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D2.1 PART 3

STATE-OF-THE-ART TECHNOLOGIES & PROTOCOLS

DESCRIPTION OF STATE-OF-THE-ART WIRELESS ACCESS TECHNOLOGIES

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Document Authors

Partners	Contributors
uSysCom	Jose Miguel Arzuaga Aitor Arzuaga
CESI RICERCA	Diana Moneta
EDF	Aline Pajot Gaizka Alberdi
Elster	Christophe Dugas
Arctaris	Frederic Tarruell (voluntary contribution)

Document Approvers

Partners	Approvers
uSysCom	Jose Miguel Arzuaga Aitor Arzuaga
CESI RICERCA	Diana Moneta
EDF	Aline Pajot Gaizka Alberdi
Elster	Christophe Dugas
OPEN meter Technical Committee	Iñigo Berganza Markus Bittner Robert Denda Thomas Schaub Willem Strabbing

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GLOSSARY AND ACRONYMS

3GPP	3rd Generation Partnership Project
AES	Advanced Encryption Standard
CDMA	Carrier Division Multiple Access
CEPT	Conference Européene del Administrations des Postes et des Télécommunications
DSL	Digital Subscriber Loop
DPSK	Differential Phase Shift Keying
DQPSK	Differential Quadrature Phase Shift Keying
DSSS	Direct Sequence Spread Spectrum
EDGE	Enhanced GPRS Evolution
EFIS	ERO Frequency Information System
EIRP	Equivalent Isotropic Radiated Power
ERO	European Radiocommunications Office
ETSI	European Telecommunications Standards Institute
EU	European Union
GFSK	Gaussian Frequency Shift Keying
GPRS	General Packet Radio Service
GSM	Groupe Spécial Mobile
HSDPA	High Speed Downlink Packet Access
HSUPA	High Speed Uplink Packet Access
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IFL	International Frequency List
IPSO	Internet Protocol for Smart Objects

ISM	Industrial, Scientific and Medical
ITU	International Telecommunication Union
LAN	Local Area Network
LBT	Listen Before Talk
LLC	Logical Link Control
LOS	Line Of Sight
MAC	Medium Access Control
MDTRS	Mobile Digital Trunked Radio System
MIFR	Master International Frequency Register
MIMO	Multiple Input Multiple Output
NAN	Neighbourhood Area Network
OFDM	Orthogonal Frequency Division Multiplexing
OPEN meter	Open Public Extended Network metering
PHY	PHYsical layer
PMR	Private Mobile Radio
PSK	Phase Shift Keying
RFID	Radio Frequency IDentification
SMS	Short Message Service
TDMA	Time Division Multiple Access
TETRA	TErrestrial Trunked Radio
UHF	Ultra High Frequency
UMTS	Universal Mobile Telecommunications System
WECA	Wireless Ethernet Compatibility Alliance
WIFI	WIreless FIdelity
WIMAX	Worldwide Interoperability for Microwave AXess

WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network
WPA	Wi-Fi Protected Access
WPAN	Wireless Personal Area Network
WTO	World Trade Organization
ZDO	ZigBee Device Object

REFERENCES

[1] ITU, International Telecommunications Union, www.itu.int

[2] European Commission, Decision No 676/2002/EC:

http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2002:108:0001:0006:en:PDF

[3] EFIS, ERO Frequency Information System. www.efis.dk

[4] ITU Survey on Radio Spectrum Management - 2007
www.itu.int/osg/spu/stn/spectrum/spectrum_resources/ITU_SURVEY_ON_RADIO_SPECTRUM_MANAGEMENT_17_01_07_Final.pdf

[5] 6lowPAN, www.6lowpan.org, www.ietf.org/rfc/rfc4944.txt

[6] IEEE 802.15.4 standards group, www.ieee802.org/15/pub/TG4.html

[7] IEEE 802.11 standards group, http://grouper.ieee.org/groups/802/11/

[8] IEEE 802.16 standards group, http://wirelessman.org/

[9] The ZigBee Alliance, www.zigbee.org

[10] IPSO alliance, www.ipso-alliance.org

[11] Communication systems for meters and remote reading of meters (Wireless M-Bus), Standard DIN EN 13757-4:2005

[12] Wavenis Alliance, www.wavenis.org

[13] The WiFi Alliance, www.wi-fi.org

[14] Bluetooth SIG, www.bluetooth.org

[15] General Packet Radio Service, www.etsi.org/WebSite/Technologies/gprs.aspx

[16][17] 3GPP, www.3gpp.org

[18] TETRA Association, www.tetramou.com

[19] The WiMAX Forum, www.wimaxforum.org

[20] RADIAN Protocol v1.0 Specification, RADIAN Association, 1999

[21] “Fundamentos de los Sistemas de Comunicaciones Móviles", Alberto Sendín, Mc-Graw Hill, 2004 (ISBN 84-481-4027-3)

1 PURPOSE

This document a state of the art for currently used Wireless Access Technologies. It has a broad scope, citing many different technologies in use for AMR and other applications. In this document many technologies will be covered, not taking into account at this first step their suitability for AMR applications.

2 INTRODUCTION

2.1 General

For a better understanding of the competitive wireless landscape and to assess the impact of the discussion in the context of the *OPEN meter* project, it must be explained that all wireless solutions, standard or proprietary, basically consist of 2 distinct parts:

a -The wireless connectivity platform. These platforms only deal with data transfer with networking communication capabilities, disregarding application data. These platforms perform data communication services that operate in different frequency bands, with different modulation schemes, different network management capabilities, and with different communication protocol services. This usually covers PHY, MAC & NET layers (layers 1 to 3 of the OSI standard model).

b - The application-oriented solution. On top of these wireless connectivity platforms, there are application-oriented protocols that take charge of all data management related to applications. For metering, typical features are included on-demand (index reading, index data logging, notification of alerts such as leak detection, low battery, backflow, tampering…). Definition here is usually covered by layers 4 to 7 of the OSI standard model.

Most solutions available today offer a combination of these 2 parts. The same applies to Industrial Automation, Building Automation, Alarm & Security, Environment and emerging track and trace applications in which active, long-range UHF RFID is used (containers, people, and valuable goods).

On the market, only a few proposals are uniquely devoted to addressing wireless connectivity platforms, such as IEEE 802 standardization groups with IEEE802.15.4a (the one selected by ZigBee), IEEE 802.15.1 (the one selected by Bluetooth) or Wavenis.

The main reason for such diversity comes simultaneously from a combination of different factors imposed by the application and the regulatory bodies for radio-communications:

- Amount of data to be transferred (a few bytes to Kbytes)
- Radio traffic: quantity of RF Tx per time unit
- Operating range
- AC powered devices or battery powered devices, and battery life
- Wireless network density
- ISM band regulation (bands, power, bandwidth, duty cycle, …)

2.2 Wireless Technologies included in this document

This document is a state of the art on Wireless Technologies, thus many wireless technologies will be analyzed, to detail their characteristics, performance, applications, strengths and drawbacks. The selection of the technologies has not been done taking into account the suitability of a particular technology for AMR applications. The assessment process will be carried out in further deliverables of WP2.

The goal of the present document is to list a comprehensive set of wireless technologies available today, and to provide some in-depth technical information on them, as well as references for further investigation.

2.3 Architecture of the document

The technologies described in this document are separated into three main classes:

- IETF sponsored initiatives, containing 6lowPAN.
- IEEE sponsored initiatives, such as IEEE802.11, IEEE802.15.4…
- Other initiatives, such as industry initiatives (ZigBee, WiMAX), ETSI initiatives (GPRS, UMTS).

The rationale behind the separation of IETF/IEEE initiatives and industry-backed initiatives is that some bodies provide standards for wireless technologies “as they are”, and other industry alliances or associations pursuing a certain commercial goal adopt these technologies to standardize a certain application. As an example, the difference between technology (IEEE802.11) and “industry alliance adopting that technology” (WiFi Alliance) must be done, in order not to confuse terms and to provide a deeper, unbiased insight.

3 EXECUTIVE SUMMARY

In recent years, several applications based on wireless access technologies are broadening and changing our habits. Each wireless solution offers a specific mix of transmission band, costs, and coverage according to the business scenario that originated it, and sometimes further applications initially not considered was successively created. A complete analysis of technologies that could be used in metering applications has to reckon that. For example, especially in small o medium sized municipalities that own the public utilities, administrations see an opportunity in including automated meter reading among services supported by their wireless broadband networks.

The Wireless Access Technologies described in this document are separated into three main classes: IETF sponsored initiatives, IEEE sponsored initiatives, and other initiatives, such as industry initiatives. The rationale behind this separation is that some bodies provide standards for wireless technologies "as they are", and other industry alliances or associations pursuing a certain commercial goal adopt these technologies to standardize a certain application.

For a better understanding of the competitive wireless landscape and to assess the impact of the discussion in the context of the OPEN meter project, all wireless solutions, standard or proprietary, basically consist of 2 distinct parts: *wireless connectivity platform* (only deal with data transfer with networking communication capabilities, disregarding application data) and *application-oriented solution* (on top of wireless connectivity platforms, there are application-oriented protocols that take charge of all data management related to applications). Most solutions available today offer a combination of these 2 parts.

After some general information about RF Spectrum Management issue, a detailed description of most important wireless technologies –in use for AMR and other applications– is provided. For each technology Frequency Bands, Key Applications and Cost Issues are discussed. Finally, a table summarizes and compares main figures/data for the previously considered technologies.

4 Radio Frequency Spectrum Management

Radio spectrum is a finite resource so its allocation requires effective and efficient coordination at national, European, and global level. Very early, all interested parties come to the conclusion that collaboration is necessary to solve interconnection (tariffs) and mutual interference problems.

The concept of *spectrum management* comprises all activities related to planning, allocation, assignment, use, and control of the radio frequency spectrum.

Spectrum blocks are *allocated*, through international agreement, to broadly defined services. National regulatory authorities then *assign* licenses for use of specific frequencies within these allocations within their jurisdictions. Governments define the rules and conditions of the frequency use: details that are not explicitly included in the international treaties may differ from country to country. Frequency assignment strategies will be used to achieve spectrum efficiency by, among other things, ensuring proper use and facilitating reuse.

Technological, economic, and social changes affect the utilization of spectrum resources. With privatization, government monopolies are disappearing and the role of nongovernmental entities is growing. There are opinions that the present management system needs to be modified to follow these changes: a spectrum "market", where negotiations take place at World Trade Organization (WTO) instead of ITU (International Telecommunications Union), is a possible solution. Not everybody shares that view, for example because universal access could not be assured. Possible future sees radio systems able to automatically coordinate among themselves the best use of spectrum resources in real time.

4.1 Regulatory Issues

The International Telecommunication Union (**ITU** – www.itu.int) since 1947 is the leading United Nations agency for information and communication technology issues. It coordinates the shared global use of the radio spectrum, established the worldwide standards that foster seamless interconnection of a vast range of communications systems.

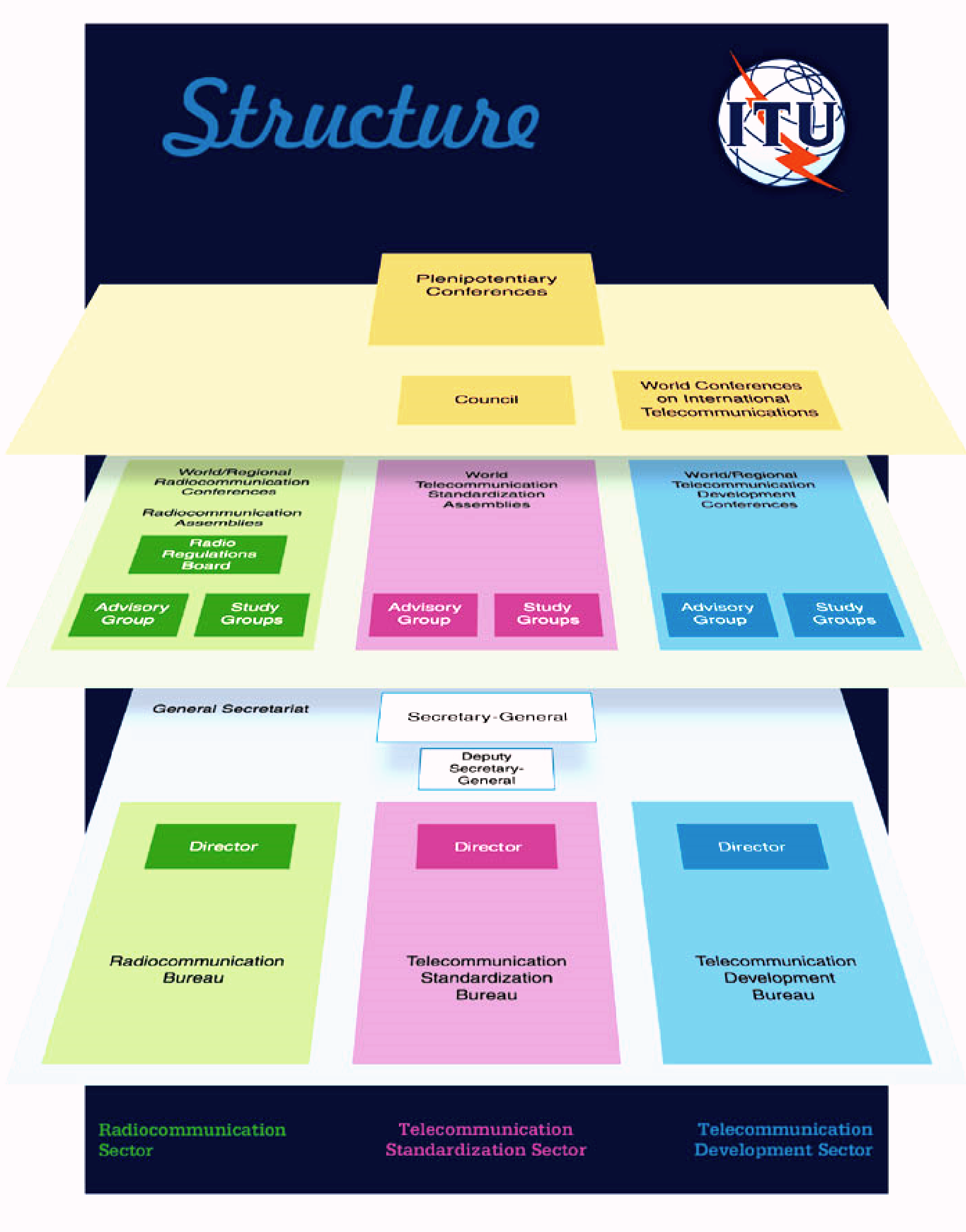

Fig. 1 – ITU structure [1]

ITU Radiocommunications Sector (ITU-R) has the duty of managing the international radio-frequency spectrum and satellite orbit resources. ITU is mandated by its Constitution to allocate spectrum and register frequency assignments, orbital positions and other parameters of satellites, “in order to avoid harmful interference between radio stations of different countries”.

Radio Regulations (RR) are an international treaty (more than 1000 pages) including principles, rules, technical characteristics, formulas, data, maps, and plans dealing with international aspects of the use and management of RF spectrum and the operation of radio services of all kinds. The ITU RR consider the spectrum as a *common heritage* shared freely by the whole of humanity.

RR contains the *frequency allocation table*: ITU divides earth surface into 3 different regions, where services/frequencies are allocated:

Region 1: Europe, Middle East, Africa, northern part of Asia;

Region 2: North and South America, Greenland;

Region 3: southern Asia, Australia, and Oceania.

The radio frequency spectrum has been divided into a number of specific frequency bands allocated to specific services in each of the three regions.

Fig. 2 – ITU regions

The Master International Frequency Register (MIFR) is the ITU database in which all frequency assignments and common frequencies are registered. The frequency assignments that may have international implications, as well as those for which the administration wishes to obtain international recognition, have to be notified to the ITU/BR with a view to their recording in the MIFR. In 2004, MIFR included 1.265.000 terrestrial frequency assignments, 325.000 assignments related to 1.400 satellite networks, more than 4.250 assignments related to satellite earth stations.

4.2 Radio Spectrum Regulation in Europe

Spectrum policy within the EU has involved global decisions made by the World (Administrative) Radio Conference of the International Telecommunication Union (ITU) and regional decisions by the Conférence Européenne des Administrations des Postes et des

Télécommunications (CEPT) encompassing all European countries, then are assignments by the member states to individual operators.

The EU institutions play two roles:

- coordinating the position of the member states to be taken at CEPT and ITU meetings,
- adopting measures that are binding on member states in the implementation of the decisions taken.

In 1988 CEPT created ETSI, the European Telecommunications Standards Institute, into which all its telecommunication standardization activities were transferred. In 1991, the European Radiocommunications Committee established the European Radiocommunications Office - ERO - with the purpose of supporting the activities of the committee and conducting studies for it and for the European Commission.

The planning and physical assignment of radio spectrum to users is the responsibility of Member States via their appropriate national authorities. These processes are also subject to the constraints of EU laws on the single market, and international radio spectrum agreements.

Decision No 676/2002/EC ("Radio Spectrum Decision") [2] requires Member States to ensure that their national radio frequency allocation table and information on rights, conditions, procedures, charges and fees concerning the use of radio spectrum, shall be published if relevant in order to meet the aim set out in Article 1 of that Decision.

Member States have to keep this information up to date: the ERO Frequency Information System (EFIS) [3] is publicly available on the Internet and allows the search for and comparison of official spectrum information within Europe, if such information is uploaded by national administrations.

4.3 Radio Spectrum Regulation in the Rest of the World

In 2007, ITU has conducted a survey which aims to gather information on the most important issues related to spectrum management policies around the world, including details of the initiatives undertaken by authorities responsible for the allocation of radio frequencies in each country.

This document "ITU Survey on Radio Spectrum Management – 2007" [4] represents a snapshot synthesis of responses received from ITU Member States:

4.4 Frequency Bands for Local / Regional / Global use

Each country has the sovereign right to regulate its telecommunication and to interpret the international Radio Regulations (RR); national spectrum management must follow the ITU RR.

Periodically, ITU publishes the International Frequency List (IFL) on CD-ROM, with information relating to frequency assignments recorded in the MIFRE and maintained by the Radiocommunications Bureau (BR).

5 Wireless Technologies Overview

5.1 Proprietary Initiatives

Taking into account the distinction between the wireless connectivity platform on one hand and the application-oriented protocol on the other hand, it is fair to say that proprietary solutions offer a packaged combination of both.

The wireless market in the license-free ISM-band is mostly served by a myriad of proprietary technologies. This phenomenon is encouraged by product portfolios from silicon vendors which are made of general-purpose RF transceivers, microcontrollers, or even more integrated Systems-on-Chip (SOC). As a result, wireless solution providers and/or integrators can quite easily develop their own proprietary protocols and solutions that must nevertheless comply with radio-communication norms (ETS 300-220 in Europe, FCC15-249 & 15.247 in North America…).

Many of today’s proprietary wireless solutions are single-channel technologies, while all emerging standards are based on spread spectrum techniques allowing multiple communication channels simultaneously. Spread spectrum (including FHSS, DSSS and UWB techniques) offers far superior robustness against interferers, as well as more coexistence capabilities compared to single- channel solutions for dense WSNs.

It must be noted that the Listen Before Talk (LBT) technique introduced by ETSI in 2006 is perceived as an inefficient way to share the RF spectrum. In other regions, DSSS and FHSS are the encouraged techniques for a smart medium access control, while higher power is allowed when efficient spread spectrum is applied.

5.1.1 Short Range Unlicensed Radio

The industrial, scientific and medical (ISM) radio bands were originally reserved internationally for the use of RF electromagnetic fields for industrial, scientific and medical purposes other than communications. The ISM bands are defined by the ITU-R in 5.138, 5.150, and 5.280 of the Radio Regulations. Individual countries' use of the bands designated in these sections may differ due to variations in national radio regulations. Because communication devices using the ISM bands must tolerate any interference from ISM equipment, these bands are typically given over to uses intended for unlicensed operation, since unlicensed operation typically needs to be tolerant of interference from other devices anyway. The most common ISM or unlicensed radio bands defined by the ITU-R are the next ones:

- 433 MHz
- 868 MHz
- 915 MHz
- 2.4 GHz

Since unlicensed devices are a category of equipment that does not require a license from the Federal Communications Commission or a frequency assignment from any National or Regional Telecommunications Administration, they offer great opportunities to system designers and program managers because of their low cost and minimal administrative overhead.

5.1.1.1 Technology Overview

Some proprietary radio solutions in use today include:

- **Io - homecontrol** in the 868MHz ISM band. It is a single-channel solution (3 possible channels).
- **Z-Wave** in the 868MHz ISM band. Also a single-channel solution (3 possible channels).
- **EnergyAxis** in the 915MHz ISM band, using FHSS technology to mitigate channel occupation.
- **Evolution**. Also working on the 915MHz ISM band with FHSS technology (Wavenis-based wireless connectivity platform).
- **OpenWay** in the 2.4GHz frequency band (ZigBee-based solution).

5.1.1.2 Frequency Bands

As mentioned before, these proprietary solutions always use the ISM bands (433/868/915MHz, 2.4/5.8GHz, depending on the region), which permit a license-free use. As these frequency bands are shared for other multiple uses, this raises the issue of channel availability and security.

The ISM bands defined by the ITU-R are:

Frequency range [Hz]	Centre frequency [Hz]	Availability (Europe)	Availability (rest of the World)
6.765–6.795	6.780 MHz	Partial	Subject to local acceptance
13.553–13.567 MHz	13.560 MHz	Yes	
26.957–27.283 MHz	27.120 MHz	Yes	
40.66–40.70 MHz	40.68 MHz	Yes	
433.05–434.79 MHz	433.92 MHz	Yes	Region 1 only
902–928 MHz	915 MHz	No	Region 2 only
2.400–2.500 GHz	2.450 GHz	Yes	
5.725–5.875 GHz	5.800 GHz	Yes	
24–24.25 GHz	24.125 GHz	Yes	
61–61.5 GHz	61.25 GHz	Partial	Subject to local acceptance
122–123 GHz	122.5 GHz	Partial	Subject to local acceptance
244–246 GHz	245 GHz	Partial	Subject to local acceptance

Table 5-1: ISM bands as defined by the ITU-R

The next table shows RF signal attenuation values obtained at various carrier frequencies in terms of Line-of-Sight (LOS) usage in the most common short range unlicensed radio bands:

Frequency (MHz) / Distance (meters)	433	868	915	2400
10	45.2 dB	51.2 dB	51.7 dB	60.0 dB
100	65.2 dB	71.2 dB	71.7 dB	80.0 dB
1000	85.2 dB	91.2 dB	91.7 dB	100.0 dB

Table 5-2: RF attenuation values for certain frequencies in LOS applications

In addition to radio wave attenuation over distance for a given frequency range, which is the main parameter to take into account for outdoor radio communications, there is another major issue that impacts coverage for indoor applications: wavelength and its dimension relative to obstacles.

Radio waves do not propagate in the same manner in buildings, across concrete, glass or metal walls, or do not cut through open holes in a similar manner. The main parameter affecting this behaviour is the wavelength (inverse to the frequency). Radio waves tend to propagate better as its wavelength is smaller (or much smaller) than the obstacles they face in their propagation.

Frequency (MHz)	433	868	915	2400
Wavelength (meters)	0,69	0,34	0,32	0,12

Table 5-3: Wavelengths vs frequencies

As a result of this, summarizing table 5.1 and 5.2, the as the frequency increases, so does the attenuation, and distance that can be obtained is reduced. But in the other hand, higher frequencies propagate better in buildings, as its wavelength is very small compared to the obstacles and holes lying in the propagation path.

5.1.1.3 Key Applications

In the market for ultra-low-power solutions, equipments based on unlicensed radio technologies are built to enable wireless applications and services reliably across several applications.

The main applications for this kind of products include: Telemetry, industrial Automation, Advanced Metering Infrastructure (AMI) and Automatic meter reading (AMR) utility meter monitoring, home comfort, alarms for protecting people and property, home healthcare, centralized building management…

5.1.1.4 *Cost Issues*

Short range radio solutions tend to be low cost for the following reasons:

- They are usually simple in architecture and protocol layers.
- They are targeted at simple, low cost applications.
- There is no need to pay fees for usage of frequency spectrum or service provisioning.
- They are low power by mandate.

5.2 IETF Sponsored Initiatives

5.2.1 6lowPAN

5.2.1.1 *Technology Overview*

6lowpan is an acronym of *IPv6 over Low power Wireless Personal Area Networks* [5]. 6LoWPAN is the standard from the Internet Engineer Task Force IETF published in 2007, which optimizes IPv6 for use with low-power, low-bandwidth communication technologies such as the IEEE 802.15.4 (see section 5.3.1).

The 6lowpan group aimed at defining header compression mechanisms that allow IPv6 packets to be sent to and received from over IEEE 802.15-based networks. The base specification developed by the 6lowpan IETF group is the RFC 4944.

Whereas IEEE802.15.4 devices are intentionally constrained in form factor to reduce costs, IPv6 requires a considerable higher bandwidth. Therefore, header compression mechanisms standardized in RFC4944 can be used to provide header compression of IPv6 packets over such networks. Furthermore, RFC 4944 proposes an adaptation layer to allow the transmission of IPv6 datagrams over IEEE 802.15.4 networks. Moreover, since the compression is completely stateless, it means that it creates no binding state between the compressor-decompressor pair. Stateless compression gives nodes the flexibility to communicate with any neighbour in compact form at all times.

6lowpan brings up the advantages already described in the IEEE 802.15.4 standard: offer the fundamental lower network layers of a type of wireless personal area network (WPAN), which focuses on low-cost, low-speed ubiquitous communication between devices; and the IP protocol advantages which has proven itself a long-lived, stable, and highly scalable communication technology that supports both a wide range of applications, devices, and underlying communication technologies.

Finally, indicate that the ZigBee specification and the 6lowpan RFC are not competing technologies but on the contrary, they can be well complementary as it can be shown in the diagram below:

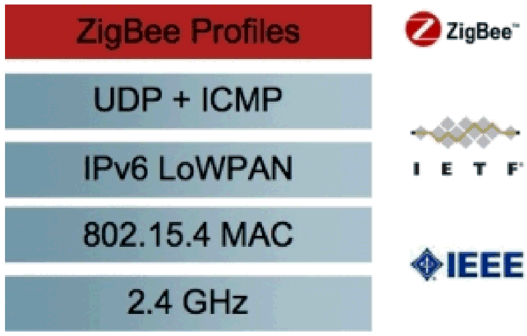

Fig. 3 – Zigbee over IPv6

Recently, the IETF has launched collaboration with the ZigBee alliance in order to provide an IETF specification for using ZigBee profiles over UDP/IP.

5.3 IEEE Sponsored Initiatives

5.3.1 IEEE 802.15.4

5.3.1.1 Technology Overview

IEEE 802.15.4 is a standard which specifies the physical layer and media access control for low-rate wireless personal area networks (LR-WPANs). It is maintained by the IEEE 802.15 working group [6].

This standard intends to offer the fundamental lower network layers of a type of wireless personal area network (WPAN), which focuses on low-cost, low-speed ubiquitous communication between devices (in contrast with other, more end user-oriented approaches, such as Wi-Fi.

The basic framework conceives a 10 to 75 meter communications area with a transfer rate of 250 kbps. Tradeoffs are possible to favour more radically embedded devices with even lower power requirements, through the definition of not one, but several physical layers. Lower transfer rates of 20, 40 and 100 kbps are defined in the standard as well.

Important features of the IEEE 802.15.4 include real-time suitability by reservation of guaranteed time slots, collision avoidance through CSMA/CA and integrated support for secure communications. Devices also include power management functions such as link quality and energy detection.

Networks can be built as either peer-to-peer (point-to-point) or star networks:

Peer-to-peer networks can form arbitrary patterns of connections, and their extension is only limited by the distance between each pair of nodes. They are meant to serve as the basis for ad hoc networks capable of performing self-management and organization

A more structured star pattern is also supported, where a network coordinator is designed and plays the role of the central node.

Since the standard does not define a network layer, routing is not directly supported, but such an additional layer can add support for multihop communications. The network topology can be extended as a generic mesh network.

Regarding secure communications, the Medium Access Control (MAC) sublayer offers facilities that can be harnessed by upper layers to achieve the desired level of security. Higher-layer processes may specify keys to perform symmetric cryptography to protect the payload and restrict it to a group of devices or just a point-to-point link; these groups of devices can be specified in access control lists.

IEEE 802.15.4 is the basis for such upper layer specifications as ZigBee, 6lowpan, WirelessHART or MiWi. These specifications attempt to offer a complete networking solution by developing the upper layers that are not covered by the IEEE 802.15.4 standard.

The IEEE 802.15.4a standard is operating at 2.4GHz band. The 868MHz band is also possible but has not been used yet. ZigBee has adopted this wireless standard to operate its ZigBee protocol, including the Smart Metering Profile and Home Area Networking related services. Wireless HART, a protocol dedicated to industrial automation, has also adopted this IEEE 802.15.4a wireless standard, as have many other “unknown” proprietary protocols for diverse sub-segments of the ISM wireless market.

Because 802.15.4a faced trouble to match the requirements for large-scale fixed network operation for metering utilities, a new task group was been created: IEEE802.15 Task Group 4g.

The IEEE 802.15 Task Group 4g is chartered with defining an amendment to the existing standard 802.15.4-2006. This amendment principally addresses outdoor Low Data Rate Wireless Smart Metering Utility Network requirements. It defines an alternate PHY and only those MAC modifications needed to support its implementation. It is at the stage of receiving Final Proposals for an amendment to the Standard IEEE 802.15.4-2006, compliant with the Project Authorization Request.

5.3.1.2 Frequency Bands

The IEEE 802.15.4 standard operates on one of three possible unlicensed frequency bands:

- 868-868.8 MHz: Europe, allows one communication channel
- 902-928 MHz: North America, up to thirty channels
- 2400-2483.5 MHz: worldwide use, up to sixteen channels

5.3.1.3 Key Applications

As this technology is based on low data rate, low range communications, it suits a variety of applications, including the following:

- Automatic Meter Reading.

- Industrial remote control communications.
- Home automation.

In these applications IEEE802.15.4 technology is often combined with upper protocol layers in order to solve network layer issues (see sections under 5.4).

5.3.1.4 Cost Issues

The IEEE802.15.4 standards are focused on very low cost communication of nearby devices with little to no underlying infrastructure, intending to exploit this to lower power consumption even more.

5.3.2 IEEE 802.11

5.3.2.1 Technology Overview

There is a set of standards comprised under the IEEE 802.11 family [7], aiming at low cost wireless LAN functionality, with the goal of providing a service equivalent to Ethernet layer 2 wired connectivity. These standards use Direct Sequence Spread Spectrum (DSSS) and Multi Carrier Orthogonal Frequency Division Multiplexing (OFDM) radio technologies. Unlike other wireless communication technologies, IEEE 802.11 makes use of unlicensed frequency bands in the range of 2.4 and 5GHz. This fact has the following advantages:

- Plenty of equipment and vendors available.
- Guaranteed interoperability via an independent product certification entity (WiFi Alliance, see section 5.4.5).
- Worldwide availability of (at least some channels) on the same frequency bands.
- Transmission data rates of the order of tens of megabits can be achieved (802.11a/g technology has a limit of 54Mbps).
- Low cost of the devices and no exploitation costs for the service.

On the other hand, there are some drawbacks that must be taken into account:

- The maximum allowed radiated power (EIRP) is very low, typically 100mW in many countries, including Europe. The link distance is therefore limited by both transmitted power and antenna directivity.
- These frequency bands are very sensible to attenuation from water molecule absorption. In this way fog, rain and snow can degrade seriously the link power budget.
- The frequency bands are free for anyone to use them, and thus there may be some interference problems arising from congestion, both by 802.11 devices and other

appliances using the same unlicensed band. This is particularly important in the 2.4GHz ISM band.

- Last, but not least, security aspects are mandatory, as IEEE 802.11 systems can be easily sniffed. Strong encryption mechanisms, such as WPA and preferably WPA2, have proved secure enough to let this technology be used in different environments such as meter reading.

- These standards were not designed with lowest power consumption in mind, so these technologies have slightly higher standby power consumptions than other WLAN/WPAN solutions, usually in the order of 1W.

The IEEE 802.11 family currently includes multiple over-the-air modulation techniques that all use the same basic protocol. The segment of the radio frequency spectrum varies between countries and includes 2.4 GHz and 5GHz.

- IEEE 802.11b and 802.11a were the first widely accepted wireless networking standard, followed by 802.11g and then 802.11n. Other standards in the family (c–f, h, and j) are service amendments and extensions or corrections to previous specifications.

- IEEE 802.11n is based on a new multi-streaming modulation technique and at the time of preparation of the present document, is still under draft development, although proprietary products based on pre-draft versions of the standard are available on the market.

5.3.2.2 Frequency Bands

IEEE 802.11 technology operates in unlicensed frequency bands. Some of these bands are not available worldwide, even though frequency spectrum harmonization tasks have been carried out since these technologies hit the market.

The frequency bands in use are:

- 2.4GHz ISM band for IEEE 802.11b, g, n.

- 5GHz band (5.15-5.825GHz) for IEEE 802.11a, n.

5.3.2.3 Key Applications

The relative low cost and use of unlicensed frequency bands makes possible the usage of IEE802.11 technologies in many application scenarios, such as the following:

- Provide wireless bridging between fixed Ethernet networks. In this case a fixed Ethernet network can be reached by means of two wireless bridges, which create a wireless link between them, and create a layer 2 bridge. This is very useful when the deployment of a fixed Ethernet connection is not feasible due to physical constraints or high costs. Link distances in the order of kilometres may be reached using standard equipment.

- Allow wireless access to the fixed Ethernet network by means of an IEEE 802.11 Access Point. This application addresses the access of itinerant users, to a fixed Ethernet LAN, without the need of a physical connection.

- Allow wireless connection of IEEE 802.11 fixed clients to a central access point. This application can be used where a fixes, wired LAN is not desired for ease of installation, cost, or other reasons, such as to achieve galvanic isolation. This application can be used to link energy meters to a central access point in a meter room.

5.3.2.4 Cost Issues

IEEE 802.11 technology has been extremely successful, with tens of millions of IEEE 802.11 enabled products shipped worldwide and hundreds of vendors providing competitive solutions. As a result of this, the cost of this technology is quite low, taking into account the bandwidth and performance provided.

On the other hand, at frequencies in the order of GHz, it is quite easy and cheap to produce antennas that are embedded in the printed circuit boards of the devices for low range applications, and this leads to very compact and simple solutions, not requiring connectors nor cabling.

5.3.3 IEEE 802.16

5.3.3.1 Technology Overview

IEEE802.16 is working group within IEEE focused in Wireless Metropolitan Area (WMAN) access technology [8]. Since its initial conception, two main standards have been developed:

- *802.16d - fixed*

IEEE 802.16d ("802.16-2004") is aimed at fixed applications and providing a wireless equivalent of DSL broadband data.

802.16d is able to provide data rates of up to 75 Mbps and as a result it is ideal for fixed, DSL replacement applications. It may also be used for backhaul where the final data may be distributed further to individual users. Cell radii are typically up to 75 km.

- *802.16e - Nomadic / Mobile*

This standard is also known as "802.16-2005". It currently provides the ability for users to connect to a cell from a variety of locations, and there are future enhancements to provide cell handover.

802.16e is able to provide data rates up to 15 Mbps with cell radius distances typically 2÷4 km.

5.3.3.2 Frequency Bands

The IEEE 802.16 standard allows data transmission using multiple broadband frequency ranges.

The original 802.16a standard specified transmissions in the range 10÷66 GHz, but 802.16d allowed lower frequencies in the range 2 to 11 GHz. The lower frequencies used in the later specifications provide improved range and better coverage within buildings; this means that external antennas are not required.

Different bands are available for IEEE802.16 applications in different parts of the world.

The frequencies commonly used are 3.5 and 5.8 GHz for 802.16d and 2.3, 2.5 and 3.5 GHz for 802.16e but the use depends upon the countries.

The 5.8GHz band is not available in most European countries.

IEEE802.16 uses OFDM (Orthogonal Frequency Division Multiplex) as its modulation scheme. For 802.16d, 256 carriers are used, but for 802.16e the system is scalable according to the conditions and requirements.

More advanced versions including 802.16e utilise MIMO (Multiple Input Multiple Output) and support for multiple antenna. The use of these techniques provides potential benefits in terms of coverage, self installation, power consumption, frequency re-use and bandwidth efficiency.

The IEEE 802.16a (256 OFDM PHY) and ETSI HIPERMAN (HIgh PErformance Radio Metropolitan Area Network) standards share the same PHY and MAC. The purpose of 802.16e is to add limited mobility to the current standard which is designed for fixed operation.

5.3.3.3 Key Applications

IEEE802.16 technologies are further along in terms of deployments with several operators throughout the world using it to provide *fixed* wireless broadband services. But so far, the technology has had a slow start as a *mobile* technology.

Most of new 802.16-based operators come from the fixed network space, and they are looking to use these technologies as an enhanced DSL service.

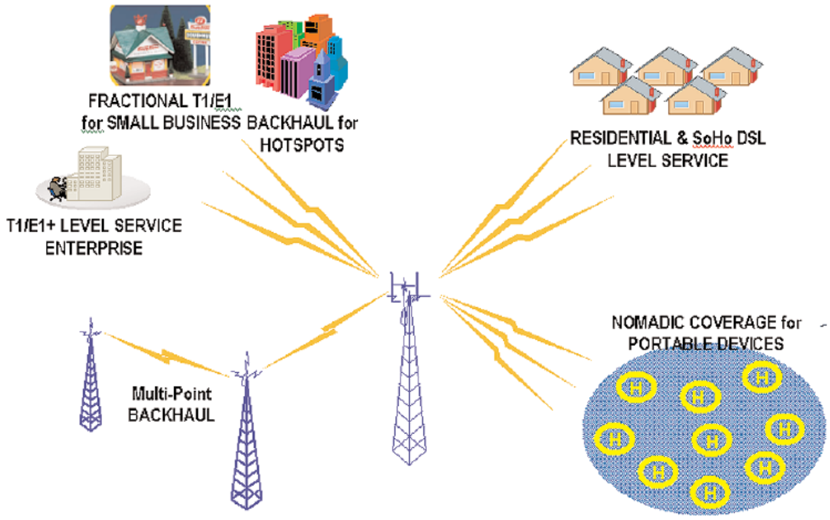

Fig. 4 – WiMAX usage model

At present, 802.16 is not used in metering applications.

5.3.3.4 Cost Issues

802.16 access technology is now being deployed in many areas and while it was initially seen as yet another wireless standard that might fall into the background, it is now emerging as a major front runner and posing threats to other areas of the industry.

It is being seen by many as a real competitor to 3G, being able to offer data transfer speeds that are more in keeping with LTE (Long Term Evolution) the new 4G standard that is starting to be developed. In view of this, very much more will be seen of 802.16 in both its 802.16d and 802.16e variants in the coming years.

In addition, the effort of the WiMAX Forum promoting the technology fosters its worldwide adoption and expansion (see 5.4.9).

Some recent indication lead to judgment that 802.16 will hand over to LTE as dominant technology towards 4G networks. Then, fixed-line voice traffic is rapidly migrating to mobile networks. The fixed-to-mobile substitution trend indicates that 70-80% of all voice traffic in Europe will be carried over mobile networks by 2015.

Costs may range over 25 k€ for the base station (depending on fixed/mobile, transmitting power) and 300 € for the Customer Premises Equipment (fixed modems/portable devices).

5.4 Other Initiatives

5.4.1 Zigbee

5.4.1.1 Technology Overview

ZigBee is a trademark of the ZigBee Alliance [9]. It is an association of companies working together to enable reliable, cost-effective, low-power, wirelessly networked, monitoring and control products based on an open global standard.

The ZigBee specification provides a low-cost, low-power, wireless mesh networking technology. The low cost allows this technology to be widely deployed in wireless control and monitoring applications, the low power-usage allows longer life with smaller batteries, and the mesh networking provides high reliability and larger range.

ZigBee is a specification for a suite of high level communication protocols using small, low-power digital radios based on the IEEE 802.15.4 standard (see section 5.3.1) for wireless personal area networks (WPANs). ZigBee devices are required to conform to the IEEE 802.15.4, which specifies the lower protocol layers—the physical layer (PHY), and the medium access control (MAC) portion of the data link layer (DLL)

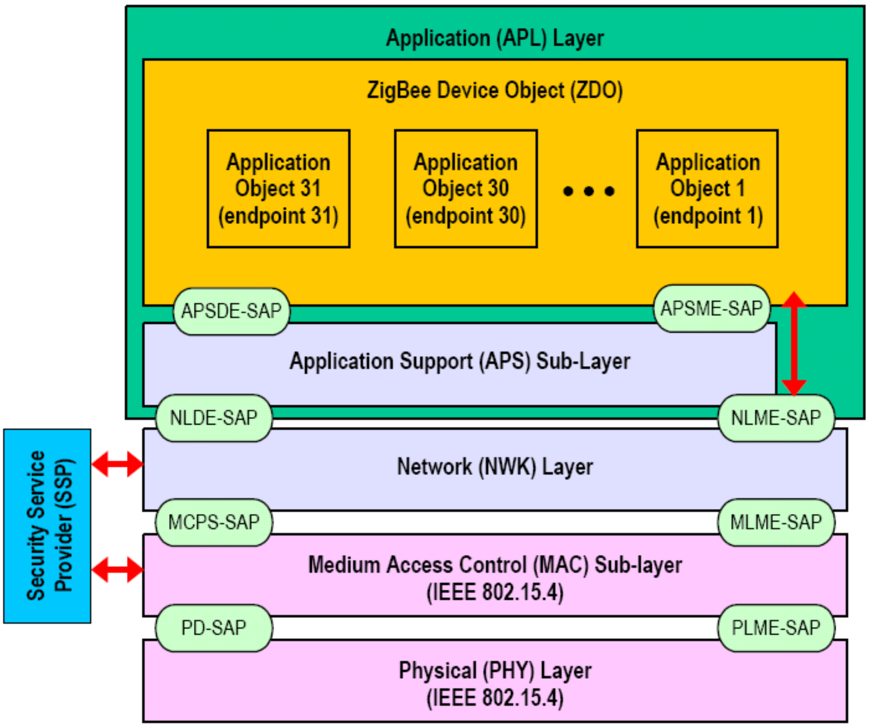

Fig. 5 – ZigBee Communication Stack

Therefore, the ZigBee specification focuses only on upper layers: starting from the network layer to the final application layer, including the application objects themselves.

The responsibilities of the ZigBee network layer include:

- Starting a network: The ability to successfully establish a new network.
- Joining and leaving a network: The ability to gain membership (join) or relinquish membership (leave) a network.
- Configuring a new device: The ability to sufficiently configure the stack for operation as required.
- Addressing: The ability of a ZigBee coordinator to assign addresses to devices joining the network.
- Synchronization within a network: The ability for a device to achieve synchronization with another device either through tracking beacons or by polling.
- Security: applying security to outgoing frames and removing security to terminating frames. For this purpose, the network layer also makes use of the Advanced Encryption Standard (AES) and the security suites are all based on the CCM mode of operation.
- Routing: routing frames to their intended destinations.

The ZigBee application layer consists of the Application Support sub-layer (APS), the ZigBee Device Object (ZDO) and the manufacturer-defined application objects.

The responsibilities of the APS sub-layer include maintaining tables for binding, which is the ability to match two devices together based on their services and their needs, and forwarding messages between bound devices. Another responsibility of the APS sub-layer is discovery, which is the ability to determine which other devices are operating in the personal operating space of a device.

The responsibilities of the ZDO include defining the role of the device within the network (e.g., ZigBee coordinator or end device), initiating and/or responding to binding requests and establishing a secure relationship between network devices. The manufacturer-defined application objects implement the actual applications according to the ZigBee-defined application descriptions

5.4.1.2 Frequency Bands

See section 5.3.1

5.4.1.3 Key Applications

Depending on the implemented ZDO and manufacturer-defined applications, several application profiles can be defined, which are oriented towards final applications. At the current state, the list of application profiles either published or in the works are:

- Home Entertainment and Control — Smart lighting, advanced temperature control, safety and security, movies and music
- Home Awareness — Water sensors, power sensors, smoke and fire detectors, smart appliances and access sensors
- Mobile Services — m-payment, m-monitoring and control, m-security and access control, m-healthcare and tele-assist
- Commercial Building — Energy monitoring, HVAC, lighting, access control
- Smart Metering

5.4.1.4 Cost Issues

ZigBee is a technology that includes as key system requirements to be low-cost, low-power, simple and reliable. It is anticipated that ZigBee enabled products will have a very low price tag due to high application volumes. However to obtain the right of use the ZigBee logo and attend interoperability tests, a manufacturing company has to be a member of the ZigBee alliance, bearing some membership costs.

5.4.2 IPSO

5.4.2.1 Technology Overview

The IPSO acronym stands for IP for Smart Objects [10]. The IPSO Alliance is an open group of member companies that are working together to market and educate about using IP as the protocol for sensor and control networks (generically defined as "smart objects"). The Alliance is a global non-profit organization serving the various communities seeking to establish the Internet Protocol as the network for the connection of Smart Objects by providing coordinated marketing efforts available to the general public. Their purpose is to provide a foundation for industry growth through building stronger relationships, fostering awareness, providing education, promoting the industry, generating research, and creating a better understanding of IP and its role in connecting Smart Objects.

The main goals of the IPSO Alliance are the following:

- Promote IP as the premier solution for access and communication for Smart Objects.
- Promote the use of IP in Smart Objects by developing and publishing white papers and case studies and providing updates on standards progress from associations like IETF among others and through other supporting marketing activities.

- Understand the industries and markets where Smart Objects can have an effective role in growth when connected using the Internet Protocol.

- Organize interoperability tests that will allow members and interested parties to show that products and services using IP for Smart Objects can work together and meet industry standards for communication.

- Support IETF and other standards development organizations in the development of standards for IP for Smart Objects.

It should be noted that the objective of the Alliance is not to define technologies, but to document the use of IP-based technologies defined at the standard organizations such as IETF with focus on support by the Alliance of various use cases.

The emerging application space for Smart Objects requires scalable and interoperable communication mechanisms that support future innovation as the application space grows. IP has proven itself a long-lived, stable, and highly scalable communication technology that supports both a wide range of applications, devices, and underlying communication technologies.

The IP stack is lightweight and runs on tiny, battery operated embedded devices. IP therefore has all the qualities to make "The Internet of Things" a reality, connecting billions of communicating devices.

The IPSO Alliance doesn't aim to define new protocols, as stated before. They will be working with International Standards Organizations such as the IETF, ISA, IEC and IEEE and will document and utilize the standards developed by them, such as IEEE 802.15.4 and 6lowpan. The use of IP in sensor and control networks and with Smart Objects will greatly simplify the development, deployment and maintenance of new applications, by providing a known programming and networking paradigm, a large number of existing protocols, existing tools both for development and for diagnostics.

The IPSO alliance, based on these International standards, will provide Use Cases, tutorials, demonstrations promoting the use of these and other open standard protocols. Additionally many of the members of the Alliance participate in the IETF and other standards groups and will work within those groups to track standards efforts for IPSO member companies and to provide a voice from member companies to those standards efforts.

5.4.3 Wireless M-Bus

Message Bus (Mbus) is an asynchronous, message-oriented coordination protocol that is based on Internet technologies and provides group communication between application components. Wireless M-Bus is a new European standard for remote reading of consumption meters (water, gas electricity and heat) as well as for various sensors and actuators. With its standardization for remote readout of meters this technology is of great importance for the energy industry as relevant users.

The standardization of the Wireless M-bus results in further technical possibilities. In particular devices of different manufacturers can be operated on the same technology; the users are free therefore in the choice of the manufacturer. On the other hand, a stimulation of the market can be expected, also regarding other M-bus based counters, so that with the very variable configuration options even difficult problems can be solved.

5.4.3.1 Technology Overview

Wireless M-Bus is a technology based on the EN standard EN13757-4:2005 [11]. It operates in the ISM 868MHz band in point-to-point mode, with single-channel operation and a basic FSK modulation scheme. One channel is dedicated to the downlink (master-to-slave) and another is dedicated to the uplink (slave-to-master). Two different data rates of 100kcps or 32kcps have been setup, depending on channel operation and operating modes: T1 (*1-way communications*, T2 (*2-way communications*), S (full time reception), R …

Wireless M-Bus does not feature spread spectrum techniques (no robustness against interferers and low capability of coexistence), without wireless relay (range extender), and in addition, neither self-configuring nor self-healing for smart, flexible, reliable and efficient management over many years operation, such as that required for covering entire cities.

On the SLAVE side:

- Receive mode on CH1 @ 32kchips (to get signal from the Master)
- Transmit mode on CH2 @ 100kchips (to send data to the Master)

T1 mode (1-way communication): SLAVE is only in Transmit mode (Push mode). Only CH2 is considered. Reception mode is never activated.

T2 mode (2-way communication): SLAVE transmits on CH2 and immediately switches in RX more on CH1 for 15ms in case ACK is requested, or up to 50ms to get more data.

T1 & T2 modes are suited to Metering

S mode (Stationary) is dedicated to Full Time Receiving mode that can only fit MASTER operation.

Wake-up: 40-60chips ~0,5ms

- Tx SLAVE -> MASTER is approx 5ms
- Tx MASTER -> SLAVE is about 15ms

P1 port defines the interface with the power meter.

P2 port provides the "P2 companion" file that defines the interface between the Metering System and the Water, Gas, Heat meters.

P3 port: TBD

5.4.3.2 Frequency Bands

Wireless M-Bus uses the European ISM 868MHz sub-band, with a maximum RF TX power of 25mW. It has separate channels for downlink and uplink:

- Channel 1 (CH1): 868.300MHz for Master's TX / Manchester coding / 32kchips => 16kbps +/-2%
- Channel 2 (CH2): 868.950 MHz for Slaves TX / 3-out-of-6 coding (4-bit data => 6-bit transmission / 100kchips +/-10% (66.66kbps)

5.4.3.3 Key Applications

Wireless M-Bus is aimed primarily at AMR applications. The remote reading of meters can take place in different ways, beginning with the classical method - manual reading by the personnel of the providers - up to the remotely controlled collection of all the meter values for a complete housing unit. The latter is a logical continuation/extension of the technical development of consumption meters and is realizable with the help of the Wireless M-Bus.

Here some substantial characteristics of this interface are mentioned regarding their new possibilities:

- The data are read out wirelessly
- when connected to a building controller, all consumption meters of a housing unit can be attached
- All meters are individually addressable
- Apart from the availability of the data at the controller, also a remote reading is possible
- A set of advantages arise, both for the supply enterprises, and for their customers:
- The reading is fast and avoids reading errors
- The data being present in machine-readable form makes the further processing easier
- A remote readout saves personnel expenditure, avoids unnecessary penetration into the private sphere of the inhabitants and permits to mount meters in places which are difficult to access
- Short reading intervals are possible, which reduces the problems with tenant change or tariff amendments
- Due to the short reading intervals, statistical data can be obtained, which can be used as a base for network optimization.

5.4.3.4 Cost Issues

Due to its simplicity, Wireless M-Bus has very simple and cheap implementations available, as it has very low power requirements and low computational power needs. In the development of the M-bus also economic and technical aspects of the interface have been considered, that are relevant for everyday use. These are essentially:

- Large number of connectable devices
- Possibility for network expansion
- Fail-safe characteristics / robustness
- Minimum cost
- Minimum power consumption in the meters
- Acceptable transmission speed

Wireless M-Bus is designed to fulfil all these constraints, with a new standardized interface for the reading of consumption meters, and optimal compromise.

5.4.4 Wavenis

5.4.4.1 Technology Overview

Wavenis is exclusively a wireless connectivity platform, promoted by the Wavenis Alliance [12]. Wavenis provides all communication services for managing ultra-low power as well as both long-range and short-range digital data wireless transport. Although the specific technical demands vary from field to field, Wavenis responds effectively to a broad range of very tight constraints.

Wavenis has maximized the radio link budget between devices in order to compensate for poor propagation conditions and signal attenuation indoors, and to compensate for poor antenna gain resulting from tiny footprint design and mandatory low-cost solutions. Among other things, this makes it possible to enable wireless communication in hard-to-reach devices. Very high receiver sensitivity is also required to obtain significant operating range and to avoid loading networks with dedicated repeater nodes (which, if nothing else, increase overall cost). With its very high receiver sensitivity and moderate output power, Wavenis offers a very high link budget:

-110dBm @ 19.2 kbps - 50kHz BW channel

-113dBm @ 4.8 kbps - 25kHz BW channel

Wavenis implements a combination of fast FHSS (every 16 bits), FEC (BCH(21,31)), data scrambling (8-bit LFSR) and data interleaving. This combination provides strong robustness against interferers while enabling it to coexist with other wireless technologies operating nearby and to operate in noisy CEM environments (industrial motors, switches, cellular phones/modems…). Wavenis intends to increase success of communications on the first attempt with associated benefit of power savings.

This mechanism is equivalent to the high-gain process of DSSS data processing, but it also takes advantage of a fast FHSS narrowband receiver for a high radio link budget (long-range capability). FHSS technology can support narrowband mono-channel operation for alarm & security applications in sub-GHz European bands by restricting the hop table to one channel.

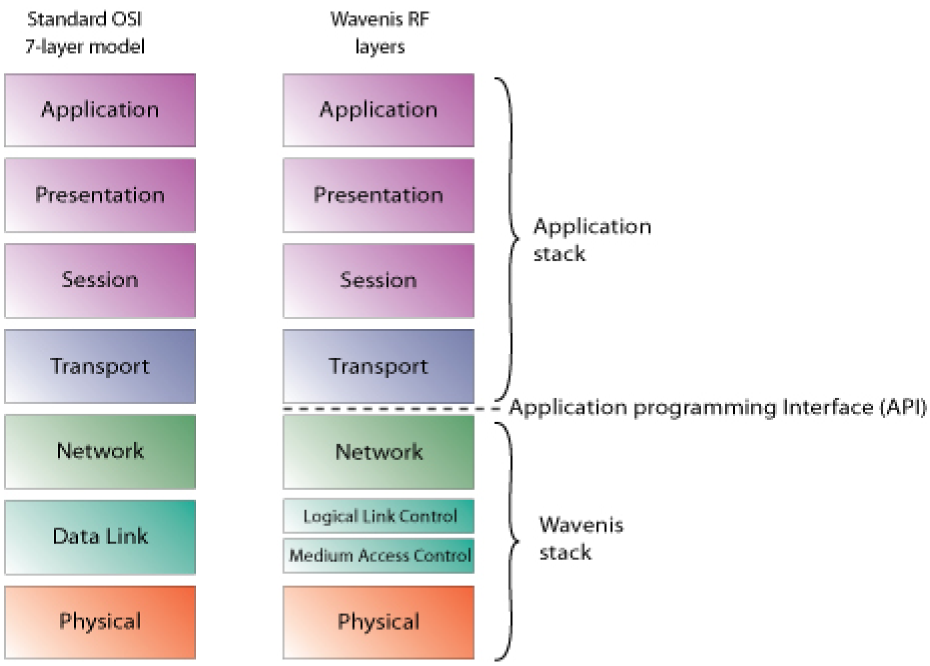

Fig. 6 – Wavenis Protocol Stack

Wavenis devices usually operate in a cyclic manner: *Standby mode* is followed by *Receive mode*. Duty Cycle is programmable and defines access time.

- RX mode only lasts 500µs to measure RSSI.
- Can be extended to 1600µs in case channel energy is detected but with a non-coherent message.
- When signal is coherent, RX time is extended to manage full communications.

As a result, this gives values as low as:

- 10µA average operating current with 1s access time and a few transmissions (25mW) per day
- 5µA average operating current with 2s access time and few transmissions (25mW) per day

The current consumption figures for this calculation are obtained taking into account the following values:

- 17mA RX current in full run mode
- 45mA TX current (25mW output power)
- 2μA standby current

Wavenis networks can be operated in the following scenarios, or in combination of the two:

- Walk-by monitoring: Wavenis modem, Compact Flash or SD-card for handheld terminals
- Fixed network monitoring: Wavenis LAN modems (USB, RS-232), Wavenis gateways (GSM/SMS-GPRS, Ethernet, PLC) and more.

5.4.4.2 Frequency Bands

Wavenis offers worldwide operation by operating in major license-free ISM bands, and complies with following regulatory standards

- 868 MHz (EU EN300-220) with strict duty cycle regulation
- 915 MHz (US FCC15-247, 15-249) – mandatory signal spreading
- 433 MHz (Asia) as straightforward extension (no duty cycle restriction)

5.4.4.3 Key Applications

Wavenis technology is optimized for ultra-low-power and long range-wireless sensor networks (WSNs), with a clear focus on markets in which communication ability and device autonomy present conflicting requirements. These markets include telemetry, industrial automation, remote utility meter monitoring, home comfort, alarms for protecting people and property, home healthcare, centralized building management, access control, refrigeration monitoring, plus long-range UHF RFID applications for the identification, tracking, and locating of people and objects.

Wavenis makes it possible to address markets with wireless devices that are not only cost-effective, but also run on a single set of batteries for many years. Wavenis does not compete with traditional technologies but rather comes as a complementary solution that adds an unlimited set of new usage scenarios.

5.4.4.4 Cost Issues

Wavenis is a low cost solution, as a result of the following factors:

- Low-cost ultra-low-power Wavenis-enabled RF transceiver

- It can be implemented in low-cost, low-power CPU
- The memory footprint of Wavenis code is small (8kB to 32kB) to keep memory costs down (RF stack + mesh algorithm)
- Low BOM with limited, inexpensive external components

The first Wavenis-enabled SOC (System On Chip) will be available during 2009.

5.4.5 WiFi

WiFi is a trademark of the WiFi Alliance, formerly known as WECA (Wireless Ethernet Compatibility Alliance) [13]. It now comprises more than 300 members from 20 countries. This alliance was launched in 1999 with the objectives of promoting the adoption of IEEE 802.11 technology as the universal wireless LAN, guaranteeing interoperability by means of a specific certification program, and assuring end user satisfaction. If this program is passed, the product gains the WiFi interoperability certificate and the right to carry the WiFi logo. Any manufacturer willing to certificate a product as WiFi must be first a member of the WiFi alliance.

In this way, every product shipped with the WiFi logo ensures interoperability with other WiFi devices. However, the product bears the cost of the WiFi certification program and WiFi Alliance membership.

WiFi- certified products implement IEEE 802.11 technology, but there are IEEE 802.11 products which are not WiFi certified, depending on the market or application at which they are oriented, where the certification may not be applicable or add any value. It is perceived that the WiFi certification program gives advantage at the time of pursuing the end user market, but it may not be required in professional applications, where interoperability is tested at project commissioning or acceptance tests, and therefore certification costs can be spared.

For detailed technical information see chapter 5.3.2.

5.4.6 Bluetooth

5.4.6.1 Technology Overview

Bluetooth is an open wireless protocol for exchanging data over short distances from fixed and mobile devices, creating personal area networks (PANs). It was originally conceived as a wireless alternative to RS232 data cables. It can connect several devices, overcoming problems of synchronization.

Bluetooth is a trademark of the Bluetooth Special Interest Group (SIG) [14], an organization devoted to promoting Bluetooth technology deployment and interoperability. Bluetooth enabled devices have to pass a certification program established by the Bluetooth SIG in order to achieve compatibility approval and carry the Bluetooth logo.

Bluetooth standard and communications protocol was primarily designed for low power consumption, with a short range (power-class-dependent: 1 meter (Class 1), 10 meters (Class 2), 100 meters (Class 3)) based on low-cost transceiver microchips in each device. Bluetooth makes it possible for these devices to communicate with each other when they are in range. Because the devices use a radio (broadcast) communications system, they do not have to be in line of sight of each other.

At the radio interface, Bluetooth uses GFSK (Gaussian Frequency Shift Keying) modulation with frequency hopping. Two modulation modes are defined. A mandatory mode, called Basic Rate, uses a shaped, binary FM modulation to minimize transceiver complexity. An optional mode, called Enhanced Data Rate, uses PSK modulation and has two variants: π/4-DQPSK and 8DPSK. The symbol rate for all modulation schemes is 1 Ms/s. The gross air data rate is 1 Mbps for Basic Rate, 2 Mbps for Enhanced Data Rate using π/4-DQPSK and 3 Mbps for Enhanced Data Rate using 8DPSK.

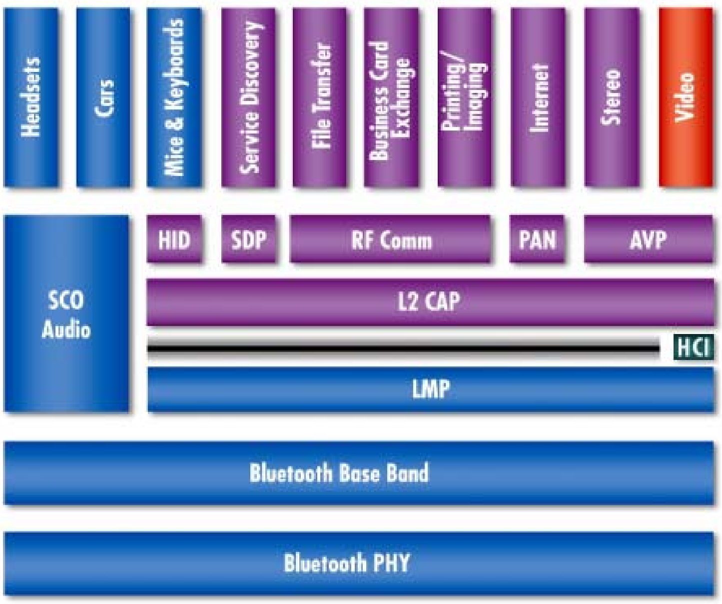

Fig. 7 – Bluetooth Protocol Stack

The original Bluetooth specification, the Bluetooth v1, which was ratified later on as IEEE 802.15.1 standard, was developed in 1994. From this date, several are the enhancements done so far to this standard. Currently in Bluetooth v 2.1, fully backward compatible with the oldest versions; the main features of this communication protocol follow:

- Extended inquiry response: provides more information during the inquiry procedure to allow better filtering of devices before connection. This information includes the name of the device, a list of services the device supports, plus other information like the time of day and pairing information.

- Sniff subrating: reduces the power consumption when devices are in the sniff low-power mode, especially on links with asymmetric data flows.

- Encryption Pause Resume & Secure Simple Pairing: enables an encryption key to be refreshed, enabling much stronger encryption for connections that stay up for longer. The Secure Simple Pairing radically improves the pairing experience for Bluetooth devices, while increasing the use and strength of security

- Near Field Communication (NFC) cooperation: automatic creation of secure Bluetooth connections when NFC radio interface is also available. This functionality is part of the Secure Simple Pairing where NFC is one way of exchanging pairing information.

5.4.6.2 Frequency Bands

Bluetooth uses the globally available 2.4GHz ISM band (2.400-2.4835MHz), dividing it into 79 1MHz channels. There are special guard bands in the lower and upper limits of the band to comply with international frequency assignment standards.

5.4.6.3 Key Applications

The more prevalent applications of Bluetooth include:

- Wireless control of and communication between a mobile phone and a hands-free headset. This was one of the earliest applications to become popular.

- Wireless networking between PCs in a confined space and where little bandwidth is required.

- Wireless communication with PC input and output devices, the most common being the mouse, keyboard and printer.

- Transfer of files, contact details, calendar appointments, and reminders between devices with OBEX.

- Replacement of traditional wired serial communications in test equipment, GPS receivers, medical equipment, bar code scanners, and traffic control devices.

5.4.6.4 Cost Issues

Bluetooth is a low cost, low power technology. However, the certification process is mandatory for all products to bear the Bluetooth logo, and the Bluetooth SIG only provides permission for usage of Bluetooth intellectual property rights if a product is certified. As a result of this, the technology can be very costly to deploy unless the number of manufactured units is very high to dilute expensive development and certification costs.

5.4.7 2G: GPRS

5.4.7.1 Technology Overview

GPRS (General Packet Radio Service) is a mobile data service offered in GSM systems, in addition to GSM service. GPRS is a packet switched, IP-based service, where subscribers use the available channels only when they have data to send [15][16]. They are nowadays globally available in nearly all the countries (except South Korea and Japan). In general terms GPRS coverage is readily available in populated areas in most countries.

In this case, as opposed to WiFi or other technologies, the infrastructure network is owned by the Mobile Operator. GPRS is widely used in IP networks today as a WAN wireless technology. Each GPRS subscriber obtains an IP address, which can be public or private, and at the same time fixed or dynamic, depending on the contracted service features and operator capabilities.

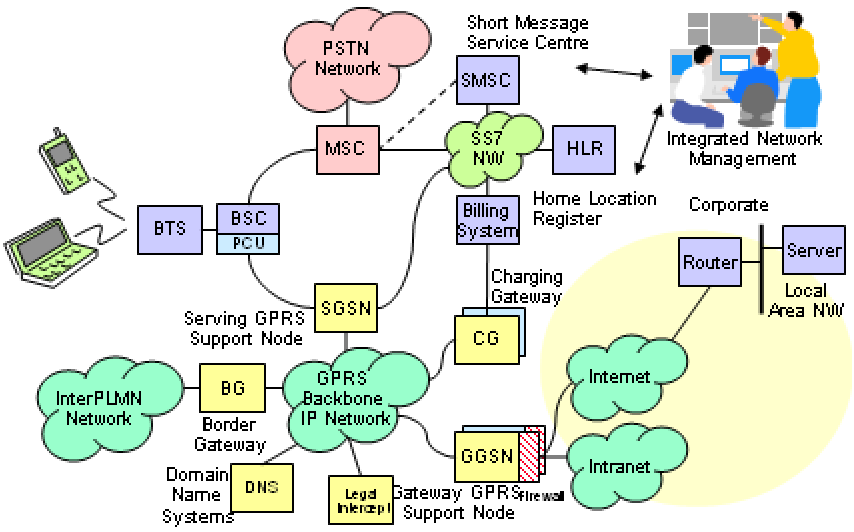

Fig. 8 – GPRS Network

Data throughput can vary from 9 to 60Kbps (downlink) and 9 to 40Kbps (uplink), depending on the GPRS terminal and the Operator Network, and is usually asymmetrical (uplink and downlink do not have the same data transmission speed), where downlink speed is somewhat higher than uplink's. In some countries, EDGE (Enhanced Evolution) networks have been rolled out (also known as 3,5G), using the same frequency bands and infrastructure, but with an improved modulation scheme, upgrading the data rates up to .

The GPRS network has a remarkable latency (usually in the 0.5 to 2 seconds range), and is non-deterministic, depending greatly on the carrier network utilization. This issue must be considered when carrying delay sensitive data.

As GPRS service is IP based, all standard security protocols on the TCP/IP stack such as IPSec, TLS/SSL… can be implemented over GPRS, in order to have secure communication links. It must be noted that many GPRS networks are not supporting currently multicast traffic.

Some network carriers offer a service based on private GPRS domains. In this application, the customer can buy or lease SIM cards which have private (not public) IP addresses. They form a private IP subnetwork, which is isolated and not accessible from the internet. The IP addresses can be chosen to fit the existing IP addressing scheme in the customer's IP network.

5.4.7.2 Frequency Bands

The GPRS service is provided by Mobile Network Operators throughout the world, using GSM licensed frequency bands (800MHz, 900MHz, 1800MHz, 1900MHz). The licenses for operating in these frequency bands are allocated by government or state agencies in charge of frequency management for each country, and they charge the operators for the usage of this part of the radioelectric spectrum.

5.4.7.3 Key Applications

As GPRS is a packet based, low bandwidth, IP native technology, it suits a lot of TCP/IP based applications where bandwidth and latency are not the main issue. Some applications may include the following:

- Remote file and data interchange.
- Remote office access for nomadic users (low bandwidth).
- Backup WAN connectivity (combined with a primary, xDSL WAN link).
- Remote metering data collection.

5.4.7.4 Cost Issues

GPRS networks are operated by Mobile Operators for a profit. Each user must sign a contract with a provider to become a subscriber to the service. In this way every subscriber of the GPRS network is charged for the service. This fee can be a flat rate, independent of the amount of traffic, or be priced per MB/KB sent to/from the network. Usually there are also hybrid tariffs, where a fixed rate is applied up to a limited total amount of traffic.

In this way, GPRS technology has recurrent exploitation cost, depending on the number of subscriptions and the traffic generated in the network.

5.4.8 3G: UMTS / HSDPA / HSUPA

5.4.8.1 Technology Overview

UMTS (Universal Mobile Telecommunication System), also known as 3G or third generation mobile technology, is an evolution of existing 2G/GPRS networks using WCDMA modulation techniques in the air interface.

UMTS is fostered by the 3GPP (3rd Generation Partnership Project) [17], an organization of different Telecommunications associations and national bodies, with the goal of having a global 3G system with universal application. There have been different releases of UMTS issued by 3GPP. The main releases, with their most distinctive additions, are the following:

- R99 (Q1/2000): first UMTS networks.
- R4 (Q2/2001): The Core network is specified to be fully IP (previously synchronous network backbones where used as a legacy from GSM systems).

- R5 (Q1/2002): Addition of HSDPA.
- R6 (Q4/2004): Addition of HSUPA
- R7 (Q4/2007): Addition of HSPA+

Data rates can reach 384Kbps in the first version (R4), or up to 7.2 Mbps in HSDPA networks. New network technologies such as HSUPA plan to expand bandwidth in the uplink section of the connection (subscriber – to – network).

UMTS network Rel 99

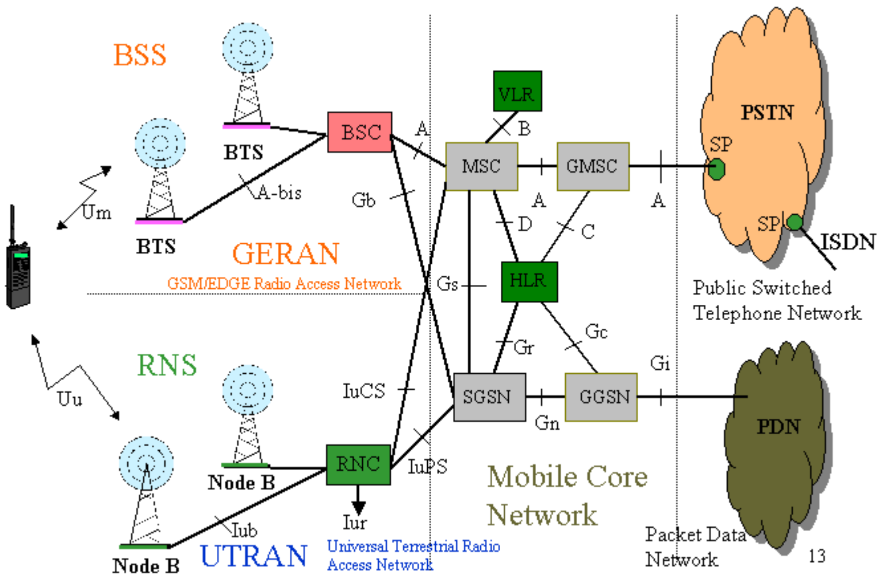

Fig. 9 – UMTS Network

However, due to the high costs of deployment of 3G networks, and the financial costs of the radio spectrum leased by the operators, in the short term these technologies will mainly be available in urban areas and zones where a high user density is expected, to maximize operator revenue.

5.4.8.2 Frequency Bands

Different frequency bands have been allocated for UMTS services in each part of the world. Some of the frequency bands are the following:

- 2100MHz IMT band for Europe, Asia, and Japan.
- 850MHz CLR band for the Americas, Australia.
- 1900MHz PCS band for the Americas.

- 2600MHz IMT-E band for Europe (available in the future).

In the following years, operators may shift some channels currently used for 2G technology (GSM/GPRS) in 900/1800MHz bands for use. This will trigger the expansion in coverage of 3G network service, since one of the main hurdles faced currently by 3G technology in Europe is the small size of a 3G cell coverage area. This comes from the fact that atmospheric radioelectric attenuation at 2100MHz is much higher than at 900MHz.

5.4.8.3 Key Applications

The data rate throughput provided by 3G networks will serve a broad range of applications, including, but not limited to, the following:

- Remote office access for nomadic users (medium/high bandwidth).
- Backup WAN connectivity (combined with a primary, xDSL WAN link).
- File exchange.
- Substitute of xDSL where no cable infrastructure available/deployable.
- Video messaging / telephony.
- Remote metering.

5.4.8.4 Cost Issues

Currently both 3G wireless devices and subscription services are more expensive than GPRS services (taking into account the difference in bandwidth). However, given the cost evolution GPRS products and services, it can be anticipated that with successive generations of UMTS devices and network roll-outs, the exploitation costs will come close to present GPRS costs.

In the same manner as GPRS technology, UMTS network technology has, and will always have, recurrent exploitation costs.

5.4.9 TETRA

5.4.9.1 Technology Overview

The TETRA project began in 1989 as Mobile Digital Trunked Radio System (MDTRS), later renamed as Trans European Trunked RAdio (TETRA) [18], and then the name was again changed in TErrestrial Trunked RAdio. The air interface was specified in 1995 (ETSI) and the first commercial deployment was in 1997. The EC adopted a decision on handsets for the emergency services.

This standard is specifically designed for mission critical applications and to guarantee service during emergencies, especially disasters.

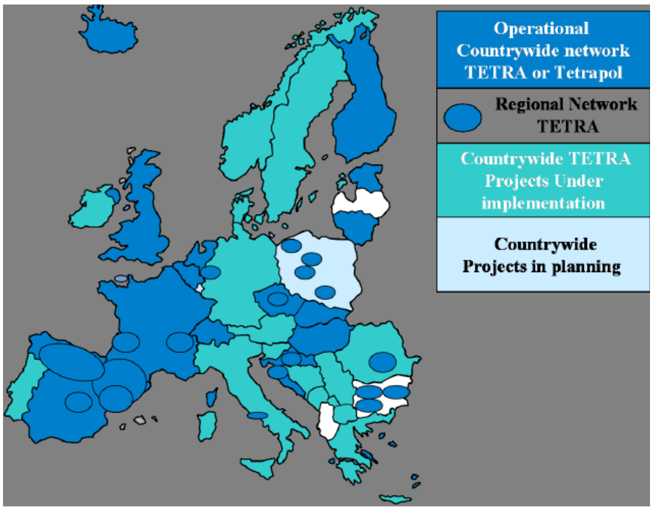

Fig. 10 –TETRA deployment in Europe, 2008 (from ETSI TC-TETRA WG4)

5.4.9.2 Frequency Bands

At a European level, specific frequency bands have been identified for TETRA (CEPT Decision ERC/DEC/ (96)04):

- 385÷390 MHz (MS) paired with 395÷399.9 MHz (BS)
- 410÷420 MHz – 420÷430 MHz;
- 450÷460 MHz – 460÷470 MHz;
- 870÷876 MHz – 915÷921 MHz.

The CEPT assigned 380÷383 MHz and 390÷393 MHz for use by the emergency services[1].

Frequency bands for Private Mobile Radio (PMR) and public safety applications are assigned on a national basis.

TETRA uses Time Division Multiple Access (TDMA) with four user channels on one radio carrier and 25 kHz spacing between carriers. Both point-to-point and point-to-multipoint transfer can be used. Digital data transmission is also included in the standard though at a low data rate.

In addition to voice and dispatch services, the TETRA system supports several types of data communication. Status messages and short data services (SDS) are provided over the system's main control channel, while Packet Data or Circuit switched data communication uses specifically assigned traffic channels.

All traffic is normally encrypted. TETRA provides both over the air encryption and end-to-end encryption.

The base stations normally transmit continuously and (simultaneously) receive continuously from various mobiles - hence they are Frequency Division Duplex. TETRA also uses TDMA. The mobiles normally only transmit on 1 slot/4 and receive on 1 slot/4 so they are both Time Division and Frequency Division Duplex.

Data transfer is efficient and long range (many km); up to 4 timeslots can be combined into a single data channel to achieve 28.8 kbps still fitting into a single 25 kHz bandwidth channel. Latest version of standard supports 115.2 kbps in 25 kHz or up to 691.2 kbps in an expanded 150 kHz channel.

5.4.9.3 Key Applications

TETRA was specifically designed for use by public services as government agencies, police forces, fire departments, ambulance, rail transportation staff, transport services, construction, Oil and Gas, and the military.

5.4.9.4 Cost Issues

Handsets are more expensive than mobile phones, because of the more difficult technology, smaller economies of scale, and different business model (e.g.: need for security, high power and robustness).

TETRA was, almost from the outset, in the shadow of GSM. In large measure the technology mirrored GSM, with the counterparts of SMS and GPRS. While TETRA had clear advantages, in encryption and in coverage, both inside buildings and in rural areas, there is a commercial battle against GSM for its wider adoption.

5.4.10 WiMAX

5.4.10.1 Technology Overview

WiMAX stands for Worldwide Interoperability for Microwave Access (AXess), a technology for Wireless Area Metropolitan Networks (WMANs) that is based on IEEE 802.16 standards. WiMAX is a trademark of the WiMAX Forum [19], a non-profit, industry led organization aimed at promoting he interoperability and compatibility of wireless products and access services based on IEEE802.16 technology. It also takes into account a certification process to guarantee interoperability. Devices and systems which pass the certification process gain the right to carry the WiMAX logo. Only WiMAX forum member companies can certify WiMAX products.

WiMAX- certified products implement IEEE 802.16 technology, but there are IEEE 802.16 products which do not bear the WiMAX logo, in the same way that this occurs with WiFi and IEEE 802.11 technology. As a result of this, the WiMAX logo ensures interoperability, raising the cost of product development, but there is no legal requirement to adhere to this certification program.

The decision whether to pursue the certification program for a certain product will depend on the end market, customer requirements and marketing aspects.

For any technical information see chapter 5.3.3.

5.4.11 EVERBLU

5.4.11.1 Technology Overview

EverBlu is an Automatic Meter Reading system based on wireless mesh point-to-multipoint communication infrastructure. It is an ultra-low-power (bi-power), bi-frequency, long-range (300m), wireless mesh technology.

The LAN layer of EverBlu is coming from the former Radian protocol [20], designed 10 years ago by a European user association (EDF, GDF, Severn Trent Water, Aquametro, Itron, Schlumberger, Sontex and Viterra).

EverBlu endpoints can be read in dual mode either using EverBlu fixed network or walk-by collection system compatible with Radian protocol.

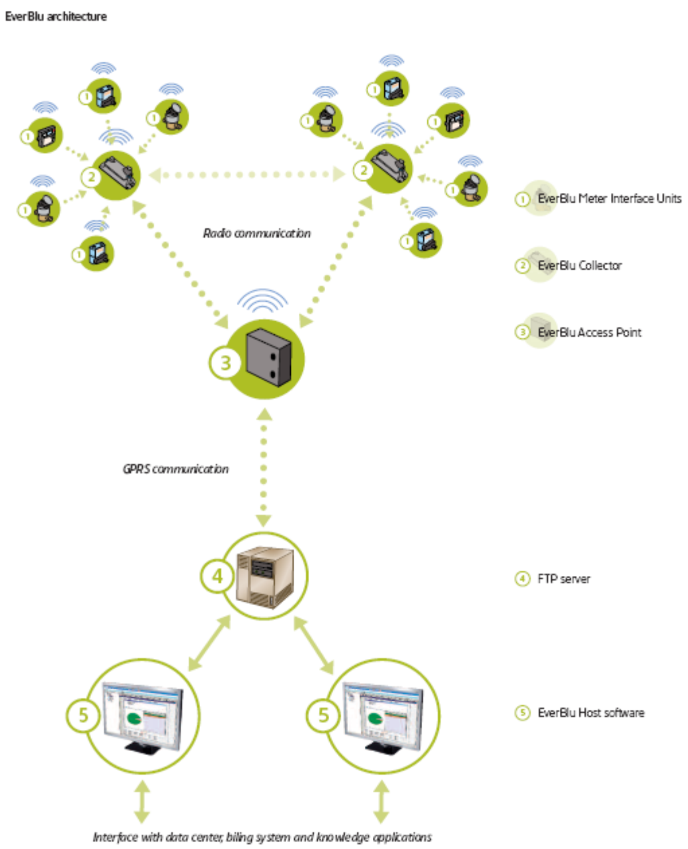

Fig. 11 – EverBlu System Architecture

5.4.11.2 Frequency Bands

EverBlu operates in major license-free bands:

- LAN: 433 MHz – 10mW (worldwide)
- NAN (Neighbourhood Area Network): 868 MHz (Europe) – 200mW / 915 MHz – 200mW (Australia)

5.4.11.3 Key Applications

EverBlu is suitable for multi-energy applications involving water, gas electricity and heat metering. As it is a long-range mesh radio network, it is convenient for urban, suburban or rural environments. EverBlu endpoints can be read in dual mode either using EverBlu fixed network or walk-by collection system compatible with Radian protocol.

About 1 million radio modules for water, gas and heat meters based on Radian protocol have been installed worldwide. These meters have been installed all around the world (except NAM), with major installations in France, UK, Italy, Australia…

5.4.11.4 Cost Issues

EverBlu is a combination of a radio mesh network combined with a WAN communication infrastructure (e.g. GPRS). Using one gateway for up to 1200 endpoints limits the infrastructure investment and significantly reduces the operation costs related with communication fees over GPRS.

6 Wireless Technologies at a Glance

Wireless Technology	Frequency Bands	Licensed/ Unlicensed	Type	Range	Typical data rate	Max. Power (Typ.)	Main Applications
Short Range Unlicensed (5.1.1)	433MHz, 868MHz, 2.4GHz (Europe), 915MHz (RoW)	Unlicensed	Proprietary	≈100m	Tens of Kbps	Low (<0.2W Tx,< 0.1W Stby)	Metering, remote control
Wavenis (5.4.4)	433MHz, 868MHz (Europe), 915MHz (RoW)	Unlicensed	Restricted (Wavenis Alliance)	≈100m	5-20Kbps	Low (<0.2W Tx, <0.1W Stby)	Metering, sensor networks
EverBlu (5.4.11)	433MHz, 868MHz (Europe), 915MHz (RoW)	Unlicensed	Proprietary	≈100m	10Kbps	Low (<0.3W Tx, <0.1W Stby)	Metering
Wireless M-Bus (5.4.3)	868MHz (Europe)	Unlicensed	Public (EN13757-4:2005)	≈100m	16-66Kbps	Low (<0.2W Tx, <0.1W Stby)	Metering
6lowPAN (5.2.1)	See 802.15.4	Unlicensed	Public (IETF)	-	-	-	IP sensor networks
IPSO (5.4.2)	-	-	Restricted (IPSO Alliance)	-	-	-	IP sensor networks
802.15.4 (5.3.1)	868MHz, 2.4GHz (Europe), 915MHz (RoW)	Unlicensed	Public (IEEE)	≈100m	20-250Kbps	High (≈3W)	PANs, Sensor networks
Zigbee (5.4.1)	See 802.15.4	Unlicensed	Restricted	≈100m	See 802.15.4	Low (<0.2W Tx, 1mW Stby)	PANs, Mesh sensor networks
Bluetooth (5.4.6)	2.4GHz (global)	Unlicensed	Restricted (Bluetooth SIG)	≈100m	1Mbps	Low (<0.3W Tx, 50mW Stby)	PANs, phone connection
802.11 (5.3.2)	2.4GHz, 5GHz (global)	Unlicensed	Public (IEEE)	≈100m	11-54Mbps	High (≈3W)	Wireless LAN access
WiFi (5.4.5)	See 802.11	Unlicensed	Restricted (WiFi Alliance)	≈100m	See 802.11	High (≈3W)	Wireless LAN access
802.16 (5.3.3)	2.3GHz, 2.5GHz, 3.5GHz (country specific) 5.8GHz (global)	Licensed / Unlicensed	Public (IEEE)	≈20Km	15-75Mbps	High (≈3W)	Wireless LAN/WAN access

WiMAX (5.4.10)	See 802.16	Licensed / Unlicensed	Restricted (WiMAX Forum)	≈20Km	See 802.16	High (≈3W)	Wireless LAN/WAN access
GPRS (5.4.7)	800MHz, 1800MHz (Europe, global), 900MHz, 1900MHz (RoW)	Licensed	Restricted (3GPP)	Operator coverage area	10-200Kbps	Medium (<1W Tx, <0.1W Stby)	WAN access
UMTS (5.4.8)	2.1GHz (Europe), 850MHz, 1.9GHz, 2.6GHz (RoW, future)	Licensed	Restricted (3GPP)	Operator coverage area	384Kbps-7Mbps	Medium (<1.5W Tx, <0.1W Stby)	WAN access
TETRA (5.4.9)	390MHz, 420MHz, 460MHz, 880MHz, 915MHz (Europe)	Licensed	Restricted (TETRA MoU)	Operator coverage area	20-700Kbps	Medium (<1W Tx, <0.1W Stby)	WAN access

Table 6-1: Wireless Technologies Overview [21]

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