The Perspective of Smart Dust Mesh Based on IoEE for Safety and Security in the Smart Cities

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1 Introduction

This chapter describes smart dust structures and its application in today's intensive Internet of Everything, Everywhere (IoEE) environment. It also presents the functionality of the smart dust microdevices in a meshed network and its application in a smart city environment, targeting security aspects.

The study based on microdevices started in 1961 when the first silicon pressure sensor was introduced. Micro-electromechanical systems (MEMS) represent a technology in which tiny integrated devices or systems are built.

MEMS are defined as an integrated microscale system that performs the following functions:

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1. Conversion of physical stimuli, events, and parameters to electrical, mechanical, and optical signals and vice versa
2. Control, diagnostics, signal processing, and data acquisition features, along with microscale features of electromechanical, electronic, optical, and biological components (structures, devices, and subsystems) [1]
3. Actuation, sensing, transducer roles

MEMS handle motion, electromagnetic, radiating energy, and optical microdevices/microstructures—driving/sensing circuitry—controlling/processing integrated circuits.

In 2000, MEMS optical-networking components were fabricated, becoming a significant invention [2]. Smart dust is intended to create a millimeter-scale sensing and communication platform for a massively distributed sensor network. It is expected to be a micro-sized device with sensors, computation, bidirectional wireless communications, and a power supply. These devices must be based on inexpensive technologies for becoming widespread globally [3].

Internet of Everything Everywhere aims to connect various devices over larger areas; thus, it can be applied for building smart cities. Having that in mind, smart dust systems meet this requirement, that is, they are easy to fabricate and maintain, for example, mesh networks comprised of sensor nodes or motes are considered appropriate for the IoEE environment. In a smart city, smart dust networks can be used for monitoring parameters such as air quality, magnetic and electrical fields, water pollution, seismic activities, closed-circuit television (CCTV), traffic control, etc.

The following paragraph presents an example of a mesh network suited for applications in smart city monitoring.

The topological structure of wireless networks is shown in Fig. 1 [3]. The mesh topology is used in the development of this network. In the mesh topology, each mote is independent.

This network is formed of a mesh topology of MEMS motes that communicate through a gateway to the Internet, sending Ambiental data, for example. Furthermore, the data are collected in the form of processed data to a database. This database can send queries to the gateway and the mesh network. The terminal user can access this

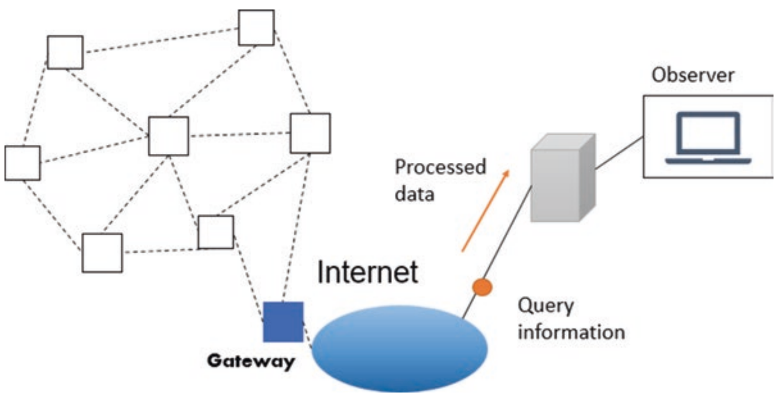


Fig. 1 The topology of mesh wireless sensor networks [3]

database to see environmental values. In this topology, the structure of the mote contains a processor, battery, interfaces to other sensors, and a radio transmitter [3].

Figure 2 shows a wireless sensor network (WSN) system diagram for real-time monitoring with a ZigBee connection. It consists of several motes for sensing temperature, humidity, dust particles concentration in the air, and acoustic level [4].

Each mote has a Global Positioning System (GPS) sensor for precise localization. The gateway module is a device with a ZigBee radio interface and a USB port that enables wireless medium transmissions to be sent over to the wired medium and to the server. The client can access information sent by the motes and their location on a map using Google Maps API, through the web application [4].

These smart city microdevices are used in the topology presented in Fig. 3.

- *Dust particles sensor (GPY21010AU0F)*: It is an optical sensor whose principle of operation is based on the detection of the infrared light emitted by an infrared

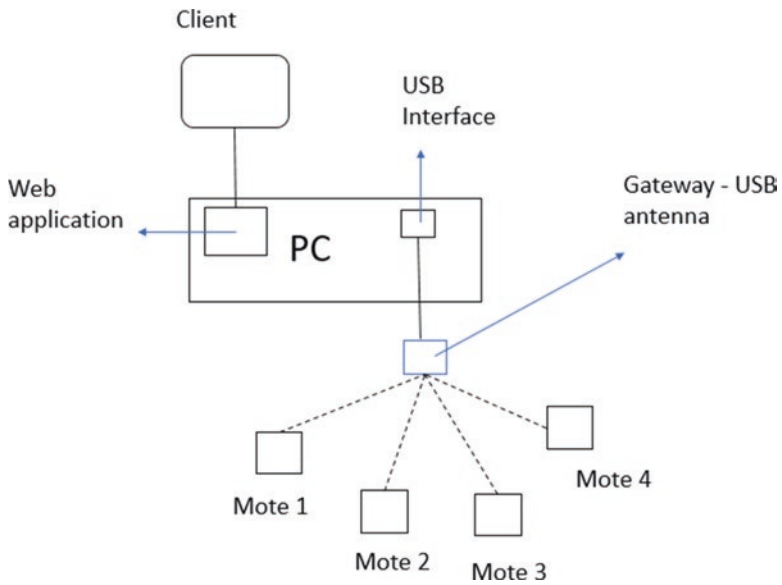


Fig. 2 A real-time monitoring system [4]

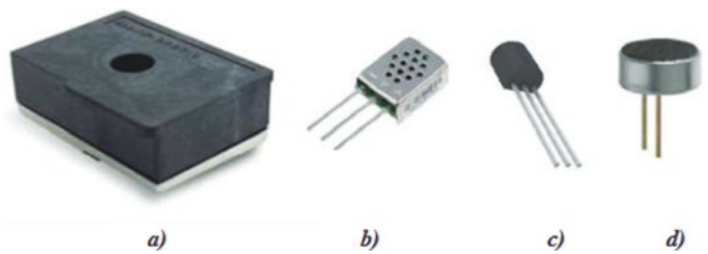


Fig. 3 Sensors used in smart city for analysis of (**a**) dust particles, (**b**) humidity, (**c**) ambient temperature, (**d**) audio

light emitting diode, reflected by the dust particles and captured through a phototransistor. The range of output values is between 0 and 0.8 mg/m^3.
- *Humidity Sensor (808H5V5)*: It is an analog sensor which provides a voltage output proportional to the relative humidity in the atmosphere. The range of output voltages is between 0.8 V (0.1% relative humidity) and 3.9 V (99% relative humidity) at 25 °C.
- *Temperature Sensor (MCP9700A)*: It is an analog sensor which proportionally changes the temperature value to an analog voltage. The output voltages range is between 100 mV −40 °C and 1,75 V 125 °C, generating a variation of 10 mV/°C, with 500 mV of output for 0 °C.
- *Audio Sensor (POM-2735P-R)*: It is an omnidirectional condenser microphone with an almost flat response in the whole frequency range of human hearing, between 20 Hz and 20 KHz. Because the output of the analog-digital converter is not correlated with the received sound pressure level, it has to be calibrated so that the return output is in the range between 50 dBA and 100 dBA.

Section 2 presents an overview of the needs, technologies, and future architectures in the context of IoT and smart cities, followed by Sect. 3 which mentions the impact of smart dust concept in healthcare surveillance for smart cities. Furthermore, Sect. 4 presents the concepts of environmental surveillance in smart cities based on IoT smart dust. Section 5 describes the main ideas about security applications based on IoT smart dust for smart cities, while Sect. 6 focuses on the privacy aspects in the context of IoEE in smart cities. Moreover, Sect. 7 introduces the concept of applications in communication, signal processing, and low power consumption by energy harvesting, which are essential in building smart dust devices. Section 8 presents the system miniaturization and architecture challenges of smart dust devices, and last but not least, Sect. 9 is the concluding section of this chapter.

2 Overview of Needs, Technologies, and Future Architectures in the Context of IoT and Smart Cities

Latest advancements of the Internet of Things (IoT) technology is to empower smart city projects and smart strategies throughout the world [1]. This section describes the actual need, future trends, technologies, and architectures of a smart city and IoT. According to a report from Gartner [1], the interest in IoT will be vital to develop and maintain smart cities and services, generating majority of the income for the economy.

A proficient smart city development should create and fuse IoT platforms that meet the requirements of the current IoT, permit the administration of a large number of associated devices, frameworks, and individuals. The main features that should be met by an IoT platform are as follows:

- Diminish expenses and create and develop IoT services
- Provide possibility to connect multiple, different systems in a city

- Reduce the implementation time and develop IoT services that are part of the smart city innovative actions
- Provide reliable and expandable service access and come up with novel opportunities for the city
- Conceive value from devices and intelligent associated data, such as top intelligent services

To create the smart city concept, numerous governments plan to adopt in the future the Information Communication Technology (ICT) concept in the administration or the public services [3].

Papers [4, 5] present the main features that an IoT platform must achieve, namely:

- Analytics
- Security
- Device management and integration
- Networking
- Protocols for data collection
- Support for visualizations

For the continuous development of the smart city market, numerous ICTs are empowering key segments, such as power, transportation, and urban planning. Latest technologies are utilized to provide intelligent and efficient innovative solutions to cities and civilians [1]. In the following, some of the trends mentioned above are highlighted, and their impact on smart cities is specified.

- *Networking and communications: LoRAWAN, 3G/4G, 5G*

- The communication technologies are fundamental for today's trends. It empowers smart cities to interface infrastructure with devices and civilians to collect information and to supply services to a multitudinous terminus. LoRaWAN technologies, 3/4G evolution, and 5G networking will play a key role in the future developments of smart cities: LoRaWAN technology uses unlicensed specter and focuses on low power and low-cost developments. Mobile technology evolutions are the focus of the 3GPP consortium which is working on CAT-1, CAT-M1, and the NB-LTE (Narrow-Band Long-Term Evolution). 5G offers a superior bandwidth and guarantees performances in energy consumption and flexibility.
- *Cloud and edge computing*
- Cloud computing has impacted the improvement of smart cities, influencing how urban communities oversee and convey services, empowering a vast number of stakeholders to enter the smart city market. Cloud computing offers different methods to reduce costs and improve efficiency. On the other hand, edge computing describes the deployment and utilization of handling inside as well as at the edge of the network.
- *Big data and data analytics*
- Big data, if organized and operated correctly, can provide insights and financial values that can be used by the stakeholders and civilians to increase effectiveness, and it can generate innovative services to enhance the quality of life.

- *Open data*
- With regard to smart cities, open data addresses the public policy that demands or gives support to public agencies to release information packages and provide accessibility to the public at large.

IoT and the other associated information technology deal with the Internet for reinforcing different devices to each other; all devices should be connected to the Internet. The most relevant applications of the IoT technology for smart city are as follows [7]:

1. *Environmental Pollution, Water, Weather, Health, and Surveillance Systems*
   Environmental pollution should be observed in a city and the gathered information transmitted to its citizens thus conveying to them the level of the pollution in their city. Sensors, such as temperature, humidity, rain, wind, etc., can be used in water and weather systems thus enhancing the effectiveness of smart cities. Also, surveillance systems can be useful to monitor the city so as to improve the degree of security continuously.
2. *Smart Grid and Energy-Efficient Operation*
   The smart grid is referring to all the newest technologies (autonomous and intelligent controllers, etc.) [5], which can create an automated and dispersed energy delivery network. The IoT technology, when applied to the power network, will contribute to a profitable power generation, consumption, transmission, and distribution.
3. *Smart Homes, Offices, Buildings*
   Sensors can maintain and control the power consumption of smart homes. The main ambition is to reduce the consumption and the resources (electricity, water, etc.) correlated with the buildings.
4. *Smart Traffic Management and Parking Lots, Urban Transportation (Public and Individual), Logistics*

Traffic management information is the most critical data source in a smart city and, by managing them properly, civilians and government could substantially profit [8]. Also, smart parking areas can be monitored; arrival and departure of various vehicles can be tracked for different parking lots in the city. Moreover, new parking lots will be built in the future when the number of vehicles exceeds the parking space.

In smart cities, sensors are essential in monitoring external parameters such as gas, smoke, air, electricity, and others. New technology must be implemented for the sensors to become robust, cheap, easy to use, and maintenance must be easy for technicians. Other ideas to monitor are to implement a series of sensors: accelerometers which can monitor acceleration and vibration, acoustic sensors used to detect sound waves. All these sensors will be minimized in size to be easily mounted and implemented with nanotechnology. Nanotechnology is especially applicable in bio-sensing applications [9].

Wireless networks are used to capture the information from the sensors, and then transmit it to a database. These networks consist of a processor, sensors, power supply,

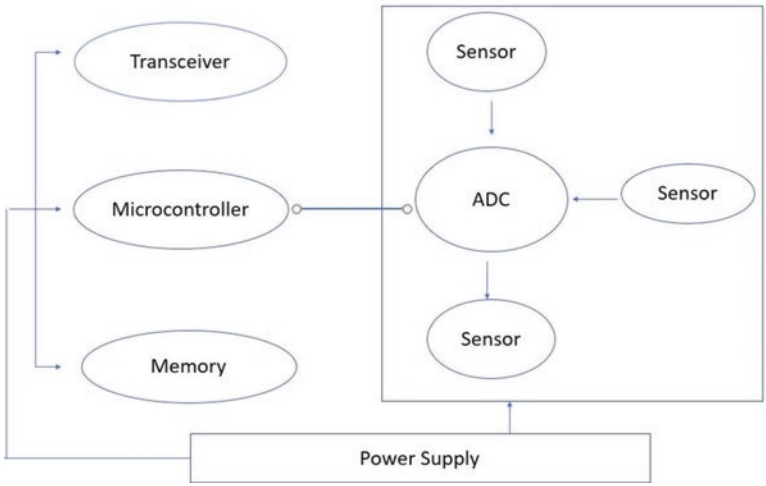


Fig. 4 Wireless sensor network

a radio interface, and a processor. Figure 4 is a diagrammatic representation of a wireless sensor network [14].

The wireless sensor network presented in Fig. 4 can be installed in a house as an indoor system based on diode (LED) lamps for capturing light and setting the intensity depending on natural light. The indoor monitoring system can be instaled on windows for capturing the factors from the room or outside to set the environmental light. These types of windows are designed to absorb or reflect light depending on the external electrical stimulus [10].

An interesting concept which arises in Big Data analytics is new in our days. This concept is used in domains like energy, transport, and smart cities. In smart cities that contain a multitude of sensors and store data on servers, these data can be analyzed.

Characteristics for big data:

- Volume: data comes from servers, social networks occupy much space, and the transmission is fast.
- Velocity: is another factor because it is based on processing speed and time to process the data.
- Variety: there are three types of data, but only two are basic: structure and unstructured and also semi-structured data. In this case, the database works for structured data [11].

Technologies and techniques for processing data:

- Store data using database and servers
- Interpret data using software programs, database, and clouds
- Collect data from sensors and process them [5]

- Enhance feasibility of algorithms using machine learning, statistics programs
- Utilize Wi-Fi networks, GPS, GPRS, LPWAN
- Visualize and interpret data for the general public

3 Healthcare Surveillance in Smart Cities Based on Smart Dust Concept

A smart city [6] has various entities, such as smart economy, smart environmental control, smart traffic system, smart governance, smart home, smart energy, and also smart healthcare. Smart healthcare doesn't necessarily mean only supervising the patient when they are in the hospital but also after the patient is discharged from the hospital. Some examples of continuous monitoring are sensing blood glucose, blood pressure, and heart rate sensors, along with the location of the patient.

Interestingly, the smart dust concept is not new; it was [7] first presented to the public in 2001 by Kristofer from the University of California. It was initially envisioned as a miniature wireless semiconductor device manufactured by using techniques from the microelectronics industry. With sizes comparable to those of grains of sand, these devices would combine sensing, computing, and communications in a single package. A smart dust network is comprised of numerous smart dust devices, enabling not only mutual communication but also data collection. Smart dust belongs to the Internet of Things environment, and at the intersection with the Web of Things, WSNs are resulted, as shown in Fig. 5.

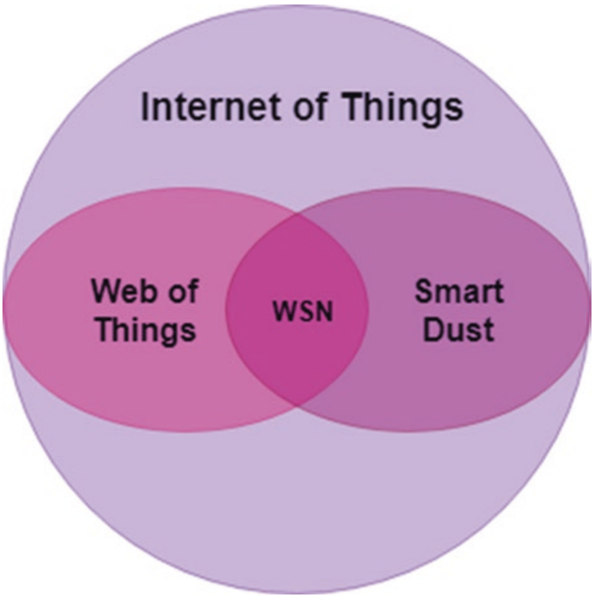


Fig. 5 The relationship between IoT, Web of Things (WoT), wireless sensor network (WSN), and smart dust [20]

Smart dust [8] overcomes the limitations brought by the sizes of surveillance equipment by deploying sensor nodes to a variety of environments and collecting real-time information.

Healthcare is a fast-growing sector and requires much attention with regard to the safety of patients and devices. As the smart city concept is newly emerging, its execution opens up vast areas for discussion. Smart dust technology can be executed in the healthcare surveillance sector in compact forms. It is common for people to go to a hospital for health-related check-ups. As the lifestyle of people has changed considerably in the last century, wearable devices have been proven to be a safe alternative for conducting health check-ups. Micro-electromechanical systems (MEMS) [9] represent mechanical and electromechanical elements at the nano-structure level. They are composed of isotropic and anisotropic etching. Also, they can include components made of thin deposition methods or anodic bonding and other technologies. One example would be microsystems sensor technology which hold an essential role in detecting data; they are low cost and work on low power microcontrollers. The main applications used in healthcare would be inertial measurement units made by accelerometers and gyroscopes. Another example would be an inertial-based system meant for motion analysis. This system is constructed based on a 9-axis complete MEMS inertial module.

The MEMS [10] accelerometers perceive the total accelerations contributed by gravitation acceleration and motion of the sensor relative to an inertial reference frame. The acceleration is detected by measuring the change in capacitance that comes from displacement between silicon microstructures forming capacitance plates. The measured capacitance may then be applied to compute acceleration. The MEMS gyroscopes measure the Coriolis force exerted by a vibrating silicon micromachine mass on its flexible silicon support when the sensor undergoes rotation. Silicon microstructures within the gyroscope use electrostatic forces exerted through capacitive plates to vibrate the suspended proof mass. The Coriolis force, generally referred to as an imaginary force, represents a mass acting on an object moving in a rotating reference frame. Rotation of the sensor includes the Coriolis force leading to a displacement of the proof mass that is proportional to the angular rotational rate.

Activities that require monitoring using MEMS inertial sensors are increasing in number. Reference [11] employs the human walking for gait analysis using two MEMS gyroscopes, one attached to each side of the lower waist. This structure allows the step detection and discrimination from other nonbipedal activities without the need for magnitude thresholds or training. It is also capable of calculating hip rotation angle in the sagittal plane which permits the estimation of step length. In [12], an ambulatory real-time rehabilitation system employs MEMS accelerometers, magnetometers, and gyroscopes to acquire the upper limb motion data of patients and to collect a group of motion quality evaluation indicators of universal significance according to the clinical needs in evaluating patient's upper limb motion quality. A novel and systematic approach [13] using MEMS sensors are estimating limb length, especially for applications such as treatment of leg limb length discrepancy (LLD).

To detect [14, 15] relative position in 3D space, data from inertial sensors require double integration. Thus, the drift and broadband noise present in the MEMS sensor result in rapid accumulation of errors. To meet the stringent accuracy requirements for use in healthcare, algorithms must be developed to reduce the impact of noise on the final result.

4 Environmental Surveillance in Smart Cities Based on IoT Smart Dust

Internet of things (IoT) can add to the commercial development of a nation. Due to the notoriety of IoT, applications identified with IoT have gained interest. Smart dust can be utilized to improve the abilities of IoT gadgets and lead to a decrease in the cost.

When it comes to talking about smart dust based on IoT applications, the basic building block is based on motes. One of the scopes of having these motes in the environment may be to develop some weather challenges, for example, how rain can affect a smart city.

There can be two essential approaches to distribute smart dust in a smart city, namely, Ubiquitous and Critical Zones.

Ubiquitous strategy can be utilized to convey smart dust to cover the entire locale of a smart city, and further, it very well may be isolated into persistent and noncontinuous monitoring.

Critical Zones can be utilized when monitoring is mandatory in zones which are sensitive to environmental activities. This system can help in diminishing establishment cost as it causes only specific zones. On the off chance that a zone is sensitive to the event of environment, at that point, vast-scale organization of the smart dust can bring about more precision in storing, sensing, communicating the events, and processing.

To make a comparison between Critical and Ubiquitous strategies, Ubiquitous is much more expensive because it needs more devices on purpose to cover the whole region.

In general, distribute smart dust is composed of several motes. Every smart dust functions as components with small size, and these are difficult to detect. Figure 6 presents systems of smart dust, which include 25 motes.

CAC or Criminal Activity Controller, helps in collecting and saving data which are transmitted by the smart dust motes.

Regarding the usability of smart dust in a smart city, it is even possible to utilize smart dust to detect microbes. For example, smart dust can be used to reduce different kinds of diseases that spread due to microbes such as fungi or bacteria.

In the future, smart dust will be used in almost every application which includes the environment. They have a huge potential in many fields such as medical, environment, engineering, and military domains.

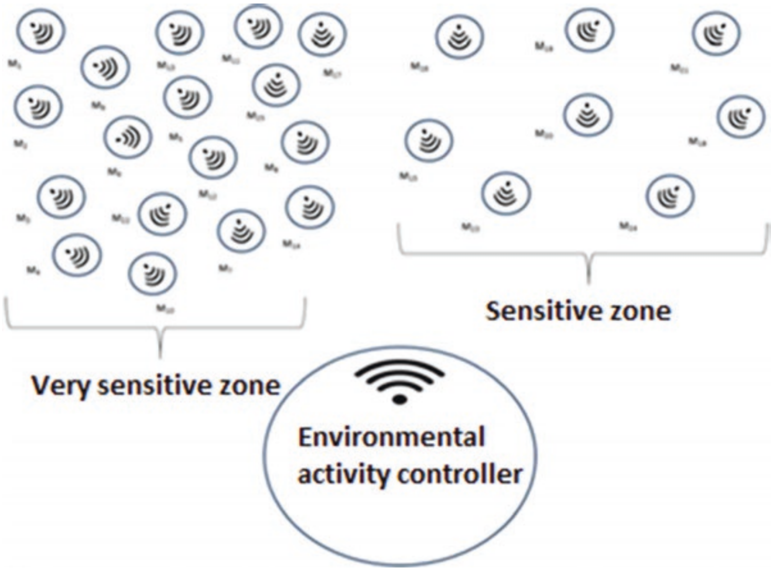


Fig. 6 Organization of smart dust in the environment [15]

On the one hand, Alvin Toffler used smart dust to analyze the environment [16]. On the other hand, Toffler and Christine Peterson [17] believe that criminals use smart dust for invading personal privacy.

Currently, a wide range of scientific authors used smart dust to detect vehicles and thus monitor vehicular activities from a specific region.

In conclusion, researchers came up with the idea that smart dust will be beneficial for the environment and people. Also, according to them, more intelligent dust sensors will improve a system that can be used in any application in a smart city.

5 Security Use Cases Based on IoT Smart Dust for Smart Cities

As a new and rising technology, smart dust brings certain risks in terms of privacy and ethics. By using this technology, data will be stored by IoT devices including smart TVs, smart speakers, toys, wearables, smart appliances, etc. These microscopic sensors which are capable of collecting visual and audio data from anywhere raise several questions about data security, privacy, and storage [18].

Sensors can be used in industrial, commercial, and security fields. Security requirements must be very tight, considering the applicability and size of the sensors and include access control, message authentication, data encryption, and key exchange.

The most sensitive fields concerning security are defense and health. To have a secure transmission of the data collected by the sensors, wireless nodes must have specific certifications and implementations of security standards included, while preserving their features such as reduced computing power and quality of communication [19]. Communication is achieved through a wireless network, more precisely through a broadcast primitive.

The requirements of a smart city include ensuring efficiency and sustainability by integrating infrastructures and services into a complete structure, simultaneously using intelligent devices for control and monitoring, as presented in Fig. 7.

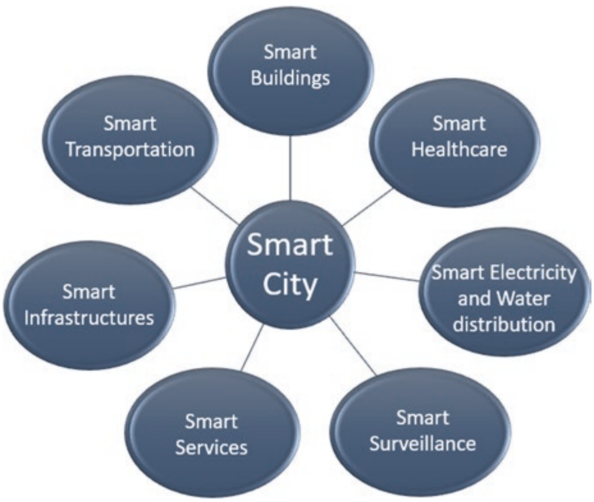
Sensor usage in monitoring public infrastructures can produce more efficient use of resources, based on the collected data. Smart monitoring is valid only when working with a large number of sensors. They must be interconnected to transmit the collected data to a system where intelligent decisions can be taken based on this information.

In terms of Internet of Things (IoT), there are some issues regarding smart sensing. First, by having a large number of sensors, cabling is not a solution to be taken into consideration. Thus, the communication between sensors must be wireless. Second, there is the problem of power consumption. Due to the heterogeneity and also the number of sensors, low power communication standards are necessary.

The primary conditions to be established require sensors to be low-cost and low-powered. The only sensors that match this requirement are smart dust sensors [20]. There are three significant advantages of smart dust sensors:

1. Low system and infrastructure costs
2. Increased productivity
3. Increased safety, efficiency, and compliance levels

Fig. 7 Sensing in smart cities



In urban areas, smart dust sensors are used to determine traffic congestion areas or, also, can be used to predict the location of an accident if any. They also have the attribute to evaluate the structural soundness of buildings. The procedure is done by incorporating motes into the foundation of the building and checking the level of vibrations, heat, humidity, etc. [21].

Regarding the smart parking use case of smart dust, Customer Streetline Inc. company designs such solutions for cities in the United States. They have embedded sensors on the surfaces of the parking lot. The drivers activate a dashboard system using their passwords, and the system finds the nearest parking spot. With this information, traffic managers can monitor and improve traffic flows and also can boost revenue from parking meters by announcing the managers when a meter has expired.

Another important application for sensors is to monitor the quality of drinking water distribution systems, industrial uses, and surface water in the smart city. The online water quality monitoring sensor is becoming popular in water distribution systems to ensure that drinking water has the required standards. Right next to the development of electrode-based sensors that monitor various water quality parameters (pH, salinity, dissolved oxygen, solubility, temperature, turbidity, etc.), the luminescent-based sensors are gaining more attention due to their reliability, less maintenance, and a longer span of life.

Also, the free chlorine and total organic carbon (TOC) sensors are successful technologies. Application of sensor array also has high potentials for the detection of hydrophobic and highly volatile organic compounds (VOC) in water. With the advancement in sensor technology and computing and pattern recognition facility, several approaches have been reported for the real-time detection of petroleum hydrocarbon and other organic components in water. The digital sensors of monitoring and controlling activated sludge wastewater treatment processes in a full-scale plant are now the backbone of the automatic control system.

For smart cities, air quality monitoring by detecting the gaseous compound in the air is inevitable for the control of air pollution. Several smart gas sensor systems for monitoring environmental changes have been invented over the past decade for this application. This particular smart gas system can sense the complex mixture of volatile substances and perform efficiently over the years with little degradation [22].

Taking into consideration privacy concerns, smart dust networks are equipped with secure encryption and security measures. Therefore, it has been proven that there are no cases of theft of data while using these sensors [23].

However, in the scope of security and privacy of personal data, which are the two most important limitations for the growth of the Internet of Things (IoT) market, the undergoing PARFAIT (Personal dAta pRotection FrAmework for IoT interoperability) project aims to implement a platform for securing personal data within IoT applications and to reduce the complexity of deploying and integrating services in the present IoT technology by offering interoperable software tools, libraries, and SDK components.

6 Privacy Perspectives in the Context of the Internet of Everything, Everywhere (IoEE) in the Smart Cities

The IoEE brings together people, data, processes, and things, network connections gaining significant importance within people's lives, as presented in Fig. 8. With the evolution of IoEE, risks regarding privacy and confidentiality of personal data are becoming a significant concern. For any technology, the privacy rights of citizens should be guaranteed anywhere and anytime. Despite the benefits of smart cities services, privacy breaches are becoming worrisome because smart city applications not only have access to a wide range of privacy-sensitive information from people's lives but also it processes this information, by manipulating it.

Smart city applications raise several concerns and challenges in terms of security and privacy. The sensitive data from smart cities should be protected from unauthorized access, disclosure, disruption, modification, inspection, and deletion, but it is still vulnerable to privacy leakage and information inferring by outside hackers since private information is collected, transmitted, and processed. The disclosed privacy in a smart city may contain a user's identity and location in transportation, a health condition in healthcare, lifestyle inferred from intelligent surveillance, smart energy in homes, offices, and community [1].

In smart cities, privacy and public safety remain a major concern that needs more legal, scientific, and political consideration. It is imperative to fight against cybercrime in smart cities. The countermeasures that can be taken in specific urban sectors and also the threats they face are enumerated in Table 1.

Most smart city services are based on ICTs. Sometimes users (especially teenagers and the elderly) do not experience security issues and become ideal targets for attackers when interacting with their smartphones, tablets, and computers with many smart city services and disclosing information.

Fig. 8 The IoEE bringing together people, data, processes, and things

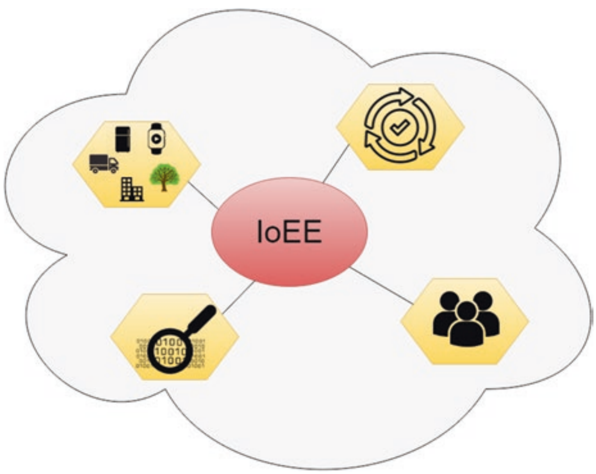


Table 1 Security and privacy concerns and countermeasures in smart cities [34]

Sector	Threats	Countermeasures
Smart buildings sector	Infection by malware systems failure Fraud by staff and unauthorized users Controlling the fire system Causing physical damage such as flooding. Disrupting building temperature (overheating or overcooling) Damaging or controlling lifts and escalators Open windows and doors Modifying smart meters Opening parking gates Disabling water and electricity supplies Starting/stopping of irrigation water system Stopping renewable energy systems (RES)	Two-factor authentication and one-time passwords for stronger authentication IoT forensics (DigiCert IoT PKI Solutions, and Symantec solutions) Threat and risk modeling Data backup and recovery solutions to ensure reliability and continuity of services
Transport sector	Sending false emergency messages Disrupting a vehicle's braking system Stopping the vehicle's engine Triggering false displays in the vehicle's dashboard Disrupting the vehicle's emergency response system Changing GPS signals	Public critical infrastructure (PKI), digital certificates (ECDSA), and data encryption solutions (ECIES and AES) Misbehavior detection solutions Pseudorandom identities
Government sector	Preventing of cybercrime Identity theft Disrupting critical infrastructures Fiscal fraud Altered files	Data leakage prevention Risk assessment Insider threat analysis Awareness training
Healthcare sector	Modifying patients record or information Exposing sensitive data unintentionally Disrupting the monitoring system Disrupting the emergency services Sending false information Jamming attacks Sending an emergency alert Eavesdropping sensitive information	Secured Wi-Fi networks to guarantee safe handling of confidential information and personal data (AirTight Networks solutions, Aerohive security solutions) Risk assessment (Rapid solutions, Health Security Solutions, SafeNet's data security solutions, Stanley security solutions, Intel healthcare security solutions)

(continued)

Table 1 (continued)

Sector	Threats	Countermeasures
Energy sector	Spoofing addresses and usernames Unauthorized access and controls Zero-day attacks Botnets (Zeus, ZeroAccess, Conficker, etc.) Denial of service and distributed denial of service (DDoS)	Intrusion detection and prevention techniques Risk assessment Insider threat analysis Cybercrime intelligence
Financial sector	Loss of privacy Accounting fraud Disrupting business processes Accessing confidential company information Accessing confidential customer information Damaging reputation(s) Defacing websites Financial and reputation concerns due to fraud and data leakage Denial of service and DDoS Phishing Mobile banking exploitation SQL injection	Anti-malware solutions Encrypted files and firewalling Fraud detection and prevention techniques Risk assessment (MEHARI, EBIOS) Insurance to mitigate cybercrime risk Cybercrime intelligence

To understand the importance of data protection challenges in smart cities, an example has been cited. The number plate of a vehicle is related to the identity of the vehicle owner. Thus, the trajectory of a vehicle can be easily tracked, even if all communications between the vehicle and the infrastructure are encrypted and each device is authenticated by others. It violates the general notion of privacy, which includes the right of individuals to live their lives in a manner that is somewhat beyond the control of the public. In a smart city, future vehicles will have various communication features, including Internet access, GPS, electronic toll collection (ETC), and radio-frequency identification (RFID). The devices connected in a vehicle store much personal information and have multiple communication functions. In a smart city, the number of connected devices is very high. With data collected by IoT devices, data users can understand the behavior of data owners or use this data to obtain highly personal information, including whereabouts of the individual.

An information system has three primary operations: data transfer, storage, and processing. All of these operations may raise privacy issues affecting the user's behavior. Services may be associated with the user's location, which can create privacy issues. For example, in a smart city, two companies can use data protection procedures to compare their activities without revealing their critical data. It is possible to use an approach based on linear algebra operations, such as matrix multiplication, to solve linear systems and calculate the correlation between distributed datasets. The proposed solution is efficient and theoretically secure. However, on a large scale, the performance of this solution is unreliable because it depends on a trusted initializer that must send data to the parties involved before running the protocol. Unfortunately, privacy techniques do not address restrictions such as frequent changes to unapproved members and third parties (cloud providers). Therefore, protection of privacy remains a significant challenge [1].

A legislation is essential to ensure privacy in smart cities. The UK Parliament recently passed a bill to give intelligence agencies unlimited access to users' Internet browsing data. Under this law, intelligence agencies can legally intercept and decipher people's communications. Service providers can save users' browsing data for 12 months. Police can also legally hack computers, networks, and mobile phones. However, Microsoft, Facebook, Google, Yahoo, and Twitter rejected this project. Human Rights Watch argued that this type of project is dangerous and too intrusive to the confidentiality of the organization. In France, a new law on surveillance was adopted in July 2015 (Law No. 2015-912 of July 24, 2015). The new law allows intelligence agencies to monitor the communication (e-mails and phone calls) of suspects [1].

7 Use Cases for Communication, Signal Processing, and Low Power Consumption by Energy Harvesting

To transfer data and to provide power, most of today's sensor networks are based on a wired infrastructure. However, this type of configuration for communication and power often leads to costs which are much bigger than the value of the sensors themselves. Moreover, during the recent years, wireless connectivity has been an essential alternative for sensors, because of its reliability. In addition, wireless communication for smart sensors systems has been reduced to cases where it is acceptable to lose occasionally the connectivity and the data. To reduce energy consumption, the technology of passing optical communication for smart dust motes was studied. One of the smallest optical motes (each wireless sensor node) in the present has only 4 mm^3, contains An 8-bit Analog to Digital Converter (ADC), a sensor for light, an accelerometer, a source for power represented by a multi-voltage solar cell, an optical receiver, a corner-cube reflector passive optical transmitter, and a limited computation. A newer version of a sensor mote presents a complete radio-frequency transceiver, an ADC, microprocessor, and a sensor interface.

The Internet revolution has represented an essential aspect of replacing point-to-point wired communications by multi-hop wired communications. The fact which makes the Internet reliable is that the Internet mesh is insensitive to the loss of a node or a path [2].

One of the most critical aspects of the smart dust network is communication between dust nodes. All the motes in the network have to communicate with each other through the base station. While considering all the design constraints due to size and power limitation, data must be collected from the motes simultaneously, sent to the base station for further action [2].

In downlink (i.e., data propagation from the base station to the dust motes), the base station broadcasts to all the specks in the network at a rate of several kbps. Moreover, in the uplink (i.e., data propagation from motes to the base station), the data transfer rate is of 1 kbps. Hence, if a total number of 1000 dust motes are employed in the network, the data throughput will be 1 Mbps. The data transfer both in uplink and downlink should support distances of a couple of hundred meters [12].

There are other specifications regarding the mote. Dust mote size should be less than 1 mm^3 and must have a power consumption of at the most 1 μW. We also need a secure and reliable transmission method for communication in the network.

The task of the communication system is to send and collect commands to and from motes:

- Radio-frequency transmission
- Optical transmission technique
- Fiber-optic communication

Radio-frequency (RF) technology has advanced a lot in the last few years and is being used widely in different applications. In this method of transmission, radio-frequency signals of range from tens of KiloHertz to hundreds of GigaHertz are used [12].

The main feature which provides the reliability in a multi-hop radio-frequency mesh sensor network is the end-to-end furnishing of time-stamped sensor data with a determined worst-case latency. The main requirement for the reliability of the time-stamping is the choice of radio, the use of spectrum, as well as the network synchronization. Most of the motes operate in large bands which have values from 902 to 928 MHz (in North America) or from 2.4 to 2.458 GHz (most of the world).

Because these kinds of bands are open to transmitters and they put out about 1 W, the motes generally have an output value of 1 mW to extend the life of the battery; in this case, they have to maintain the reliability by avoiding high-power interferers. These kinds of interferers, as well as the unpredictable fading ones, exclude the use in high-reliability applications of fixed-frequency radios. A solution can be considered reliable if it is capable of avoiding or working near the parts of the spectrum that are jammed or very faded [17].

RF communication is a perfect potential candidate for smart dust networks, but at the same time, there are a couple of problems associated with it:

- RF transceivers, it is almost impossible to achieve the low power specification requirements needed for smart dust system.
- One of the issues addressed in antenna design is the size limitation. Size of a fabricated antenna is limited by margins based on the range of its cubic millimeter. An antenna size cannot exceed a quarter of the wavelength of the carrier, and the size shall be defined in the area of very short of the wavelength which results in having an operation which does not necessarily run at efficient power consumption.

- Due to the high number of dust motes, it is necessary to use multiplexing techniques for achieving RF communication; multiplexing techniques, such as code-division multiplexing or time/frequency multiplexing. This means that several kinds of RF circuitry like filters, modulators, and demodulators are needed, and they should be designed for low power consumption.
- Using multiple access techniques such as TDMA or CDMA or similar SDM has their complexity, which is not compatible with the smart dust system.

Optical communication utilizes semiconductor lasers and diode receivers for transferring optical signals. This optical communication method is more compatible with the low power design requirements due to the small size of optical transceivers. In optical communication, we can easily create a 1GHz signal from a millimeter aperture, but to produce the same signal in RF communication an antenna of 100 meters is required (due to the wavelength difference between two transmissions). Concerning power, once again, optical communication is advantageous because it has a simple circuit.

The passive reflective communication consists of a particular device called CCR (corner-cube retroreflector) with three mutually orthogonal mirrors. Light enters the CCR, and the reflection is parallel to its direction [13]. In the case of the MEMS version, there is only one mirror mounted on the device, at an angle that is not perpendicular to the other mirrors [24].

When the mirror is positioned as described above, a value of digital 0 is obtained, because there is only a small amount of light that returns to the source. If a value of digital 1 is desired, we have to apply a voltage between an electrode that is underneath the mirror and on the mirror itself to obtain a position of the mirror perpendicular to the other mirrors. Due to the low mass of the mirror, the CCR device can switch between the 0 value and the 1 value up to thousand times per second, and using a small amount of energy, less than a nanojoule per transition.

In this type of communication, an onboard light source is necessary for the dust mote. However, by using a particular configuration composed of mirrors, it may or may not be possible to reflect the light to a source that is remote. Figure 9 presents the corner-cube retroreflector (CCR) that is utilized to adapt the idea of the smart dust [2].

For the mote-to-mote communication, a system active-steered laser uses an onboard light source to send a light beam to a receiver.

The advantage of this laser communication is its high power density. The density of a 1 milliwatt laser radiating into 1 milliradian is approximately 318 kilowatts per steradian, as opposed to a 100 watt light bulb that radiates 8 watts per steradian isotropically.

A smart dust transmitted beam has a divergence of approximately 1 milliradian, allowing transmission over enormous ranges using milliwatts of power [2].

Every mote carefully weighs the needs to sense, compute, communicate, and evaluate its energy reserve status before allocating nanojoules of energy to turn on its transmitter.

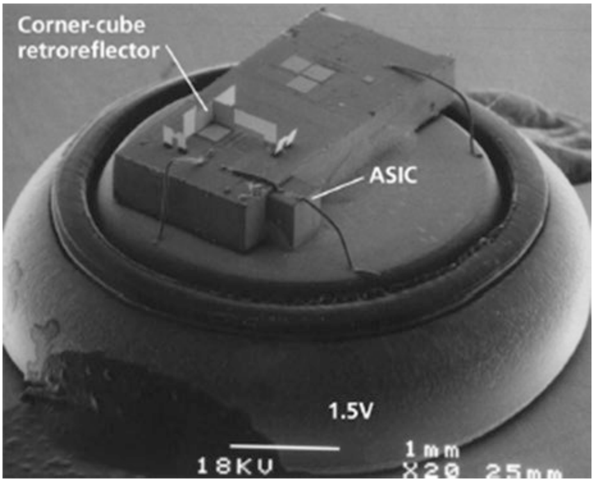


Fig. 9 Autonomous bidirectional communication mote with a MEMS optics chip containing a corner-cube retroreflector on the large die, a CMOS application-specific integrated circuit (ASIC) for control on the 300 × 360 microns die, and a hearing aid battery for power. The total volume is 63 mm^3

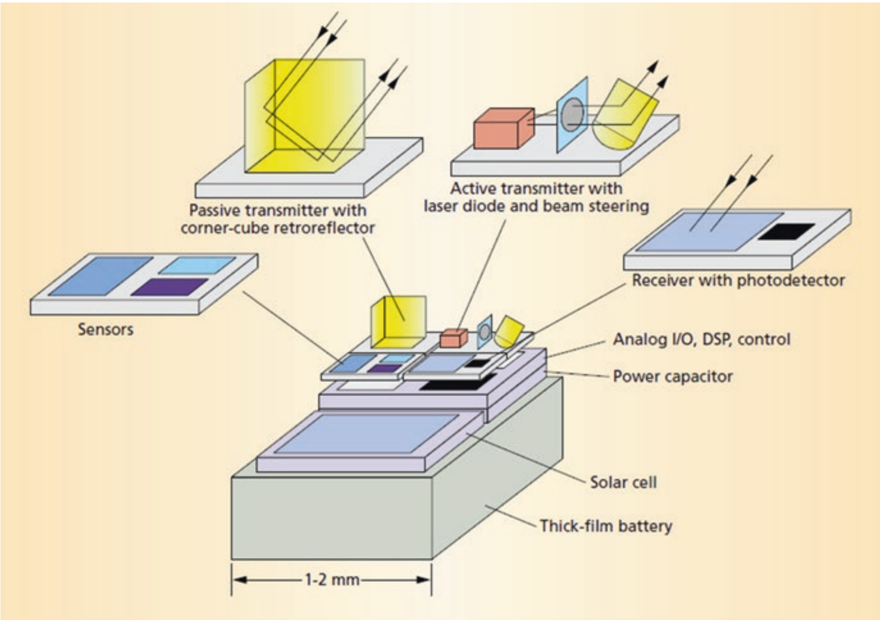


Fig. 10 Power system

Using burst mode transmission, in which the laser operates at up to several tens of Mbps for a few milliseconds, it assures the best energy-efficient method to program this mesh. This system utilizes the energy reserves and minimizes the mote's duty cycle, as shown in Fig. 10.

A semiconductor laser, a fiber cable, and a diode receiver are utilized to generate, transfer, and detect the optical signal. The power consumption is low due to the small size of the optical transceiver, and there is no need for a light source on the dust mote itself [12].

There are some advantages and disadvantages in fiber-optic communication. In fiber-optic communication, there is no need for the line-of-sight, because it uses fiber-optics to transfer and receive optical signals. This method is also safer for human eyes as no laser is involved. An extended range of communication and guaranteed communication between the dust motes and base station are two other advantages.

The fiber-optic cables are the source that limits the movement and mobility of dust motes. Moreover, each dust mote should have a connection to the base station (lots of cables), which makes the design of the base station a complicated task.

Generally, in a smart dust design, the main challenge concerns the minimum energy consumption that is necessary to power the circuits and MEMS devices. Moreover, the primary constraint after fitting the entire mote into 1 mm^3 volume is the energy density of the power supply [2].

Nowadays, most of the applications in the building as well as in the industrial automation require a lifetime which can be measured in years. In this situation, the need of the hour is a battery that has a lifetime from 1 to 10 years, thus avoiding the costs of the replacement of a high-powered battery. Using a battery of type AA that has a charge about 12000 J, an inch-scale mote needs to have an average power consumption that does not exceed a few joules or tens to hundreds of microwatts per day.

To achieve the values mentioned above, and to meet the current consumption of tens of microamps, a deep duty cycle is required. This implies the ability of the hardware to switch quickly from the powered state to the unpowered state (and low leakage) and vice versa. In the digital circuits, especially the SRAM, at shallow duty cycles, the leakage power can dominate the energy of the system.

In a profoundly duty-cycled environment, besides the problem of leakage, there are other significant challenges for multi-hop mesh networking which has radio communication. Most of these challenges concern the development of the algorithms and the software. In this situation, it is preferable to have hardware support that can provide some combination of more-to-more time synchronization, fast radio polling, and also a low-power detection of RF energy [17].

8 System Miniaturization and Architectural Challenges

Miniaturization allows integration of any type of mote into a single device and its functioning with a smart dust system. Size reduction is significant in reducing the cost of the nodes and making its implementation easy.

Smart dust can include hundreds to thousands of dust motes, each containing one or more sensors, analog circuitry, a power supply, bidirectional communication, and a programmable microprocessor.

Advances in miniaturization, integration, and energy management in a digital circuit, micro-electromechanical systems (MEMS) led to the manufacturing of small sensors, optical communication components, and power supplies.

Micro-electromechanical systems consist of extremely tiny mechanical elements, often integrated with electronic circuitry. All these are measured in micrometers, similar to computer chips. In addition to the advantage of making small structures, this manufacturing process can simultaneously fabricate thousands or even millions of system elements. This makes the system highly complex and extremely low in cost.

It is certainly expected that future prototypes of smart dust could be small enough to remain suspended in the air, beyond air currents, sensing and communicating for hours or days on end.

According to the requirements of power constraints in smart dust, the performance is handled this way: a cubic-millimeter battery supports one Joule of energy (1 J/mm^3). With the corner-cube reflector described in Fig. 11, communication costs about 1 nJ/bit, while sensing can be achieved at ~1 nJ/sample. For example, the StrongARM SA1100 processor computes ~1 nJ per instruction.

A smart dust constraint is related to its design for the minimum energy consumption of MEMS devices. The challenge here is to integrate a mote into a 1 mm^3 volume, but the energy density of the power supply is the primary issue. The existent batteries have ~1 J/mm^3 of energy and high series resistance. The existent capacitors can achieve maximum ~10 mJ/mm^3 with a low series resistance [40, 41].

The size of a MEMS is in the range of 1 mm and 1 μm, and the size of a NEMS is in the range of 1 nm to 100 μm. A MEMS/NEMS structure is thin-walled, and it is exposed to mechanical loading, high temperature, and electromagnetic fields. MEMS/NEMS can interact mechanically and thermally with other layers, bases, and elements. This contact is realized with thin heat-conducting layers [2].

A team from the University of Michigan designed the Michigan Micro Mote, which is 2 millimeters wide—the smallest size known. Reducing the size of the

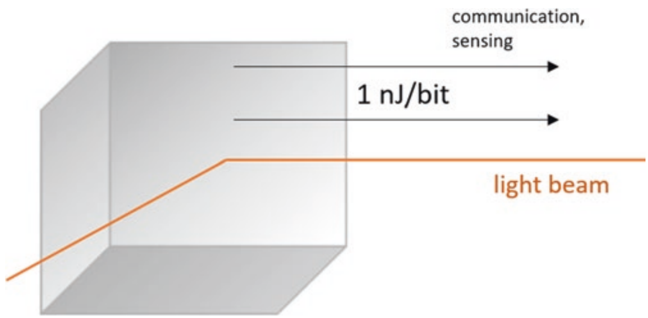


Fig. 11 The corner-cube reflector (CCR) [39]

battery was a great challenge. According to Blaaw, an application is needed that drives the final production of smart dust sensors to remain low cost. Building such an application presented to be a challenge in the smart dust economy [2].

The MEMS cubic device is presented in Fig. 12 [2]. It is structured in an analog I/O and DSP control, a passive transmitter, an active transmitter, a receiver which is a photo-detector, a solar cell, a thick-film battery, and a power capacitor, as shown in Figs. 13, 14, and 15.

The challenge in MEMS microcubes is to maintain low power consumption and to maximize the life of a mote. The total energy stored on average a micro-sized power battery is 1 J. The solution is to keep the total energy consumption under microwatt values and to use solar cells that produce 1 J per day

The architecture presented above is included in the structure of a mote, along with the sensors. Therefore, a mote gathers data from the environment related to

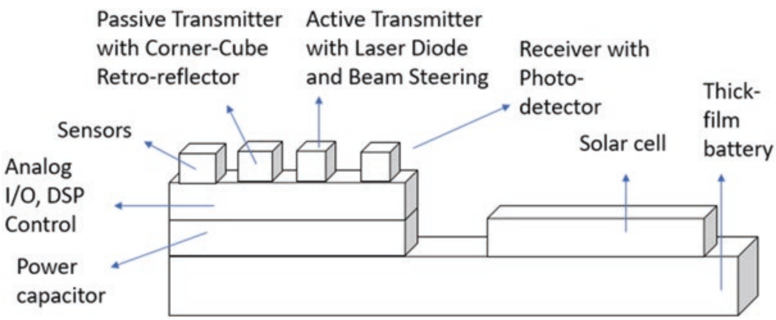
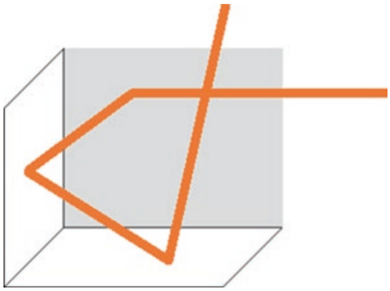


Fig. 12 The MEMS architecture

Fig. 13 The passive transmitter which is a corner-cube retroreflector is hit by a light beam



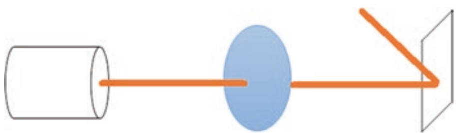


Fig. 14 The active transmitter in which a light beam from a laser diode (left) is being directed through a steer lens, toward a reflector (right)

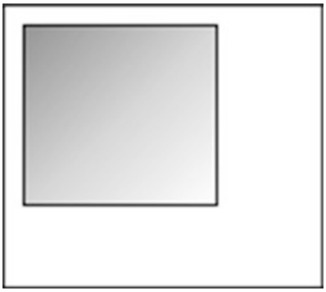


Fig. 15 Receiver with photo-detector

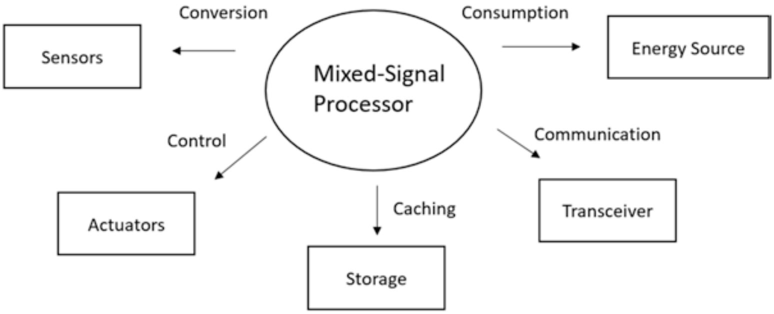


Fig. 16 A wireless body area sensor network

temperature, light, and other parameters, depending on which domain the mote will be installed. The MEMS mote is well suited for air monitoring and video monitoring in a smart city.

Low-cost microsystem sensor technologies are available in healthcare [25] with inexpensive low-power microcontrollers and reliable telemetry modules. These technologies are upgraded versions. MEMS-based sensors have emerged recently. Therefore, inertial measurement unit having accelerometers and gyroscopes in their structure are well known, for example, the 3-axis MEMS accelerometer [21].

A wireless body area sensor network [44] is shown in Fig. 16. This figure highlights how each node of a body area sensor network has an interface with the organic tissue. Each node has an integrated energy source. Nodes can be in the form of sensors with an integrated processor, a sensor with an integrated transceiver, and sometimes data storage or feedback control to body-based actuators, such as an insulin pump or robotic prosthetic.

Signal processing is the main challenge posed by wireless body area sensor network—the way they interconnect, handle energy, and the way sensors gather information from the environment.

In the MEMS application of body area sensor networks, a small-size thermoelectric generator is attached to the skin. For this purpose, a thermoelectric bracelet using commercial BiTe thermopiles is designed and tested. The average energy power is 100 μW, so the sensor layer is connected and sends data. Furthermore, generator parameters can be sent to a PC through a self-powered wireless module [45].

9 Conclusions

Internet of Everything, Everywhere (IoEE) [28, 29] concept represents the basic technology behind connecting smart dust systems in sectors such as healthcare or smart cities. Security, privacy, and safety are also in the scope of this chapter's research, since the sensors which equip a smart dust system collect different types of data from various devices that belong to individuals. Applications related to smart city generally have access to a broad range of people's privacy-sensitive data. Therefore, security breaches are a concern that must be reduced or even eliminated.

Smart dust[26–29] sensors are small dimension sensors used to monitor and collect data for efficient usage of resources. One of the main advantages of these sensors is that they are safe to be used in terms of the designed encryption, knowing that there are no known cases of information theft.

Within smart cities, with numerous entities, such as smart economy, smart environmental control, smart traffic system, smart governance, smart home, smart energy, and also smart healthcare merge together; thus, smart dust [30, 31] technology overcomes the limitations resulting from the size of the surveillance equipment, has low system and infrastructure costs, and also collects real-time information.

Several case studies have been presented, in which the benefits of smart dust technology have made an impact, in terms of healthcare surveillance and environmental surveillance in smart cities[32–37], communication, signal processing, and low power consumption by energy harvesting [42, 43].

As future work, development of smart dust surveillance [38] system will be undertaken in hospitals, to gain better management of patients, bearing in mind their privacy and confidentiality and sensitivity involved.

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