A Review on Optical and Radio Frequency based Wireless Sensor Network for Industry 4.0

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***Abstract*—Many research papers are studied and their results are presented in this review paper. Introduction to wireless sensor network (WSN) and its implementation using different wireless communication protocols are studied. Optical and radio based wireless data transmission are used for different applications. Concept of industry development industry 1.0 to industry 4.0 is reviewed from different literatures. Application of WSN using optical and radio medium for industry 4.0 is concluded.**

***Index Terms*—WSN, Optical WSN, Radio Frequency based WSN, Industry 4.0, Internet of things (IoT).**

I. INTRODUCTION

A Wireless sensor network is combination of various motes like source nodes, intermediate nodes and sink nodes. Each node consisted of processing unit, sensor unit and wireless communication modules. Sensor unit is responsible access raw data from environment and analog to digital converter (ADC) converts analog signal of sensor to digital form compatible to controllers, wireless modem transmits and receives information generated by network and controller unit reads sensor and send modem to transmit other node and also process received data by wireless modem.

For past few years, technologies are changing very rapidly. Internet of things became extremely popular from 2017 while it was coined in 1999. Two types of communication systems are used in WSN implementation; optical communication system and RF based communication system. IoT is a kind of RF based communication protocol. Wireless communication applied in optical spectrum is termed as optical wireless communication. In optical communication there are three window ultraviolet (UV) window, visible window and infrared (IR) window [1]. These three bands exhibits different types of properties in terms of optical channel characteristics between transmitter and receiver, propagation characteristics and optical characteristics. In clear sky and day light, IR photons are capable to transmit information over a range of 3kilometers [2]. On the basis of this concept, Texas instruments (TI) manufactured IR (Infrared) LED based first commercial product in 1962, which used GaAS (Gallium arsenide) material based LED having emission wavelength range of 900nm [3]. A research team of Keio University, Japan proposed base of visible light communication (VLC) for wireless home link using WLED for data transmission and illumination simultaneously [4]. In 2011, a group working under IEEE 802.17.5 standard, standardized VLC technology as a matured wireless communication medium [5]. Now a day's LiFi (Light fidelity) term become more popular providing VLC based bidirectional communication system. IEEE802.15.7 aimed to provide communication model for three different sectors, LED identification (LED-ID), LiFi and OCC (Optical camera communication) [6].

Wireless ultraviolet communications (WUVCs) utilizes the UV spectrum with some special properties to mitigate the specific challenges in OWCs. As ultraviolet light form Sun is absorbed by ozone layer, WUVC provides a noiseless communication channel so proved an excellent SNR performance [7]. Scattering is observed in UV light by haze, aerosols, fog, molecules and other atmospheric particles due to its short wavelength which is known as Rayliegh scattering.

IR based commercial devices are available since 1940s, but Infrared data association (IrDA) planned their first meeting in 1993 with motive to develop wireless communication through IR for short range of 1 meter in line of sight (LoS). Today millions of users are using beam based data transmission for mobiles, camcorders and laptops [1]. For IR based communication a standard IEEE802.11 was released in 1999, medium access control (MAC) layer technologies and diffuse infrared physical layer (IR PHY) were specified [1]. IR PHY is not directed so it can be used for outdoor applications, it works reliably over range of 10 meters with optical transmitter having peak power wavelength from 850nm to 950nm [8]. But optical communication is reliable for long range communication hence to overcome this limitation RF based wireless communication system is used.

Frequency band used for radio frequency electromagnetic spectrum is 3kHz to 300GHz and it is completely governed by international and local authorities. Most of the sub-band of radio frequency are licensed to specific operators like point to point microwave links [9], television broadcasters and mobile phone operators. Now these wireless communication technologies are used in WSN deployed in industry for automation. According to industry revolutions, Industry 4.0 is the latest revolution which promotes to automate the industries with WSN network. Industry 4.0 is combination of information technology and operational technology in production industries [10-12].

II. OPTICAL COMMUNICATION FOR WSN

Optical wireless communication system has wide range of distributed frequency bands in electromagnetic spectrum, but few bands are used for communication. Many researchers has been used OWC with high data rates in optical bands of UV, VLC and IR [13-16]. Electromagnetic spectrum is presented in table 1.

Table 1 Optical Spectrum [17-20]

Optical	Sub-category	Frequency	Wavelength

Medium			
IR	FIR (Far IR)	0.3 THz - 20 THz	1mm - 0.015mm
	TIR (Thermal IR) : Long	20 THz - 37.5 THz	0.015mm - 0.008mm
	TIR Thermal Infrared : Mid	37.5 THz - 100 THz	0.008mm - 0.003mm
	SWIR (Short Wavelength)	100 THz - 214.3 THz	0.003mm - 1400nm
	NIR (Near IR)	214.3 THz - 394.7 THz	1400nm - 760nm
UV	UV-A	750 THz- 952.4 THz	400nm - 315nm
	UV-B	952.4 THz- 1071 THz	315nm - 280nm
	UV-C	1071 THz- 3 PHz	280nm - 100nm
	NUV (Near UV)	750THz- 1PHz	400nm - 300nm
	Mid UV	1 PHz- 1.5 PHz	300nm - 200nm
	Far UV	1.5 PHz- 2.459 PHz	200nm - 122nm
	Hydrogen Lyman Alpha	2.459 PHz- 2.479 PHz	122nm -121nm
	EUV (Extreme UV)	2.459 PHz- 30 PHz	121nm - 10nm
	VUV (Vacuum UV)	1.5 PHz- 30 PHz	200nm - 10nm
Visible Light	Violet	666.7 THz- 833.3 THz	450nm - 360nm
	Blue	600THz- 666.7 THz	500nm - 450nm
	Green	526.3 THz- 600THz	570nm - 500nm
	Yellow	507.6 THz - 526.3 THz	591nm - 570nm
	Orange	491.8 THz - 507.6 THz	610nm - 591nm
	Red	394.7 THz - 491.8 THz	760nm - 610nm

In most of wireless sensor network IR based communication is used at high frequency range. Using optical communication point to point and point to multipoint both type implementation is possible, but for point to point communication complex and precise pointing [21], better tracking methods and acquisition is required. So its challenge to align optical nodes having narrow beam divergence transmitter and wide angle receiver unit. In such a network there are two main categories of nodes; sensor node and cluster head (CH).

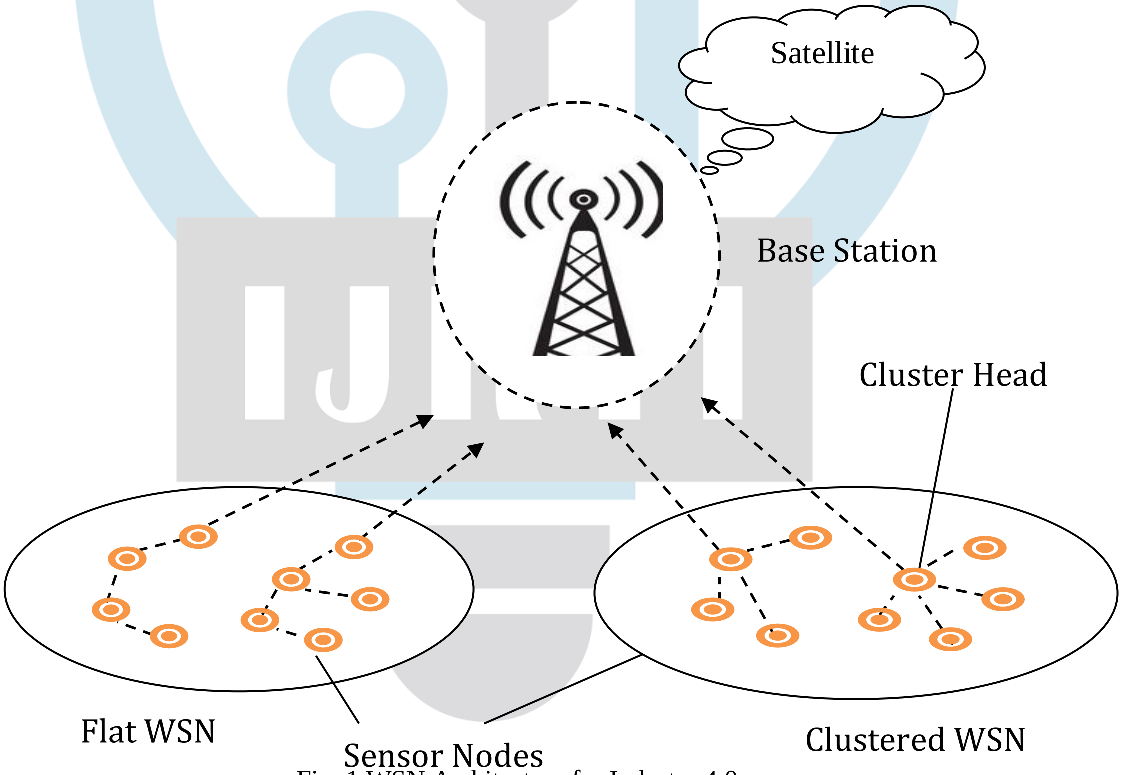


Fig. 1 WSN Architecture for Industry 4.0

To assure successful and reliable communication between optical nodes design of directional MAC (DMAC) protocol is mandatory. There two types of sensor network used in industry 4.0 applications; one is flat network and second is clustered wireless sensor network. Optical wireless sensor network used for industry 4.0 is shown in fig. 1.

According to the architecture in figure 1, different WSNs are deployed for different geographical locations and these WSNs separately communicated to base station to share their information. And ultimately collected information at base station end will share to IoT cloud. So administrator can access individuals nodes from anywhere worldwide.

III. RF Communication based WSN

T For long distance communication, radio frequency based trans-receiver modules are used as it is capable in non-LOS environment also. RF modules available in market are having different frequency band, range of transmission, path loss and encoding and decoding algorithm. Frequency band available for radio waves are from 3KHz to 100GHz. These spectrum categories are presented in table 2.

Table 2 Radio Wave Electromagnetic Spectrum [17-20]

RF Medium	Sub-category	Frequency	Wavelength
	VLF	3 kHz - 30 kHz	100 km - 10 km
	LF	30 kHz - 300 kHz	10 km - 1 km
	MF	300 kHz - 30 MHz	1000 m - 100 m
	HF	3 MHz - 30 MHz	100 m - 10 m
	VHF	30 MHz - 300 MHz	10 m - 1 m
	UHF	300MHz - 3 GHz	1m - 0.1m
	SHF	3 GHz - 30 GHz	100mm - 10 mm
	EHF	30 GHz - 300 GHz	10 mm - 1mm
Microwave	P-Band	0.225 GHz - 0.39 GHz	1330 mm - 769 mm
	L-Band	0.39 GHz - 1.55 GHz	769 mm - 193 mm
	S-Band	1.55 GHz - 5.2 GHz	193 mm - 57.7 mm
	C-Band	3.9 GHz - 6.2GHz	76.9 mm - 48.4 mm
	X-Band	5.2 GHz - 10.9 GHz	57.7 mm - 27.5 mm
	Ku-Band	12 GHz - 18 GHz	25 mm - 16.67 mm
	K-Band	10.9 GHz - 36 GHz	27.5 mm - 8.33 mm
	Q-Band	36 GHz - 46 GHz	8.33 mm - 6.52 mm
	V-Band	46 GHz- 56 GHz	6.52 mm - 5.35 mm
	W-Band	56 GHz- 100 GHz	5.35 mm - 3 mm

Due to the large electromagnetic spectrum band, radio frequency has board range of capabilities to apply in different application area from home automation to satellite communication link. Most of the radio frequency module works on 3.3v and 5 v power supply with low power consumption high range of transmission like cellular network, local radio module, bluetooth module, WiFi module, GSM module, zigbee module etc.. Characteristics of these protocols are listed in table 3.

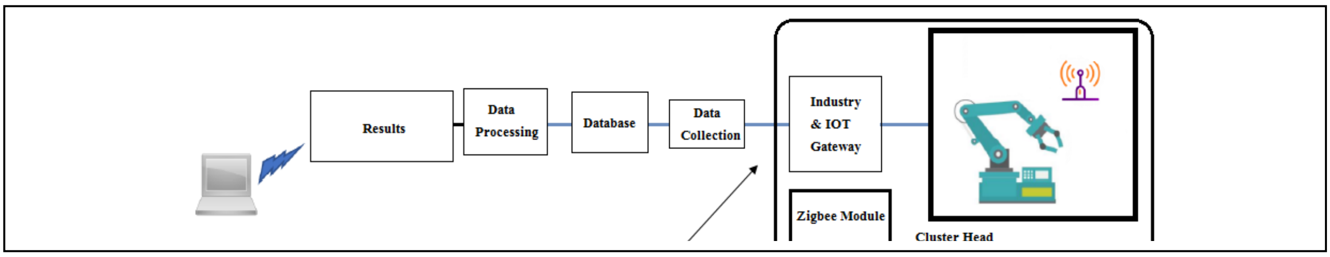
Table 3: Comparison of Radio Frequency Standards [22]

Wireless Standard	Power Consumption	Communication Range	Data Transfer Rate	Reliability of Data	Cost
Cellular	High	1m - 100m	14.4 kbps - 3.6 Mbps	High	High
Bluetooth	Medium	10m	1Mbps - 3 Mbps	High	Medium
Proprietary ISM	Variable	Variable	Variable	Variable	Variable
WiFi	Medium	100m - .... km	10Mbps - 100+ Mbps	High	Medium
Zigbee	Low	10m - 100m	20Kbps - 250 Kbps	Medium	Low
Z-Wave	Low	15m - 150m	9.6 Kbps - 40 Kbps	Medium	Low

Zigbee based communication is most secure and reliable communication. Zigbee modules are available in different version having different feature like range of communication, power rating etc.. For unlimited range of communication GSM module that uses cellular network and IoT module that is useful because of internet and cloud based connectivity.

IV. WSN Architecture for Industry 4.0

Industry 4.0 comes under industrial revolution forth, according to which production and manufacturing industry moved towards automation of industry. It consists of IoT technologies for sharing information of whole industrial activities effectively to administrator, cloud computing and cyber physical systems [23]. Architecture of wireless sensor network used in industry 4.0 is presented in fig. 2.



According to the architecture, different nodes deployed at various locations co-ordinate with cluster head and finally cluster head transmit collected information to server and as per database commands transmitted to cluster head from server side to control processes if any fault occurred.

V. WSN Performance Metrics

To analyze the performance of WSN, some basic parameter needed to be evaluated and compared for different algorithm and strategies. These parameters are energy consumption, delivery ratio, throughput and lifetime of network. The delivery ratio can be calculated as

$$Delivery\ Ratio = \frac{N_{received}}{N_{transmitted}} \quad (1)$$

where Number of data frames received without any error is presented by $N_{received}$ and number of transmitted frames from sensor node to cluster head is represented by $N_{transmitted}$.

The throughput is calculated as

$$Throughput = \frac{N_{received} * L}{T} \quad (2)$$

where L is data frame length of MAC payload, T is difference of initial transient time interval and simulation time.

Energy consumption of WSN can be calculated with sum of energy consumption of individual nodes. Energy consumption per bit of network is calculated as

$$E_{per\ bit} = \frac{\sum_{i=1}^{n} E_i}{N_{received} * L} \quad (3)$$

where i^{th} node energy consumption is presented by E_i, n is number of nodes in network.

Conclusions

Research papers based on optical wireless communication and radio frequency wireless communication for wireless sensor network applied to industry 4.0 applications. Internet of things is key component of industry 4.0 based implementation which is used to monitor and control manufacturing processes like production rate, machine health, voltage, current power consumption and other environmental parameters. Industry 4.0 can be implemented using both optical communication module as well as radio frequency modules. But optical communication is applied to low communication range and high speed data transmission while RF based modules can be used where LOS connectivity is not possible.

Acknowledgment

We thank Er. Arun Kumar Yadav (Researcher at Sapro Electronics & Electricals Ind. Pvt. Ltd.) for his assistance in providing knowledge about industrial revolution use of IoT in industrial automation for converting previous industrial processes to Industry 4.0 and how industry 4.0 will change the rate of production and other services on fast mode.

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