Chapter 5 – WIRELESS PERSONAL AREA NETWORKS (WPANs)

5.1 AN ELABORATION OF THE MULTISPHERE REFERENCE MODEL

The Book of Visions 2000 attempts to propose a reference model, so called the MultiSphere model. Based on the issues and ideas mentioned therein, we present here a more detailed level in terms of functionality and then technologies involved. This is in line with the horizontalisation introduced by 3G's mobile Internet, whereby future vertical applications and services will draw together a multitude of wireless technologies in an ad-hoc manner. In the following paragraphs some of the various spheres of the MultiSphere model are identified. Those addressing general market and commercial needs are omitted and emphasis is placed on the lower, communication related layers.

The technological choices described here aim primarily at a user-centric WPAN, cantered around the person (soldier). This consists (with decreasing emphasis) of his wearable and portable equipment, his immediate neighborhood and his ability to communicate with the wider environment via larger area (wired or wireless) backbones. As a first step we derive corresponding preliminary communications needs. The Book of Visions describes three typical situations: the smart healthy home, the professional environment and the fancy futuristic multimedia traveler. Corresponding environment for military applications have to be considered. It is expected that in both civilian and military environment end-to-end networking with security are the most important concerns, with the additional constraint that the system could comprise a lot of devices.

Except from the general considerations mentioned above there is a number of important and widely employed standards and protocols, either of a generic nature, or particularly adapted to specific application environment. Therefore a survey of recommendations and standards from IEEE 802.15 are attached (see below).

5.2 THE "SPHERES OF THE MODEL"

Communication occurs in three different spaces or spheres: the space that is centered on the person itself, the "outer" local space and the "outer" distant space. These three different spaces translate themselves in three different possible networks: the Personal Area Network (PAN), the Community Area Network (CAN) and the Wide Area Network (WAN).

User requirements of a user-centric Wireless Personal Area Network (WPAN) start from general application scenarios and preliminary communications needs arising from these scenarios. The professional environment, the fancy futuristic multimedia traveler and the combat soldier case, taken as rough first steps call for scalability and end-to-end networking with security. The WPAN, or several WPANs in proximity, could comprise a lot of devices. In the military environment the set of possible devices is also open ended in terms of functionality and scope. So there is a need for scalability in terms of numbers, but also for flexibility to accommodate an open ended set of application possibilities. Finally low-power and possibly low-cost should also be primary design goals for WPAN-based systems and their successful deployment.

5.3 MULTISPHERE LEVEL 1 – THE PAN

In the MultiSphere Level 1 consisting of the PAN, the closest interaction with the Wireless World will happen with the elements that are the nearest to the person or might even be part of his body.

Communication facilities will be contained in clothes, wearable items and equipment carried on a semi permanent basis. We should imagine these devices as starting to discover each other and constituting (spontaneously or at user request) a common virtual terminal the person.

5.3.1 WPAN Devices and Data Rates

At this level Devices and Data Rates have to be considered. This is different from the following spheres presented below, where more "traditional" terminals are to be accommodated in the usual way.

WPAN devices are assumed be in a range from very low power devices with very low communication possibilities to high-end devices covering the full range of communication standards. Low rate devices, e.g. sensors, will have a rate in the range of bits/s while a high rate is considered to be in the range of 10 Mbits/s.

To address this wide range of data rates, two basic options are possible:

- Different physical layers (e.g. 2 or 3), where each address a data rate range (for example 10 bps to 10 Kbps and 10 Kbps to 10 Mbps); and
- Scalable physical layers (data rates, power and cost at least).

Clearly, certain devices will be more capable and costly than others. Simple personal devices (e.g. sensors) must be very low cost and certain less capable devices may even be throw-away. Other more capable devices may incorporate bridge, router or even gateway functionalities, as required to support advanced networking features (see below) and more traditional environments (tactical radios sets, civilian mobile devices, etc.). Relative to other wireless technologies, the WPAN approach should be inherently low cost, due to a scalable and hierarchical architecture and (possibly multiple) air interface options tailored to the service class.

5.3.2 Meshed Nodes with Hierarchy within the WPAN

In the simplest case, the PAN may be a stand-alone network capable of operation independently from other networks. Still, due to the very large range in data rates, it might be useful to put some hierarchy in this simple network by separating the low rate devices from the high rate devices. Hence the need to concentrate several low end devices around a "Virtual Device".

5.3.2.1 The Virtual Device

A Virtual Device is made of two types of devices: Slave Terminals (STs) that can be very simple tele-monitoring sensors or actuators and a Master (M). Indeed, as the distance between these devices is short (about 2 meters for a person) and as the use of direct communication between the STs does not appear to be mandatory, the natural topology is a star topology. Hence, there needs to be a Master (M) that co-ordinates the communications and can serve as a display/control terminal. The whole "network" acts as a concentrator from low data rate to higher data rate through the master and can be seen as virtual device from high rate PAN network.

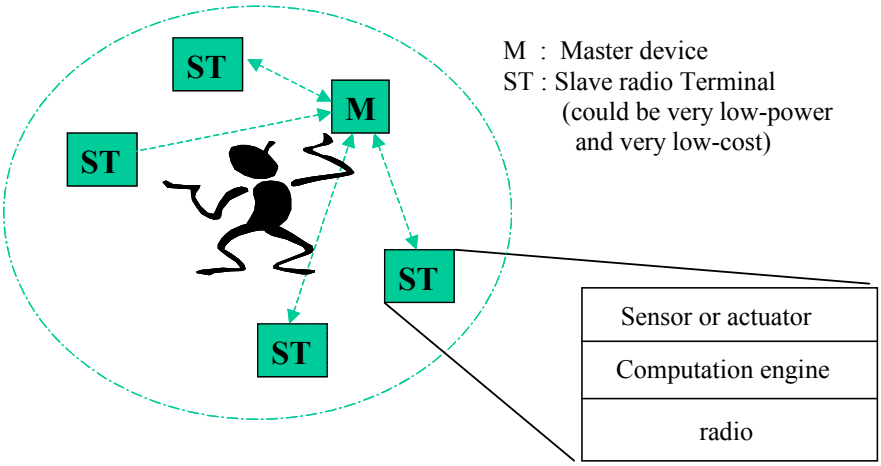

Figure 5-1: The Virtual Device (VD): A Small Standalone Network – A Master with its Accompanying Slave Terminals.

5.3.2.2 The WPAN Consisting of Virtual Devices

Apart from small sensors, a person could also carry a camera, a display (e.g. virtual glasses on which you can see an electronic display), or even more data oriented devices (e.g. computer, keyboard, or printer, weapons with data interfaces). To accommodate higher data rate without wasting bandwidth by duplicating the communications (which would occur if the data going from the camera to the display has to go through the master), the natural topology here is a meshed network (hopefully fully connected, but this can not be guaranteed). Hence, the global picture of a PAN is a meshed network where one of the nodes is a Virtual Device, regrouping the low data rate devices and the other nodes are "advanced Terminals" (aT) (Figure 5-2). Note that dynamic reconfiguration of the network and security issues are less crucial and complex at this level than for the CAN or WAN (see below).

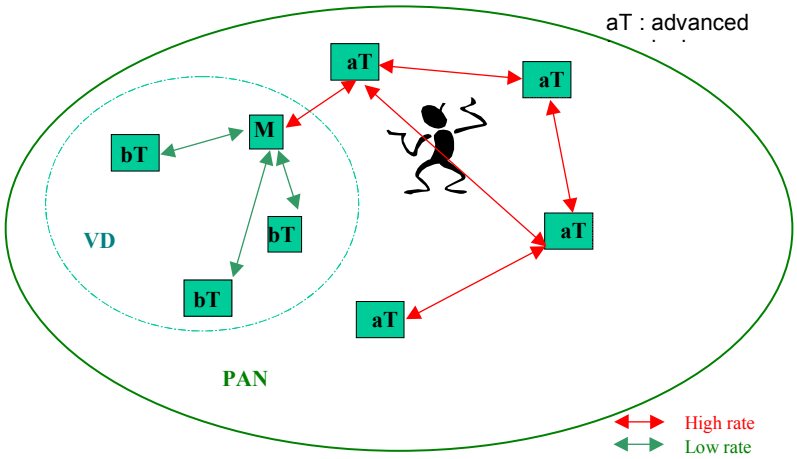

Figure 5-2: The Personal Area Network: A Network of Terminals.

5.4 MULTISPHERE LEVELS 3 & 4: INSTANT PARTNERS

The Book of Visions 2000 addresses here interaction with devices in the immediate PAN environment activated by sensing the physical proximity. This level is here omitted on two ground:

- It can be incorporated within the lower one above; and
- It has reduced military relevance, since these devices are in the civilian case supposed to be "friendly" devices, already programmed for this cooperative behavior. Such an assumption could not be maintained in the military environment case.

5.5 MULTISPHERE LEVEL 5 (INTERCONNECTIVITY) – THE CAN

Next comes the ability to offer advanced networking functionalities and information services through ad-hoc networking, which is the ability to form networks anytime, anywhere, while maintaining the integrity of the information and applications within an individual personal area space. To support ad-hoc networking, the network must be made of bridges (B) (devices that can handle the Layer 2 in the OSI taxonomy) and routers (R) (devices that can handle the Layer 3 in the OSI taxonomy). Community Area Networks (CANs) are formed between two or more PANs, or equivalent network entities The CAN network in itself will be a meshed network and, to enable compatibility with most of the other networks, should be seen as a packet-based IP network. Network elements may be static or mobile. Figure 5-3 provides an illustration.

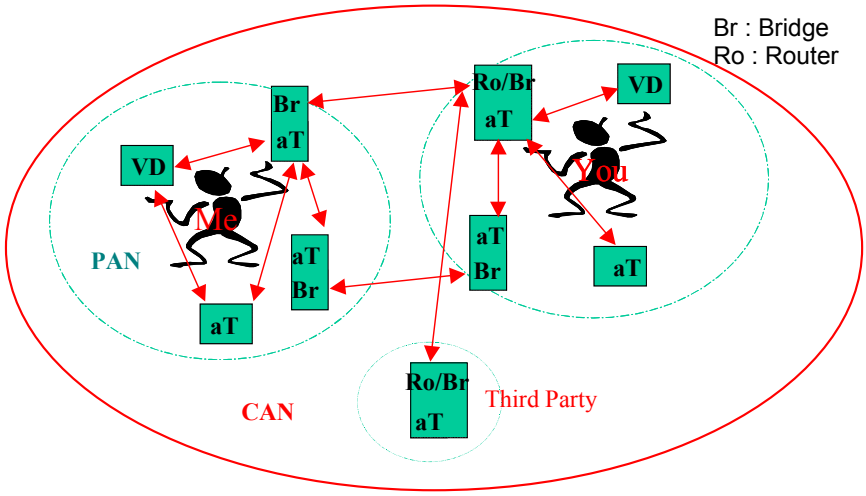

Figure 5-3: The Community Area Network: A Local Network of PANs.

In the wider CAN context, the user's WPAN becomes a private, virtual domain. The capabilities of the user's WPAN may be tailored to support a range of services and quality-of-service (QoS) requirements and scaled in accordance with the available resources per service class and adapted to the prevailing networking capabilities. Tailoring WPAN capabilities includes adaptation to the available resources and downloadable software radio interfaces (i.e. for more capable devices) as well as enhancement of a basic handset or PDA with new software or services, which means that reconfigurable hardware and hardware/software partitioning should be provided.

5.5.1 Gate Keeping Functionality – Security Considerations

Moreover, a person will certainly want to control his privacy and need a gatekeeper to take care of it. This gatekeeper functionality can be tackled by security mechanisms that already exist in, for example, Internet networks. Still, the gatekeeper functionality could be concentrated on one device, or totally distributed among the terminals. A lot of these mechanisms could be borrowed to the existing security schemes. The role of certificate based authentication has to be examined in detail in this context.

5.6 THIRD LEVEL: THE WIDE AREA NETWORK (WAN)

Beyond the WPAN such an envisaged system has to provide global communication possibilities to the user, which calls for the use of classical Wide Area Network systems (mainly, but not necessarily wireless). To enable this, the communications go through a Gateway over these systems (Figure 5-4). Central issues that arise here are security and end-to-end QoS.

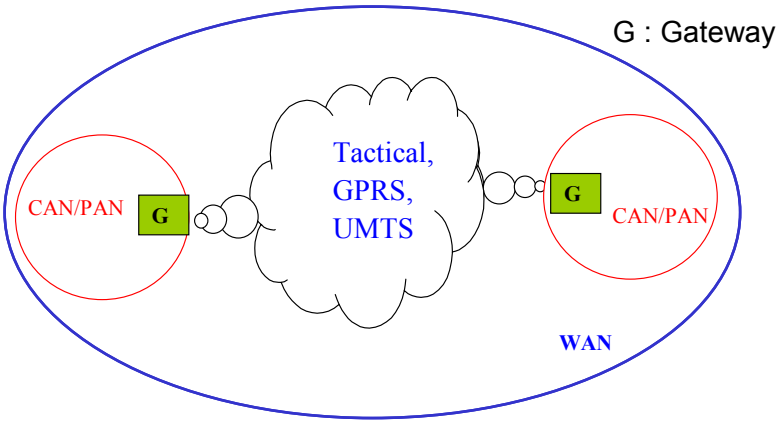

Figure 5-4: The Wide Area Networks (WANs) – PANs/CANs Communicating through External Networks.

Here we have the possibility to rely on ubiquitous coverage of a wide area systems, either directly from the PAN or via the interconnection possibilities offered at CAN level. Adaptivity to various terminals and simple inter-action with the backbone are key issues.

5.7 MULTISPHERE LEVEL 6: CYBERWORLD

According to the MultiSphere Level 6, the outmost sphere, most remote from the immediate real world, represents the CyberWorld. In the CyberWorld one can in touch with (semantic) agents, knowledge bases, communities, services and transactions.

The value of communications technologies is sometimes said to grow proportionally to the square of the number of the connected devices. Therefore, it will be a crucial task to maintain universal wireless interconnectivity, as in today's mobile Internet core networks. To offer the right level of support for the various specialised radio interfaces and terminals will be a key requirement. One can therefore see an emerging need for both a radio convergence layer and a number of APIs beside the evolved IP transport and networking layers. Evolutions of interconnectivity in the Wireless World will convey radio interface state specific information to applications and also allow for seamless integration of synchronous direct communication services with asynchronous message based services.

5.8 OVERVIEW OF RELEVANT STANDARDS

5.8.1 IEEE 802.15

The IEEE 802.15 is the IEEE working group for Wireless Personal Area Networks (WPANS) and is developing standards for Personal Area Networks or short distance wireless networks. Established in January 1999, the WPAN working group, which is part of the Local and Metropolitan Area Network Standards Committee of IEEE, has since formed four task groups, each work on necessary standards.

The idea of WPAN is to create standards that allow devices such as PCs, PDAs, mobile phones, pagers, and other handheld devices to communicate and collaborate with one another. Unlike LAN devices, which are fixed, WPAN devices will travel and transfer. This means that the same standard should work everywhere, in a car, on a boat or a plane, and in different countries. Also, in our days people expect some synchronous services, at least voice, to be provided apart from data applications.

Those familiar with Bluetooth will recognize that these are some of the same considerations that are handled by Bluetooth. The WPAN standardization effort started at least a year before the public announcement of the Bluetooth standard. The goal of the 802.15 standards is to accommodate wider adoption and applicability. The main characteristics of a WPAN are:

- Low cost,
- Low power,
- Short-range,
- Small networks.

5.8.2 Architecture of the 802.15 and Relation with Bluetooth

The IEEE 802 Standards Committee is primarily focused on the layers 1 and 2 (Physical and Data Link) of the Open System Interconnection (OSI) Reference Model. The 802.15 WPAN is one of the IEEE series of standards that falls under the 802 standard. The 802.15 WPAN committee is working on standardizing the PHY and MAC layers of Bluetooth. Below is the architecture of the 802 standard illustrating where the focus of the standard is in relation to the OSI Reference Model and how it relates to Bluetooth:

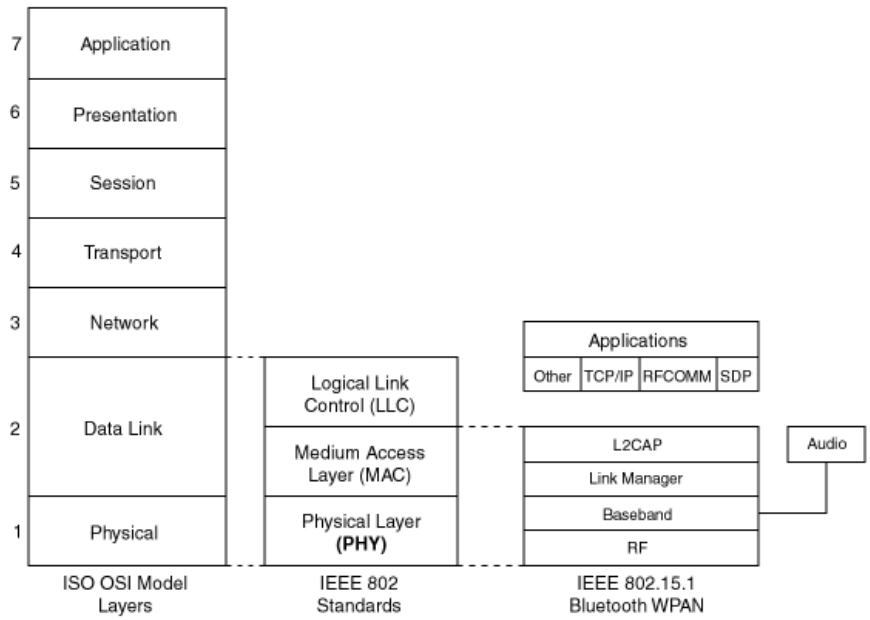

Figure 5-5: IEEE 802.15.1 Protocol Stack.

5.8.3 (UWB) 802.15.3a – Main Characteristics

In Ultra Wide Band (UWB), pulse modulation involving extremely short bursts of RF occur. A typical pulse can be in the order of 0.1 to 2 nsec with resulting emission bandwidth of GHz heavily depending on the rise time of the leading edge as well as on the antenna pass band. The spectrum spread in extremely high in the order of 25% of the center frequency, which also makes UWB signals very difficult to detect.

Besides the razor thin rise time, the precise timing of UWB pulses can be employed in communication (pulse position modulation) as well as in radar applications (soil penetration radars, seeing and positioning through walls, etc.). Also indoors localization via triangulation methods is another promising area of applications.

UWB is excelling in spatial capacity, measured in kilobits per second per square meter (kbps/m2). Spatial capacity focuses not on bit rates for data transfer alone, but on bit rates available in the confined spaces defined by short transmission ranges. Thus the extremely low power to be used in UWB in the context of WPANs (Wireless Personal Area Network – WPAN) ensures extremely high bandwidth at very low range (few meters) and power. It thus achieves very high spatial capacity.

UWB is expected to become the solution adopted in the 802.15.3a IEEE standard and corresponding regulatory activities are now well advanced. FCC has given qualified approval to UWB usage, following nearly two years of commentary by interested parties. Issues like UWB interference with existing services such as GPS, radar and defense communications and cell-phone services have been considered. UWB communications are allowed for applications with full "incidental radiation" power limits of between 3.1 and 10.6 GHz. Outside that band, signals must be attenuated by 12 decibels (dB), with 34 dB of attenuation required in areas near the GPS-frequency bands. More liberal restrictions were permitted for law-enforcement and public safety personnel using UWB units to search for earthquake or terrorist attack victims.

5.9 SECURITY REQUIREMENTS

The security requirements for 802.15 networks are different from more static networks because of the dynamic nature of wireless PANs. As a result, the working group is looking into specifying public-key solutions for authentication and key exchange, letting devices that have not been in contact previously establish secure communications without revealing any secret keying material.

Once the devices have been authenticated, each device in the wireless PAN shares common group (symmetric) payload protection keys for encryption and data integrity. Devices also may use the authentication mechanism to establish two-party secure subnetworks. This procedure is similar to this for establishing an SSL connection between a server and a client.

5.10 FUNCTIONS OF LOWER LAYER PROTOCOLS

5.10.1 RF Layer

The air interface is based on antenna power range starting from 0 dBm up to 20 dBm. Bluetooth operates in the 2.4 GHz band and the link range is anywhere from 10 centimeters to 10 meters.

5.10.2 Baseband Layer

The Baseband layer establishes the Bluetooth physical link between devices to make up a piconet. A piconet is an ad-hoc network of devices using Bluetooth technology. A piconet is created when two Bluetooth devices connect, and it can support up to eight devices. In a piconet one device acts as the master and the other devices as slaves.

5.10.3 Link Manager

The link manager sets up the link between Bluetooth devices. Other functions of the link manager include security, negotiation of Baseband packet sizes, power mode and duty cycle control of the Bluetooth device, and the connection states of a Bluetooth device in a piconet.

5.10.4 Logical Link Control and Adaptation Protocol (L2CAP)

This layer provides the upper layer protocols with connectionless and connection-oriented services. The services provided by this layer include protocol multiplexing capability, segmentation and reassembly of packets, and group abstractions.

5.10.5 Differences of the WPAN (802.15) from the WLAN (802.11)

A wireless local area network (802.11), uses high-frequency radio waves instead of wires to communicate between nodes in a network. Wireless personal area networks differ from wireless local area networks at the interaction, packet format, type of devices, network build-out timeframe, relative cost, and general network architecture. The Wireless personal area network concerns highly mobile devices; it is cheaper and consumes less power.

5.10.6 802.15 WPAN Task Group 1

The 802.15 WPAN Task Group 1 (TG1) is using the Bluetooth v1.0 specifications to derive the WPAN standard. The scope and focus of TG1 are to define PHY and MAC specifications for wireless connectivity between devices that are either fixed or portable within the personal operating space. The goal will be to allow low complexity, low power consumption wireless connectivity to support data transfer to and from a WPAN device and an 802.11 device. The proposed standard will take into account coexistence with all 802.11 devices.

5.10.7 802.15 WPAN Task Group 2

Task Group 2's (TG2) scope and focus is to address the coexistence of WPANs and WLANs. TG2 is developing a coexistence model to quantify the mutual interference of a WLAN and a WPAN. The Task Group is also developing a set of coexistence mechanisms to facilitate coexistence of WLAN and WPAN devices.

5.10.8 802.15 WPAN Task Group 3

Task Group 3's (TG3) scope and focus is to publish a new standard for a high data rate, 20 Mbps or greater, for WPANs. TG3 will also be looking at providing a solution that is low power and low cost, addressing the needs of digital imaging and multimedia applications. The new standard will comply with the TG1 standard.

5.10.9 802.15 WPAN Task Group 4

Task Group 4's (TG4) scope and focus is to determine a solution with a low data rate and long battery life, potentially months to years, with very low complexity. The solution determined would need to operate within an unlicensed and global frequency band. The solution could potentially be applied to sensors, remote controls, appliances, toys, etc.

5.11 REFERENCES

- http://www.ee.iitb.ernet.in/uma/~aman/bluetooth/tut6.html
- http://www-106.ibm.com/developerworks/library/wi-checking/?dwzone=wireless
- http://www.nwfusion.com/news/tech/2002/0311tech.html
- WWRF, "Book of Visions Parameters" based on the devices and communications of the scenarios.

The following table lists the most significant devices of relevance to WPANs together with corresponding requirements in relation to the communications that these devices will need.

Table 5-1: PAN Specifications

Devices	Information Rate	BER needed for the application	Latency (End-to-end, possibly IP)	Power	Range	Size/Weight	Autonomy	Mobility/ Speed	Price
Virtual Glasses + headset	8 kbits/s (terminal) 500 kbits/s (MPEG4 – VHS quality) 10 Mbits/s (MPEG2 – HDTV quality)	10^{-3} FER : possible for MPEG-4 10^{-7} for MPEG-2 at MAC-layer (MPEG -2 asks for error-free transmission)	< 150 *ms* preferred <400 *ms* limit Lip-synch: < 100 *ms* [1] for fixed images or one way streaming: <10 sec	Today 4 or 18 watts ? 100 mW for the visual part bet on < 1 W 5 Mbits/s with picoradios 5 nJ/bit : 25 mW radio + MPEG : 250 mW for UMTS videophone chip .25 um chip (JVLSI 2000) + 100 mW visual → 250 mW	2 m for Master 10 m for Bridge	100 to 250 gr virtually invisible	1 day → 2 days	Low mobility (< 0.5 m/sec) for movie Medium mobility (< 3 m/sec) for terminal/sound type	Target 100 $ (Sony wired 18 W : 600 $) MPEG 2-coder/decoder about 100 Kgates
Video camera	10 kbits/s for non-real time still images 500 kbits/s (MPEG 4 – VHS quality) 10 Mbits/s (MPEG2 – HDTV quality) (depends on the local intelligence)	Not applicable (N/A)	N/A coding	Same as above for radio: 25 mW Camera?	2 m for BT 10 m bridge	100 gr	2h → 2 days	Low mobility (< 0.5 m/sec) for movie Medium mobility (< 3 m/sec) for still image	Target price 10 $
Plain headset	8- kbits/s up to 1.4 Mbits/s (HiFi) MP3: <250 kbits/s HiFi	10^{-3} (toll-quality+ intelligence)	For conversation : < 100 *ms*	Radio < 10 mW (aim 1 mW) Sound: 20 mW (verify) Coding ?	2 m for BT 10 m for bridge	25 – 50 gr	Minimum 1 day up to 1 month	Medium mobility (< 3 m/sec)	Target price for the radio 1$ (low quality headset 5 $)

[1] Taken from 3gpp specs : 3G TS 22.105 V4.1.0 (2001-01).

Devices	Information Rate	BER needed for the application	Latency (End-to-end, possibly IP)	Power	Range	Size/Weight	Autonomy	Mobility/ Speed	Price
Wireless microphone	8 to 64 kbits/s	N/A	Coding latency ?	ALAP Coding ? Radio < 1 mW (otherwise it should be on the M-WAP)	2 m for BT 10 m for bridge 10 m for me to you (hearing aid)	10 gr	Minimum 1 day up to 1 month	Medium mobility (< 3 m/sec)	Target price : very low (< .5 $)
Translation device (probably in the M-WAP)	8 to 64 kbits/s (x2)	10^{-3} (toll-quality+ intelligence)	1 sec for the radio	For the radio: 1 – 2 mW	2 m for BT 10 m for bridge	To be determined	To be determined	To be determined	Target price for the radio 1$
Sensors (passive : tags)	< 1 kbits/s	Service dependent	< 1 sec	100 uW 1 mW 10 mW	2 m for BT 10 m for bridge	1 – 10 gr	Up to 1 Year for the low power	Low mobility	For the radio 10 – 20 cents Other < 1$
Joysticks (power can come from force)	Up to 1 kbits/sec	To be determined	< 10 *ms*	Radio < 1 mW	2 m for BT 10 m for bridge	To be determined	To be determined	To be determined	Target price for the radio 1$

5.12 PAN IN THE CONTEXT OF WIRELESS TECHNOLOGIES STANDARDS

The table bellow shows the relationship between established wireless technologies standards and the PAN approach, as described above. Main points to be emphasized are (i) the split into PAN and CAN which brings the need of a wide range of supporting wireless technologies (in terms of range, speed, mobility, bandwidth) and (ii) the possibility to realize the PAN/CAN approach by employing upcoming standards and maturing technologies.

Table 5-2: Comparison of PAN with other Technologies

	802.11a	802.11b	802.15	Homerf	Bluetooth	Infrared (IrDA)	Personal Area Network	
							PAN	CAN
Speed	0.5 m/s	0.5 m/s	0.5 m/s	0 m/s	0.5 m/s	0 m/s	0.5 m/s	3 m/s
Mobility Support	Micro-mobility support	Micro-mobility support	Micro-mobility support	No mobility support	No-mobility support	No-mobility support	No-mobility support	Full-mobility support (QoS handover, distributed resource management)
Market	Wireless Local Area Network (WLAN)	Wireless Local Area Network (WLAN)	Wireless Personal Area Network (WPAN)	Wireless Local Area Network (WLAN)	Wireless Personal Area Network (WPAN)	Wireless Personal Area Network (WPAN)	Wireless Personal Area Network (WPAN)	Mobile ad-hoc Network
Technology	Radio Frequency 5 GHz, OFDM	Radio Frequency 2.4 GHz, FHSS, DSSS	Radio Frequency 2.4 GHz, FHSS, QPSK, QAM16	Radio Frequency 2.4 GHz, FHSS	Radio Frequency 2.4 GHz FHSS	Optical 850 nm	Wider frequencies and channels	Wider frequencies and channels different than in PAN
Transmit Power	1 Watt	Moderate 100 mW	.5 .. 4 mW	100 mW	Low 1 – 100 mW		.1 mW	1 – 100 mW
Data Rate	High 54 Mbits/s	High 2 / 11 Mbits/s	Low / High up to 41 Mbits/s	0.8 and 1.6 Mbits/s	Moderate 1 Mbits/s	Low 115 kbits/s / 4 Mbits/s	Low…High 1 kbits/s … 10 Mbits/s	Low…High 1 kbits/s … 10 Mbits/s
Distance		30 meters / 98 feet	10 meters (20 Mbits/s) / 5 meters (41 Mbits/s)	50 m	10 meters / 32 fee	5 meters / 16 feet	2 m	2 m – 10 m
Topology	128 devices CSMA (?)	128 devices CSMA	10 devices point-to-multi-point	128 devices CSMA/ CA+TDMA	8 devices point-to-multi-point	10 devices point-to-multi-point	10 – 30 BT	Infinite … 1 – 5 RGB/m2 30 BT/m2
Security	??	Optional WEP	Public/Private key authentication and encryption	56 bit shared key encryption	Public/Private key authentication and encryption	Application Layer		Layered security, firewalls, application

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