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SENSORS AND SENSOR NETWORK APPLICATIONS

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ABSTRACT

This decade has been characterized by a tremendous interest in sensors and sensor networks. The renewed interest was the outcome of the advances that wireless cellular networks have scored such as massive MIMO cooperative communications, the Internet of Things (IoT) where it is predicted that billions of devices would be connected to the internet to communicate in some fashion, and Micro-Electro-Mechanical Systems (MEMS) technology which has facilitated the development of smart sensors. All these and more suggest that sensors will be at the front and center of most technologies in the future. This paper presents a review on sensors, their applications as well as their manufacturers whenever relevant. The work presented can be used to inform any further developments in the area of sensors as research gears up to meet the challenges of the emerging technologies.

Keywords: *Sensors, Sensor Applications, Conversion Techniques, Sensor's Integration*

1. INTRODUCTION

With the advancement in technologies and reduction in size, sensor networks have gained access to almost every aspect of life. The diverse range of low-cost sensors fostered the emergence of pervasive sensing. Sensors and sensor networks can now be worn or integrated into our living environment or even into our clothing with minimal disruption to our daily activities. In short, sensors can now be made to be embedded in our bodies, automobiles, airplanes, cellular telephones, radios, chemical plants, industrial plants and countless other applications. Furthermore, without the use of sensors, there would be no automation. Imagine an assembly line making any product or an airplane flying safely without sensors (the classic Pitot Tube).

While, the research related to sensors and sensor networks is not new, still, the material presented in this article is a compendium of knowledge that is timely and can be relied upon as a body of knowledge that establishes the foundation for immanent and future research efforts such as IoT, massive MOMOs, and UAVs technologies and their applications. Also by considering the applications illustrated in this paper, the aim is to foster research in certain areas that have the potential for great impact on sustainable development that is slowly gaining global interest. At the same time, it is worth mentioning that the paper is not intended to cover all conceivable sensor applications, rather, the intent is to focus on key applications such as agriculture, health care, and gas and petroleum that would serve as illustrations. Furthermore, the novelty of this review resides in the fact that it provides a balanced coverage of technical concepts about sensors and sensor networks, their application in key fields, as well as information about manufactured sensing products. Thus giving the appropriate backgrounds to novus researchers engaging in the sensor research field as well as expert researchers who are seeking applications for sensors.

The rest of the paper is organized as follows. Section 2 provides an overview on sensors that includes a necessary background of relevant technologies, types of sensors, difference between sensor and transducer, common conversion methods etc. Section 3 includes detailed uses of sensors in different routine and emerging applications. Section 4 provides a discussion about the integration of sensors with different future key technologies. Section 5 identifies current and future trends and highlights potential research areas. Finally, section 6 concludes this article and offers new potential considerations influencing sensors and sensor applications.

2. OVERVIEW ON SENSORS

Wireless sensors and sensor networks (WSNs) have gained attention of researchers from all around the globe during the last couple of decades. Therefore, as one may expect, there is a

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myriad of papers addressing one issue or another about sensors. This overview is, however, guided by the stated objectives of the paper that are established to fulfill current and future research needs in the area of sensors and sensor networks. This is while putting a proper amount of due diligence in conducting a reasonable and unbiased literature search appropriately embedded in the different parts of the paper.

There has been several survey papers on a variety of topics relating to sensors and sensor networks that formed a basis for this paper [1-5]. [1-2] surveyed routing algorithms for efficient sensor energy consumption, [3] surveyed data gathering protocols for security considerations, [4] surveyed technological solutions for challenges facing Body Area Networks (BAN), and [5] surveyed new developments in sensors and actuators. The intent of the survey reported in this paper is rather to complement and augment the body of knowledge cited above by providing elaborate timely applications and presenting sensor based products when pertinent.

The proliferation in Micro-Electro-Mechanical Systems (MEMS) technology has facilitated the development of smart sensors [6]. While these sensors are small and pack limited processing and computing resources, they are inexpensive as compared to traditional sensing equipment. They can detect, measure, and gather information from their environment and, based on some local decision process, they can transmit it to the user. Thus lending themselves to applications that cater to technology based sustainable development that takes into account social, and environment and economic considerations. Thus the motivation for this paper is to both inform emerging technologies as well as foster new applications, especially, those addressing sustainable development as unattended sensors and sensor networks providing both the relative reliability and reduction in cost. This, in addition to, pointing out unresolved issues in WSNs that maybe hindering or at least constraining their use in some applications.

In terms of challenges that are yet to be overcome in the case of WSNs, one can, for example, mention the routing issue. Routing in WSNs remains very challenging due to the inherent characteristics that distinguish these networks from other wireless networks like mobile ad hoc networks or cellular networks. First, due to the relatively large number of sensor nodes in some applications, it is not possible to build a global addressing scheme for their deployment as the overhead of ID maintenance is high. Thus, traditional IP-based protocols may not be suitable for WSNs. Furthermore, sensor nodes that are deployed in an ad hoc manner need to be self-organizing as the ad hoc deployment of these nodes requires the system to form connections dynamically and cope with the resultant nodal distribution especially that the operation of the sensor networks is not supervised. In these networks, nodes typically play similar roles and they collaborate together to perform the common task.

2.1 Sensor vs Transducer

The sensor is a device that detects a physical quantity and converts it into an analogue quantity which can be measured electrically such as voltage, capacitance, inductance and ohmic resistance. The output needs to be operated, interfaced & regulated by the system designer [7]. Different kinds of sensors are available depending on the application at hand. Motion sensors such as those used in numerous systems like home security lights and automatic door fixtures normally send out some kind ultrasonic waves, microwaves or light beams and detect when the energy flow is interrupted by an obstacle in their paths.

The transducer is considered as the heart of the sensor. It is a device that convert the measured quantity into a standard electrical signal such as 0-10V DC, -10 to +10V DC, 4 to 20mA, 0 to 20mA, 0-25mA etc. The output of the transducer can be directly used by the system designer. Transducers are used in electronic communication systems to convert signals of different physical forms to electronic signals. Examples of transducers include microphones, loudspeakers, etc

Various types of sensors and transducers are available to choose from like analog or digital. The type of input or output transducer being used depends upon the kind of signal sensed. Basically, a sensor or a transducer can be defined as they convert one physical quantity to another. In short, a device which processes an input is called sensor because it senses a physical change of a stimulus, while transducer is also a device, however it converts the energy from one form to another.

2.2 Common Conversion Methods

In order to choose a particular sensor for a given application, there are many factors to be considered. These factors (or specifications) can be divided into two main categories: environmental factors and economic factors. Most of the environmental factors determine also the

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packaging of the sensor. The term packaging stands for the encapsulation or insulation which provides protection and isolation and the input/output leads or connections and cabling. The economic factors determine the type of manufacturing and materials used in the sensor and to some extent the quality of the materials (with respect to lifetime). For example, a very expensive sensor may be employed if it is used repeatedly or for very long time periods. On the other hand, a non-reusable sensor, often desirable in many medical applications, is normally inexpensive [6]. A common characterization of sensors deals with the type of stimuli to be measured. These sensors can be categorized in two broad clusters namely those sensing physical quantities (temperature, pressure, force, etc..) and those directly sensing electrical quantities (currents and voltages). Table 1 shows sample parameters and corresponding work in literature.

Table 1: Sensor Classification (Signal Detection) and Phenomena with some Proposed Techniques

Parameter	Literature Examples
Temperature	Boonsawat [8]
Moisture Content	Bogena [9]
Flow Rate& Velocity	Tsung-Te [10], Stoianov [11]
Turbidity	Sridharan[12]
Conductivity	Nguyen [13], Postolache [14]
pH	López [15]
Dissolved Oxygen	Sridharan [12]
Heavy Metals	Cai, [16]
Organic Compounds	Chen [17], Manes [18]
Microorganisms	Bertoldi[19]
Biological Inspired Contaminates	Hongliang[20]

3. SENSOR APPLICATIONS

Although sensor network research is initially driven by military applications such as battle field surveillance and enemy tracking, however, during the past few years, many wireless sensor networks had been deployed in different civil applications. Process optimization in industry, increased safety and security, saving water and energy in household appliances, and usability in consumer electronics determine the need and benefits of sensors. In real estate automation and, in particular, environmental monitoring, the situation is much more complex. It is very important to minimize energy and water consumption in properties, however, the key issue is how to achieve this without the huge investment. Household appliance manufacturers boast about the low energy consumption of their appliances, however, it can affect the equipment service life. In other words, the ecological footprint of a product's entire life cycle is usually considered more important than, for example, energy-efficiency of an appliance or lamp. Further, considering healthcare, everyone knows that it is challenging to care for the aging population and ensure quality healthcare with the current methods. The following subsection illustrate sensor applications that have been proven to address important needs.

3.1 Agriculture

The use of Wireless Sensor Networks enables efficient and inexpensive agriculture as they can provide real time feed-back on a number of different crop and site variables [21]. WSN provides precision in both the size of the crop area it monitors as well as in the delivery irrigation water, fertilizer, etc. This technology can isolate a single plant for monitoring and nurturing, or more typically an area in the tens or hundreds of square feet. The IFDC (International Fertilizer and Development Center), a center for soil fertility and agricultural development has reported that because of haphazard fertilizer usage, the levels of soil nutrients are declining at an annual rate of 30 Kg /ha in 85 % of African farm land [22].

This cycle of degradation was confirmed by IFDC researchers who further reported that agriculture, in conjunction with factors such as deforestation, soil erosion and that if erosion rates continue unabated, the yield of some crops could fall drastically by 2020 [23]. Growers must then cultivate more land at the demise of wildlife and forest. This suggests that WSNs might be of use to address this issue. Papers and reports like [24] and especially [25] have discussed WSN platforms in precision agriculture. The data collection, monitoring and materials application to the crops allows for higher yields and lower cost with less impact to the environment. Each area receives only what is required for its particular space and at the appropriate time and duration. Numbers of different sensors are developed by different manufacturers and are being used for getting quality and quantity of crops; some of them are listed in tables 3 and 4.

3.2 Maritime (Oceanic)

With the development of society and economy, more and more people have started to

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pay attention to the marine environment during the past decade; various marine environment monitoring systems have been developed. The traditional marine environment monitoring system using an oceanographic research vessel is expensive [26,27]. Wireless Sensor Networks (WSNs) have recently been considered as potentially promising alternatives for monitoring marine environments since they have a number of advantages such as unmanned operation, easy deployment, real-time monitoring, and relatively low cost. For marine environment research, a WSN-based approach can dramatically improve the access to real-time data covering long periods and large geographical areas [28]. According to Tateson et al. [29], a WSN-based approach is at least one order of magnitude cheaper than a conventional oceanographic research vessel.

A water quality monitoring system is usually developed to monitor water conditions and qualities including temperature, pH, turbidity, conductivity and dissolved oxygen (DO) for ocean bays, lakes, rivers and other water bodies. An ocean sensing and monitoring system is used to monitor ocean water conditions and other environmental parameters. A coral reef monitoring system is normally installed to monitor coral reef habitats using an autonomous, real-time and in-situ wireless sensor network. A marine fish farm monitoring system is developed to monitor water conditions and qualities including temperature and pH, and accurately quantify the amount of fecal waste and uneaten feed for a fish farm.

In a WSN-based marine environment monitoring system, various kinds of sensors are used to monitor and measure different physical and chemical parameters such as water temperature, pressure, wind direction, wind speed, salinity, turbidity, pH, oxygen density, and chlorophyll levels. Such WSN-based marine environment monitoring has a broad coverage including a number of application areas; water quality monitoring, ocean sensing and monitoring, coral reef monitoring, and marine fish farm monitoring. Different application areas require different WSN system architectures, communication technologies, and sensing technologies. Some important sensors used for different marine applications and parameters are listed in tables 2.

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Table 2: Different Monitoring Parameters and Supporting Sensors for Marine Applications

Monitoring Parameter	Sensor	Supported Range	Accuracy	Power Supply	Product Reference
Pressure (bar)	AST4000	up to 10,000 PSI	<±0.5% BFSL	4-20 mA	www.astsensors.com
	DCT 533	0-400 bar	0.35 % FSO	N/A	www.bdsensors.de
	SBE 50	20 to 7000 dbars	± 0.1%	8 - 30 VDC	www.seabird.com
Temperature (°C)	109-L	-50° to +70°C	±0.2° Cover	2500 mA	www.campbellsci.com
	MBT 5560	-50 °C - +200°C	N/A	4 - 20 mA	www.danfoss.com
	Si7050	-40 to +125 °C	± 1.0 °C	195 nA	www.silabs.com
Conductivity/ Salinity (s/m)	SBE 4	0.0 to 7.0 S/m	± 0.0003 S/m	6 - 24 VDC	www.seabird.com
	OBS-3A	0 to 65 mS/cm	1% of reading	2500 mA	www.campbellsci.com
	SAL-BTA	0 to 50 ppt (salinity)	±3%	N/A	www.vernier.com
Turbidity (NTU)	WQ730	0-50 NTU	+ 1%	10-36 VDC	www.globalw.com
	OBS500	0 to 4000	±2%	9.6 to 18 Vdc	www.osil.co.uk
	TurbiLux	0 to 1,00 NTU	<±2%	9 to 36 Vdc	www.chelsea.co.uk
pH (pH)	SeaFET	6.5 - 9.0 pH	0.02 pH	6 - 18 VDC	www.satlantic.com
	WQ201	0-14 pH	2%	10-30 VDC	www.globalw.com
	SBE 18	0 to 14 pH	± 0.1 pH	6 - 24 VDC	www.seabird.com
Dissolved Oxygen(mg/L)	Hydrolab DO	0 to 50 mg/L	±0.2mg/l	N/A	www.osil.co.uk
	SBE 63	120% of surface saturation	±3 µmol/kg	6 - 24 VDC	www.seabird.com
Pollution/CO_2	pCO2 Sensors	1 – 25 % CO2	± 5 %	18 VDC	www.presens.de
	SAMI-CO2	150-700 µatm	± 3 µatm	N/A	www.sunburstsensors.com
Oxidation- (mV) Reduc-Potential	CSIM11-ORP	700 to +1100 mV	±0.1%	3 VDC	www.campbellsci.com
	ORP Sensor	-450 to + 1100 mV	N/A	7 mA (5VDC)	www.vernier.com

3.3 Health Care

Driven by the confluence between the need to collect data about people's physical, physiological, psychological, cognitive, and behavioral processes in spaces ranging from personal to urban and the recent availability of the technologies that enable this data collection, wireless sensor networks for healthcare have emerged in the recent years[30,31].

Healthcare sensor networks (HSNs) now offer the possibility to continuously monitor human activity and physiological signals in a mobile environment. Such sensor networks may be able to reduce the strain on the present healthcare workforce by providing new autonomous monitoring services ranging from simple user-reminder systems to more advanced monitoring agents for preventive, diagnostic, and rehabilitative purposes. Potential services include reminding people to take their medication, providing early warning for the onset of heart attacks or epileptic seizures, and monitoring a child's physical activity in order to assess their growth and mental development.

3.4 Gas and Petroleum

With the fast development of oil producing countries and increase of demand for energy and water all over the world, petroleum, natural gas, water resources and facilities have become important assets for the these nations. Maintaining the economic progress of these countries strongly depends on protecting these resources and facilities. Since Oil & Gas process areas fall within the category of hazardous locations, strict requirements apply for any equipment installed in these potentially explosive areas. To address this, wireless sensors are considered a promising

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solution with the autonomous equipment, operating from an internal battery pack which eliminates the need for any type of wiring. Not only this, but mobile sensor units contain horns and beacons for warning about hazardous levels of harmful gases. The terrestrial wireless sensor networks replaced with traditional monitoring systems have dramatically improved operational efficiency of offshore pipelines [32,33].

3.5 Safety and Security

Home security has been an issue that motivated a variety of measures to prevent intrusion. Many researchers are focusing on projects to investigate a cost effective solution that can provide home monitoring and enable home safety and security in the absence of the owners. Usually, traditional building monitoring systems exist in most of the commercial buildings with the first duty of providing convenience and safety. However, implementation and maintenance of wired systems are time consuming, and error-prone and costly. Further, another serious issue is when crises like earthquakes or fires happens in a building, the damage can be fatal. New technologies of wireless sensor network has brought a new level of building monitoring systems by saving the cost and time of implementation and maintenance, providing more safety.

Table 3: Leading Sensor Manufacturers for Different Applications and Parameters

Application Area	Manufacturer	Products/ Components	Sensing Parameters/ Applications	References
Agriculture	SensaTrack	Sensor, Adaptors, Gateways	Saving water, Soil moisture, Temperature, Humidity, light	www.sensatrack.com
	Stevens	Sensor, Data loggers	Irrigation, Golf courses/ sports turf	www.stevenswater.com
Marine Environment	Satlantic	Sensors, Radiometers, Observing Systems	Depth, Density, Salinity, pH, Fluorescence, UV Absorbance	www.satlantic.com
	Sea Bird Elec.	Sensors, Buoys, AUVs, ROVs, Underway systems	Water samples, Wave, Tide, pH and Oxygen sensors, Dredging, Oil spills	www.seabird.com
Healthcare	SOL-CHIP	Tracking Sensors, Medical wristband and bracelets	Tracking elders and children, Monitoring, Hearing aids	www.sol-chip.com
	MICRO-EPSILON	Measurement, Sampling and positioning tools	Dental samples, Tablet color, Surgical equipment position.	www.micro-epsilon.com
Environment Monitoring/ Forecasting	ACURITE	Weather Sensor and station, Rain gauges	Environment, Weather forecasting, Rain, Humidity, Lunar cycle	www.acurite.com
	Stevens	Weather stations, Gauges, Wind sensors	Rain gauges, Wind direction and speed, Solar radiation, Evaporation	www.stevenswater.com
Gas and Petroleum	RigStat	Sensors, Cameras, GPS, Horns, Obstruction lights	Rig and Met-Ocean monitoring, Inspection, Emergency operations, Tracking	www.rigstat.com
	Gems Sensors & Controls	Sensor, Level-Indicators, Switches, Gauges. Valves	Flow and Presser sensing, Level measuring, Boiler control, Indications	www.gemssensors.com
Safety and Security	PURELINK	Sensors, Badges, Tags, Severs, Software	Anti-Aggression, Visit control, Zone access, Emergency, Safety, Prevention	www.purelink.ca
Home Automation	SOL-CHIP	Sensors, Meters, Switches, Alarms	Remote home control, Smoke detection, Motion, Gas leakage	www.sol-chip.com

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Table 4: Examples of Prototype for Different Sensor Network Areas and Applications

Applications	Prototype/Test-bed	Monitoring Parameters	Scale and Density	Data Amounts/ Frequency	Year	Country
Agriculture	Root Zone Irrigation [34]	Irrigation, moisture, Water Salinity	6 Number of nodes and 3 repeaters	Depends on irrigation interval, 5 months duration	2008	Italy
	Smart [35] Irrigation System	Irrigation, Moisture	2-Sensor motes, 1 EC-5 soil humidity sensors	Small amount of data. After every 4.40 hours, Continue for 2 days	2011	Greece
Healthcare	Three Layer WBSN [36]	Different physical activities in elderly	Few shimmer nodes on Body, Smart phone as base station	Minimal, Periodically data transmission	2010	Germany
	Smart Healthcare Clothing [37]	Body temp., Heart beat, Respiration,	Sensors and RFID tags, Cloths	Small amount of data, React only during emergency	2007	South Korea
Marine Environment	Ocean-TUNE UCONN Testbed [38]	Acoustic channel behavior, Conductivity	Sensors are sparsely deployed, 3 surface buoys	Frequently, Mostly with 15 mints sampling, Stayed for 7 months.	2013	USA
Safety and Security	SASA [39]	Structure Variations, Detect collapses locations	27 Mica-2 Motes. Large number of sensors nodes.	Large amount of data packets are generated, Frequent transmission	2006	Hong Kong
	WINS Area Monitoring [40]	Area monitoring, Surveillance, Security	Few nodes in area of Interest, can support 100m range.	Depends on app. requirement and network's current status.	1999	USA
Weather	Great Duck Island[41]	Habitat monitoring, Data collection, Sampling	32 Sensor Motes Over 1 KM2	Frequently, 2-4 hour intervals, Stayed for 4 weeks	2002	USA
Transportation	Multi-sensor Automated Highway[42]	Intelligent transport, Embedded control	4 Vehicles equipped with 2 different classes of sensors	Case depended	2006	France
Livestck	Monitoring Wildlife Passages [43]	Safe animal crossing, Target identification	Variable node density in 40 m of radius (Detector, Cameras)	Whenever target detected, Real time action is not required	2009	Spain

4. SENSORS INTEGRATION WITH OTHER NETWORKS AND TECHNOLOGIES

Sensor networks may indeed interface or integrate with other networks and technologies, such as WiFi, cellular networks, the Internet or nanotechnology devices. In that case, what can be the best way to interface these networks or technologies? Should the sensor network protocols support the protocols of the other networks? Or should the sensors have dual network interface capabilities? For many sensor applications, these questions will be crucial and researchers' attention is required to find suitable solutions. Integrating different technologies while having different capabilities and functionalities is not a simple task.

4.1 Sensors and Nanotechnology

Nanosensors are any biological, chemical, or surgical sensory devices that are used to convey information about nanoparticles [44,45]. Their uses mainly include various medicinal purposes as well as providing gateways to build other nanoproducts, such as computer chips that work at the nanoscale and nanorobots. Presently, there are several ways proposed to make nanosensors,

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including top-down lithography, bottom-up assembly, and molecular self-assembly.

Nanotechnology-enabled sensors are providing new solutions in physical, chemical, and biological sensing that enable increased detection sensitivity, specificity, multiplexing capability, and portability for a wide variety of health, safety, and environmental assessment capabilities. These sensors address both the opportunity of using nanotechnology to advance sensor development and the challenges of developing sensors to keep pace with the increasingly widespread use of engineered nanomaterials.

Nanotechnology-enabled sensors offer significant advantages over conventional sensors. This may be in terms of better sensitivity and selectivity, lower production costs, reduced power consumption as well as improved stability. The unique properties of nanoscale materials, such as increased surface area and confinement effects make them ideal candidates. Nanomaterials can be integrated into existing sensing technologies or can be used to develop new devices. Various types of sensors, such as physical sensors, electro-sensors, chemical sensors and biosensors have greatly benefitted from nanotechnology [46].

4.2 Sensors and Cellular Networks

Despite all the success of wireless and sensor networks, Internet connectivity will still be crucial issue for sensor networks. One of possible solution is to use sensor networks as an extension of the cellular air interface, leading to improvements in their capacity and coverage.

A static topology of sensors deployment can lead to a serious problem as the energy of a node close to the sink or destination will be depleted fast. If the sensor nodes around the sink fail, the connectivity and coverage of a WSN will suffer. To handle this, one of the possible solution is to use an overlaying cellular network as ”backbone” network to support the WSN connectivity. This obviously improves the energy-efficiency of the WSN by saving their precious energy reserves. The cellular terminals, called mobile sinks in this context, are assumed to be equipped with multi-radio transceivers to interact with the sensors to enable sensor originated data collection and processing [47,48]. Due to the mobility within a large area, where sensor networks are deployed, the mobile sinks can bring the benefits of dynamic clustering, high energy efficiency, and prolonged lifetime of WSN.

So far very little research has been conducted to explore the possibility of integrating sensor and cellular networks. However, few authors show the interest and proposed different architectures for this purpose. In [49] authors target mobile telemedicine application, which is supported by third generation (3G) cellular networks, to provide highly flexible medical services. This integrated architecture called telemedicine scheme, which takes advantage of the low cost mobile sensor networks and 3G cellular networks to support multimedia medical calls with differentiated Quality of Service (QoS) requirements. In [50,51] the author discusses GSM based global wireless sensor network to measure increase of global warming & air pollution.

Future networking need to integrate different heterogeneous terminals and access technologies like adhoc, cellular, WLAN and WPAN networks and for this accessibility alternatives provide different QoS and coverage levels. However, the complexity of such a heterogeneous environment must not only be hidden from end users and should be transparent to the applications. The task of designing future adaptable heterogeneous networks that provide QoS guarantees is not simple but extremely complex and challenging.

4.3 Sensors and Big-Data

Currently, “big data” is considered one of the hot topics due to substantial growth of the Information and Communication Technology (ICT). One of the expected key contributors of the big data in the future networks is the densely deployed Wireless Sensor Networks (WSNs). Although the data generated by an individual sensor node may not appear to be significant, however overall data generated across numerous sensors in a distributed WSNs can lead to a significant amount. Internet of Things (IoT) can be another source of big data which actually comprise billions of devices that not only can sense and compute but also communicate as well. Data streams with such big amounts coming from these devices will challenge the traditional approaches responsible for data processing and management. Usually, big data consists of some high-valued information mixed with erroneous and raw data. The advanced techniques and innovative technologies can efficiently process such massive amounts of dirty data and extract useful information from it.

Due to its flexibility and scalability, cloud computing is considered one of the promising and excellent way to process big data as it can offload substantial amounts of computation and data from both data centers and terminal devices. However,

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cloud computing may not be suitable for all applications like WSN due to its real time response requirements and geographically distributed and mobility support. For such applications, usually target areas are close to the physical world, while cloud moves part of data storage and computation toward the edge of the network. Accepting the challenge, research on this area require concentrated efforts by ICT researchers and practitioners to meet the challenge of big data in order to ride the wave of information implosion.

4.4 Sensors and Wi-Fi

Due to high energy consuming nature of WSN, the usage of low power protocols like Zigbee, Bluetooth and proprietary protocols, are common. Although, these protocols provide the most energy efficient solutions, they have little or no existing infrastructure overlaid in metropolitan areas. On the other hand, 802.11 based protocols have a very widespread network with a high market penetration, which enables users to easily receive and transmit information from almost every computer or any handheld device, yet it is not commonly utilized in sensing applications.

With the evolution of wireless and SoC (system on-a-chip) technology, different kinds of WiFi wireless sensor SoC chips for low power applications have been developed for Wireless Sensor Network. Such WiFi based WSNs are the combination of WiFi wireless mesh networks and WSNs. The power consumption of WiFi sensor nodes is so low that one AA battery is enough for 5 to 10 years [52].

Comparing with other Zigbee wireless sensor network technologies, WiFi wireless sensor networks have significant advantages. Firstly, with WiFi technology data transfer rate can reach 300Mbps and about 100M to 150Mbps throughput. While, Zigbee's data transmission rate is only 10-250Kbps. So clearly, WiFi transmission is more efficient, face less delay, better real-time, and works without complex scheduling algorithm to solve the congestion problems. Secondly, WiFi has some non-line-of-sight (NLOS) transmission capacity, at the same time, it can communicate through barriers. While Zigbee has no NLOS transmission capacity and it is weak in data transmission through barriers. Thirdly, WiFi radio waves have broader coverage as they can work for upto 300m outdoor and support 100m indoor barriers [53]. However Zigbee radio waves have lower coverage as its transmission distance is usually in 10-75 meters range, and the data transmission through the load-bearing walls are not effective. Another advantage of WiFi based WSN over Zigbee based networks is cost and ease in expansion. Currently, WiFi networks are available in many intelligent buildings In addition to that, interoperability with other Zigbee devices need not to be taken into account, which ultimately results shorter development cycle and lower project costs.

In short, using WiFi-based WSN to make a variety of applications of Internet of Things (IoT), like automatic meter reading, has many advantages so the research on WiFi-based WSN technology and its applications have far-reaching significance to develop the current world Internet of Things and the Smart Grid.

Table 5: Applications Of Wireless Sensors with other Integrating Technologies

Integrated Technology	Relevant Areas and Applications
Nanotechnology	A Wireless Interface for Nanowire-Based Gas Sensors [54] Nanotechnology-Enabled Wireless Sensor Networks: From a Device Perspective [55]
Wi-Fi	A Wi-Fi Cluster Based Wireless Sensor Network for Wildfire Detection [56] A WiFi based Smart WSN Agricultural Environment [57]
Cellular	Integrated Ad-Hoc and Cellular Networking in Indoor or Faded Environments [58] Sensor Integration underlying Cellular Networks through Mobile Sink [59]
Big Data	Body Sensor Networks: In the Era of Big Data and Beyond [60] Wireless Sensor Network and Big Data in Cooperative Fire Security System[61] The Internet of Energy: Smart Sensor Networks and Big Data Management [62]

5. CURRENT AND FUTURE TRENDS

Although, the advancement of technology provides the foundation for developing sensors and wireless systems. However, new technologies must provide significant added value to the consumer as well as create profitable business for manufacturers within a reasonable time span. Use of sensor technology considered a commonplace in industry for a long time. However, mere baby steps have been taken in the fields environmental monitoring and healthcare.

Measurement technology and data transfer still pose many challenges, which require further

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study [46]. For example, new and affordable sensors are required for monitoring the health and the environment. The correlation of sensor data with a subject's health requires further study. The current technologies already allow extended operation using small size low ampere-hour batteries. This is achieved with both low consumption components but mainly by keeping the nodes in standby as long as possible. Further, still some applications will require battery recharge. Factors like sun, wind, vibration and bio-energy are some of the possible solutions that are being studied.

Over the next decade and even further, wireless sensor nodes will probably evolve into a much less distinct as well as less visible form. Devices will gradually migrate out of their little boxes and will be incorporated directly with different objects and materials. Many will draw energy directly from the environment in which they operate. To the extent that these kinds of systems will reach homes, workplaces, transportation terminals, farms and shopping sites and are smart enough to sense the presence, motion and even physiological states of individuals.

There remains many challenges facing the use of wireless sensor and sensor networks. Among the most persistent ones are: resistance to whether elements such as temperature, cold, pressure, and humidity; battery life in the face of continuous communication and data transfer; efficiency, efficiency and reliability of routing algorithms; security and data integrity of data and data transfer; mobility and data collection; as well as many other general and application specific issue.

6. CONCLUSION

A growing list of applications are employing WSNs for increased effectiveness; as well as to collect data from areas that are not readily accessible. Considering the current progress in sensor fabrication techniques, coupled with increasing multi-disciplinary research and development, one can expect that even more new applications will emerge. Such applications are bound to be the outcome of the eminent deployment of 5G. Therefore, one would expect self-awareness, organization and reorganization, and adaptivity of sensors will be at the forefront in the researcher agenda. At the same time, other developments will be required for WSNs to live up to the expectations, namely increased battery life and materials that are resistant to harsh environment while enabling the communication functions of the individual sensors. Furthermore, the proclaimed advantage of being able to be deployed in remote and inaccessible areas creates the challenge of data gathering from the devices. In some instances it was found that using unmanned aerial vehicles (UAVs) provide the solution. Hence the need for devising protocols for data gathering as well as procedures for controlling swarms of UAVs including deconfliction, and self and situational awareness.

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