Chapter 2
Wireless Multimedia Sensor Network Technology

Abstract This chapter presents background material for wireless multimedia sensor network (WMSN) technology. The chapter will describe the general structure for a WMSN and various architectures and platform classifications for WMSNs. The chapter will also discuss the various components in a WMSN node such as the sensing, processing, communication, power and localisation units. The efficient processing of information in a WMSN is of primary importance, and the chapter will discuss various multi-camera network models and information reduction techniques such as event detection and event compression. The chapter concludes with a discussion of applications of WMSNs.

2.1 Introduction

The emergence of wireless multimedia sensor networks (WMSNs) is an evolutionary step for wireless sensor networks as audio and visual sensors are integrated into wireless sensor nodes. It has been a focus of research in a wide variety of areas including digital signal processing, communication, networking and control systems. WMSNs are able to store, correlate and fuse multimedia data originating from several camera input sources. The main applications for WMSNs are those that benefit from distributed and multi-camera vision systems. Deploying multiple, low-cost visual sensors both improves the coverage of the application and provides for a more robust operation. Also, multiple cameras provide redundancy to improve its reliability and usability. A single point failure will not cause a system failure, nor an obstruction or occlusion. Furthermore, multiple visual sources provide the flexibility to adaptively extract data depending on the requirements of the application. A multi-resolution description of the scene and multiple levels of abstraction can also be provided. A typical application for a WMSN would be as a surveillance and monitoring system. The WMSN provides several advantages over traditional monitoring and surveillance systems which include [36]:

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- *Enlarging the view.* Viewpoints from multiple cameras can provide a close-up view of an event either through the images captured by a camera nearer the scene or by engaging a node with a more advanced camera such as a pan-tilt-zoom (PTZ) camera. In such a system, an event detected by a node with a lower resolution camera can signal another node with a PTZ camera to detect and track the event.
- *Enhancing the view.* The use of multiple cameras can also enhance the view of an event by providing a larger field of view (FOV) or by using cameras with different capabilities such as mixing cameras for the visible and infrared spectrum in the network. Such systems are very useful when the view is obscured or when there is little or no illumination in the scene.
- *Providing multiple viewpoints for the same event.* When a single camera is considered for a surveillance application, the coverage of the application is only limited by the FOV of a fixed camera or the field of regard (FOR) of a PTZ camera. This is limiting as parts of a scene may often be obscured especially in monitoring areas of high object density such as in public transportation hubs.

These advantages come at the cost of an increase in the data generated in the network which in turn increases the energy consumption in the network. To ensure that the typical battery-powered WMSN lifespan is not significantly affected by this, the amount of data routed through the network can be reduced with the use of in-network processing techniques such as to remove redundancy from multi-camera systems, selective transmission of the data and compressing the data. These processing tasks can be performed at the node, cluster or distributed throughout the network. The use of error detection and correction can also help reduce the likelihood of a costly retransmission. In this chapter, a broad coverage on WMSN technology will be provided as the background information for understanding the WMSN design, its architectures, challenges and design considerations. These design considerations are strongly dependent on the application. Aspects such as deployment density, cost, size, geographic location and purpose determine the components for the implementation of a specific WMSN.

2.2 WMSN Network Technology

This section will describe the layout of a typical WMSN as shown in Fig. 2.1. The network typically consists of a large number of sensor nodes deployed in a region of interest and one or more base stations. The base station or sink acts as the main network controller or coordinator. In this role, its primary function is to coordinate the functions of the nodes. It also collects information gathered by the nodes to be stored or further processed. The sink also serves as a gateway to other networks. The sinks are normally located close to the nodes to avoid high energy-consuming long-range radio communications. The energy consumption in the WMSN will determine the network lifespan. The energy consumed for communication is much higher

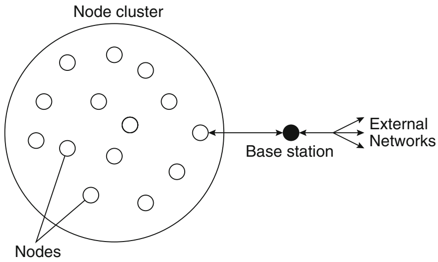

Fig. 2.1 Typical WMSN layout

than that for sensing and computation and grows exponentially with the increase of transmission distance. Therefore it is important that the amount of transmissions and transmission distance be kept to a minimum to prolong the network lifespan. This is one of the main motivations for in-network processing—the reduction of the information required for transmission for the efficient use of energy. In [60, 91], it was reported that the transmission of data can take 1,000–10,000 times more energy than processing, and this difference will increase as processor technology improves.

To reduce the transmission distance, a multi-hop short-distance communication scheme is preferred, and in most sensor networks, this is how it is implemented. In a multi-hop communication network, a sensor node transmits data towards the sink via one or more intermediate nodes. The architecture of a multi-hop network can be organised into two types: flat and hierarchical. The next sections will describe the structure of a WMSN and its various architectures and classifications.

2.2.1 Structure of a WMSN Network

Figure 2.2 shows a general structure of a WMSN consisting of four main components: wireless multimedia node (WMN), wireless cluster head (WCH), wireless network node (WNN) and base station. There is a decreasing information flow from the WMNs to the base station. The captured scene data are processed and transformed to useful event data. The focus for the upper levels of the network (WMN and WCH) is on information processing, and the focus for the lower levels of the network (WNN) is on wireless network communications. The primary theme for both upper and lower network levels is to achieve energy efficiency within the constraints of the battery-powered nodes.

2.2.1.1 Wireless Multimedia Node

The WMNs form the end points of the network. Each WMN consists of a camera or audio sensor, processing unit, communication unit and power unit. The camera

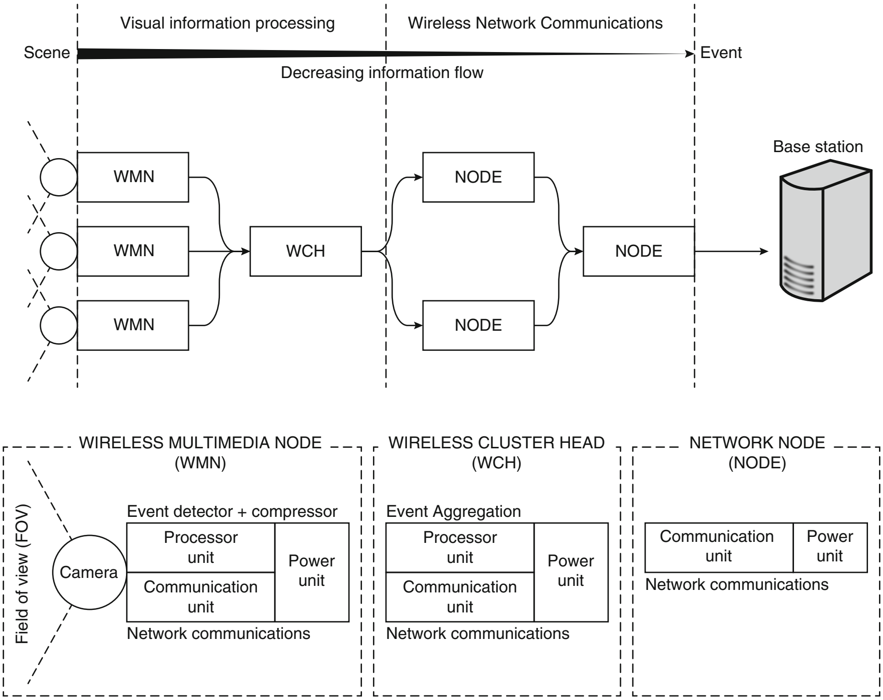

Fig. 2.2 General structure of a WMSN

sensor has a FOV of the scene. A captured scene is called an image frame. The processing unit performs the visual processing to reduce the high amount of scene data. Two approaches can be used. The first approach uses event detectors to identify useful events in the scene data. If an event is not detected, then the image frame is discarded and there is no need to transmit the frame through the network. The second approach uses event compressors to reduce the data for image frames that have to be transmitted through the network. Various image and video information processing techniques can be used, and this will be briefly described in Sect. 2.4 and discussed in detail in Chaps. 5 and 6. The communication unit transmits the compressed data to other nodes. Each WMN receives its power supply from a power unit which is mostly battery-powered.

2.2.1.2 Wireless Cluster Head

The WCHs receive data from several WMNs. Each WCH consist of a processing unit, communication unit and power unit. Each WCH receives data from several WMNs. The FOVs of WMNs may overlap, and the WCH can further reduce the data by performing event aggregation by consolidating the information from the WMNs. For example, the image frames from different WMNs may be stitched into a single frame to remove the overlapping data. This will be further discussed in Chap. 7. The communication unit and power unit perform a similar role as for the WMN.

2.2.1.3 Wireless Network Node

The WNN performs the same role as for a traditional wireless sensor network and consists of a communication unit and power unit. The communication unit relays the data from node to node until it arrives at the base station.

2.2.1.4 Base Station

The base station is the destination of all the data gathered throughout the network. This is likely to be a conventional computer capable of powerful processing and connected to a main power supply. Thus, energy efficiency and power issues are not important here.

2.2.2 WMSN Network Architecture

This section will discuss various architectures and classifications for WMSNs in terms of its composition (homogeneous or heterogeneous), its tier architecture (single-tier or multi-tier) and its mote platform architectures (lightweight-class, intermediate-class or PDA-class).

2.2.2.1 Homogeneous and Heterogeneous Architectures

A homogeneous WMSN consists of nodes that have the same capability in terms of energy, computation and storage, whereas a heterogeneous WMSN would have nodes that have differing capabilities in terms of sensing, processing and communication [5]. A heterogeneous WMSN may contain sensor nodes that are better equipped with more processing power, memory and energy storage and also better communication compared to other sensor nodes. Using better nodes such as this, the network can assign more processing and communication tasks to these sophisticated nodes (e.g. as WCHs) in order to improve its energy efficiency and thus prolong the network lifetime.

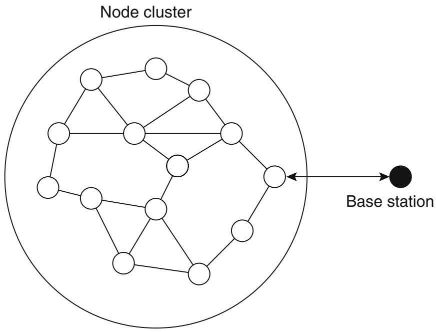

Fig. 2.3 Multi-hop homogeneous flat network architecture

2.2.2.2 Single-Tier and Multi-Tier Architectures

In a typical WSN, the focus of the architecture design is on it being scalable. This is usually achieved through a flat and homogeneous architecture with nodes that have the same physical capabilities. An example of this is a multi-hop homogeneous flat architecture where all the nodes in the network are peers and perform the same sensing function and transmit the data to the base station or controller. This is shown in Fig. 2.3. In contrast, the WMSN is inherently heterogeneous in nature and generates different types of network traffic such as still images, video, audio or scalar data, all of which have to be supported by the architecture. The large amount of data generated by multimedia sensors may not be suited for flat architectures. Similarly, the data processing and energy requirements for communication may differ between the nodes. A node with only a microphone will generate less data and require less processing power than one which has an image sensor. These intrinsic differences of WMSNs require heterogeneous network architectures. These architectures can be classified into two categories: single-tier and multi-tier architectures. Single-tier architectures are based on a flat topology where the network can be composed of either homogeneous or heterogeneous components. Multi-tier architectures, on the other hand, exploit the higher processing and communication capabilities of high-end nodes and use a hierarchical network operation.

The hierarchical network is a type of network where the nodes are grouped into clusters as shown in Fig. 2.4. It divides a large network into smaller groups. The cluster members send their data to the cluster heads, while the cluster heads serve as relays for transmitting the data to the base station. The advantage of this is that not all raw data which are collected from the nodes need to be sent to the base station. The data can be combined together to extract only the useful information and is termed as data aggregation [106]. Another advantage of a hierarchical network is that different nodes can be used to optimise the use of energy. A low energy node can be designed to perform sensing tasks and short-range communication, while a node with higher energy can be selected as a cluster head to process the data from its cluster members and transmit the processed data to the base station.

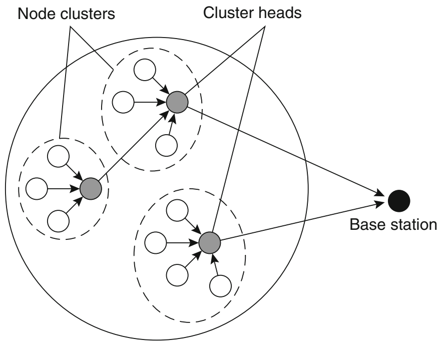

Fig. 2.4 Hierarchical single-tier single-hop network architecture

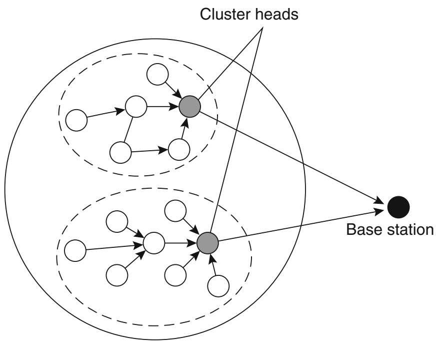

Fig. 2.5 Hierarchical single-tier multi-hop network architecture

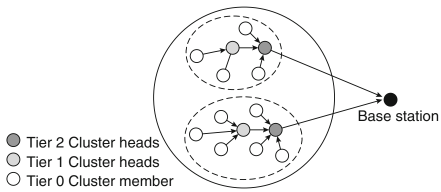

Fig. 2.6 Hierarchical multi-tier multi-hop architecture

This process not only reduces the energy consumption for communication but also balances the traffic load and improves scalability when the network grows. The major problem with clustering is how to select the cluster heads and how to organise the clusters. In this context, there are many clustering strategies. Depending on the number of tiers in the clustering hierarchy, a sensor network can be organised into various architectures. Figure 2.5 shows a single-tier clustering architecture, and Fig. 2.6 shows a multi-tier clustering architecture. There have been many clustering algorithms which have been proposed to address the clustering issues.

Table 2.1 Comparison of mote platforms

Platform	Mote	Microcontroller	RAM	Flash memory
Lightweight	FireFly	8-bit ATmega128L	8 kB	128 kB
Intermediate	TelosB	16-bit TI MSP430	10 kB	1 MB
PDA-class	Stargate	32-bit PXA255 XScale	64 MB	32 MB

2.2.2.3 Mote Platform Architectures

Researchers have classified wireless mote platform architectures into three categories depending on their processing power and storage: lightweight-class platforms, intermediate-class platforms and PDA-class platforms [6]. Lightweight-class platforms have low processing power capability, small storage and are usually equipped with basic communications only. These motes consume a very low amount of energy. An example of a lightweight-class mote platform is the FireFly [86]. Intermediate-class platforms have better computational processing power and a larger storage memory than lightweight devices but are also usually equipped with basic communications. An example of a intermediate-class mote platform is the TelosB [35]. PDA-class platforms are designed to process multimedia content and have more powerful processing capability and large storage. It supports different operating systems and multiple radios. The drawback is that they consume more energy. An example of a PDA-class mote platform is the Stargate platform [34]. Table 2.1 shows a comparison of the different mote platforms in terms of their processing power and memory.

To minimise the mote energy requirements, most commercial manufacturers allow the motes to be configured for different operational modes. For example, the Waspmote from Libelium has four operational modes: on, sleep, deep sleep and hibernate [78]. Figure 2.7 shows a state diagram of the Waspmote operational modes. It is important to utilise the mote in the correct mode to maximise energy efficiency. Table 2.2 shows the power consumption for the Waspmote modes. The normal operation mode is on. The consumption in this state is 9 mA. In the sleep mode, the microcontroller is put into a latent state. It can be woken up by asynchronous interrupts and by the synchronous interrupts generated by the watchdog timeout. The duration interval of this state is from 32 ms to 8 s. The consumption in this state is 62 µA. In the deep-sleep mode, the microcontroller is put into a latent state and can be woken up by asynchronous interrupts and by the synchronous interrupts triggered by the real-time clock (RTC). The duration interval of this state is from 8 s to minutes, hours or days. The consumption in this state is 62 µA. In the hibernate mode, the microcontroller and all the Waspmote modules are completely disconnected. In this mode, it can only be woken up through the programmed alarm in the RTC. The duration interval of this state is from 8 s to minutes, hours or days. The consumption in this state is only 0.7 µA.

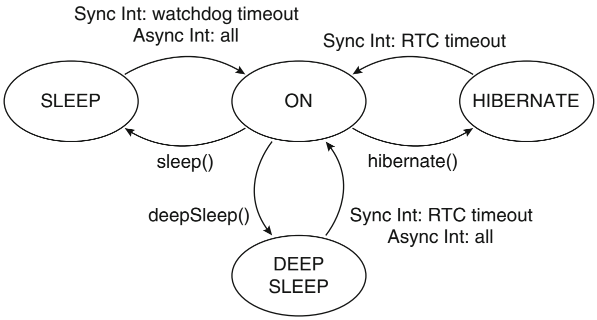

Fig. 2.7 State diagram for Waspmote operational modes

Table 2.2 Operational modes for Waspmote

	Consumption	μProcessor	Cycle	Accepted interruptions
ON	9 mA	ON	–	Synchronous and asynchronous
Sleep	62 μA	ON	32 ms–8 s	Synchronous (watchdog timeout) and asynchronous
Deep sleep	62 μA	ON	8 s–min/h/d	Synchronous (real-time clock) and asynchronous
Hibernate	0.7 μA	OFF	8 s–min/h/d	Synchronous (real-time clock)

2.3 WMSN Node Technology

A notable difference between the WMSN and the WSN on which it is based on is its multimedia handling capabilities. Typical WSNs are not designed for multimedia tasks, but embedding audio and video capture devices on the WSN enhances its capabilities and broadens its potential applications. The primary challenge for the WMSN hardware architecture and its components is the need to support the higher bandwidth and processing requirements needed for audio sensors such as microphones and low-resolution and medium-resolution image sensors. Low-resolution image sensors can be built specifically for WMSNs and are part of an embedded system which may consist of low-end transceivers as well as specialised processor and memory units that are required for low-power image processing and storage.

2.3.1 Structure of a WMSN Node

The structure of a WSN node is designed to be physically small, low cost and with low power consumption. A typical node consists of four main components:

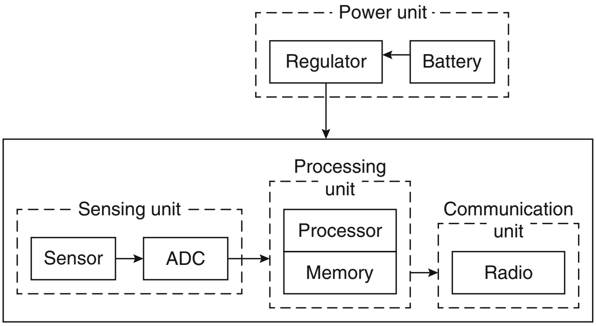

Fig. 2.8 Components of a typical WSN node

sensing unit, processing unit, communication unit and power unit. Figure 2.8 shows the components for a typical WSN node.

- The sensing unit consists of one or more sensors and analog-to-digital converters (ADCs). The sensors detect and measure the physical occurrences which are analog in nature. This analog signal is converted to a digital signal using an ADC. This digital signal is then input to the processing unit.
- The processing unit usually consists of a microcontroller or microprocessor with memory as part of the same die or integrated circuit package. The processing unit could also be or contain a digital signal processor (DSP) or application-specific processor. The processing unit provides intelligent control and processing of information to the sensor node.
- The communication unit consists of a short-range transceiver, typically based on the IEEE 802.14.3 or ZigBee™ standard. There are also many other wireless communication protocols which could be used.
- The power unit regulates power to and from an energy storage unit. This energy storage unit is typically a compact and portable storage such as a battery.

  In most configurations, the ADC, processor, memory and radio are integrated into a single system on a chip (SoC). The details of each of these units will be discussed in the following sections.

2.3.2 Sensing Unit

The sensing unit comprises of the sensors and supporting circuits to capture data from the area or environment being monitored. Examples of scalar sensors are those which monitor physical environmental conditions such as temperature, pressure, humidity, light or sound pressure levels. These sensors are typically

Table 2.3 SHT1x, 2x and 7x series of humidity sensors from Sensirion

		Max. tolerance			
Sensor model		Packaging	RH	T	Sensor output
SHT10		SMD	±4.5%RH	±0.5°C	Digital Sbus
SHT11		SMD	±3%RH	±0.4°C	Digital Sbus
SHT15		SMD	±2%RH	±0.3°C	Digital Sbus
SHT21		DFN	±3%RH	±0.4°C	I^2C, PWM, SDM
SHT25		DFN	±2%RH	±0.3°C	I^2C
SHT71		Pins	±3%RH	±0.4°C	Digital Sbus
SHT75		Pins	±1.8%RH	±0.3°C	Digital Sbus

low-powered passive devices. Examples of multimedia sensors are electromagnetic wave detectors such as visible spectrum, infrared and ultraviolet image detectors and acoustic detectors. The sensed data collected is analog in nature and is usually amplified before digitisation by an analog-to-digital converter (ADC). This can be performed by either the sensor package or the processor unit. The earlier is preferred as low-level analog signals are kept within the sensor package minimising possible external interference and loss, and the amplifier, filter and ADC can be better matched to the capabilities and characteristics of each sensor.

2.3.2.1 Scalar Sensor

A common example of a scalar sensor application is to sense the temperature and humidity of an environment. These can be achieved through the use of a combined sensor such as the humidity sensors from Sensirion [112]. Table 2.3 shows the Sensirion series of humidity sensors. These integrated digital sensors combine a temperature and humidity sensor with an on-chip calibration memory, ADC and digital interface in a complementary metal oxide semiconductor (CMOS) design. This helps ensure the sensors are small (the SHT25 measures $3 \times 3 \times 1.1$ mm) and easy to interface via the digital interface.

2.3.2.2 Image Sensor

The image sensors found on WMSNs are typically CMOS sensors. Figure 2.9 shows the structure for a (Bayer pattern) CMOS sensor. These CMOS sensors are produced in the same manner as computer-integrated circuits. The high production volume of such devices and the high yield through continuous improvements in CMOS manufacturing processes ensures that these sensors remain low cost, small in size and ideal for use in WMSNs. By integrating the photosites, amplifiers and image processing circuits on the same chip, CMOS sensors consume much lower

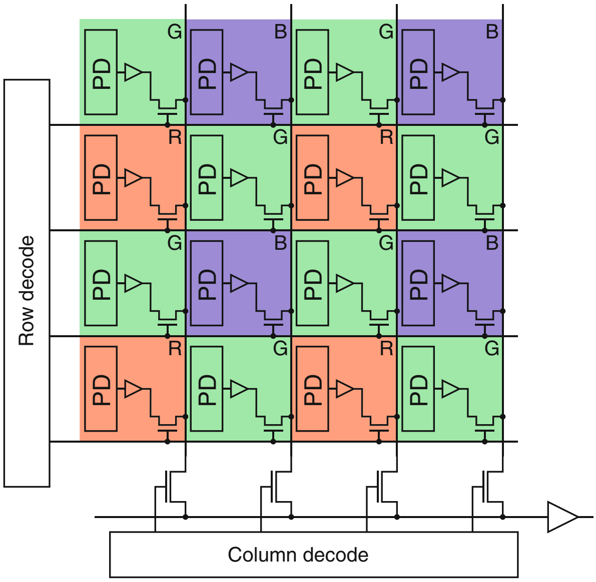

Fig. 2.9 A typical CMOS sensor arrangement (Bayer pattern filter)

energy than charge-coupled device (CCD) image sensors. These sensors also benefit from the continuous improvements in CMOS manufacturing scale reduction by allowing the supporting circuits to be smaller. This allows for more space on the chip for photosites which leads to better low-light performance or further sensor miniaturisation. Recent backlighted (or back-illuminated) CMOS (BSI) sensors offer much better low-light performance for a given size than their non-backlighted counterparts. BSI technology involves turning the image sensor upside down and applying colour filters and micro-lenses to the backside of the pixel so that light is collected through the backside of the sensor. It reverses the arrangement of layers so that metal and dielectric layers reside below the sensor array, providing the most direct path for light to travel into the pixel, which optimises the fill factor to deliver best-in-class low-light sensitivity, image quality and colour reproduction. This approach differs from conventional front side illumination (FSI) architectures, where light travels to the photosensitive area through the front side of the pixel. This requires the light to first pass through transistors, dielectric layers and metal circuitry, which can block or deflect it into neighbouring pixels, causing a reduced fill factor and additional problems such as cross talk between pixels. An example of a BSI sensor is the Omnivision OV16820 [98] which is a 16-megapixel chip capable of capturing 30 fps, with a manufacturer claimed power consumption of only 10 μA in standby and 310 mA when active. This sensor outputs the captured image as a 10- to 12-bit RAW RGB image or a 8- to 10bit differential pulse-code modulation (DPCM) compressed image. Figure 2.10 shows the difference between a FSI and BSI CMOS sensor architecture.

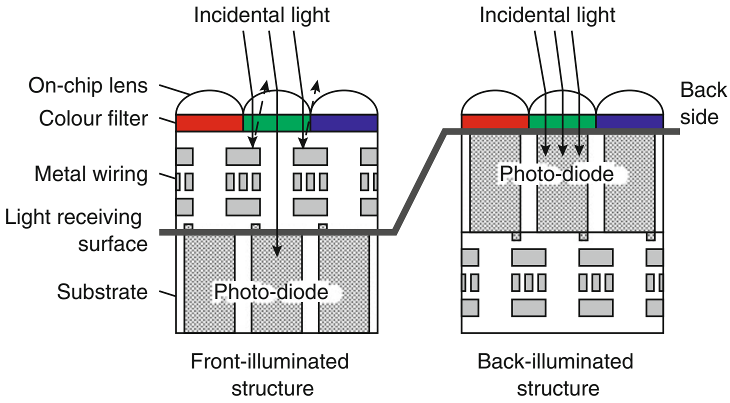

Fig. 2.10 Front-illuminated vs. back-illuminated CMOS sensor

2.3.2.3 Audio Sensor

Audio sensors on WMSNs have to be low powered and small in size. These sensors vary in size, cost and application. Other environmental factors such as vibration, humidity and temperature also need to be taken into consideration when selecting an audio sensor. The typical audio sensor consists of a microphone, amplifier (can be several stages), filters and an ADC. Generally, there are two types of audio sensors which are suited for WMSNs. These are either based on the electret condenser microphone (ECM) or the microelectrical-mechanical system (MEMS) microphone. In some monitoring applications such as structure or traffic monitoring, an audio sensor could be very useful as a sentry. The sensor node can be in a deep-sleep state to conserve energy and wakes up only when an audio threshold is exceeded such as from a collision or from structural stresses and strain. Figure 2.11 shows the structure of a the ECM.

The ECM is a type of condenser microphone with a permanently charged electret material fixed to the capsule back-plate. It eliminates the need for a polarising power supply as required by condenser microphones. ECM microphones provide a good dynamic range and are found in many applications from high-quality recording to built-in microphones in telephones. It is widely available, low cost and small enough to be embedded into many applications. The MEMS microphone is a solid-state microphone that typically comes integrated with a matching ADC, filter, power management, hardware control and communication port. A major advantage of the MEMS microphone over the ECM microphone is that it is able to interface to the node processor over a digital serial link. Other advantages of the MEMS are as follows:

- *Higher performance density.* For the same volume, MEMS microphones can achieve better noise performance than equivalent ECMs.

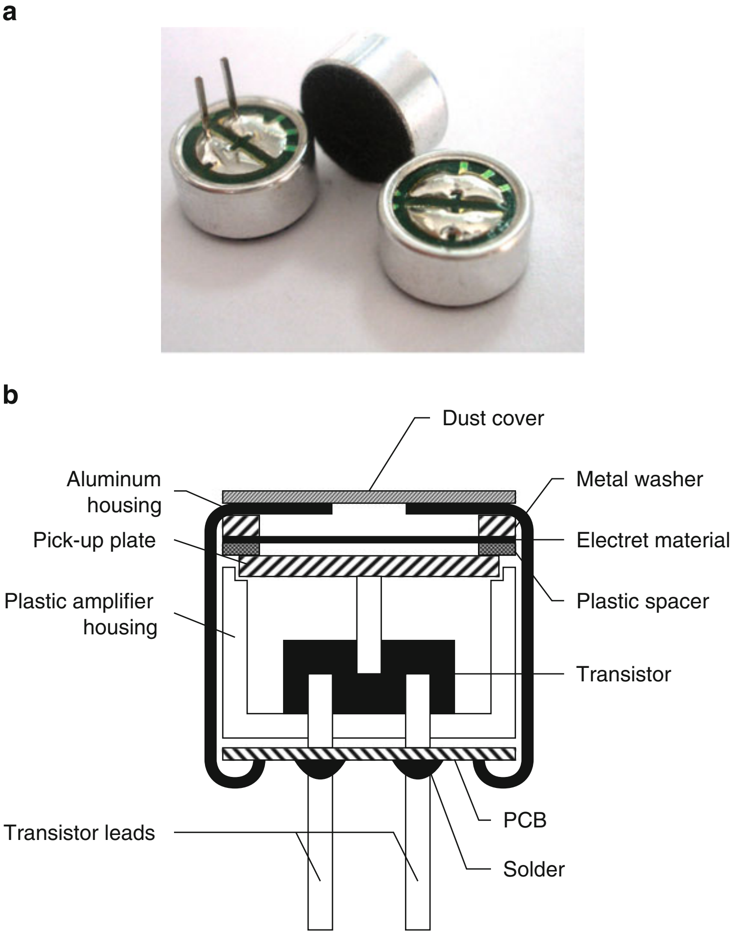

Fig. 2.11 The ECM microphone (foil type or diaphragm type) (**a**) Photo of ECM. (**b**) Cross-section of ECM

- *Less variation in sensitivity over temperature.* The sensitivity of an ECM may drift as much as ± 4 dB over its operating temperature range, while an MEMS microphones sensitivity may only drift by 0.5 dB over the same range.
- *Lower vibration sensitivity.* The mass of a MEMS microphone diaphragm is lower than that of an ECM, leading to less response to vibrations in a system. This is important in applications where vibrations are a common occurrence.
- *More uniform part-to-part frequency response than ECMs.* A random selection of MEMS microphones of the same type will have near identical responses. This is important in microphone arrays such as those made possible using WMSNs. Otherwise, different sensor nodes may capture different information from the same event.

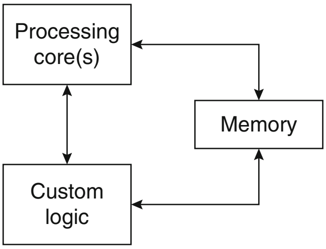

Fig. 2.12 Processor unit

- *Can be reflow soldered.* This saves cost by allowing assembly on the same reflow soldering process as most other integrated circuits on a printed circuit board (PCB) and helps to reduce the manufacturing costs.
- *Semiconductor manufacturing process.* Like the CMOS image sensors, the solid-state MEMS microphone also benefits from the advancements in semiconductor manufacturing processes.

2.3.3 Processor Unit

The WSN processor unit consists of very low-powered and deep-sleep-capable processing cores. Figure 2.12 shows an architecture of a processor unit. The processor unit consists of at least one processing core and local memory. In some configurations, it may also contain custom logic which is more efficient in terms of the processing/power consumption ratio over using a general-purpose processor (GPP).

2.3.3.1 Processing Core

Processor architectures can be classified into three categories: GPPs, DSPs and application-specific instruction set processors (ASIPs). These processor architectures will be discussed in the following sections.

General-Purpose Processors

A typical WSN will contain at least a basic processor for coordinating the functions on the WSN. This processor can be termed as a GPP and needs to be sufficient for making simple computations, serialisation and packetisation of data for transmission. It is also responsible for decoding and interpreting incoming messages. To conserve energy, the processor should have the following features: a deep-sleep state with low-current wake-up, a scalable clock and a simple instruction set. However, the emergence of WMSNs has changed the role of the processor from its basic role to one that has to process more complex multimedia data such as to pre-process and compress the data from the multimedia sensors before transmission. To meet the multimedia requirements, a different kind of low-power processing core with more processing power is needed. Another consideration in choosing the processing core is that it needs to have enough I/O interface which is usually serial in nature such as SPI (Serial Peripheral Interface Bus), I^2C (Inter-Integrated Circuit) or 1-wire. This is required for connecting various components of the system such as the external memory, ADCs and radio. Examples of GPP processors are the Atmel AVR and those based on the ARM [12] and MIPS [95] architectures.

Digital Signal Processors

Higher-end WMSN sensor nodes may also contain a digital signal processor (DSP). DSPs are specialised processor architectures to exploit data and instruction-level parallelism in signal and image processing algorithms. Although DSPs in general can use a fixed-point or floating-point arithmetic format, DSPs for WMSNs would use a fixed-point format to be more energy and area efficient. DSPs are often optimised to perform operations such as digital filtering or fast Fourier transform (FFT) operations. A typical DSP would be able to achieve a throughput of one clock cycle per filter tap. It is able to achieve this using a Harvard computer architecture with multiple registers and specialised hardware like circular buffering and multiply-and-accumulate (MAC) units where multiple operations can be performed in a single clock cycle. A Harvard architecture would contain separate memories and buses for instructions and data storage termed Instruction Memory and Data Memory, respectively. This allows a new instruction to be fetched from the Instruction Memory in the same cycle as data is accessed from the Data Memory. The circular buffer is a data structure in memory which is used to store incoming data. When the buffer is filled, the incoming new data is written at the beginning of the buffer and overwrites the old data. DSPs also use pipelining architectures to improve the execution throughput where the operations of the instruction cycle are split into smaller sequential tasks that are executed in parallel by different units within the processor.

Application-Specific Instruction Set Processors

In contrast to GPPs and DSPs which target a broad range of applications, ASIPs are optimised to target a single application. ASIPs are often implemented by customising the instruction set architecture (ISA) of a GPP processor. It takes advantage of user-defined instructions and a user-defined datapath which is optimised for a particular application. The resulting optimisation achieves a higher computational performance and energy efficiency than a GPP processor. Examples of ASIP

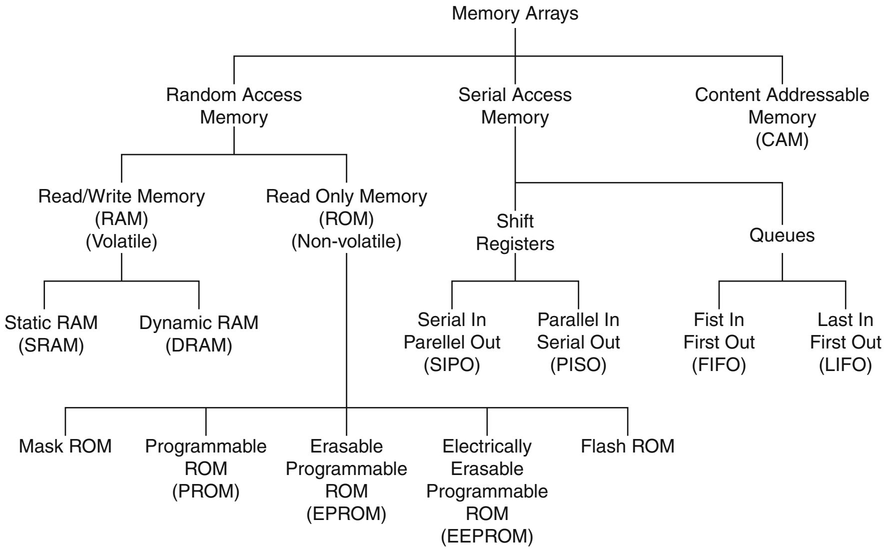

Fig. 2.13 Different memory types

processor customisations for WMSNs are for applications involving encryption, error correction and compression. The work in [127] describes an ASIP processor for encryption. In this work, the authors describe four ASIP designs (8-bit, 32-bit, 64-bit and 128-bit ASIP) for optimising the Advanced Encryption Standard (AES) for implementation in a WSN. The authors performed a comparison among the four cryptographic designs in terms of performance, power consumption, energy dissipation and area occupation and concluded that the smallest ASIP (8-bit design) is the most power efficient.

2.3.3.2 Local Memory

The local memory found in a WMSN is either used to store program codes or sensed data. The program codes are normally stored on non-volatile memory built into the processor core. Sensed data such as those from an image sensor is normally stored in an external memory. There are typically two types of memory used: random access volatile and non-volatile. Figure 2.13 shows the different memory types. Random access volatile memory describes memory that requires power to maintain the stored information, whereas non-volatile memory does not require a maintained power supply. Dynamic random access memory (DRAM) is a random access memory that stores each bit of data in a separate capacitor. This is commonly found in applications where large amounts of memory are needed and power is not a major concern. For most embedded systems such as that used in WMSNs, the use of DRAM seems impractical as it requires a refreshing circuitry because

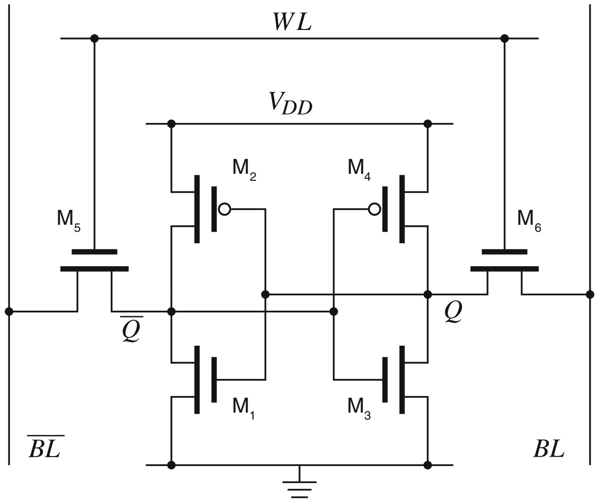

Fig. 2.14 A six-transistor CMOS SRAM

the capacitors it uses lose charge over time. The need for a refresh cycle increases the integration complexity and decreases the overall performance and can also lead to higher power consumption. However, it is relatively much cheaper compared to static random access memory (SRAM) and is available in large sizes with modules in the gigabyte range.

SRAM uses a bistable latching circuitry to store each bit and does not require a refresh circuit. Figure 2.14 shows a CMOS SRAM cell which uses six transistors. This is configured as four transistors to store a bit and another two transistors for control access. Furthermore, this design can be extended to implement more than one read/write port (termed as a multiport memory), allowing the memory to be read and written within the same clock cycle. SRAMs are more expensive to manufacture and are typically found in smaller sizes from a few kB to 512 Mbit. Also available are cheaper pseudo SRAM (e.g. Winbond W968D6DKA [136]) which works like SRAM but is built on a DRAM core using capacitors with an integrated on-chip refresh circuit.

Another type of memory commonly found on many embedded systems is the non-volatile memory. These are typically NOR- or NAND-based flash based on their gate types. For many systems NAND flash memory provides a low-cost and large capacity upgradable memory and is commonly available as Secure Digital Cards (SD) and Multimedia Cards (MMC) which uses SPI to communicate. These can be used as a backup memory or used to store large amounts of data that do not require fast access as these are not random access. In the NOR-based flash, the individual memory cells are connected in parallel, which enables the device to achieve random access. This configuration enables the short read times required for the random access of microprocessor instructions. NOR flash memory is ideally

Table 2.4 Comparison of NAND and NOR flash memory operating specifications

	SLC NAND flash (x8)	MLC NAND flash (x8)	MLC NOR flash (x16)
Density	512 Mbit–4 Gbit	1 Gbit–16 Gbit	16 Mbit–1 Gbit
Read speed (MB/s)	24	18.6	103
Write speed (MB/s)	8	2.4	0.47
Erase time (ms)	2.0	2.0	900
Interface	I/O indirect access	I/O indirect access	Random access
Application	Program/data mass storage	Program/data mass storage	eXecuteInPlace

used for lower-density, high-speed read applications, which are mostly read only and often referred to as code-storage applications. The characteristics of NAND flash memory are its high density, medium read speed, high write speed, high erase speed and an indirect or I/O-like access. The characteristics of NOR flash are lower density, high read speed, slow write speed, slow erase speed and a random access interface. Due to the lower density nature of NOR memory, it is also more expensive and require more power. Table 2.4 shows a comparison between the NAND and NOR flash memory operating specifications.

2.3.3.3 Custom Logic

The custom logic located in the processing unit handles certain specific tasks that have been earlier determined for the application. They help to augment the processing core. In WMSNs such tasks would be basic image and audio processing tasks. Examples for image processing tasks include edge detection, colour conversions, mathematical transforms and image compression, and examples for audio processing tasks include peak detection and audio compression. Custom logic can be implemented via an ASIC or a low-power FPGA such as the Actel IGLOO.

2.3.4 Communication Unit

The communication unit is responsible for all incoming and outgoing transmissions from the sensor node. Figure 2.15 shows several typical communication methods used in WSNs; however, it is most common to use radio frequency (RF) waves. Three common standards can be used for RF communication: IEEE 802.11 wireless LAN (normally termed Wi-Fi), Bluetooth and IEEE 802.15.4 (normally termed ZigBee™). Table 2.5 shows a comparison of the RF communication standards. Although the use of RF-based communications is common for WMSNs, it is

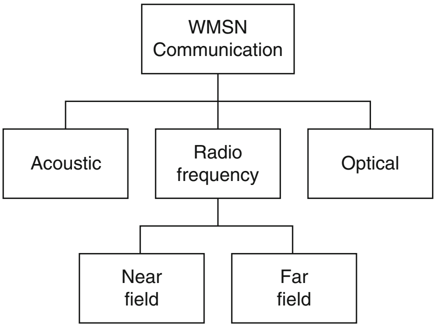

Fig. 2.15 Communication types

Table 2.5 Comparison of RF communication standards

Market name	Wi-Fi™	Bluetooth™	ZigBee™
Underlying standard	802.11b	802.15.1	802.15.4
Application focus	Web, email, video	Cable replacement	Monitoring & control
Battery life (days)	0.5–5	1–7	100–1,000+
Network size	32	16	100s to 1,000s
Bandwidth (kbits/s)	11,000+	720	20–250
Range (m)	1–30+	1–10+	1–1,000+
Network architecture	Star	Star	Mesh
Optimised for	Speed	Low cost, convenience	Reliability, low power, low cost, scalability

not limited to RF-based communications only and can be implemented using optical- or acoustical-based techniques which may be more applicable in some environments. For example, underwater WMSNs can use acoustical-based communications. Another benefit of non-RF-based communications is that the deployment of the WMSN is eased as it does not require any regulatory approval or licences unlike RF-based communications.

Recently, a carrierless RF transmission system called ultra-wide-band (UWB) technology has been proposed to meet the requirements for use in WSNs [145]. UWB is a wireless radio technology designed to transmit data at very high bandwidths (∼480 Mbps) within short ranges (∼10 m) using little power. The UWB has been added to the IEEE 802.15.4a standard as an additional physical layer. Other benefits of the carrierless UWB is that it offers a simplified radio compared to narrowband communication and the large bandwidth offered by the UWB helps in node positioning by allowing centimetre accuracy in ranging [60]. The large bandwidth also decreases the power spectral density and reduces the interference to other systems. The next four sections will describe three non-RF-based communication methods, optical, acoustic and magnetic, followed by a description on the RF-based

ZigBee standard. Typically, the low data rate (max of 250 kbits) of ZigBee is not feasible for use in WMSNs, but advancement of in-node processing techniques has enabled low data rates suitable for use in ZigBee networks.

2.3.4.1 Optical Communications

Optical communication takes place by encoding data into pulses of light (visible or otherwise) which is typically from the lower end of the electromagnetic spectrum wavelength of 600–1.000 nm This is done by modulating the light from a transmitter such as a light-emitting diode (LED) or a laser diode (LD) which can be captured by a photodiode at the receiver end and decoded. The result is an intensity modulation with direct detection (IM/DD) system. This system can be implemented over a solid light guide (e.g. optical fibre cable) or through free space (e.g. air or vacuum). A common form of optical communication is to use infrared communication. Infrared communication has been used mainly for short-range communications in portable devices such as cell phones, laptops and PDAs. This has been replaced by alternative RF-based methods like Bluetooth which does not require line-of-sight (LoS). The LoS point-to-point communication is the most commonly used IR communication type. Another type is diffuse IR which does not require LoS but works by reflecting the light from surrounding objects. This would normally require a wide angle transmitter and receiver. An example of an implementation of optical communication is the Smart Dust mote [70, 134].

2.3.4.2 Acoustic Communications

Acoustic communications are used only when both RF and optical transmission options are not feasible such as in an underwater environment. A low frequency (30 Hz–10 kHz) acoustic signal can propagate in water over very long distances. However, there are several issues to be overcome such as attenuation and noise, multipath propagation and the Doppler effect. Sound propagates underwater at a very low speed of 1.500 ms, and the propagation occurs over multiple paths. The delay spreading over tens or even hundreds of milliseconds results in a frequency selective signal distortion while motion creates an extreme Doppler effect [117]. All of these depend on the properties of the water such as temperature, depth and composition.

2.3.4.3 Near-Field Radio Frequency Communications

In a far-field RF communication system, most of the energy is contained in the electric field. Near-field RF communication makes use of the strong magnetic fields in the near field of the signal but weak in the far field. In essence, a

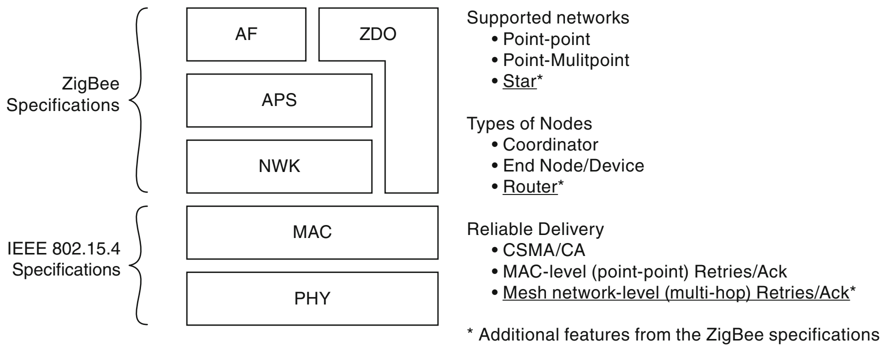

Fig. 2.16 ZigBee layers and specifications

near-field magnetic induction (NFMI) communication system is a short-range wireless physical layer that communicates by coupling a tight, low-power and non-propagating magnetic field between devices. The system uses a transmitter coil in one device to modulate a magnetic field which is measured by means of a receiver coil in another device. NFMI systems are designed to contain transmission energy within the localised magnetic field. This magnetic field energy resonates around the communication system but does not radiate into free space. The standard modulation schemes used in typical RF communications (amplitude modulation, phase modulation and frequency modulation) can be used in NFMI systems.

2.3.4.4 Far-Field Radio Frequency Communications

The objective of the IEEE 802.15.4 standard was to provide a wireless communications standard for ultra low complexity, ultra low cost, ultra low power consumption and low data rate (maximum of 250 kbits) wireless connectivity among inexpensive devices such as alarms, sensors and automation devices. The standard defines the physical and medium access control layers that specify a low rate personal area network (LR-PAN). Although, there are several protocols which uses the 802.15.4 as its underlying layers such as the Wireless HART [57], ISA-SP100 [122] and IETF IPv6-LoWPAN [96], the most widely known is the ZigBee standard [146].

ZigBee Network Layers

Figure 2.16 shows the ZigBee layers and specifications. ZigBee operates in the industrial, scientific and medical (ISM) radio bands. The original IEEE 802.15.4 (2003) standard specifies the physical (PHY) and medium access control (MAC) layers at the 868 MHz, 915 MHz and 2.4 GHz ISM bands. Both contention-based and contention-free channel access methods are supported. Data transmission rates vary from 20 to 250 kbits. ZigBee builds upon the PHY and MAC defined in IEEE standard 802.15.4 for low-rate WPANs. The specification goes on to complete the standard by adding four main components: network layer, application layer, ZigBee device objects (ZDOs) and manufacturer-defined application objects which allow for customisation and helps integration. The ZDOs are responsible for a number of tasks which include keeping of device roles, management of requests to join a network, device discovery and security. The air interface is direct-sequence spread spectrum (DSSS) using BPSK for 868 and 915 MHz and O-QPSK for 2.4 GHz. The access method in IEEE 802.15.4-enabled networks is carrier sense multiple access with collision avoidance (CSMA-CA). The IEEE 802.15.4 PHY includes receiver energy detection (ED), link quality indication (LQI) and clear channel assessment (CCA). Table 2.6 shows a summary of the ZigBee PHY layer.

ZigBee Network Nodes

The ZigBee specification defines three node types: coordinator, router and end device. Table 2.7 shows the tasks performed by the different network node types. These nodes can be configured into three different topologies: tree, star or mesh as shown in Fig. 2.17. Every ZigBee network is controlled, initiated and maintained by a coordinator, and there is only one coordinator in a network. The coordinator node is tasked with the network creation, the control of its parameters and basic maintenance. Within star networks, the coordinator must be the central node. In a star network, the end devices communicate directly with the coordinator. Using this topology, up to 65,536 end devices can be supported using a 16-bit address. The star network has a simple layout and has low latency. In a tree and mesh network, data is passed through routers before arriving at the coordinator. Because ZigBee nodes can go from sleep to active mode in 30 ms or less, the latency can be low and devices can be responsive, particularly compared to Bluetooth wake-up delays, which are typically around 3 s. Because ZigBee nodes can sleep most of the time, the average power consumption can be low, resulting in long battery life.

2.3.5 Power Unit

The power unit of a WMSN node is responsible for regulating power from the node power source. The power unit must be able to supply the peak current demands of the processor when transitioning from a deep-sleep state to a fully operational state and during radio communications. The node power source is typically a cell (either primary or secondary) and can be augmented with an energy-scavenging system such as a photovoltaic (PV) panel which extracts solar energy or fluid turbines which extract energy from fluid flow such as a wind or wave turbine. A cell generates

Table 2.6 ZigBee PHY layer [IEEE 802.15.4 specifications, 2003–2012]

Band (MHz)	Region	Channel Page	Channel Num	Center frequency (MHz)		Modulation type	Bit rate (kb/s)	Notes
780 (c2009)	China (802.15.4c-2007) 8 channels	5	0–3	780 (2 MHz channel spacing)	DSSS	M-ary PSK	250	• 4-bits per symbol • 16-chip PN • Raised cosine pulse shaping
			4–7			O-QPSK	250	
868	Europe	0	0	868.3 (2 MHz channel spacing)	DSSS	BPSK	20 (2003)	• 15-chip PN • Raised cosine pulse shaping
		2	0			O-QPSK	100 (2006)	
(2006)		1	0		20-bit PSSS	ASK	250	
915	USA and Australia 30 channels	0	1–10	906–954 (2 MHz channel spacing)	DSSS	BPSK	40 (2003)	
		2	1–10			O-QPSK		
		1	1–10		5-bit PSSS	ASK	250 (2006)	

950 (d2009)	Japan (802.15.4d-2009) 22 channels	6	0–7 (1 mW)	951.2–955.4 (0.6 MHz channel spacing)	DSSS	BPSK	20	
			8–9 (10 mW)	954.4–954.6 (0.2 MHz channel spacing)				
			10–21	951.1–955.5 (0.4 MHz channel spacing)		GFSK	100	
2,400	Worldwide 16 channels	0	11–26	2,405–2,480 (5 MHz channel spacing)	DSSS	BPSK	250 (2003)	• 32-chip PN • Half sine pulse shaping

PSK phase-shift keying, *DSSS* direct-sequence spread spectrum, *BPSK* binary phase-shift keying, *O-QPSK* offset quadrature phase-shift keying, *ASK* amplitude-shift keying, *PSSS* parallel sequence spread spectrum, *GFSK* Gaussian frequency-shift keying

Table 2.7 ZigBee and 802.15.4 network node types

Node type		
802.15.4	ZigBee™	Tasks
Full function device (FFD)	Coordinator	The coordinator is the "master" device; it governs all the network nodes • One per PAN • Establishes and organises the PAN • Mains-powered (typically)
	Router	Routers route the information which sent by the end devices • Optional in a network • Several can be in a PAN • Mains-powered (typically) • Can serve as motes
Reduced function device (RFD)	End device, end nodes, motes	These are the sensor nodes, the ones which take the information from the environment • Several can be in a PAN • Low power-, mostly in a deep-sleep state • Battery-powered (typically)

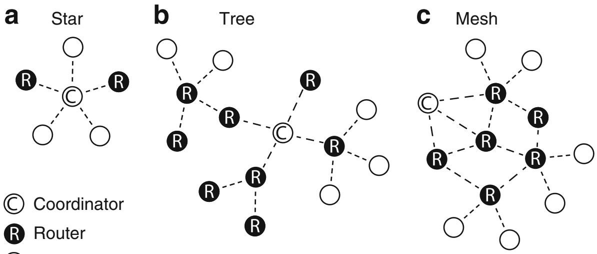

Fig. 2.17 ZigBee network topologies

electrical energy through a electromechanical conversion from stored chemical energy. A cell is typically known by its chemistry type such as the more commonly used primary cells such as the zinc-carbon or alkaline (zinc-manganese dioxide). For secondary cells, these are lead acid, nickel cadmium (NiCd), nickel metal hydride (NiMH), lithium ion (Li-ion) and lithium ion polymer (Li-ion polymer). In systems with both a secondary cell and an energy-scavenging system, the power unit must also be able to regulate the charging of the cell. There are several considerations when selecting a cell type for a node. Most important is the environment or conditions it will operate such as the operating temperature, vibration, transient and steady-state current drain of the node. For instance, lithium ion cells have a diminished capacity at subzero temperatures.

2.3.6 Frame Memory

The frame memory is a memory space used to temporarily store the image (or a sequence of images). It is similar to that of the local memory except that it serves only one purpose which is as an image buffer. This is needed as the image capture rate can be higher than the processing ability of the node.

2.3.7 Localisation Unit

In many applications, the location or position of the nodes whether in relation to each other or their absolute positions are important. The gathered information needs to be associated with the location of the sensor nodes to provide an accurate view of the observed sensor field. This is especially true if the events being monitored is time varying or if the nodes are mobile. Positioning systems can be divided into three main categories: time-of-arrival (TOA), angle-of-arrival (AOA) and signal-strength (SS)-based systems. The TOA technique estimates the distance between nodes by measuring the travel time of the received signal. The AOA technique measures the angles between a given node and a number of reference nodes to estimate the location. The SS approach estimates the distance between nodes by measuring the energy of the received signal. One of the most commonly used positioning system GPS is time-based. Trilateration is used to determine the position by the measurement of distances. These distances are obtained by measuring the travel times of signals between nodes. If two nodes have a common clock, the node receiving the signal can determine the TOA of the incoming signal that is time stamped by the reference node. The main challenge in such systems is ensuring that the clock is synchronised throughout the system as it affects the TOA estimation accuracy. Many outdoor deployments of WMSNs which require positioning are fitted with a GPS localisation unit for positioning as they are relatively low cost, available off-the-shelf and easy to implement. Most units return the position in the NMEA 0183 (National Marine Electronics Association) format and can be as accurate as pm2 m.

In indoor locations, GPS signals are often too weak for providing positioning information. However, this has been somewhat overcome by the use of massively parallel correlation processing that makes it possible to fix position with GPS signals as weak as $-150\,\text{dBm}$ [54]. One possibility is to use radio signals from the WMSN units, but localisation of radio signals indoors is difficult because of the presence of shadowing and of multipath reflections from walls and objects. By using UWB radios, the wide bandwidth of its signals implies a fine time resolution that gives them a potential for high-resolution positioning applications using the time-difference-of-arrival (TDOA) method provided that the multipaths are dealt with. Due to the short-burst and pulse-like nature of UWB signals, multipaths are easily detected and overcome by the correlator in the multipath combining receiver.

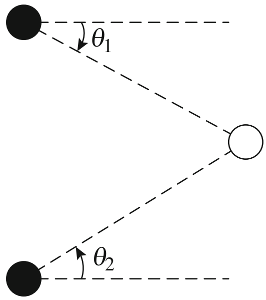

Fig. 2.18 Position calculation using angle-of-arrival

An AOA-based positioning technique involves measuring angles of the target node seen by reference nodes (triangulation) which is done by means of antenna arrays. To determine the location of a node in a two-dimensional (2D) space, it is sufficient to measure the angles of the straight lines that connect the node with the two reference nodes as shown in Fig. 2.18.

The AOA approach is not suited for implementation in WMSNs because it requires the use of expensive antenna arrays and WMSN nodes typically use a low-cost omnidirectional antenna. Furthermore, the number of paths may be very large, especially in indoor environments. Therefore, accurate angle estimation becomes very challenging due to scattering from objects in the environment. The SS positioning estimation relies on a path loss model. The distance between two nodes can be calculated by measuring the energy of the received signal at one node. This trilateration technique is similar to the TOA technique but uses the SS or received signal strength indicator (RSSI) for distance estimation rather than travel time. To determine the distance from SS measurements, the characteristics of the channel must be known. SS-based positioning algorithms are very sensitive to the accurate estimation of those parameters.

2.4 Information Processing in WMSN

To realise the full potential of the WMSNs, the nodes can collaborate with each other to achieve the goals of the application. This section will discuss various issues for collaborative information processing in WMSNs such as multi-camera network models, collaborative object detection, tracking and recognition and information reduction techniques for WMSNs.

2.4.1 Multi-Camera Network Models

Researchers have classified multi-camera networks into three models: centralised processing, distributed processing and clustered processing [4]. Figure 2.19 shows

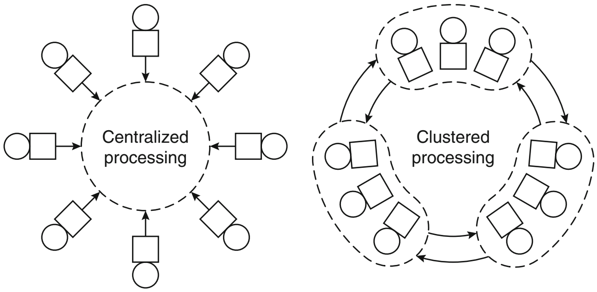

Fig. 2.19 Multi-camera network models

the centralised and clustered processing models. The centralised processing model resembles a traditional WSN architecture where the data sensed by the nodes are sent to the base station for specific application processing. The processing performed in the nodes are only for energy efficiency requirements, for example, compression. The clustered processing model allows the nodes to perform the visual processing at the node level. Each cluster may also collaborate and share data with its neighbouring clusters. The distributed processing model is a clustered processing model where each cluster only consists of a single node.

2.4.2 Collaborative Object Detection, Tracking and Recognition

Typical visual processing tasks to be performed collaboratively are to detect, track and recognise objects in the scene. Object detection refers to a visual processing task to locate a certain class of objects in the image frame (e.g. humans and vehicles). The goal of object tracking is to associate target objects in different video frames. Object recognition refers to a visual processing task where the general class of the object is known and the objective is to recognise an objects exact identity. There are two approaches which can be used for object detection: detection of objects using static features and detection of moving objects. The first approach, where the object is detected using features from a single frame, involves maintaining a model of the objects of interests. The detection process is then decomposed into two steps of first finding the features in the image and then validating whether the features sufficiently explains the presence of the object. This approach has the disadvantages of being computationally intensive and also requiring training of the detection system beforehand. The second approach involves detection of moving objects. A common approach is to use a technique termed as background subtraction. Figure 2.20 shows a general model for background subtraction [26]. There are four stages in the model: pre-processing, background modelling, foreground detection and data validation. In the initial stage, smoothing operations for temporal or spatial

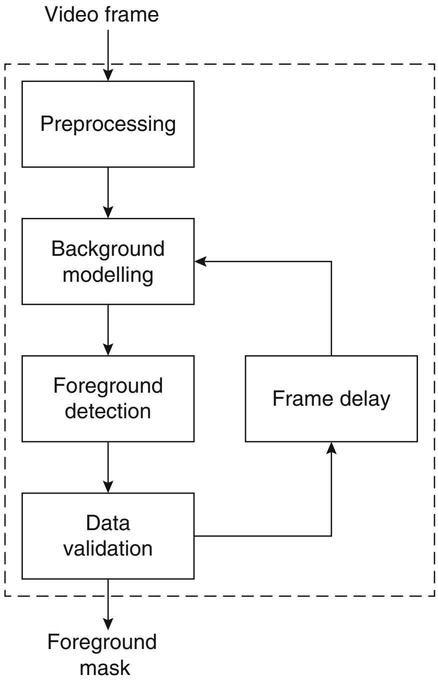

Fig. 2.20 General model for background subtraction

pre-processing can be performed to reduce camera and environmental noise such as rain and snow. Frame size reduction can also be performed to reduce the data processing rate. Background modelling is then performed to use the new video frame to calculate and update the background model. Various models can be used. These range from simple frame differencing to more sophisticated models using mixture of Gaussians.

The aim of object tracking is to generate the trajectory of an image over time by locating its position in every frame of the video. There are two approaches which can be used for object tracking: deterministic approaches or stochastic approaches. Deterministic approaches pose tracking as an optimisation problem, whereas stochastic approaches estimate the posterior distribution of the object location using Kalman filters or particle filters. The authors in [88] present an object tracking algorithm suitable for a network of wireless cameras. The algorithm uses a clustering protocol to establish connections among cameras that detect the target and to enable the propagation of the state of the target as it moves. Data aggregation is carried out using a decentralised Kalman filter. They carry out a series of experiments and show that the algorithm is capable of tracking a target with accuracy comparable to that achieved by a centralised approach wherein every measurement is transmitted to the base station. There are two approaches which can be used for object recognition: feature-based approaches and global approaches. Feature-based approaches detect points of interest in each image of an object and describe the object using descriptors of these local feature points. Global approaches describe the object using their global properties such as shape, silhouette, texture or colour.

2.4.3 Information Reduction in WMSN

In general, two different approaches can be employed to reduce the image data. The approaches can be divided into single-view approaches and multi-view approaches. Single-view approaches attempt to reduce the image data from each individual WMN. Two techniques can be used here: event detection and event compression. The first technique uses event detection to reduce data by only transmitting frames in the network when significant events are detected. Image frames which are not significant are discarded by the WMN. The second technique is to perform event compression by performing compression on the image frames which have to be transmitted. Event compression approaches rely on image and video compression algorithms to remove redundancy from the data. These algorithms range from current standards like JPEG, MPEG-x and H.26x to newer techniques using distributed video coding and compressive sensing. While single-view approaches attempt to reduce the scene data from each individual WMN, multi-view approaches perform the data reduction by aggregating the data from different WCHs. This is possible because of the overlapping FOVs of the different WMNs.

2.4.3.1 Event Detection

Event detection approaches reduce scene data by only transmitting image frames when significant events are detected for the application. For example, a surveillance application could use a face detector to decide which image frames to send to the base station. However, the face detector would need to have low computational complexity to meet the energy requirements in the WMN. There is a trade-off between energy required for processing and energy required for transmission. On the one hand, using an event detector in the WMN requires more computational power. On the other hand, this could result in a saving of transmission power when frames are discarded. The other advantage of an event detector is that it could also serve as an early stage for visual pre-processing. To perform the facial recognition process, the central computer would need to perform at least two stages. The first stage is to locate the face location in the image, and the second stage would then perform the recognition task by comparing the facial features with a stored database. To reduce the large amount of image data for processing by the central computer, the event detector performs the face detection task, and the location of the face is then communicated to the central computer to perform the facial recognition task. An example of a WMSN employing an event detector can be found in the paper by [37]. The authors propose an event detector using simple image processing at the camera nodes based on difference frames and the chi-squared detector. Their algorithm performs well on indoor surveillance sequences and some, but not all, outdoor sequences. The research challenge is to find suitable detectors which are reliable and can be efficiently implemented within the hardware constraints of the WMSN. Further discussions of using event detection in WMSNs are given in Chap. 5.

2.4.3.2 Event Compression

There is a wide range of image compression techniques. The research challenge is to identify algorithms which are suitable for implementation in WMSNs. As a main characteristic, the algorithms should have low computational complexity and memory requirements while maintaining high coding performance to achieve energy efficiency. In general, image coding can be categorised under first generation and second generation image coding approaches and is carried out in two steps. The first step converts the image data into a sequence of messages. In the second step, code words are assigned to the messages. First generation approaches put the emphasis on the second step, whereas second generation approaches put it on the first step and use available results for the second step. Examples of first generation approaches are algorithms based on the discrete cosine transform (DCT) and discrete wavelet transform (DWT). An image captured by the camera sensor nodes is first transformed to a domain that is more suitable for processing. Quantisation is then carried out on the transformed image data. The image compression algorithm is then applied followed by entropy coding. This generates a bit stream that is ready for transmission. At the decoder side, the above processes are reversed which finally leads to the reconstruction of the original image. Second generation approaches require more computational processing compared to first generation approaches. Thus, researchers have focused on adapting and modifying first generation algorithms to lower computational and memory requirements while still maintaining the coding performance. Further discussions of using event compression in WMSNs are given in Chap. 6.

2.4.3.3 Event Fusion

WMSNs can employ multi-view approaches to further reduce the data. Each WCH receives data from several WMNs. The FOVs of WMNs may overlap, and the WCH can further reduce the data by performing event aggregation by consolidating the information from the WMNs. This requires solving what is known in computer vision as the correspondence problem. This is to find a set of points in one image which can be identified as the same points in another image. The application of multi-view compression approaches for WMSN is a very recent development. Note that the role of a WCH could be played by WMNs as well. For example, the WMN with the highest remaining energy level could be designated as the current WCH, and when its energy level decreases to a certain level, another WMN could take over the role of the WCH. Further discussions of using event fusion or stitching in WMSNs are given in Chap. 7.

2.5 Applications of WMSNs

The applications of WMSNs include current applications that make use of audio and visual sensors with perhaps the most common being video surveillance. Some applications of WMSNs are as follows:

- *Multimedia Surveillance Sensor Networks.* Multimedia surveillance sensor networks help enhance current surveillance systems by allowing large-scale deployment of low-cost low-powered audio-visual nodes. These nodes are capable of processing and transmitting multimedia data. Use of these networks can help deter crime through monitoring, detection and recording of potentially relevant activities (thefts, automobile collisions, traffic violations or suspicious behaviour). Audio can be used to detect abnormal sounds or disturbances such as gunshots, and a network of audio detectors can help determine the source of such occurrences.
- *Traffic Avoidance, Enforcement and Control Systems.* WMSNs can be used to monitor and determine the average travelling time on roads and highways. Data from this system can be used to offer traffic routing services to avoid congestion and to reduce user travelling time. An example of this is via GPS devices. The traffic data can be obtained via Radio Data System-Traffic Message Channel (RDS-TMC) or General Packet Radio Service (GPRS). WMSNs can also be deployed in intelligent parking systems to monitor available parking bays. This information can be used at an area wide level to help drivers decide where to park their vehicles (i.e. which parking facility), and once there the data can also be used for directing the drivers to the available parking bays.
- *Advanced Healthcare Delivery.* WSNs have been used to provide ubiquitous healthcare services [62, 148]. A patients vital and physical parameters such as pulse, blood pressure and body temperature can be monitored, recorded and transmitted to be stored for immediate or later access. WMSNs with the ability to deliver multimedia information will allow a greater wealth of information to be gathered.
- *Environmental and Home Monitoring.* WMSNs are highly suitable for habitat and home monitoring applications as they can be densely deployed for complete coverage. For habitat monitoring, WMSNs can aid in studying the patterns of wildlife in their natural environment. The inconspicuous WMSN nodes can provide a good coverage of the environment while not affecting the environment or causing changes to the behaviour of the subjects being monitored. Home monitoring is important for those in need of care such as the elderly and those who are physically or mentally impaired. Visual information from the network can be used to detect and infer if untoward occurrences have happened such as

medical emergencies, falls and even burglaries or thefts. The system can then contact emergency services or remote assistance services.

- *Industrial Process Control.* Visual information from the visible and non-visible spectrum can be used for industrial process control. This can be used for both quality control and plant monitoring. The use of imaging sensors for quality control is not new in quality control, but the WMSN will allow greater flexibility for its placement to have finer monitoring on the manufacturing process. The audio-visual sensors can also be used in the same manner as that in environment monitoring to detect and infer emergency or exceptional situations.

2.6 Chapter Summary

This chapter has presented an overview of existing technologies for WMSNs. These include the network architectures of WMSNs, node technologies and a discussion of some of the components and information processing in WMSNs. There are many design challenges arising from the limited resources in WMSNs such as size, cost and power. This chapter also presented a possible solution to the increase of data generated through the use of in-network data processing for redundancy elimination from multi-camera systems and selective transmission and compression of the data. The following chapters will describe these solutions in detail and how it can be achieved through the use of reconfigurable hardware.

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