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Technologies and Architectures for Multimedia-Support in Wireless Sensor Networks

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1. Introduction

Wireless Sensor Networks (WSNs) are an emerging technology in the area of sensory and distributed computing. A WSN consists of many, theoretically up to some thousand or even millions of sensor nodes. A sensor node is generally defined as a cheap and small piece of hardware, which consists of four main units:

- One or more **sensors** that detect physical phenomena. Common sensors monitor scalar values of temperature, pressure, humidity, light intensity, etc.
- The sensor is coupled with a **data processing unit**. The latter controls sensing, application logic and network transfer. It receives data from the sensors as well as it can filter (e.g. thresholding), compress or correlate data from a series of measurement. The network structure, the communication process and the power management of the node are also organized by the processing unit.
- The data's wireless transmission is provided by a **communication interface**. Most nodes' transfer is usually based on the IEEE 802.15.4 standard because of the low power consumption of this transfer technology and the availability of low cost radios.
- For every operational electronic system an **energy source** is needed. Although significant progress has been achieved in the area of energy harvesting, today's standard power supply for sensor nodes is still the battery.

Generally sensor nodes are designed to be widely spread without pre-configuration. A sink, also called a base station, is normally an embedded or a personal computer which is configured to collect, save or react according to the data. The network between the nodes and the sink is built dynamically and is considered to be self-organizing.

1.1 Specifications of Wireless Multimedia Sensor Networks

In contrast to the scalar data collected by classical WSNs, some applications need to collect multimedia (mm) based data. Mm data can be defined as image, video or sound. These types of data are relatively large and are likely to be represented in an array or stream. Due to the greater amount of data, processing operations on these are more calculation-intensive than on scalar data. So a new class of WSNs has been developed to sense mm data. These Wireless Multimedia Sensor Networks (WMSNs) form a special group of WSNs and need new designs to master their challenges. The main challenges resulting from the amount of produced data are:

- The wireless link has to provide a reliable and fast connection to transmit the produced amount of data. As wireless transfer is quite power consuming and the nodes are mostly battery-driven, the power management of a WMSN has to be sophisticated in order to overcome the power shortage.
- Data can be either transferred as a stream (e.g. a live video) or as snapshot (e.g. a single picture). The requirements for streaming are a high sampling rate as well as a fast connection, which satisfies Quality of Service demands. Therefore packages can be dropped, because reordering and retransferring of old packages would disturb time synchronization even more. On the other hand all packages have to be delivered for a snapshot, and reordering or retransmitting may have to be established.
- Beside the network, the node itself has to do more calculations and therefore has a higher need for performance than in classical scalar WSNs. The tasks on the node include compression and event detection, which can be solved either on the node alone or in cooperation with distributed algorithms.

Not only for the design of the system, but also for the deployment of the nodes a significant difference has to be taken into account.

- Image sensors have a field of view. Although sound propagates wavelike, microphones have directionality, which means they are variably sensitive to sound at different angles. So that mm sensors should be deployed with caution and by plan.

The ideal mm node should have a lot of processing power to work with the data, a high speed network to transfer it, a strong power source to keep the system running and it should be carefully deployed. These demands stand in open contrast to the idea of classical WSNs. In return to all these high demands, nodes with mm capabilities make a wide range of novel applications possible. The remainder of this chapter will give an overview of available wireless transfer standards including their capabilities and limits, as well as node hardware for mm support and the commonly used design patterns for system architectures in WMSNs. Although protocols are an important part of WSNs and should fulfil special requirements to be used in WMSNs, they are not part of this chapter due to page limitation. Likewise, data gathering and mining algorithms as well as software in general are not covered in this chapter.

1.2 Related Work

The basic ideas and tasks of WSNs were presented in (Pottie & Kaiser, 2000) about ten years ago. A good general overview about applications of WSNs is given in (Akyildiz et al., 2002) and (Arampatzis et al., 2005). An overview of WMSNs is provided by Akyildiz et al. in (Akyildiz et al., 2007a), (Akyildiz et al., 2007b) and (Akyildiz et al., 2008). Römer and Mattern introduce classification criteria for the WSN design space and present applications ranked by their classifications (Roemer & Mattern, 2004). Melodia published detailed work on connecting mm sensor nodes to actors and has also proposed a heterogeneous architecture for his system (Melodia, 2007).

2. Wireless Transmitting Technologies

In this section a short overview of the most important wireless technologies is given. The wireless transfer is the main critical task in WSNs. It needs a lot of energy and the limited transfer range is a key factor for the network topologies. Thus the underlying technologies have to be understood in order to understand the design of WSNs.

2.1 IEEE 802.15.4

Region	*Frequency band (MHz)*	*Communication channels*	*Data rate per channel (kb/s)*
Worldwide	2,400.0 – 2,483.5	16 channels	250
North America	902.0 – 928.0	10 channels (2003), 30 channels (2006)	40 (2003), 250 (2006)
Europe	868.0 – 868.6	1 channel	20 (2003), 100 (2006)

Table 1. The Industrial, Scientific and Medical (ISM) bands used in IEEE 802.15.4.

The Institute of Electrical and Electronics Engineers (IEEE) 802.15.4 standard (*IEEE Std 802.15.4-2003*, 2003) is designed for very low-power Wireless Personal Area Networks (WPAN). The Physical Layer and accompanying MAC protocols of the Data Link Layer are defined by this standard. The medium access operates based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). One of the three unlicensed Industrial, Scientific and Medical (ISM) frequency bands is used for transfer. In the basic IEEE 802.15.4 (2003) standard there is a total number of 27 channels in the ISM bands. The properties of the free frequency bands are shown in Table 1. The typical usage range is 30 – 50 m and can reach up to 100 m. The data throughput is low, but a 30 ms network join time can be achieved. 802.15.4 can be used for different topologies, like star or peer-to-peer. For energy efficiency the duty cycle of communication is around 1 % and results in a very low power average. In order to safe power a beacon mode is supported. The number of supported devices in a network is high, with a support for up to 216 devices. The power saving concepts can result in a long life time of over a year on typical batteries and make this standard a good choice for scalar WSN applications. ZigBee may use 802.15.4 on the lower layers.

The suitability of 802.15.4 as a base for mm data transfer is limited. The frame length is limited to 127 Byte of payload. A realistic payload is around 80 Byte, when using extended addressing and full security information. The definition of a data frame according to the IEEE 802.15.4 standard is shown in Figure 1. Additional Bytes may be needed in higher network layers. The small packet size causes a lot of fragmentation for transferring big mm data. Through the chapter some solutions and ideas to overcome the transfer shortages of 802.15.4 as well as some more powerful transfer technologies will be presented.

2.2 ZigBee

ZigBee (*ZigBee Alliance Webpage*, 2010) is a suite of high level communication protocols for small, low-power digital radios. It sits on top of the layers of the IEEE 802.15.4 standard. Therefore ZigBee uses the free ISM bands and operates with a radio output power of 1 mW. A range from 10 to 100 m can be achieved. The ZigBee standard provides three types of devices:

- The ZigBee **Coordinator** (ZC) is the most powerful device, which maintains and coordinates the network with overall network knowledge.
- The ZigBee **Router** (ZR) works as a router in the network by passing on data.
- The ZigBee **End Device** (ZED) only has limited functionalities to safe cost and complexity. It just reports to his parent device node.

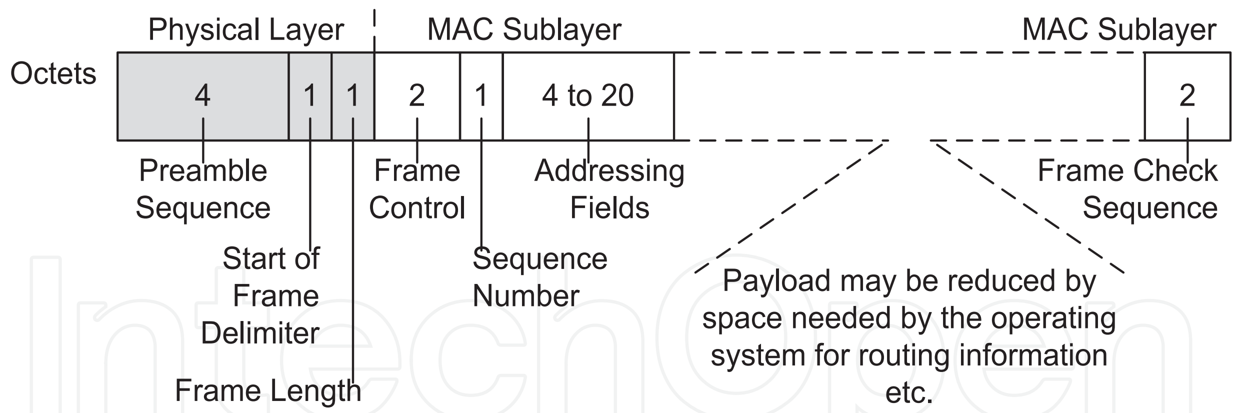


Fig. 1. An IEEE 802.15.4 standard data frame. The full frame can reach a maximum of 127 Byte.

Figure 2 gives an overview of the topology of a ZigBee network. ZigBee provides two network modes: a non-beacon CSMA mode and a beacon-enabled mode with Guaranteed Time Slots.

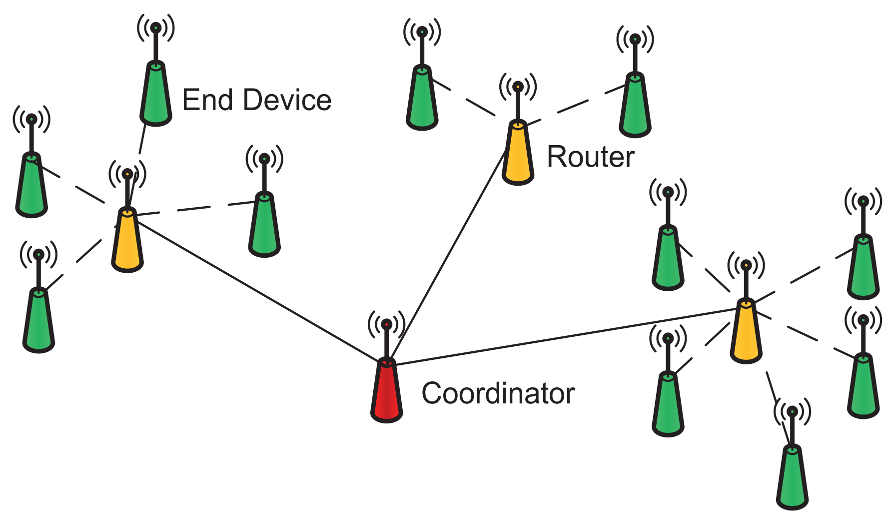


Fig. 2. ZigBee network topology. End devices with limited functionalities send their data to Routers that forward the data to the Coordinator, the device that finally maintains the network structure.

2.3 Bluetooth/IEEE 802.15.1

Bluetooth (*Bluetooth - How it Works*, 2010) is designed to be a low-cost, medium-power, robust, short-range communication protocol for wireless links to replace cables (RS-232) for mobile phones and computers. It was initially published by Ericsson and is now managed by the Bluetooth Special Interest Group (SIG). Bluetooth also uses the worldwide free 2.4 GHz ISM band. It covers in comparison to the 802.15.4 standard a whole product including radio-frequency transceiver, baseband and protocol stack. So it might be comparable to ZigBee running on 802.15.4. An attempt to give a comparative overview of 802.15.4 + ZigBee and

Bluetooth is made in section 2.6. The transfer range of Bluetooth differs with the used Bluetooth class, it is: 1, 10 or up to 100 m. Table 2 shows the details for the different Bluetooth classes.

Bluetooth Class	*Free-Space Range (m)*	*Maximum Output Power (mW)*
1	100	100
2	10	2.5
3	1	1

Table 2. Bluetooth classes.

Bluetooth allows data rates of 1 Mb/s in version 1.2 and up to 3 Mb/s in Version 2.0 with Enhanced Data Rate (EDR). In July 2010 Bluetooth Version 4.0 was formally adopted. This new version supports Bluetooth Low Energy (see section 2.4), formerly known as WiBree, and a High Speed specification. The Bluetooth radio is designed for busy environments with lots of users. The network topology consists of clusters. Up to eight devices join a Piconet. One device is the master of a Piconet, the others are slave devices. Piconets can connect together as Scatternets. The seven slaves of a Piconet are in active communication with the master. Up to another 248 (= 256 - 8) slaves can work passively, while listing for the synchronization with the master, but they can become active at any time. This network topology is shown in Figure 3.

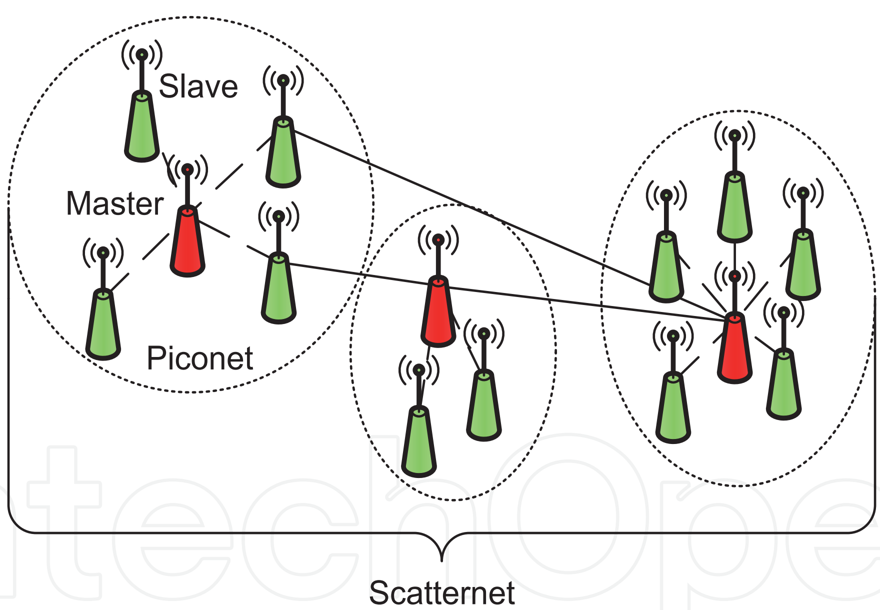


Fig. 3. Bluetooth network topology. A Piconet consists of one master and up to seven slaves. A Piconet master can be a slave in another Piconet. All connected Piconets form a Scatternet.

Bluetooth uses 79 different 1 MHz wide channels and can avoid interference with other ISM devices (either 802.11, 802.15.4 or other Bluetooth devices) by using Frequency Hopping Spread Spectrum (FHSS). The carrier switching is controlled by the Piconet master. Bluetooth also provides adaptive power control, Channel Quality Driven Data Rate (CQDDR) and Adaptive Frequency Hopping (AFH). Some nodes use Bluetooth. Bluetooth has the advantage that it can communicate directly with many laptops or smart phones and is a widely accepted standard in industry. Another advantage is the higher data rate, which allows live audio streaming. A clear disadvantage is the higher energy consumption in comparison to 802.15.4. In the next section Bluetooth Low Energy/WiBree, as a specialized part of the new Bluetooth version, is discussed.

2.4 Bluetooth Low Energy/WiBree

Bluetooth Low Energy (*Sig Introduces Bluetooth Low Energy Wireless Technology, The Next Generation Of Bluetooth Wireless Technology*, 2010), formerly known as WiBree (Hunn, 2006), is designed to work with Bluetooth. It covers scenarios for end devices with very low capabilities or energy resources, so it is suitable for sensor nodes. In contrast to classic Bluetooth it has a lower application throughput and is not capable of streaming voice. The data rate is 1 Mb/s and the packet length ranges from 8 to 27 Byte. Instead of the Scatternet topology it uses a one-to-one or star topology. Over 4 billion devices can be connected by using a 32 bit address space. This new standard widens the spectrum of applications of Bluetooth and creates an overlapping use case with ZigBee.

2.5 Wi-Fi/IEEE 802.11

Some WMSNs avoid data rate problems by using IEEE 802.11 (*IEEE Std 802.11-2007*, 2007). This standard is commonly known as Wi-Fi or Wireless LAN. This technology has a theoretical data rate up to 11 Mb/s (802.11b) or 54 Mb/s (802.11a, g), but is much more power consuming than the already discussed standards. Even more than Bluetooth, this standard has the advantage that it is widely spread in today's usage and therefore nodes can be included into existing networks. Beside these advantages, IEEE 802.11 is quite improper for small wireless nodes because of its high energy consumption, the complex network stack and expensive hardware units. The usage requires an embedded computer and seems therefore improper for the classical idea of small, low-cost and battery-driven nodes.

2.6 Comparison of ZigBee, Bluetooth and Wi-Fi

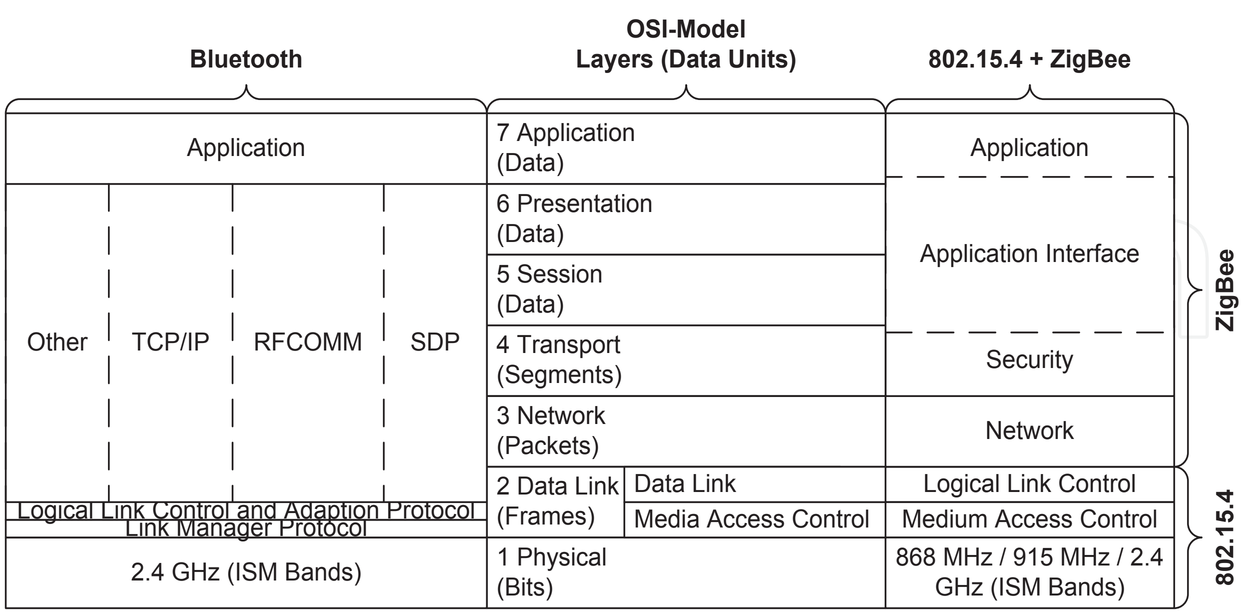


Fig. 4. Comparison of ZigBee and Bluetooth layers based on the OSI-Reference-Model-Layers.

IEEE 802.15.4 + ZigBee, Bluetooth and Wi-Fi are the most frequently used communication technologies for WSNs. Because of their acceptance and the widely available hardware a short summary and use cases for them are given in the following section. For more comparisons see also (Sidhu et al., 2007). ZigBee is meant to target scalar sensors and the remote control market with very low power consumption and very little communication. ZigBee does not allow streaming of any mm data. Bluetooth allows interoperability and the replacement of cables and targets on wireless USB, hand- and headsets, so that audio-streaming is supported. Figure 4 shows a comparison of ZigBee and Bluetooth based on the well-known OSI-Reference-Model-Layers. Wi-Fi is designed for computer networks and allows high data rates, but it needs a lot of energy and is quite expensive in hardware costs. Wi-Fi allows even video-streaming in high quality. However, even scalar nodes, such as the Tag4M (Ghercioiu, 2010), (Folea & Ghercioiu, 2010), (Ursutiu et al., 2010), use Wi-Fi because of its wide availability and good integration into the Internet. Table 3 shows all technical details in a comparison of the presented technologies.

2.7 Summary

Technology	*Theoretical Data Rate (Mb/s)*	*Output Power (mW)*	*Free-Space Range (m)*	*Frequency Band (GHz)*
IEEE 802.15.4	0.25	1	100	0.868, 0.915, 2.4
Bluetooth	1 – 2	100	100	2.4
IEEE 802.11a	54	40 – 800	120	5
IEEE 802.11b	11	200	140	2.4
IEEE 802.11g	54	65	140	2.4

Table 3. Survey of common transfer technologies. Properties are the theoretical values defined by the standard.

The low bandwidth of the nodes is a problem for streaming media in the network. Live uncompressed video streaming with meaningful resolutions is often impossible. All given transfer rates are the theoretical maximum of the different standards. The real transfer rates will be much slower because of necessary calculations for sending, wrapping to layers and interference on the communication channel.

A single-hop communication between a SunSPOT sensor node and the SunSPOT base station can be mentioned as a real world example. These nodes use a proprietary protocol based on 802.15.4, they have a 180 MHz CPU and can be programmed in Java. Figure 6(a) shows an image of the node and Table 4 provides the basic properties of the SunSPOT. For more information about these nodes see (Sun, 2007) and (*Sun SPOT World*, 2010). The SunSPOTs have, by using the Java objects for easy communication programming, a throughput on the application layer (goodput) of approximately 3 kB/s for big amounts of automatic fragmented data, as an array that is typically used for mm data. The underlying layers provide encryption and security mechanisms, so that the available throughput is small. This example shows that the overhead of underlying layers is big compared to theoretical data rates. Wireless communication can be also jammed and interfered, which decrease the achieved data rate in the real world. More problems will come up in a multi-hop network. To sum up the different transfer technologies, Table 3 gives an overview about the different standards.

Name	*Sun Small Programable Object Technology (SunSPOT)*
Manufacturer	Sun/Oracle
Main Processor	180 MHz 32-bit Atmel ARM920T
Random Access Memory (RAM)	512 kB
Flash Memory (to store programs)	4 MB
Radio Chip	Chipcon/Texas Instruments CC2420
Operating System	Squawk Java Virtual Machine (JVM) on the bare metal
Programming Language	Java ME Squawk implementation

Table 4. Technical preferences of a Java SunSPOT sensor node. Data taken from (Sun, 2007).

3. Multimedia in Wireless Sensor Networks

The following section presents applications offered by WMSNs. Then sensor nodes and basic platforms are described. Systems and architectures are discussed afterwards.

3.1 Applications

Mm **surveillance sensor networks** can be used for monitoring public places and events, private properties, borders or battlefields. One of the first wireless sensor networks was designed in 1967 by the US army to monitor troop movements in the Vietnam War. The so called Igloo White system consists of air-dropped sensors made of analog technology. Acoustic and seismic data was sent by a radio and received by special aircrafts. Around 20,000 sensors were deployed (Correll, 2004). Military target classification is still a wide research topic today. In (Malhotra et al., 2008) target tracking and classification is done by acoustics. The sounds of moving ground vehicles are recorded by mm nodes. The network is able to classify the vehicles with the help of a distributed k-nearest neighbor classification method. Another application is the combination of a WSN with cameras for surveillance of roads or paths (He et al., 2004).

For civil use a parking space finder was developed, which is intended to provide the service of locating available parking spaces near a desired destination. A set of cameras detects the presence of cars in spaces and updates a distributed database, so that a navigation system for finding available spaces can be realized (Campbell et al., 2005). The paper of (Ardizzone et al., 2005) describes the work to design and deploy a system for the surveillance and monitoring of an archaeological site, the “Valley of the Temples” in Agrigento, Italy. The archaeological site must be monitored to be protected. Wireless sensors have advantages because of the size of the area and they are less intrusive than wires which would have to run all across the site. Ardizzone et al. developed an architecture for the surveillance of the site and for monitoring the visitors’ behavior.

WMSNs can be used for **habitat monitoring** and **environmental research**. Hu et al. developed a wireless acoustic sensor network for the automatic recognition of animal vocalizations to census the populations of native frogs and an invasive introduced species (Cane Toads) in the monsoonal woodlands of northern Australia (Hu et al., 2005). WMSNs are also able to classify birds by their voices (Wang, Elson, Girod, Estrin & Yao, 2003), (Wang, Estrin & Girod, 2003). Mainwaring et al. deployed a sensor network at James San Jacinto Mountains Reserve (*James San Jacinto Mountains Reserve website*, 2010) for long-term environmental observation. A coastal imagining application was developed by Campbell et al. in collaboration

with oceanographers of the Argus project (*The Coastal Imaging Lab Web*, 2010) on base of Iris-Net (Campbell et al., 2005).
Wireless sensors with mm capabilities can be used in **industrial environments**. 42 nodes were deployed in a coal mine to improve security and rescue operations in case of an emergency. The used WMSN provides real-time voice streaming (Mangharam et al., 2006).
An emerging area for all kinds of sensors is **elderly care** and **elderly support** by **home automation**. The Aware Home is a combination of many heterogeneous WSNs (Kidd et al., 1999). For example there is a vision-based sensor to track multiple individuals in an environment based on the system presented in (Stillman et al., 1998). The usage of the combination of audio and image, which are also the main information sources for human perception, are presented in (Silva, 2008). Silva presents the possibilities of smart sensing using a multitude of sensors such as audio and visual sensors in order to detect human movements. This can be applied in home care and home security in a smart environment. The combination of audio and video sensors increases the variety of different detectable events. A prototype implementation to detect events like falling, walking, standing, shouting etc. was presented. In (Meyer & Rakotonirainy, 2003) requirements for sensor networks to enhance the quality of life for people at home are shown. Meyer and Rakotonirainy give an overview of using sensors for different tasks in everyday's home life. Mm sensors can help to solve a lot of tasks like tracking persons, interaction via gestures and speech recognition for house automation and so on.
The key to acceptance of sensor networks at private homes is to provide an improved and safe environment for the individual. The paper of (Mynatt et al., 2000) shows the support of elderly people by a monitored home. Image cameras are used to identify some scenarios, like the immobility of a person either due to a fall or a collapse and they monitor dangerous situations in a household. WMSNs can deliver novel technology for new medical equipment. The publication of (Itoh et al., 2006) presents a one-chip camera for capsule endoscopes. A pill-sized prototype supports a resolution of 320×240 pixels with the help of a 0.25 µm Complementary Metal–Oxide–Semiconductor (CMOS) image sensor. Pill-sized wireless sensors like this could revolutionize medical treatments in many areas and improve diagnosis for illnesses.
Another big field of application will be **education** and **entertainment**. Srivastava et al. have developed a WMSN to be used in early childhood education. The system of software, wireless sensor-enhanced toys and classroom objects is called "Smart Kindergarten" (Srivastava et al., 2001).

3.2 Sensor Nodes with Multimedia Capabilities

WMSNs have high demands on the hardware of the nodes. In the following section nodes and sensor boards, which address these demands, are presented. The range of processors currently used in nodes starts at simple 8 bit processors and ends at embedded computer systems. In small low-power nodes as the MEMSIC's Iris Mote (MEM, 2010c) an ATMEL ATmega1281 (Atm, 2007) microprocessor is used. The MEMSIC's TelosB Mote (MEM, 2010d) uses a Texas Instruments' MSP430 (Tex, 2010) processors. On the high performance side, nodes as the MEMSIC's Imote2 (MEM, 2010a) are built on an Intel/Marvell XSCALE PXA271 processor (Int, 2005). This processor is also used in handhelds and portable media centres and supports "Single Instruction, Multiple Data" (SIMD) extensions such as "Multi Media Extension" (MMX) and "Streaming SIMD Extension" (SSE). These extensions allow the usage of a mathematical operation on more than one value at a time. This kind of vector operations is a major advantage in working with mm data. Filter and other operations on mm data can be boosted

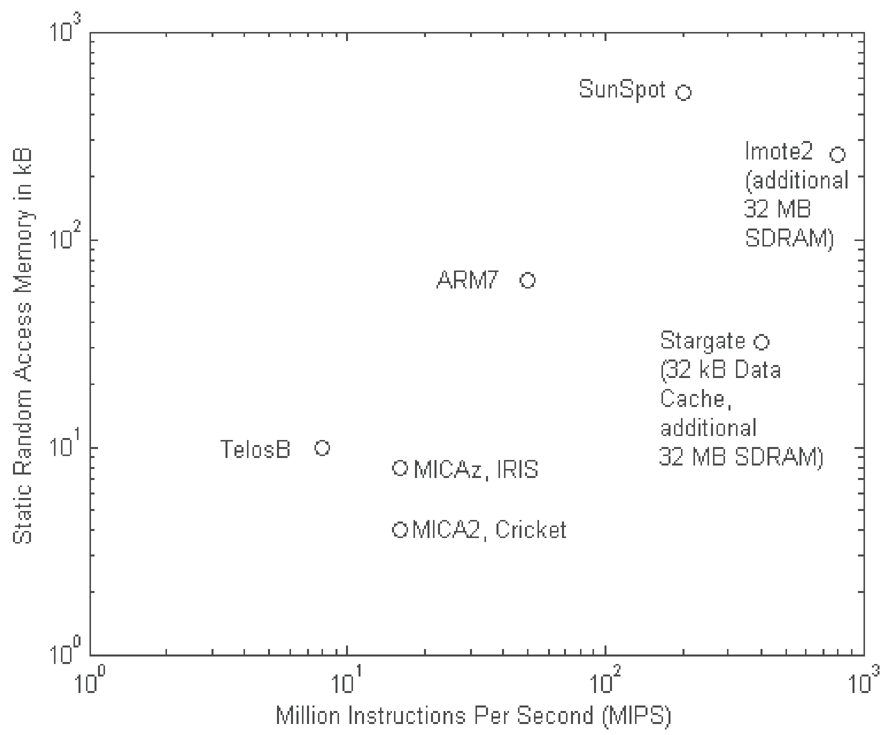


Fig. 5. Plot of processor performance and memory of different nodes. The performance can differ on the clocking of the processors. MIPS values are given by producers/distributors. RAM amount can differ if memory is not onboard, access speed may also differ.

with using these extensions. Even embedded computers, e.g. the discontinued Crossbow's Stargate Platform (Cro, 2007), can be used as sensor nodes.
An overview of the performance of the nodes is given in Figure 5.

3.2.1 Cyclops

The Cyclops imaging platform was a collaboration project between Agilent Technology Inc. and the University of California. Cyclops is a board for low-resolution imaging that can be connected to a host node such as Crossbow's MICA2 or MICAz. It also provides software libraries for image processing on the node. Although it found interest in the research community this project was not a success. As of January 2008 Cyclops is no longer supported by Agilent (Rahimi & Baer, 2005), (Rahimi et al., 2005). The Cyclops board with an attached MICA2 node is shown in Figure 6(b).

3.2.2 ARM7 Based Wireless Image Sensor

Downes et al. present the design of a node for distributed image sensing. The node is based on a 48 MHz 32-bit ARM7 microcontroller with 64 kB of memory on the chip. The communication is based on the IEEE 802.15.4 standard. The image acquisition provides interfaces for two Common Intermediate Format (CIF) resolution (352 $\times$ 288 pixels) sensors and four low resolution (30 $\times$ 30 pixels) sensors. So up to six different image sensors can be connected to one node (Downes et al., 2006).

3.2.3 Wireless Smart Camera

A so called Wireless Smart Camera (WiCa) is presented in (Kleihorst et al., 2007). It is a sensor node based on an 8051 microcontroller and ZigBee, and thereby IEEE 802.15.4 compatible, transfer module. It has two cameras and provides the direct storage of two images of a resolution of 256 × 256 pixels. The term "Smart Camera" is used in the field of computer vision for cameras with integrated image processing capabilities. In (Belbachir, 2010) "a smart camera is defined as a vision system which, in addition to image capture circuitry, is capable of extracting application-specific information from the captured images, along with generating event descriptions or making decisions that are used in an intelligent and automated system."

3.2.4 Stargate Board with Webcam

Stargate is a processing platform for WSNs which can be used itself as a sensor node. It was developed by Intel Research and was sold by Crossbow (Cro, 2007). This platform is often chosen for video sensor networks. The Stargate board is connected to a webcam. This node provides medium-resolution imaging. Since low-power radios are limited, live streaming of video is only possible with Wi-Fi, the Stargate board has no wireless interface at all, but it can be connected to a sensor node or a Wi-Fi card. Normally embedded Linux is used as operating system. The processor is a 400 MHz Intel PXA255 model. Feng et al. present a comparison of the Panoptes video sensors: one based on Strong ARM PDA and the other based on the Crossbow Stargate platform (Feng et al., 2005). The Stargate board with an attached webcam is shown in Figure 6(c).

(a) Java SunSPOT sensor node (*Sun SPOT World*, 2010).

(b) Cyclops with an attached MICA2 node (Rahimi et al., 2005).

(c) The Crossbow Stargate platform with an attached webcam (Feng et al., 2005).

Fig. 6. Images of sensor nodes.

3.2.5 MeshEye

MeshEye is a vision system with two layers. It consists of a low resolution stereo vision system to determine position, range and size of moving objects and a high resolution color camera for further image processing. The system is ARM7-based and is used for real-time object detection. An IEEE 802.15.4 compatible transfer module is provided for interconnection. A power model is also presented to estimate battery lifetime for the node (Hengstler et al., 2007).

3.2.6 CMUcam

CMUcam3 is an open source programmable embedded color vision platform. The CMUcam3 is developed at the Robotics Institute at Carnegie Mellon University and is the latest of a series of embedded cameras. It is based on an ARM7 processor and includes an Omnivision CMOS camera sensor module. CMUcam3 supports CIF resolution with a RGB color sensor and can do some basic image processing on its own processor. Open source libraries and example programs are provided to develop C programs for the camera. There is the possibility to connect it to wireless sensor nodes like the Tmote Sky and FireFly (Car, 2007).

3.2.7 Imote 2 with Multimedia Sensor Board (IMB400)

The Imote multimedia board is a new sensor board for the Imote 2 sensor node. It includes Passive InfraRed sensor (PIR), color image and video camera for image processing, microphone, line input, miniature speaker as well as line output for audio processing. The Imote 2 is considered to be a high-performance sensor with many different power modes and can be clocked up to 416 MHz. The Imote 2 processor even supports MMX and SSE integer instructions, so it is suitable for mm operations. While there is a special version of the Imote 2 for development with the .net microframework, the mm board is not yet supported by the .net microframework, but it is expected to be supported in future. The board is quite recent, so there are no publications or projects available yet (MEM, 2010a), (MEM, 2010b).

3.3 Sensor Networks with Multimedia Support

After introducing some nodes the following section gives an overview about WMSNs. The focus is on the architecture and the design of the whole system.

3.3.1 Meerkats

Meerkats is a wireless network of camera nodes for monitoring and surveillance of wide areas. On the hardware side it is based on the Crossbow Stargate platform. The whole architecture includes a number of techniques for acquiring and processing data from image sensors on the application level. These include acquisition policies, visual analysis for event detection, parameter estimation and hierarchical representation. The architecture also covers resource management strategies that level power consumption versus application requirements (Boice et al., 2004), (Margi et al., 2006).

3.3.2 SensEye: A Multi-tier Camera Sensor Network

SensEye is a multi-tier network of heterogeneous wireless nodes and cameras. It consists of three different camera sensors. There are Cyclops nodes for the lowest layer, ordinary webcams for the middle layer, and pan-tilt-zoom (PTZ) cameras for the highest layer. Details of the different layers are shown in Table 5. The system fulfils three tasks: object detection, recognition and tracking (Kulkarni et al., 2005).

Camera	*Power (mW)*	*Cost ($)*	*Resoultion*	*Features*
Cyclops	33	unpriced	128×128	10 fps, fixed-angle
Webcam	600	75	640×480	30 fps, auto-focus
PTZ camera	1,000	1,000	1024×768	30 fps, retargetable pan-tilt-zoom

Table 5. Different camera sensors of the SensEye-architecture and their characteristics. (Kulkarni et al., 2005)

3.3.3 IrisNet

IrisNet is an Internet-scale architecture for mm sensors. It provides a software framework to connect webcams worldwide via the Internet. The pictures are taken by a Logitech QuickCam Pro 3000 with 640×480 pixels. IrisNet stores the sensor readings in a distributed XML database infrastructure. IrisNet provides a number of mm processing primitives that guarantee the effective processing of data in-network and at-sensor (Campbell et al., 2005).

3.3.4 Explorebots

Dahlberg et al. present the Explorebot, a wireless robot built around the MICA2 node. The low-cost Explorebots can be used as a mobile network experimentation testbed. The robot is equipped with sonic sensors, bumper switches and a magnetic 2-axis compass. Additionally it uses a X10 Cam2 with a resolution of 320×240 pixels, which communicates over its own proprietary wireless transmitter with 15 fps (Dahlberg et al., 2005).

3.3.5 Mobile Emulab

Johnson et al. have developed a robotic wireless and sensor network testbed. While simulation is the dominant research methodology in wireless and sensor networking, there are few real world testbeds. Even fewer testbeds exist for WSNs with mobile nodes. In order to overcome this weakness and to allow more and cheaper experiments in real world environments the Emulab testbed was created. This testbed provides software, which allows remote access. Robots carry sensor nodes and single board computers through a fixed indoor field of sensor-equipped nodes, of which all of them are running the user's selected software. In real-time, interactively or driven by a script, remote users can place the robots, control all the computers and network interfaces, run arbitrary programs, and log data. Webcams are used to supervise the experiments by remote control. The Hitachi KP-D20A cams have a resolution of 768×494 pixels and provide a vision-based tracking system accurate to 1 cm (Johnson et al., 2006).

3.3.6 iMouse

The iMouse system consists of static sensor nodes that sense scalar data and mobile sensor nodes for taking images of the detected events. The system is shown in Figure 7. The mobile nodes are based on a Crossbow Stargate processing board connected to a node for IEEE 802.15.4 communication, an 802.11 WLAN card, a webcam and a Lego-based car to provide mobility. This connection of a mobile sensor with a classical static WSN can provide advanced services at lower cost than traditional surveillance systems (Tseng et al., 2007).

3.3.7 PlantCare

Robots can deliver new services in a WSN. LaMarca et al. used a robot in a WSN to take care of houseplants in an office. The used nodes are UC Berkeley motes, commercially available under the MICA brand, running TinyOS. The robot is based on the Pioneer 2-DX platform and uses a laser scanner for orientation. The robot has a human calibrated sensor board equal to the static nodes, so the robot improves calibration of the distributed nodes (LaMarca et al., 2002). Robot and sensors are shown in Figure 8.

3.4 Summary

In this section WMSN applications, their hardware as well as their system architecture have been reviewed. Table 6 summarizes the presented applications. Even if the "killer application" of WMSNs is still missing, they have already started influencing classical WSNs and the

Name	*Basic Devices*	*Network-Size (real deployment)*	*Communication*	*Sensors*	*Mobility*
Meerkats	Stargate	not mentioned	802.11b	Logitech Quick Cam Pro 4000	no
SensEye	MICA2	not mentioned	802.15.4	CMUcam	no
	Stargate	not mentioned	802.15.4, 802.11	Webcam	no
	Embedded Computer	not mentioned	Ip-based	Sony SNC-RZ30N Pan-Tilt-Zoom camera	no
IrisNet	PC	$\approx$ 500	Internet	Logitech Quick Cam Pro	no
Explorebots	MICA2	$<$ 10	802.15.4	Sonic sensors, bumper switches, magnetic 2–axis compass, X10 Cam2	yes
Mobile Emulab	Stargate board connected to MICA2	6	802.11b, 802.15.4	Infrared proximity sensors	yes
	MICA2	25	802.15.4	not mentioned	no
	Webcam	6	not wireless	Hitachi KP-D20A	no
iMouse	MICAz	17	802.15.4	light intensity sensor	no
	Stargate	2	802.15.4, 802.11	light detector, infrared receiver	yes
PlantCare	MICA	not mentioned	802.15.4	photo resistor (light level), thermistor (temperature), irrometer (soil moisture), power charge	no
	Pioneer 2-DX	not mentioned	802.11 b	Human-calibrated sensor node (see row above), laser scanner	yes

Table 6. Overview of selected WMSN architectures. For heterogeneous architectures every stage is presented. The properties are based on publications mentioned in this section.

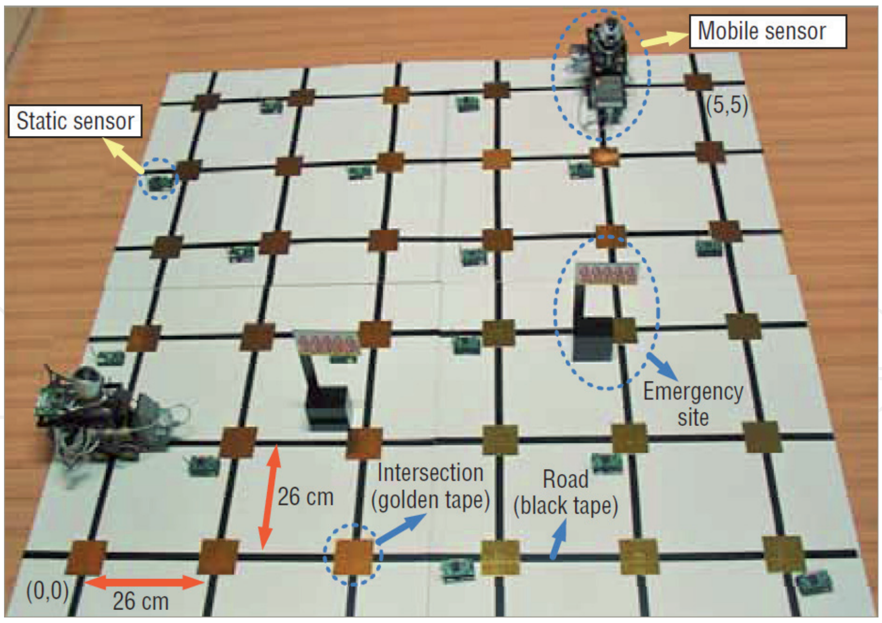
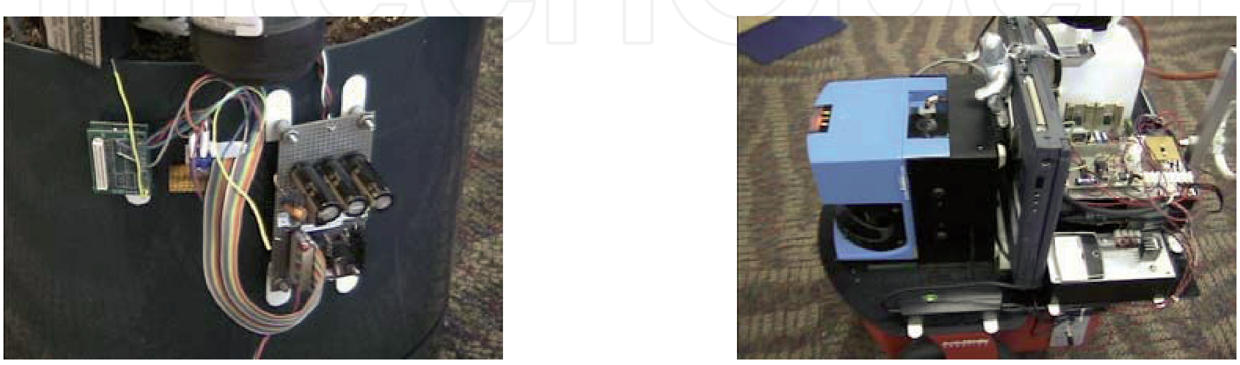


Fig. 7. The iMouse testbed. Static sensors and Lego-based robots on an 6 × 6 grid-like sensing field (Tseng et al., 2007).

Internet. Their impact has gone beyond their original use cases for military applications. A very important fact for WSNs in general, but even more urgent for WMSNs, is data security and privacy. The picture of a human face or the recording of a voice are very personal and can be dedicated to a person via software. Most of the discussed publications and this chapter have not accomplished further research on security and privacy issues. Nevertheless, first prototype nodes and systems have been designed and deployed for research purposes. In the next section, conclusions are drawn from the existing deployments, which will be classified into patterns of system architectures.

4. Architectures of Wireless Multimedia Sensor Networks

The basic architecture for a WSN, which senses scalar values, is a flat homogeneous network of equal sensor nodes reporting to a single base station. This concept is very limited and even scalar WSNs have been designed in different ways. For demanding WMSNs there has



(a) PlantCare sensor (LaMarca et al., 2002). (b) PlantCare robot (LaMarca et al., 2002).

Fig. 8. Images of the PlantCare sensor network.

not been found a reference architecture yet, but most systems can be grouped into one of the following four architectures.

4.1 Homogeneous Networks of Multimedia Sensor Nodes

This type of network uses the classical WSN technology presented in section 3.2. However the IEEE 802.15.4 standard is designed for very low-power, delay tolerant and slow networks with a very small duty cycle and the theoretical data rate is just 250 kb/s. This is not usable for fluent image transfers. An uncompressed 640×480 pixel black-white image would for instance be transferred in over one second under the best theoretically possible conditions. Multi-hopping, interference and network traffic make this impossible for a real application, as it is shown in the SunSPOT example in section 2.7.

A solution would be to transfer less data. In order to achieve this, the requirements on the data collection have to be checked. In many applications the data analysis result is important and not the data itself. So reducing the amount of data can sometimes already be achieved while monitoring.

Zheng et al. present the approach of using line scan cameras instead of two-dimensional cameras (Zheng & Sinha, 2007). In comparison to other image processing methods, this concept is less computationally intensive. They sum up the capabilities of the sensors in data processing, compression, and streaming in WSNs. They focus on several unsolved issues such as sensor setting, shape analysis, robust object extraction, and real-time background adapting to ensure long-term sensing and visual data collection via networks. All the developed algorithms are executed in constant complexity, which reduces the sensor and network burden. The latter algorithms can for example be applied in traffic monitoring. Another usage of line cameras in WSNs is shown in (Chitnis et al., 2009).

Computation is less power consuming than sending data via the radio. The restrictions of a weak processing unit and a short battery capacity produce a need to further investigate algorithms. These are either algorithms with small complexity running on a single node or distributed algorithms running in the network.

Culurciello et al. present a low complex compression algorithm for videos based on pixel-change-events, which can run on today's nodes' hardware (Culurciello et al., 2007). Besides its low computational costs this algorithm compresses a 320×240 pixel video to the point where it can be transferred by nodes with over 10 fps. The idea of Address Event Image Sensors presented in (Teixeira et al., 2006) is biologically inspired and keeps the privacy of monitored people. Therefore it is suitable for monitoring of elderly people at home or other privacy-sensitive applications.

An example for a distributed algorithm is given in (Oeztarak et al., 2007). They present a framework for mm processing in WSNs and consider the needs of surveillance video applications. This framework automatically extracts moving objects, treats them as intruder events and exploits their positions for efficient communication. Then a joint processing of collected data at the base station is applied to identify events using fuzzy (multi-valued logic) memberships and to request the transfer of real image data from the sensors to the base station.

4.2 Heterogeneous Networks of Scalar Sensor Nodes Connected to Multimedia Sensor Nodes

As shown in the previous sections and based on the bandwidth problems that occur, not many existing WMSNs rely on sensor nodes with mm capabilities. A common design is the combination of a scalar WSN with a second network, which is triggered, to measure mm data. This architecture tries to overcome the restrictions of classical WSNs by the usage of computer networks. The mm network is mostly an Internet protocol-based computer network using the IEEE 802.11 standard. This architecture is quite easy to realize and is widely used as shown by the amount of applications using this architecture in section 3.3. The disadvantages of using a personal computer or even an embedded computer instead of a microcontroller are big size, high power consumption and high costs.

4.3 Wireless Sensor Networks with Mobile Nodes

Another concept to collect more information in a WSN is the usage of mobile nodes, as presented in section 3.3.4, 3.3.5, 3.3.6 and 3.3.7. While static nodes are mostly low-power, unreliable and cheap, the mobile node or robot can be equipped with high-class sensors, which make more detailed measurements and take pictures or videos. Beyond this, a robot can accomplish a whole new class of missions, like node replacement, deployment, recharging and redeployment or hole recovery (Sheu et al., 2005), (LaMarca et al., 2002). The architecture can still vary between one network or two connected networks and the control of the robot can be done via a server or it can be decentralized. With the usage of mobility new problems arise as the localization of the robot, the creation of a map and the navigation through the WSN, which are just some new challenges. As far as the authors know, none of the mobile nodes has been used in real-life environments yet.

4.4 Wireless Sensor Networks without Base Station/Instrumentation Cloud

Recently, sensor nodes have been connected directly to the Internet. When the nodes are computers as in (Campbell et al., 2005), a direct Internet connection is easy. In the trend of Cloud Computing some WSNs deny the need of a base station. Ghercioiu (Ghercioiu, 2010) presents the word “Instrumentation Cloud”. In this architecture sensors send their results directly to the Internet. The results will be available to every device with a standard browser and Internet connection. Everything, apart from the physical Input/Output, will take place on the web (Ursutiu et al., 2010), (*Tag4M Cloud Instrumentation*, 2010). If security is a major concern, a closed system should be used alternatively. Hereby, the advantage is that the data is not leaving the private network. Thus, automation and security monitoring are no suitable applications for the Instrumentation Cloud.

4.5 Summary

Figure 9 gives an illustrative summary of the discussed architectures for WMSNs without mobility. The design concepts of WMSNs are still developing. Even if there is no widely used reference pattern yet, the authors believe that publishing the data on the Internet is a key point to success. And as a learned lesson from the Internet as the network of networks, homogeneous network architectures seem to be not flexible enough to stand the challenges of the future. Internet Protocol Version 6 (IPv6) has the potential to be used in WSNs. IPv6 over Low-power Wireless Personal Area Networks (6LoWPAN) as part of the new protocol standard will clear the way for an enormous amount of nodes to be directly addressable worldwide (*IPv6.com - The Source for IPv6 Information, Training, Consulting & Hardware*, 2010), (Hui & Culler, 2008). So it will be probably possible to search the Internet for live sensor data in the near future. The technological bases are already developed and since search providers (e.g. Google) search real-time web-applications (e.g. Twitter), this vision is not far away. Internet-based WSN real-time data storage is already available today (*pachube - connection environments, patching the planet*, 2010).

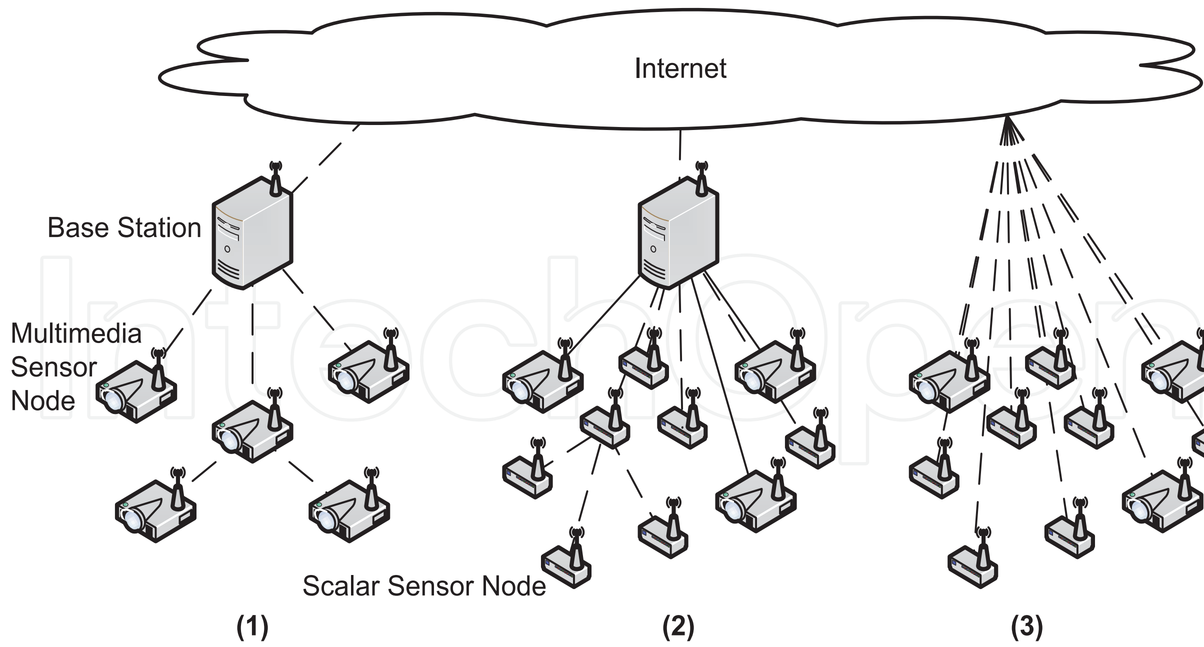


Fig. 9. Three of the most common architectures for Wireless Multimedia Sensor Networks without mobility. The illustrations assume that the sensor data will be uploaded on the Internet. (1) Homogeneous network of multimedia sensor nodes (2) Heterogeneous network of scalar sensor nodes connected to multimedia sensor nodes (3) Instrumentation Cloud

5. Conclusion and Outlook

This chapter reviewed available transfer technologies and hardware for WMSNs. Applications were presented and their architectures have been discussed. The advantages and disadvantages for each of the architectures have been shown. At the moment there are many fast evolving standards and new technologies for WSNs. Mm support is still a minority requirement but has grown in the last few years. Mobile nodes will become a source of information: not only in the form of robots but also as devices that can be carried around by humans. Even today's mobile phones are full of sensors and will be part of tomorrow's WSNs. Other sources of data will be the sensors built in cars or digital Internet-connected meters sensing the electricity, gas and water consumption of a household. These new meter devices are called "Smart Meters" and the vision of a network of many households is named "Smart Grid". All in all, an increasing number of devices will be active on the Internet without direct assistance of humans. New quantities of information will be available and will allow the development of new knowledge. This widening of the possibilities of the Internet will lead to the new version of the Internet, referred as the "Internet of Things".

The connection of actuators in WSNs will also become more important in the next few years. With more reliable WSNs and event recognition algorithms WSNs will become integrated into automation applications. Wireless technologies, as WirelessHART (*HART Communication Protocol - Wireless HART Technology*, 2010) or ISA100.11a (*ISA-100 Wireless Compliance Institute*, 2010), will be used more and more in industry in the next years. Image processing is an important part of today's process for quality controlling, so the authors expect wireless image processing nodes to be part of new WMSNs for automation (Melodia, 2007).

All these new emerging developments create new research challenges. As the authors believe, research is not only needed in the direct realization in terms of hardware or basic transfer technologies, but also in security and privacy. Maintenance, like wireless update delivery, coexistence of networks as well as the redelivery, recycling and disposing of sensor nodes, will become an important topic of future research. Middleware for the connection of all the novel networks will be also needed. Finally new operating systems, programming models and patterns will be created for efficient usage of the WSNs.

6. Acknowledgement

The authors wish to thank the following for their financial support: the Embark Initiative and Intel, who fund this research through the Irish Research Council for Science, Engineering and Technology (IRCSET) postgraduate Research Scholarship Scheme.

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MEM (2010c). *Iris Wireless Measurement System*. formerly Crossbow.

MEM (2010d). *TelosB Mote Platform Datassheet*. formerly Crossbow.

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