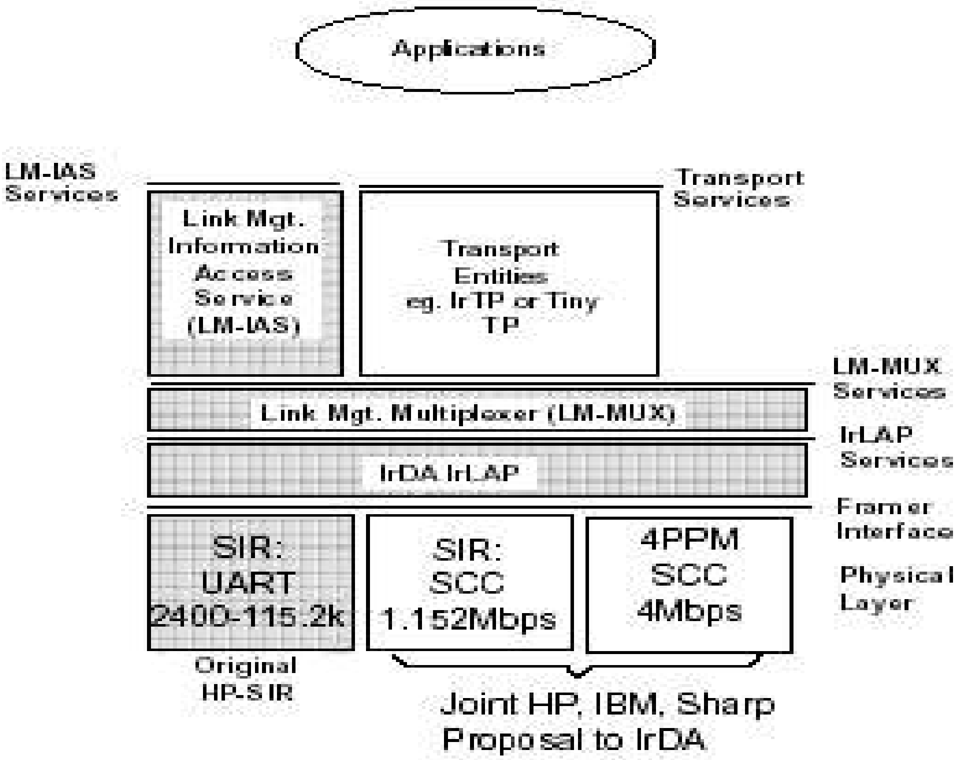


Figure 15 IrDA Achitecture

1. The original 2400bps-115.2kbps HP-SIR based scheme using a conventional UART with character stuffed packet framing.
2. A 1.152Mbps scheme that retains the same modulation scheme, but uses a asynchronous communications controller and conventional HDLC bit stuffing.
3. A 4Mbps scheme that uses a 4PPM modulation scheme and frames packets with a sequence of code violations.

From the point of view of the Link Access Protocol (IrLAP), the recent 1.152Mbps and 4Mbps extensions are regarded merely as extra speeds that may be negotiated when a device-to-device connection is established. All three physical layer schemes are designed to have a range of 1m at off axis angle of up to ±15 degrees. In practice, due to component tolerancing, on axis ranges can be substantially greater, and satisfactory operation can be achieved at off-axis angles of 30 degrees or more.

The Link Access Protocol (IrLAP) is a variation of multi-drop HDLC. It provides facilities for:

1. Controlling Hidden Terminal problems
2. Device Discovery
3. Device-to-device connect/disconnect and QoS negotiation
4. Data Transfer.

IrLAP is an asymmetric protocol and uses HDLC in its normal response mode (NRM). This means that once an IrLAP connection has been established, one station becomes a primary whilst the other becomes a secondary. In the context of a point-to-point connection there is very little difference between the behavior of primary and secondary stations. However, as we shall see, IrLAP has a the potential to be extended to provide point-to-multipoint device-to-device connectivity. In this case a single primary device would be able to communicate with several secondary devices, but the secondary devices will not be able to communicate directly with each other.

The Link Management Protocol (IrLMP) consists of two parts, a connection oriented multiplexer (LM-MUX) and a directory service (LM-IAS). With the exception of the directory service itself, there are no fixed addresses within the IrDA architecture.
Device addresses are chosen at random and exchanged during IrLAP discovery. Address space collisions are resolved by the device that initiates discovery. Likewise 'port' space above LM-MUX is dynamically assigned. The LM-IAS directory service then serves as a means to identify the application services present within a device and the addressing information required establish contact between application peers.

[Internet Ref 10 Infrared Data Association Official Site http://www.irda.org/associations/2494/files/Publications/irda_platform.pdf]

2.5.1 Overview of IEEE 802.15.4 Developing Standard for Low-Powered Low-Cost Wireless Personal Area Networks

A low-rate wireless personal area network, or LR-WPAN, is a network designed for low- cost very-low-power short-range wireless communications. Until now, the main focus in the wireless industry has been on communication with higher data through-put, leaving out a set of applications requiring simple wireless connectivity with relaxed throughput and latency requirements. LR-WPANs will connect devices that previously have not been networked and allow applications that cannot use current wireless specifications, including applications in fields such as industrial, agricultural, vehicular, residential, medical sensors, and actuators. Task Group 4 of the IEEE 802.15 Wireless Personal Area Network working group is currently working to define a wireless communication standard for LR-WPANs.

In recent years, wireless communication has experienced exponential growth caused by the need for connectivity. Wireless networking has followed a similar trend due to the increasing exchange of data in services such as the Internet, e-mail, and data file transfer. The capabilities need-ed to deliver such services are characterized by an increasing need for data throughput.

Other applications in fields such as industrial, agricultural, vehicular, residential, medical sensors, and actuators have more relaxed throughput requirements. Moreover, these applications require substantially lower power consumption than is currently provided in existing standard implementations. For instance, battery-powered devices for certain types of industrial and medical sensors, smart tags, and badges should last from several months to many years. In addition, cost plays a fundamental role in applications requiring wireless connectivity for inexpensive or disposable devices and for applications with a large number of wireless nodes in the personal operating space (POS). These intended applications require low-complexity wireless links that are low in cost relative to the device cost. Until now, these devices either have used proprietary wireless technologies or were deemed too expensive to implement. Thus, in order to reduce the cost of the components and facilitate volume production of such devices, the development of standardized solutions is necessary.

The above constraints suggest the design of a low-complexity wireless transceiver with minimal requirements to sustain a communications link with the least amount of overhead. Furthermore, the combination of low cost and low power consumption implies that this definition would provide a limited data rate for applications that do not require a large bandwidth.

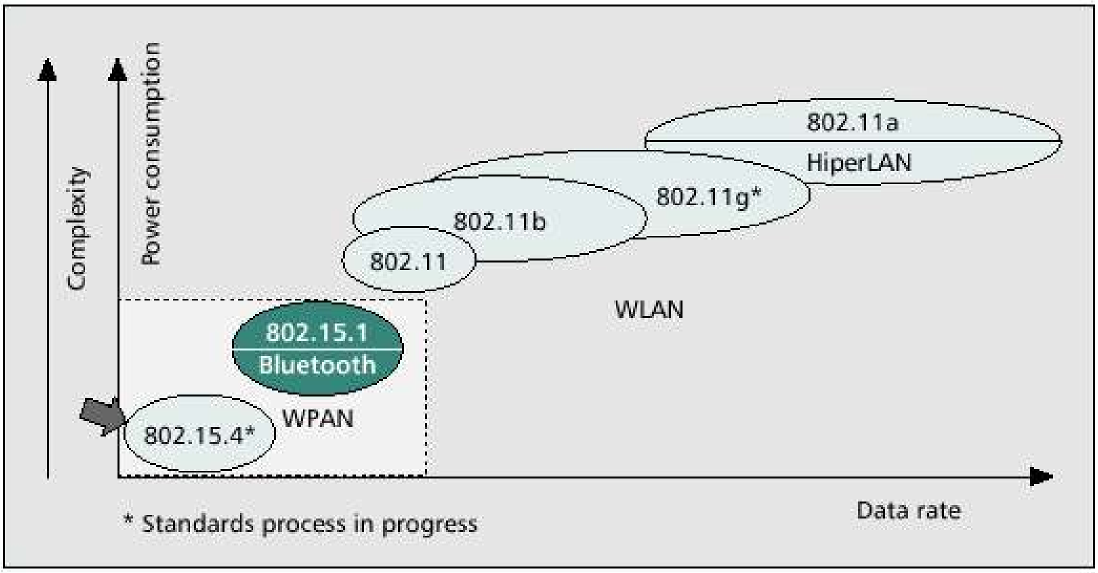


Figure 16 The operating space of various WLAN and WPAN standards

There are other efforts addressing these types of requirements. Among them are the SensIt project from the Defense Advanced Research Projects Agency (DARPA), which focuses on wireless ad hoc networks for large distributed military systems, and ZigBee, a spin off group of HomeRF with roots in home automation that has recently expanded its charter to include industrial and vehicular applications.

Recently, IEEE 802 Working Group 15 was created to develop a set of standards for short-range wireless communications commonly referred as *wireless personal area networks* (WPANs). To address the need for low-power low-cost wireless networking, the IEEE New Standards Committee (NesCom) officially sanctioned a new task group in December 2000 to begin the development of a low-rate WPAN (LR-WPAN) standard, to be called 802.15.4. The goal of Task Group 4, as defined in the Project Authorization Request, is to provide a standard having ultra-low complexity, cost, and power for low-data-rate wireless connectivity among inexpensive fixed, portable, and moving devices. Location awareness is being considered as a unique capability of the standard. The scope of Task Group 4 is to define the physical and media access control (MAC) layer specifications.

This task group is developing specifications in the industrial, scientific, and medical (ISM) bands due to their unlicensed nature and the available bandwidth. These bands are occupied by devices that implement other wireless specifications, so coexistence is an important aspect to consider. Coexistence issues will be addressed in a joint effort with the IEEE coexistence task groups, such as 802.15.2 and 802.11/ETSI-BRAN/MMAC 5GSG.

Some of the expected characteristics of the LR-WPAN are shown in Figure 17 and have been translated into a selection criteria document by Task Group 4 to aid in the definition of the LR-WPAN standard.

Property	Range
Raw data rate	2–250 kb/s
Range	Typical 10 cm to 10 m or up to 100 m with trade-offs
Battery life	Application-dependent and optimized for long battery life; asymmetrical power consumption nodes; might operate without battery (power scavenging); expected battery life might be as long as the shelf life itself
Latency	10–50 ms; or larger than 1 s
Location awareness	Optional
Nodes per network	Up to 65,534 (exact number to be determined)
Topology	Star and mesh are desired
Complexity	Lower than current standards
Types of traffic	Asynchronous data-centric; option to support synchronous communication
Desired frequency band	Unlicensed and international band
Temperature	Industrial temperature range –40° to +85° C

Figure 17 Expected characteristics of the LR-WPAN standardization effort

[Article Ref 1 Page 1-2]

2.5.2 LR-WPAN Applications

This section explores a broad range of potential applications requiring low-power low-throughput wireless communication networks. Figure 5 shows the general application space for LR-WPANs. In response to a Call for Applications [8] by Task Group 4, several ideas were presented at the IEEE 802 meeting in January 2001. Some of these applications are discussed in the following paragraphs.

The industrial market is a natural place for sensor net-works. Using a combination of sensors and LR-WPAN devices, data will be gathered, processed, and analyzed to determine whether or when user interaction is required. Examples of wireless sensor applications include detecting emergency situations, such as hazardous chemical levels and fires, and monitoring and maintenance of rotating machinery. An LR-WPAN would significantly reduce the installation cost of new sensor networks and simplify expansion of existing net-work installations. The initial implementations will most likely occur in monitoring applications with non critical data where longer latencies are acceptable. These industrial monitoring applications, in general, do not need high data throughput or constant updating. Instead, emphasis is placed on low power consumption in order to maximize the lifetime of the battery-powered devices that make up the network.

Wireless communication is finding its way into cars, as driver comfort and the number of features increase. In a similar manner, the number of wires required in a car has grown significantly, having a great impact on installation cost. In contrast to the home or office environment, the automotive environment represents a relatively underdeveloped application field regarding the provision of new services or updating existing services. One of the key factors missing for accomplishing this task is an appropriate wireless delivery medium based on standard specifications. The wireless option introduces flexibility in installation and an advanced alternative to wired connections. A special challenge for automotive applications is meeting the harsh automotive environment with a solution low enough in cost to find volume applications. Some of the applications WPANs can address in a vehicle are control and monitoring of non critical sensors. An application example is a tire pressure monitoring system. The system consists of four pressure sensors, one mounted on each tire, and a central station to receive the collected data. Since the pressure sensors have to be mounted on the tires, this application does not permit the use of any communication wires or power cables. Therefore, sensors have to be battery-powered. Since it is impractical to replace the sensors or their batteries between tire changes, it is required that the sensor batteries last at least three, preferably up to five, years. This puts significant constraints on the power consumption of the electronic components and requires power management capabilities. The data that needs to be communicated is, in most cases, only a few bits in size and indicates the measured tire pressure. This information is transmitted about every 1–10 min under non-alarm conditions. Unless there is a fast loss of pressure, the message latency is not of significant concern. In case of sudden pressure loss, the central control unit should be notified immediately, in which case power consumption is not of concern since most likely the tire has to be replaced. Extreme automotive environmental conditions and the metallic structure hinder RF propagation. In addition, the shape of the rim has a significant impact on the radiation pattern from the wireless sensor. To overcome this issue, repeater nodes, which will not add significant cost to the system, can be added to the network to increase communications reliability.

Another challenging application for LR-WPANs is precision farming, also called precision agriculture. Precision agriculture is an environment-friendly system solution that optimizes product quality and quantity while minimizing cost, human intervention, and variation caused by unpredictable nature. Today agriculture is still both user- and environment-demanding. It is mainly hardware-oriented with manual and on-site control using independent dumb machines, which produces unpredictable quality and quantity. With the new paradigm of precision agriculture, farming would become more information- and software-oriented, using automatic and remote-controlled networked smart machines. The drivers for this new paradigm are industrial mergers and consolidations, increased global competition, and increased environmental concerns. This application requires large mesh-type networks consisting of potentially thousands of LR-WPAN devices linked with sensors. These sensors will gather field information such as soil moisture content, nitrogen concentration, and pH level. Weather sensors for measuring rainfall, temperature, humidity, and barometric pressure will also provide the farmer with valuable information. Each sensor will pass the measured data to its corresponding LR-WPAN device, which in turn will pass it through the network to a central collection device. In order for the sensor data to be useful, location awareness technology is necessary for correlating each sensor with its specific location in the field. The combined information will give the farmer an early alert to potential problems and allow him to achieve higher crop yields.

The precision agriculture application is at the low end of the LR-WPAN application range, requiring the transmission of only a few bits of data per day by each deployed device. The data flow will be asynchronous in nature, with minimal restrictions on data latency. This combination of factors is advantageous for achieving long battery life. The challenge of this application is the topology of the network, since the application requires a mesh topology: some nodes serve as repeaters for others, relaying messages to the final destination, while still being power-conscious to obtain the required usage life. The network should also be self-configuring since manual setup of a network of the proposed size is not feasible.

The consumer and home automation market presents significant potential because of its size. LR-WPAN devices will replace wires in consumer electronics at very low cost due to the reduced capability set (e.g., a lower data rate) while still enhancing everyone’s life and entertainment experience. Types of potentially networked devices include televisions, VCRs, PC peripherals, and interactive toys and games, and the applications may include monitoring and control of the home’s security system, lighting, air conditioning system, and appliances. Most of these devices have an industry group interested in using a low-cost low-data-rate wireless solution. The potential for such networked devices within the home may be as high as 100–150 devices, and is well suited to a star topology.

A unique application scenario, falling within the consumer market, is a classroom calculator network. This network would operate in a master-slave mode in a star topology. The teacher workstation, the network master, would send tasks and math problems to each of the student's graphic calculators, the network slaves. After completion, the students would upload their solutions back to the teacher workstation. This network would need to support only a small number of nodes, typically around 30, and would require disallowing any peer-to-peer communication to prevent students from exchanging the solutions. The typical payload would be 100–500 bytes of information, sent several times per student per hour. It is desired that the batteries to power the calculator and communication function last the duration of a semester. While this is definitely a more throughput-consuming application than those presented so far, it is still well suited to an LR-WPAN.

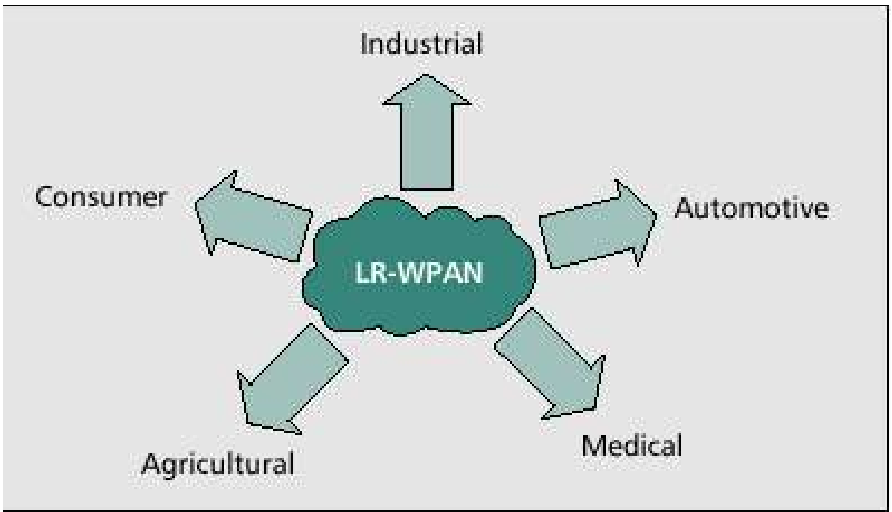


Figure 18 The LR-WPAN application space

[Article Ref 1 Page 7-8]
[Internet Ref 11 Official site of the IEEE for 802.15 http://grouper.ieee.org/groups/802/15]

3. PAN Paradigm

The person-centered networks continue to develop beyond the Bluetooth and all the other existing concepts towards the dynamic network concept, which will allow easy communications with personal wearable devices and seamless movement within the existing network environment. The PAN approach is foreseen as a network paradigm, which attracts the interest of the researchers, and the industries grow toward the more advanced network solution, radio technologies, higher bit rates, enhanced terminals, new mobility patterns and more sophisticated software support.

The PAN covers the area around the person recognised as a personal space. The general PAN network model is presented in Figure 19. It should provide end-to-end connectivity, secure communications, and QoS guarantees to the users. The system should be able to support different applications and operating scenarios and to comprise several devices.

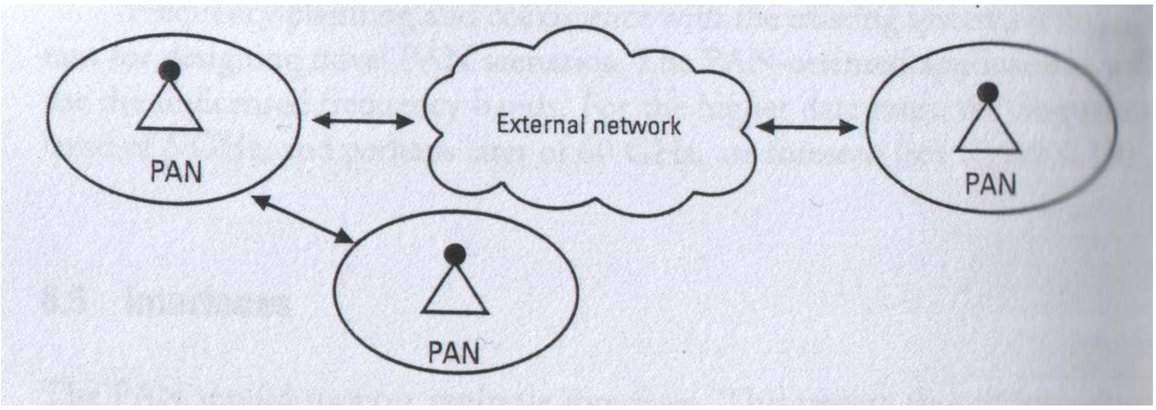


Figure 19 The PAN network concept.

[Book Ref 3 Chapter 6 pages 201-202]

4.1 Architecture Principles

The PAN is a network for you, and for you and me, and for you and the outer world. To comprise these it should develop layered architecture where different layers cover the specific types of connectivity (see Figures 20-22).

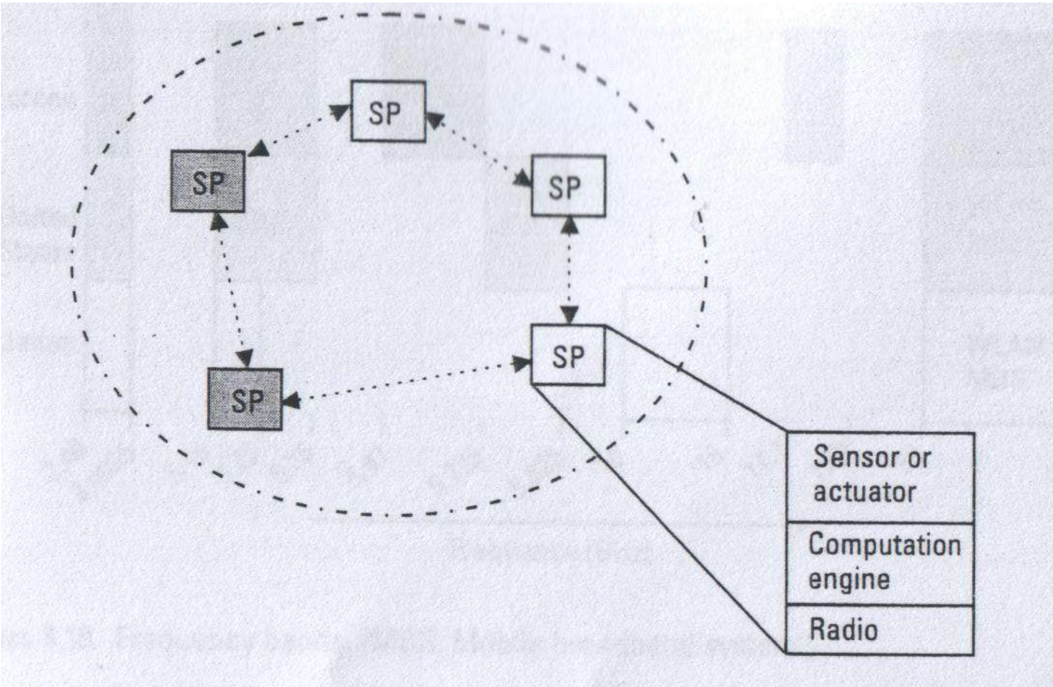


Figure 20 PAN is for you. It constructs a personal sphere of smart peripherals (SPs).

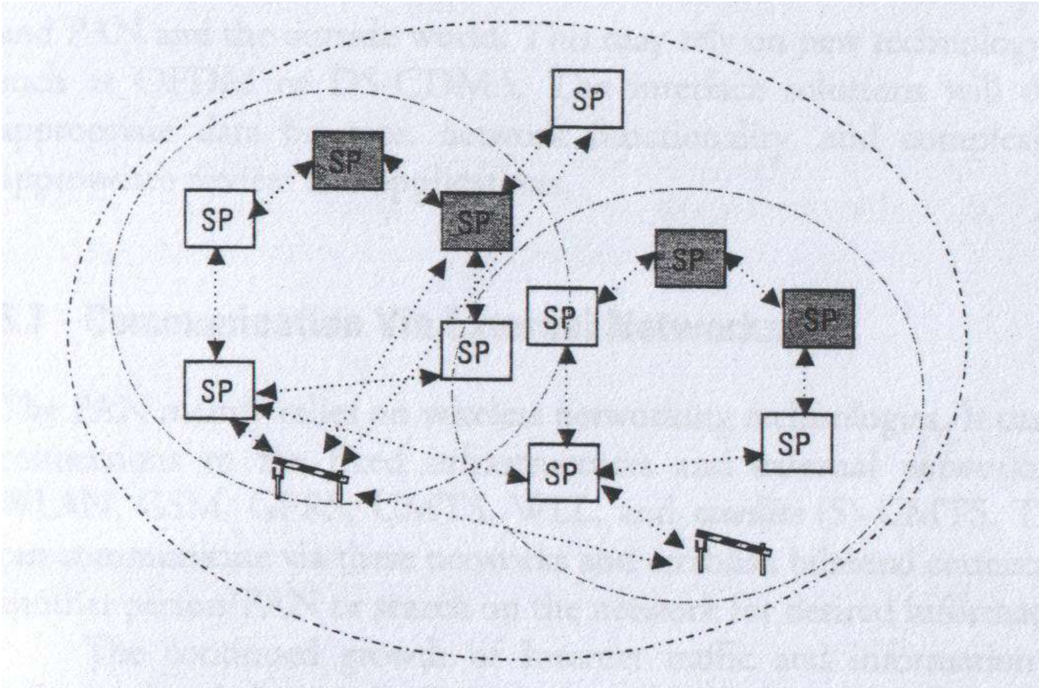


Figure 21 PAN is for you and me. When people and appliances meet, gatekeepers are needed. This is a dynamic distributed application platform.

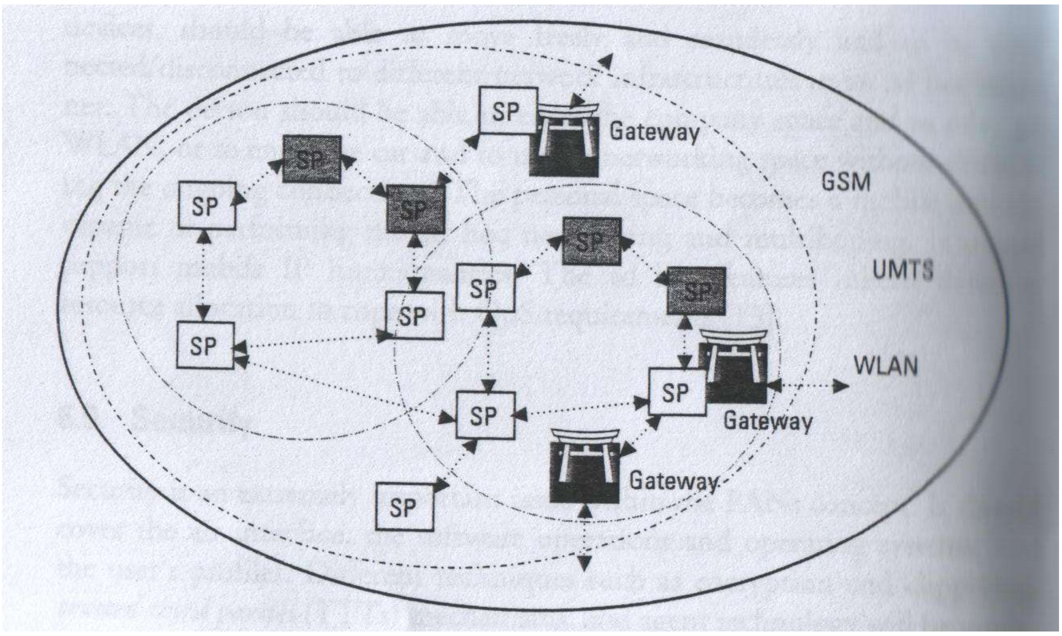


Figure 22 PAN is for you, me and the outer world. Extending your reach requires a multimode gateway. This is distributed resource control with QoS.

The connectivity is enabled through the incorporation of different networking functionality into the different devices. For the standalone PAN, the person should be able to address the devices within the personal space independent of the surrounding networks. For direct communication of two persons (i.e., their PANs), the bridging functionality should be incorporated into each PAN. For communication through the external networks, a PAN should implement routing and/or gateway functionalities.

Layer-oriented scalable architecture should support the functionalities and protocols of the first three layers and should provide the capacity to communicate with the external world through higher layer connectivity. It should provide the appropriate middleware structures and consist of a well-defined protocol stack, with identified information transfer through appropriate interfaces

The PAN should develop middleware structure capable of managing the system according to the access to the networks, resource discovery, support for scalability and reconfigurability, and QoS provisioning. It should also support the downloadable applications. The standardization of topology and architecture are still open issues within the PAN.

From the user point of view, PAN should offer plug-and-play connectivity. The network architecture should be seamless to the user.

Frequency planning and coexistence with the existing systems is important for designing novel PAN scenarios. The PAN-oriented applications will use the unlicensed frequency bands. For the higher data rates, the frequency band of 5 GHz, and perhaps later of 60 GHz, are foreseen (see Figure 23).

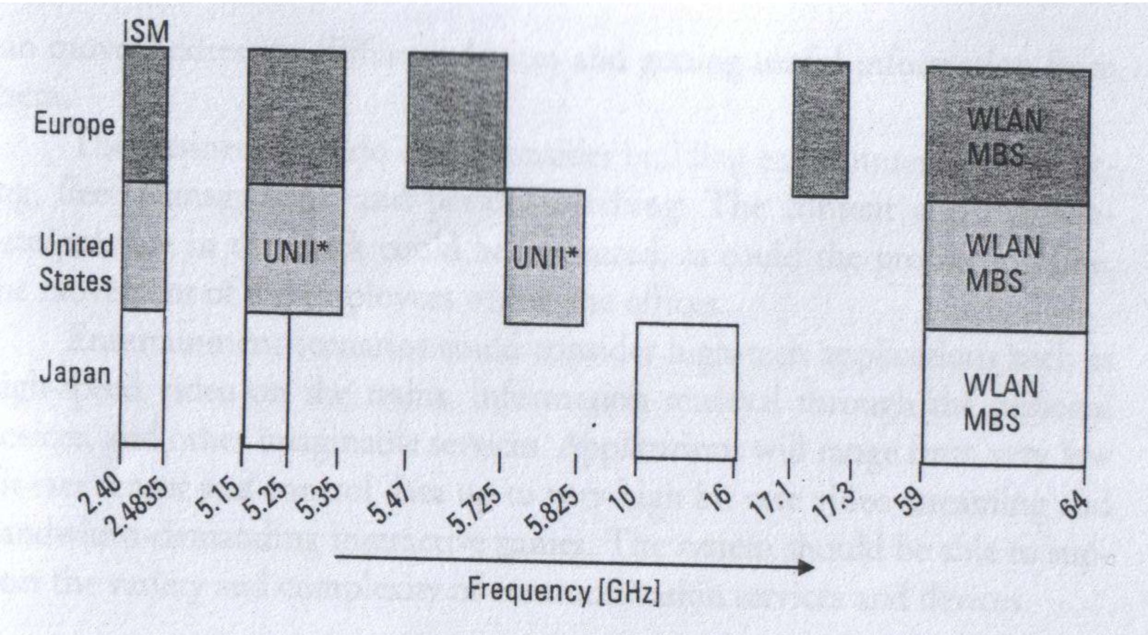


Figure 23 Frequency bands. (MBS: Mobile Broadband System.)

[Book Ref 3 Chapter 6 pages 202-204]

4.2 Interfaces

Then Pan should support multiple interfaces. This system should introduce new types of interfaces between the person and his or her devices, two PANS, and PAN and the outside world. This may rely on new technology solutions such as OFDM or DS-CDMA. The interface solutions will depend on appropriate data bit rate, network functionality, and complexity of the appropriate devices and applications.

[Book Ref 3 Chapter 6 pages 204]

4.3 Communications via External Networks

The PAN mainly relies on wireless networking technologies. It can establish connections to the fixed infrastructures and external networks, such as WLAN, GSM, GPRS, UMTS, WLL, and satellite (S)-UMTS. The person can communicate via these networks and establish bilateral connections with another person/PAN or search on the network for desired information.

The continued growth of Internet traffic and information exchange influenced and shaped the PAN concepts. The future PANs will be the IP-based networks with support of the IPv6 protocols. They will introduce a new type of *domain mobility.* A variety of devices, applications, and services will raise different QoS demands towards availability, reliability, and security issues.

[Book Ref 3 Chapter 6 pages 205]

4.4 Ad Hoc Networking

To support the person's mobility, PAN implements the characteristics of the wireless mobile networks. The person, together with personal wearable devices, should be able to move freely and seamlessly and to be connected/disconnected to different network infrastructures in an ad hoc manner. The person should be able to enter the company space and to relay on WLAN, or to enter the car and to use its networking space without disrupting the ongoing connections. The personal space becomes a mobile domain capable of performing the ad hoc networking and multihoping. It should support mobile IP functionalities. The ad hoc features inherit dynamic resource allocation to cope with QoS requirements.

[Book Ref 3 Chapter 6 pages 206]

4.5 Security in PANs

Security is an extremely important issue within the PANs concept. It should cover the air interface, the software operations and operating systems, and the user's profiles. Different techniques such as encryption and clippering, trusted third parties (TTTs) mechanisms, and agent technology will be implemented. Security communications between the foreign PANs should be realized through the gatekeeping functions. The PAN security should offer:

- Full identity
- Full anonymity
- Data security
- Integrity.

[Book Ref 3 Chapter 6 pages 206]

5.1 Main Applications and possible Scenarios

The PAN searches for technical challenges and applications that will turn it into a system really serving the person and improving the quality of his or her personal and professional life. Many different operating scenarios can be foreseen, mainly concentrated around:

- Personal device
- Business services
- Entertainment

The personal services include medical telemonitoring and control applications and smart homes. Medical professionals can constantly monitor the sick person wherever he or she moves. Within his or her home a person can move , addressing different devices and getting useful information from them.

The business scenario could consider building environmental monitoring , fleet management and person searching. The content and temperature/pressure in the truck could be measured, as could the production line, the movement of the employees within the offices.

Entertainment scenarios could consider high-tech applications such as high-speed video on the trains, information retrieval through the personal devices, and other imaginable services. Applications will range from very low bit rate sensor and control data up to very high bit rate video streaming and bandwidth-demanding interactive games. The system should be able to support the variety and complexity of communication services and devices.

[Book Ref 3 Chapter 6 pages 206-207]

5.2 Possible Devices

Different service demands and application scenarios in PAN build up different approaches towards the terminal functionalities and capacities. Some devices, such as simple personal sensors, must be very cheap and must incorporate limited functionalities. Others should incorporate advanced networking and computational functionalities, which will make them more costly. Scalability regarding the following items is foreseen as crucial:

- Functionality and complexity
- Price
- Power consumption
- Data rates
- Trustworthiness
- Supporting interfaces.

The most capable devices should incorporate multimode functionalities that will enable the access to multiple networks.

Some of the devices should be wearable or attached to the person (i.e., sensors); some could be stationary or associated temporarily to the personal space (i.e., environmental sensors, printers, and information desks). A set of possible devices for PAN applications is presented in Figure 24.

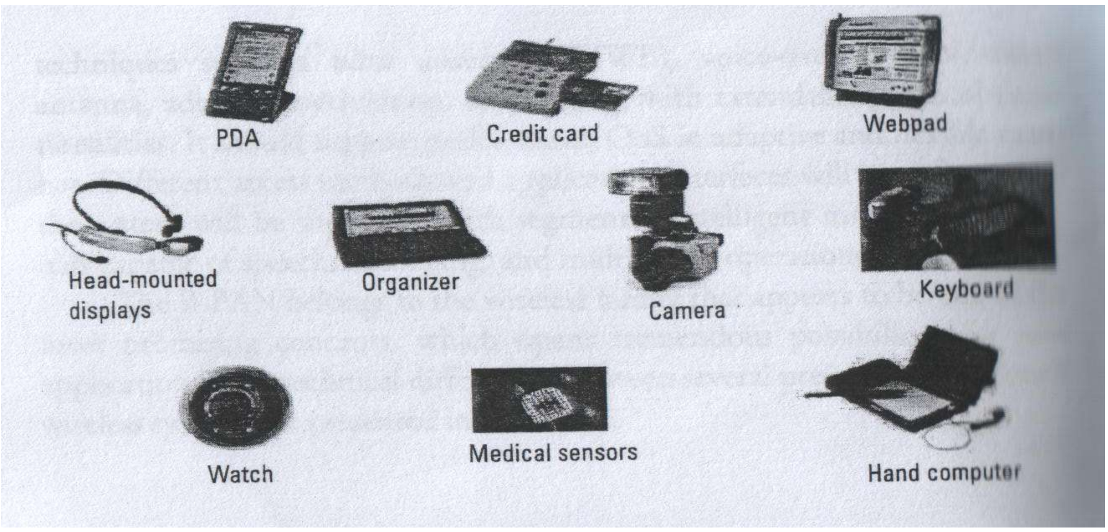


Figure 24 Possible devices for PAN applications.
[Book Ref 3 Chapter 6 pages 207]

6.1 PAN Challenges and Open Issues

Building the system with demanding system solutions for personal and network requirements stress many challenges to the scientific and industrial world.

Pan should build up applications on a dynamic distributed platform and provide distributed resource control with QoS. It should develop the low-power, low-cost radio and a variety of reconfigurable terminals. The PAN should blend into the living environment, allowing seamless network connectivity and secure communications.

To fulfil these goals, PAN should address important issues, such as:

- Low-power, low-cost radio integration,
- Definition of possible physical layers and access techniques
- Ad hoc networking
- Middleware architecture
- Security (different security techniques, gatekeeping functionalities)
- Overall system concept
- Human aspects.

Standardization activities regarding PAN are continuing within the IEEE 802.15 groups. They will try to standardize the overall system concept and to point out the general requirements for PAN as guidepost to the researchers and industry in bringing PAN into everyday life.

The consistent demand for the higher bit rate pushes the PAN concept towards the new border. The new network paradigm will present the *broadband PAN (B-PAN) system*, which will be able to support high data rates up to 400 Mbps and more demanding multimedia and broadband interactive applications.

[Book Ref 3 Chapter 6 pages 208-209]

6.2 B-PAN

The B-PAN is a future development of PAN towards the wideband adaptive novel techniques capable of broadband wireless communications (see Figure 25). It will support applications up to 1 Gbps and probably will operate over 5 GHz or 60 GHz frequency bands. B-PAN will implement novel such as *ultra wideband (UWB),* voice—over B-PAN, smart antenna, adaptive modulation, and coding, with extendable protocol functionalities. It should support performance QoS in adaptive and flexible manner. Different access methods and application interfaces will be defined, and the system will be supported with segmented intelligent multi-access terminals capable of speech, messaging, and multimedia operations.

The B-PAN belongs to the wireless family that appears to be one of the most promising concepts, which opens tremendous possibilities for new applications. The technical differences between several previously mentioned wireless systems are presented in Figure 26.

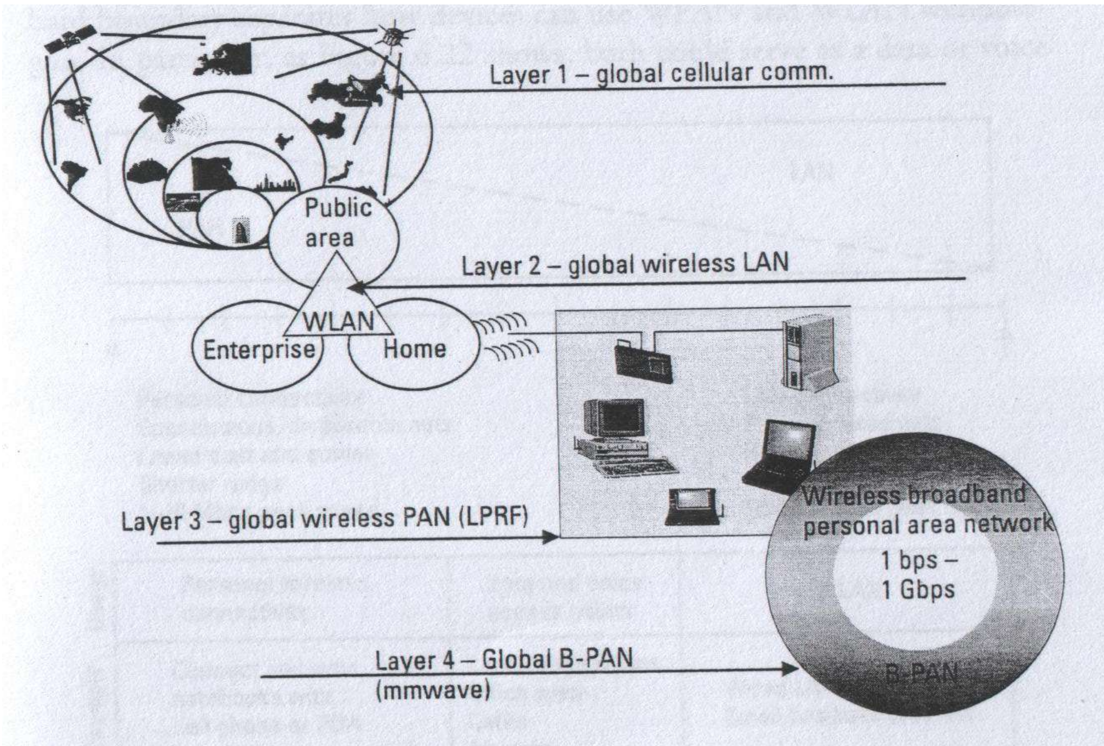


Figure 25 Four-layer wireless communication provides mobile services everywhere, and they complement each other (LPRF: low power radio frequency).

Technical Differences and Applications

	UTRA	**WLAN**	**Bluetooth**	**PAN**	**B-PAN**
Data rates	Maximum 2 Mbps (384 Kbps)	5.1–54 Mbps	Maximum 721 Kbps	Maximum 10 Mbps	1 Gbps
Technology	TD-CDMA and W-CDMA	OFDM	DS or FH	OFDM	OFDM/DS-CDMA/SHF-CDMA
Cell radius	30m–20 km	50–300m	0.1–10m	To the distance a voice reaches	Similar to PAN
Mobility	High	Low	Very low	Very low	Very low
Standard availability	1999	2000	1999	2004	2012
Frequency band	2 GHz	5 GHz	2.4-GHz ISM band	5/10 GHz	60 GHz
Frequency license	Necessary	Not necessary	Not necessary	Not necessary	Not necessary
Application	Public environments (likely restricted use in places such as hospitals and airplanes)	Corporate environments (industrial applications); public hot spots (such as airports, exhibitions, convention centers)	Substitution for infrared communica-tions; low cost networks for *small office home office* (SoHo) and residential applications	Personal peripheral device commu-nications	Surrounding environment

Figure 26 Technical Differences and Applications

[Book Ref 3 Chapter 6 pages 209-210]

7. WLANs versus PANs

Regarding the rapid development of WLAN standards during recent years, as well as some of the target WLAN applications, a natural question arises: why is there research into PANs when there is already a well-traced line of progress for WLANs? WLANs can also afford wireless connectivity to the proximate portable computing devices, which is an initial drive for designing PANs.

WPANs technologies emphasize low cost and low power consumption, usually at the expense of range and peak speed. WLAN technologies emphasize higher peak speed and longer range at the expense of cost and power consumption. Typically, WLANs provide wireless links from portable laptops to a wired LAN via access points. To date IEEE 802.11b has gained acceptance rapidly as a WLAN standard. It has a nominal open-space range of 100m and a peak over-the-air speed of 11 Mbps. Users can expect maximum available speeds of about 5.5 Mbps.

Although each technology is optimized for its target applications, no hard boundary separates how devices can use WPAN and WLAN technologies. In particular as Figure 27 shows both could serve as a data or voice access medium to the Internet, with wireless WLAN technologies generally best suited for laptops and WPAN technologies best suited for cell phone and other small portable electronics.

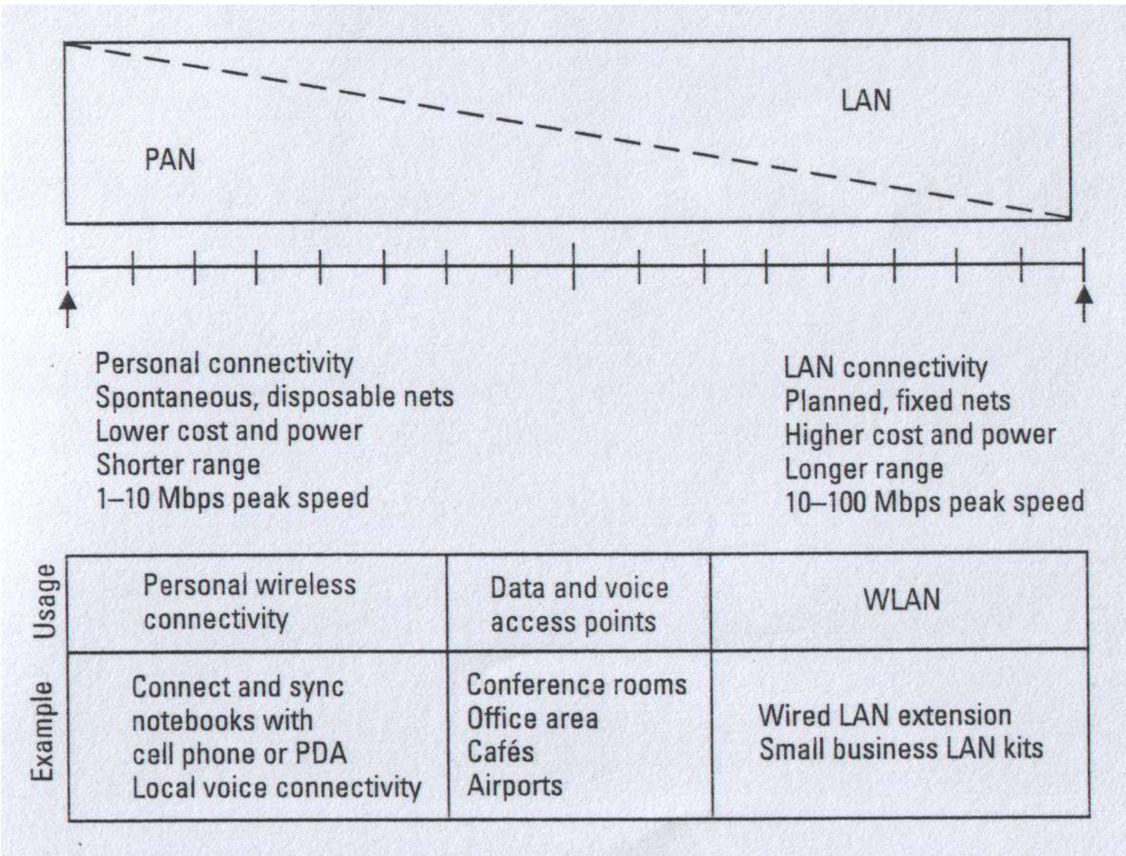


Figure 27 The complementary position of WLANs and PANs

A problematic topic about the Bluetooth PAN and IEEE 802.11b LAN is the coexistence issue because both operate in the unlicensed ISM band. When operated simultaneously in the same physical space, these two technologies degrade each other's performance.

Over the long run, researchers anticipate that WLANs will migrate to the 5 GHz unlicensed band, which may eliminate most coexistence issues. In particular, the companion standard IEEE 802.11a, designed for the 5 GHz band, will operate at peak over-the-air speeds up to 54 Mbps over distances up to 50m. Maximum data speeds available to users are projected to be between 24 and 35 Mbps.

[Book Ref 3 Chapter 6 pages 211-212]

8. WPANs versus LR-WPANs

To better understand LR-WPANs, it is appropriate to define WPANs and their market space. WPANs have just arrived on the scene and, at first glance, may appear to be in competition with wireless local area networks (WLANs). However, significant differences justify both network types. Figure 1 illustrates the operating space of the various 802 wireless standards and activities.

WPANs are focused around the POS, that is, a space around a person or object that typically extends up to 10 m in all directions and envelops the person whether stationary or in motion. In contrast, the desirable traits of a WLAN system are long range, complexity to handle seamless roaming, message forwarding, and hundreds if not thousands of nodes attached and ready for instant communication.

WPANs focus on low cost, low current drain, and very small size. As a point of reference, the peak current drain of the typical WLAN is about five times that of a low-power WPAN. Further-more, a typical WLAN device is designed as a PC card suitable for a desktop or laptop PC, while the WPAN is the size of a compact flash card, suitable for a palm-size or handheld PC.

The IEEE 802.15 working group has defined three classes of WPANs that are differentiated by data rate, battery drain, and quality of service (QoS). The high-data-rate WPAN (802.15.3) is suitable for multimedia applications that require very high QoS. Medium-rate WPANs (802.15.1/Bluetooth™) will handle a variety of tasks ranging from cell phones to PDA communications and have a QoS suitable for voice applications. The last class of WPAN, LR-WPAN (802.15.4), is intended to serve a set of industrial, residential, and medical applications with low power consumption and cost requirements not considered by the above WPANs and with relaxed needs for data rate and QoS.

Figure 28 shows a general summary of the characteristics of an LR-WPAN compared with 802.11b and a standard WPAN such as Bluetooth.

In accordance with IEEE 802 practices, the 802.15.4 task group is planning to create specifications for the physical and MAC layers. The physical and MAC proposals presented to Task Group 4 at the IEEE meetings are in.

	WLAN	BT-based WPAN	Low-rate WPAN
Range	~100 m	~10–100 m	10 m
Data throughput	~2–11 Mb/s	1 Mb/s	<0.2 Mb/s
Power consumption	Medium	Low	Ultra low
Size	Larger	Smaller	Smallest
Cost/complexity	> 6	1	0.2

Figure 28 A comparison of LR-WPANs with other wireless technologies

Provisions must be made in the higher communications layers to interface an LR-WPAN network to other existing network standards and to provide authentication and security ser-vices if necessary. Figure 29 shows the International Organisation for Standards' (ISO's) Open System Interconnect (OSI) model with IEEE 802's model.

The intent of an LR-WPAN is to pursue those applications where existing WPAN solutions are still too expensive and the performance of a technology such as Bluetooth is not required. LR-WPANs complement other WPAN technologies by providing very low power consumption capabilities at very low cost and enabling applications that were previously impractical. To summarize, LR-WPANs are characterized by:

- Low data rate
- Very low power consumption-battery operation from several months to years
- Variable network topologies
- Location awareness

The most obvious defining characteristic of an LR-WPAN is its data throughput, which ranges from a few bits per day to a few kilobits per second. Many low-end applications do not generate large amounts of data and therefore only require limited bandwidth. Often these applications do not require real-time data transmission or continuous updates. However, there are exceptions: LR-WPAN applications.

The low data rate enables the LR-WPAN to consume very little power. Many applications that suit LR-WPANs, such as the monitoring and control of industrial equipment, require exceptionally long battery life so that the existing maintenance schedules of the monitored equipment are not compromised. Other applications, such as environmental monitoring over large areas, may require a very large number of devices that make frequent battery replacement impractical. There are still other applications for which batteries themselves are impractical, and energy for the LR-WPAN transceiver and the device must be extracted or "mined" from the environment.

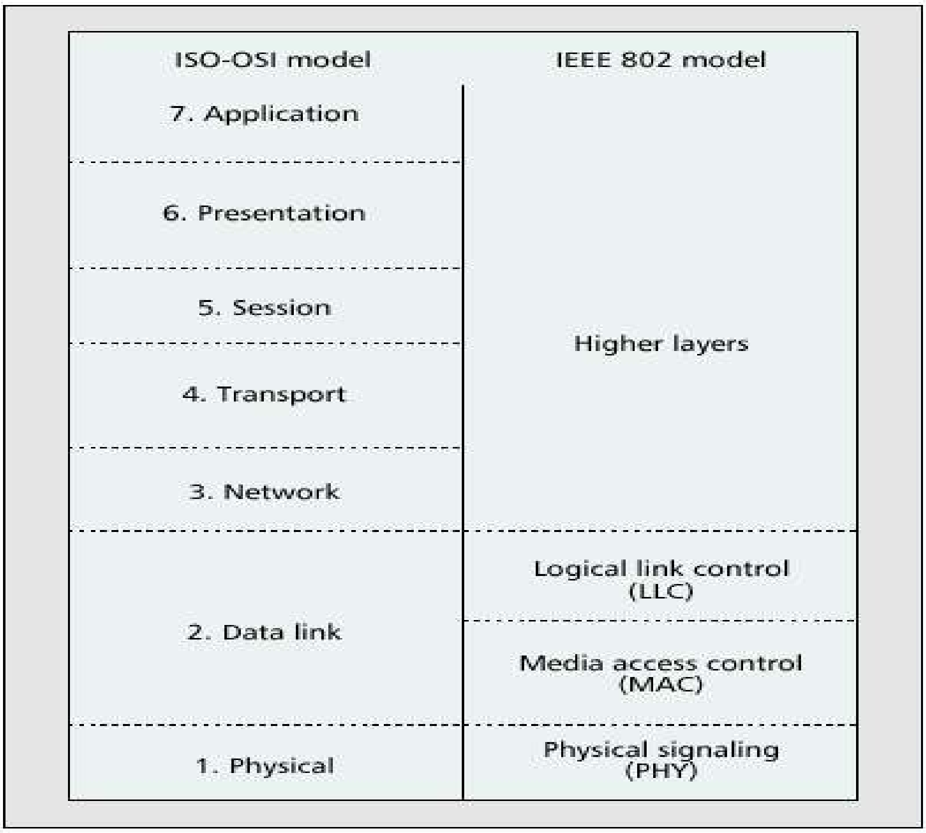


Figure 29 *The seven-layer ISO-OSI and IEEE 802 standards models.*

[Article Ref 1 Page 3-4]
[Internet Ref 10 Official site of the IEEE for 802.15 http://grouper.ieee.org/groups/802/15]

9. References

Book References

- Book Ref 1 Wireless Personal Area Networks and HomeRF, Salim KHIRAT, Akram KADHI, DESS February 2002.

- Book Ref 2 Wireless Personal and Local Area Networks, Axel Sikora, Wiley 2003

- Book Ref 3 WLANs and WPANs towards 4G wireless, Ramjee Prasad, Luis Munoz, Artec House Publishers, Universal Personal Communication Series, 2003.

- Book Ref 4 Computer Networks, Fourth Edition, Andrew S. Tanenbaum, Prentice Hall, March 2003

Article References

- Article Ref 1 IEEE 802.15.4 Developing standard for Low-Power Low-Cost Wireless Personal Area Networks, Jose A. Gutierrez, Marco Naeve, Eaton Corporation, Ed Callaway, Monique Bourgeois, Motorola Labs Vinay Mitter, Qualcomm Inc., Bob Heile, consultant

Internet References

- Internet Ref 1 IBM Almaden Research Center PAN Fact Sheet http://www.almaden.ibm.com/cs/user/pan/pan.html

- Internet Ref 2: The Official Bluetooth Website http://www.bluetooth.com/

- Internet Ref 3: Official Site for the Bluetooth standard (Membership Site) http://www.bluetooth.org

- Internet Ref 4: Bluetooth Web The Wireless Directory for Bluetooth Products and Services, Bluetooth Protocol Stack http://www.thewirelessdirectory.com/Bluetooth-Software/Bluetooth-Protocol-Stack.htm

- Internet Ref 5 MIT Oxygen Project Pervasive Human-Centered Computing, Project Overview http://oxygen.lcs.mit.edu/Overview.html

- Internet Ref 6 MIT Oxygen Project, Pervasive Human-Centered Computing, Network Technologies http://oxygen.lcs.mit.edu/Network.html

- Internet Ref 7 *Hari Balakrishnan, Networks and Mobile Systems* http://nms.csail.mit.edu/

- Internet Ref 8 *M. Frans Kaashoek, Robert Morris, Parallel and Distributed Operating Systems* http://pdos.csail.mit.edu/

- Internet Ref 9 Information about PicoRadio http://www.gigascale.org/picoradio/ and Official DARPA proposal papers for PicoNodes http://www.gigascale.org/picoradio/pdf/IIB_TechRation.pdf]

- Internet Ref 10 Infrared Data Association Official Site http://www.irda.org/associations/2494/files/Publications/irda_platform.pdf

- Internet Ref 11 Official site of the IEEE for 802.15 http://grouper.ieee.org/groups/802/15