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Review Article

Wireless Sensor Network (WSN) Applications in Plantation Canopy Areas: A Review

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Abstract

Recently, the developments in sensor technologies, such as wireless communication, micro electro mechanical systems (MEMS) and embedded systems have contributed significantly to wireless sensor network (WSN). The agriculture industry is applying WSN in their systems for surveillance and monitoring the environment. For plantation applications, a WSN is used for control and protection and for providing a real-time system. These applications include, for instance, to detect the presence of disease, temperature and moisture of the soil. The quality and coverage of a wireless link in a plantation area needs to be understood due to the effect of vegetation such as propagation loss resulting from the ground and canopy reflection. In this paper, the development of wireless sensor networks in canopy areas is reviewed. The problem of propagation link in canopy areas is identified. The structure of WSN is discussed with suggestions to create a reliable communication link. From the studies reviewed, the information to design a wireless sensor network in canopy areas for application in plantations is provided.

Key words: WSN structure, propagation link, attenuation, frequency, transceiver

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INTRODUCTION

Importance of wireless sensor network in agriculture: Wireless sensor network (WSN) is important in agriculture. It provides real-time information about the lands and crops that will help farmers to make right decisions. Various types of sensing techniques were developed for many aspects of agricultural processes including land preparation[1-4], irrigation[5-9], crop management[10-14], harvesting[15-19] and post-harvest handling[20-27]. The combination of sensing electronics with wireless communications enhanced the technologies and brought forth the idea of a WSN. The network formed by a large number of sensor nodes where each node is equipped with a sensor to detect physical phenomena such as moisture, pH, light, heat, etc. The network has low power consumption, low cost of production, the small size of multifunctional sensors and is able to communicate over short distances[28-33]. Collected data from the sensors are transmitted to software for analysis. Then, the software will give feedback on action to be taken at field.

Each node in WSN is comprised of a microcontroller, memory and transceiver. The microcontroller is an electronic circuit for interfacing with the sensors and an energy source. It is used to implement the task, data processing and support the other components' function in the sensor node. The data is stored in the memory. The transceiver is work based on the transmitter and receiver functions[34]. The WSN architecture is depicted in Fig. 1. It is composed of a sink node, sensor nodes and user. Sensor nodes collect the information and transmit the data to the sink node via wireless communication. The sink node that also called a gateway and will gather the information from the entire sensor node. The analysed data are transmitted to the user via the internet[28].

Recently, WSN is widely used in environment monitoring applications, especially in the agricultural field. Based on the report in Global Harvest Initiative[29], the human population will continue to rise more than 2.3 billion people. Thus agricultural output must necessarily increase to provide the human essentials such as food, fibre, fuel and others. The use of WSN in agriculture fields will enable an increase in the quality and the quantity of production due to real time monitoring of the plant status using various types of sensors. For instance, the use of precision agriculture assists in spatial data collection, precision irrigation, variable rate technology and supplying data to farmers[30-33]. The network presents the data of environmental parameters that affect the development of the agricultural production. As reported in Gomide *et al.*[35], the WSN was applied to collect the data of soil water availability, soil fertility and insect disease-weed infestation. The network is also used to enhance the irrigation system for continuing high crop yield[36,37].

Plantations, such as rubber, oil palm, mango and others are significant crops that promote the Malaysian economy[38]. Surveillance and monitoring of large plantation areas such as monitoring of nutrient status[39] and disease status[40] are essential for plantation efficient management that assures high yield productivity. Such surveillance and monitoring becomes easier through of the application of WSN. However, there are several elements that contribute to the attenuation while designing WSN in that area. These are the topography, vegetation component and the geometry of the trees. The complicated topography of plantation areas influences signal propagation. The non-flatness of earth surfaces causes signal reflection. Besides this, the propagation link of radio waves is also affected by vegetation components, such as trunk, branch, twig and fruit. The geometry of the trees is another factor that degrades a signal. The broad leaves of the trees create a green roof called the canopy layer. Hence, it will be challenging for the signal to propagate to a base station because of propagation loss due to the canopy's reflection of

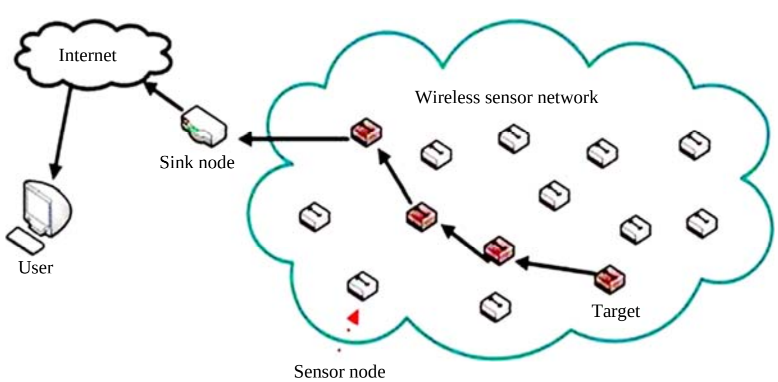


Fig. 1: Wireless sensor network architecture[28]

signals. Therefore, this paper focuses on the structure of WSN in canopy areas in order to create a reliable wireless communication for plantation applications.

STRUCTURE OF WIRELESS SENSOR NETWORK IN CANOPY AREA

There are several requirements that need to be considered while creating a WSN, such as the propagation link, the antenna radiation, frequency selection and configuration of the transceiver. The requirements of each are discussed in detail in the following sections.

Propagation link of WSN: The WSN is used in plantation areas for environmental monitoring, to improve crops, control and to detect disease to get optimised results. In this area, the propagation link of a wireless sensor network needs to be recognised due to the effect of vegetation, topography, ground conditions and canopy reflection. The reduction of signal in radio systems is known as attenuation. The received signal strengths are degraded due to the propagation loss. This situation happens because of the presence of trees along a radio path[41,42].

The existence of trees can be either as a single tree or a group of trees. Trees can be homogeneous or a mixture of tree types. The effect of radio wave propagation link will be totally different for each type or grouping, even at the same frequency. This circumstance happens because the attenuation is influenced by many factors regarding variation and parameters. Vegetation in the transmission path is considered to be a random medium because there are many dielectric things: Leaves, branches and trunks. The incident electromagnetic field is attenuated and scattered due to the presence of tree foliage. There are many factors that contribute to the extent of signal scattering, such as the canopy size, the height of the tree and the density of leaves[43]. Furthermore, the propagation loss in plantation area is contributed from the ground reflection and canopy reflection[44].

Investigations of propagation loss in canopy areas were reported in Saxton and Lane[45], Whale[46] and Brown and Curry[47]. The signal propagates in different manners, called diffraction, scattering, reflection, transmission and refraction, which all cause the attenuation. Figure 2 illustrates the propagation of electromagnetic waves from the transmitter (T_x) to receiver (R_x) being diffracted by the tree canopy, thus a three mode of propagation is presented[48].

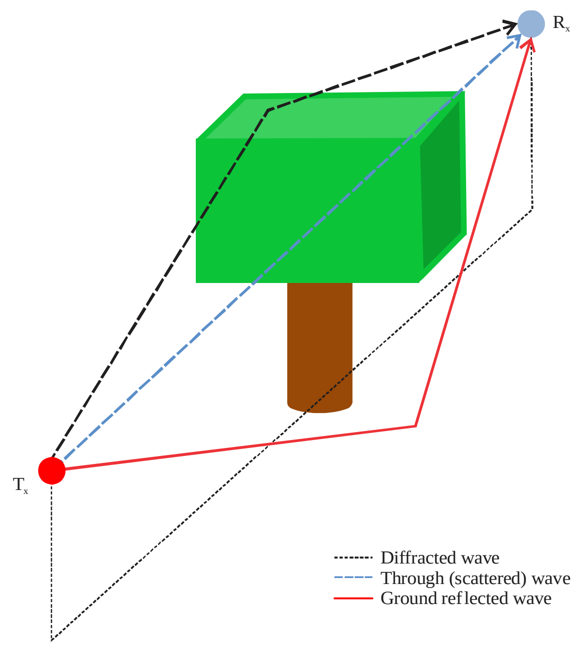


Fig. 2: Propagation of electromagnetic wave through the tree[48]

A report by Tamir[49] describes the theoretical models for radio wave propagation in the forest where the canopy layer exists. However, the models only consider the absorption of the forest. The scattered signals due to the vegetation are discounted. The propagation loss model in Xu and Li[50] is applied to estimate the losses of the lateral wave, directed wave and reflected wave in forests, as shown in Fig. 3. L (f) represents the propagation loss in the free space, L (dB) represents the propagation loss in a forest environment and L (d) represents the propagation loss of diffraction. The model also includes the consequences of the forest ground floor and the difference between the vegetation and tree trunks. Results verified that the dominant wave in the forest is a lateral wave. The forest layer model is constructed in Seker[51] to observe the propagation in a more realistic model. Each layer may represent air, canopy, trunk and ground, as illustrated in Fig. 4. The transmitter (T) and receiver (R) are placed in trunk layer. The electromagnetic field was found in the receiver and the results proved that the radio wave propagation might be comprised of three components: Direct, reflected and lateral wave.

Other studies in Tewari *et al.*[52] described radio wave propagation through rain forests in India. Most of the trees have canopy geometry. According to the analysed data, the frequency and polarisation are dependent on radio wave attenuations. Increasing antenna height decreased transmission losses.

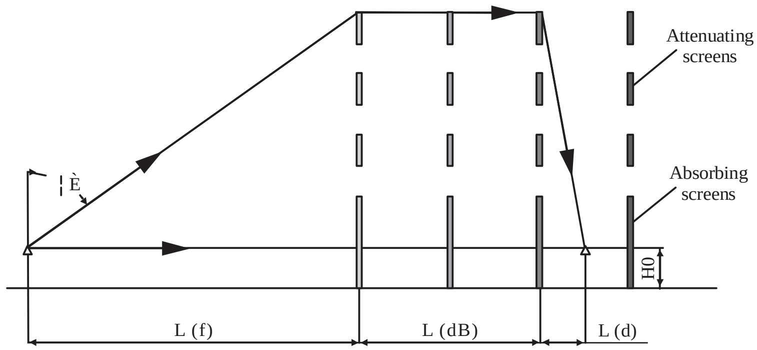


Fig. 3: Propagation loss model[50]

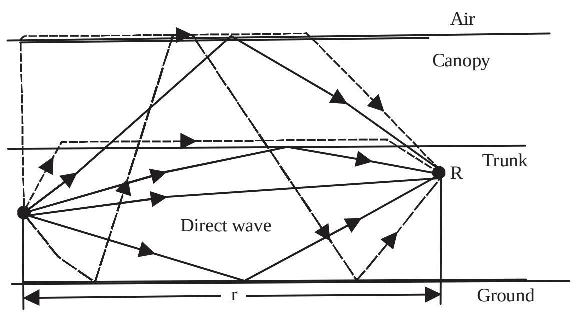


Fig. 4: Forest layer model[51]

Several vegetation attenuation models are presented in Ndzi *et al.*[53] that can be categorised as an empirical model. The experimental data were taken to develop the empirical vegetation model. However, these models do not account for the measurement geometry and the modes of propagation. The modified exponential decay (MED) model is widely used for the generic empirical model. Equation 1[53] describes the MED model:

$$\mathrm{Att}_{MED} = Xf^{Y}\, d^{Z} \quad (1)$$

Where:

f = Frequency (M Hz)
d = Vegetation depth (m)
Y, Z = Model parameters

The values of the parameters are different from data from various studies that were applied to this model. Consequently, some of the modified exponential decay models were presented in Table 1[53]. Another model that was mostly used for generic empirical models is the maximum attenuation (MA) model. This model is suggested by the international telecommunication union (ITU) for the frequency range of 30 MHz-30 GHz, especially for a case where the transmitter is placed outside while the receiver is placed inside the vegetation. Equation 2[53] describes the MA model:

Table 1: Modified exponential decay model[53]

Model	Equation	
ITU-R	$ATT_{ITUR} = 0.2f^{0.3}\, d^{0.6}$,	d<400 m
Weissberger	$ATT_{WEIS} = 1.33f^{0.284}\, d^{0.588}$,	14 m<d<400 m
	f is in GHz in this model	
	$ATT_{WEIS} = 0.45f^{0.284}\, d$,	0 m<d≤400 m
	f is in GHz in this model	
COST 235	$ATT_{COST} = 26.6f^{-0.2}\, d^{0.5}$,	out-of-leaf
	$ATT_{COST} = 15.6f^{-0.009}\, d^{0.26}$,	in-leaf
FITU-R	$ATT_{FITUR} = 0.37f^{-0.18}\, d^{0.59}$,	out-of-leaf
	$ATT_{FITUR} = 0.39f^{-0.39}\, d^{0.25}$,	in-leaf

$$\mathrm{Att}_{MA} = A_m\left(1 - e^{(\frac{Rd}{Am})}\right) \quad (2)$$

Where:

A_m = Maximum excess attenuation
$e^{(\frac{Rd}{Am})}$ = Initial gradient of the attenuation curve

The other empirical model, which is suggested to overcome the problem of the MA model while operating at frequencies 5 GHz and above is the non-zero gradient (NZG) model. Equation 3 describes the NZG model:

$$\mathrm{Att}_{NZG} = R_{\infty} d + k\left(1 - e^{((-d)\frac{R_0}{k} - \frac{R_{\infty}}{k})}\right) \quad (3)$$

Where:

R_{∞} = Final gradient of the attenuation curve
R_0 = Initial gradient of the attenuation curve
d = Vegetation depth
k = Offset of the final gradient

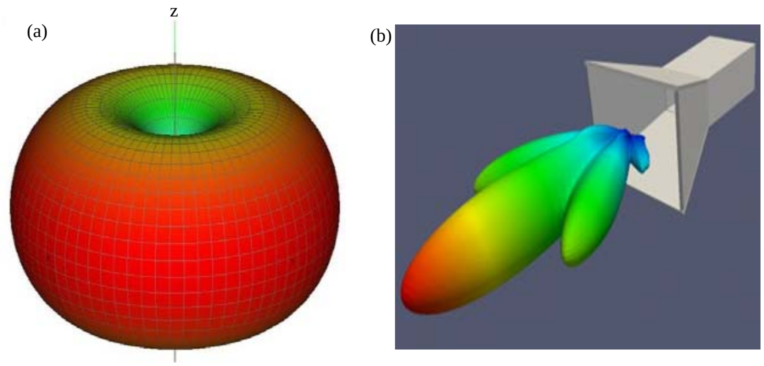


Fig. 5: Antenna radiation (a) Omni- directional[54] and (b) Directional[55]

Antenna radiation: Antenna radiation can be described as the radiated power of the antenna as a function of the direction away from the antenna. There are two main types of antenna radiation, which are omni-directional or also called non-directional and directional. Figure 5 illustrates the antenna radiations.

For plantation applications, there are advantages and disadvantages for each radiation pattern. For omni-directional, the radiated signal has the same strength in all directions. Therefore, by applying the antenna with the omni-radiation pattern, the signal can cover all directions. However, the gain of the antenna might be low because it needs to be divided equally in all directions. With the directional radiation pattern, the signal is focused in one or two directions. Hence, it can cover a long distance with high gain. Nevertheless, the effect of beam width is decreased. Thus, it cannot cover large areas. The antenna with a directional radiation pattern is helpful in near line of sight coverage.

There are various antenna that were used for designing a wireless sensor network for plantation application. Table 2 shows the types of antenna that were used in the plantation application and their features[56-58].

As reported in Ndzi *et al.*[53], a wideband horn antenna was applied to this network in mango and palm oil plantations. The horn antenna is chosen because it provides high gain, broad bandwidth, moderate directivity and is easy to setup. The horn antenna is also able to operate on wide frequencies because there is no resonant element while designing the antenna. The other type of antenna that is frequently used for a wireless sensor network is the monopole antenna[59]. The monopole antenna can be designed in small size due to its characteristics[60]. This kind of antenna provides a high gain and omni- directional radiation pattern. Therefore, it is suitable to apply in a plantation area.

Another type of antenna suggested for use in canopy areas is a reconfigurable antenna. This type of antenna focuses on the main beam direction. The user can choose the direction of radiation by switching a button. Consequently, it decreases the reflections from surrounding objects and reduces the destructive multipath interference. Based on the report in Adegoke[61] a panel antenna was used to measure the propagation loss in trees area. The antenna provided a directional radiation pattern and high gain and thus offers a better signal. Investigation in Rizman[43] measured microwave signals in oil palm plantations. The Yagi Uda antenna was applied to implement the experiment. The features, such as large gain, high directivity, cheap cost, low weight and uncomplicated profile make the antenna suitable for use designing a wireless sensor network in canopy areas.

Frequency selection: The selection of operating frequency plays an important part while designing a wireless sensor network. Most of the applications operate in the microwave frequency range (from 300 MHz-30 GHz). The wireless sensor network for plantation applications is suitable to work in this frequency range because it is more easily focused into narrower beams due to their short wavelength. Moreover, the frequency may be reused. The increasing of operating frequency allows high data transmission rate and broad bandwidth. Table 3 describes the applications in the microwave range from 1-8 Ghz.

A report in Arsad *et al.*[59] presents the investigations of the effect of vegetation associated with oil palm trees on the terrestrial propagation of wireless communication at 433 MHz. The low operating frequency is used because a low data rate needs to be transferred. The study of propagation in oil palm plantation was reviewed in Rizman *et al.*[43]. The experiment used the global system for mobile communications (GSM) frequency range, which is 0.9 and 1.8 GHz. Another report in

Table 2: Type of antenna and features

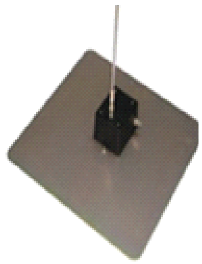
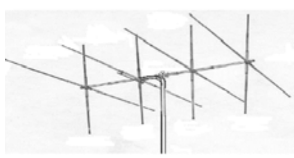
Types of antenna		Features
Horn antenna		• High gain • Broad bandwidth • Moderate directivity • Wide frequencies • Simple construction and adjustment • Low standing wave ratio
Monopole antenna		• Length of the antenna depends on the frequency to use it • Mounted on the ground plane high gain • Omni-directional radiation • Most simple antenna
Panel antenna		• Directional radiation pattern • High gain • Wider beam (can cover a large area) • Thin • Low profile package
Yagi-uda antenna		• Large gain • High directivity • Low cost • Low weight • Simple construction

Table 3: Application in microwave range from 1-8 Ghz

Frequency range (GHz)	Wavelength range (cm)	Applications
1-2	15-30	Military telemetry, GPS, mobile Phone (GSM), amateur, radio
2-4	7.5-15	Weather radar, surface ship, radar, Bluetooth, ZigBee, GPS, satellite Communication, wireless LAN
4-8	3.75-7.5	Long distance radio telecommunication

Adegoke[61] examines the signal measurements from single trees, a group of trees and lines of trees using microwave frequencies (3.2-3.9 and 4.9-5.9 GHz) in order to investigate the influence of trees on radio waves. Most of the applications were operated in industrial, scientific and medical (ISM) radio bands, which are at 2.45 or 5.8 GHz. These bands were created for short-range and low power communications systems and allowed for unlicensed operation.

Configuration of transceiver: Locations of nodes in a wireless sensor network should be considered to create a reliable wireless link. The inappropriate position will affect the microwave signals. In plantation areas, various elements influence signal propagation, such as the deep of vegetation, ground floor condition and the presence of broad leaves. Therefore, several studies have been done to identify the best configuration of the transceiver to get optimised results.

According to the report in Ndzi *et al*.[53], a wireless sensor node can operate well in a grid-like plantation and the position of the node should be at tree trunk height or above the canopy for optimal signal coverage. This is because smaller attenuation gradients happen due to low ground and canopy reflection. The measurements were conducted in mango and oil palm plantations.

Similar observations were published in Savage *et al*.[62] where the authors conducted experiments on oil palm trees at different receiver antenna heights, which are 7.5 and 2.5 m. Results proved that the higher attenuation occurred at an antenna height of 7.5 m compared to 2.5 m. This factor could happen at greater antenna heights because the branch and leaf density is increased.

The combination of branches, twigs and leaves in the canopy geometry create attenuating elements. Therefore, the transmitted signal is intercepted by these attenuating elements. It is caused by the extent of multipath resulting from scattering. The transmitted signal is obscured by canopies that block the direct line of sight (LOS). Furthermore, the thickness of high canopies is another factor that contributes to high penetration loss. The trunk has a small diameter range compared to the thickness of canopy. Therefore, less loss occurs when the air space is unobstructed or less obstructed, depending on variables described above.

The distance for each node in WSN is another significant factor to consider when creating a reliable wireless communication link. The report in Ndzi *et al.*[53] stated that the maximum range for each node in their plantation area was 90 m. Another measurement was done where the propagation loss of the signal was measured at various distances starting from 2 m upto 30 m[43]. In the forest environment, the WSN was applied to detect forest fire, where the maximum range for each node was 100 m[63]. It can be concluded that the signal gets more attenuated when travelling for long distances until it fades completely due to losses.

The study reported in Abd El-Kader and El-Basioni[64] describes the proposed node deployment and how to determine the number of sensor nodes for planting a potato crop in Egypt. The planting field is divided into tubs (each represents 1-2 carat for irrigation flapping). The sensor nodes are uniformly distributed based on the division. The field is assumed to divide into tubs, each of one carat. Each carat is comprised of two nodes distributed on it with an estimated separation of 6 m. The node is located on every edge shared with another carat as shown in Fig. 6.

The number of required sensor nodes according to the proposed node deployment can be calculated by Eq. 4[64]:

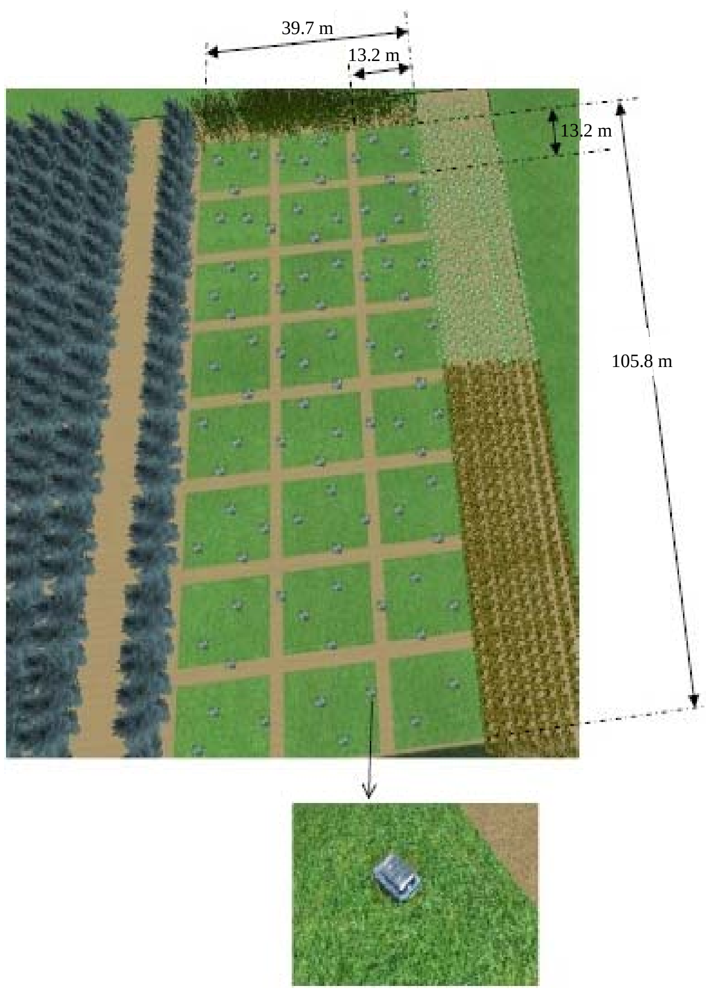


Fig. 6: The proposed node deployment[64]

Table 4: Comparison between Wi-Fi, Bluetooth and ZigBee[65]

Features	WiFi	Bluetooth	ZigBee
Radio	DSSS	FHSS	DSSS
Data rate (Mbps)	11	1	250
Nodes/master	32	7	64000
Data type	Video, audio, graphic, pictures, files	Audio, graphic, picture, files	Small data packet
Range (m)	100	10	70
Extendability	Roaming possible	No	Yes
Battery life	Hours	1 week	>1 year
Complexity	Complex	Very complex	Simple

$$N_s = N_c \times 2 + (f_w - 1) + \left((N_c - f_w)\times\frac{1}{f_w}\times 1\right) + \left((N_c - f_w)\times\frac{1}{f_w}\times 2\right) \quad (4)$$

Where:
N_s = Number of sensor nodes
N_c = Number of carats
f_w = Field width in carats

Figure 6 shows the field of potato is divided into 24 carat tubs. From the calculation in Eq. 4, it can be concluded that the field required 85 sensor nodes.

WIRELESS STANDARD AND PROPRIETARY WIRELESS SENSOR TECHNOLOGIES

There are several wireless standards that are recognised, such as wireless local area network (WLAN), wireless personal area network (WPAN), IEEE 802.11b (WiFi), IEEE 802.15.1 (Bluetooth) and IEEE 802.15.4 (ZigBee). Most of these standards are widely used for measurement and automation applications:

- Wireless local area network (IEEE 802.11) is a method for wireless distribution for two or more devices that use a higher frequency signal. Regularly, it consists of access points to the Internet. The bandwidth of IEEE 802.11b is 11 Mbps and it operates at the 2.4 GHz frequency. By using a WLAN, the users are allowed to move around the coverage area (while maintaining a network connection), usually in a small office or home
- Bluetooth (IEEE 802.15.1) is a wireless technology standard that is used for transfering data over short distance. It operates at a frequency from 2.4-2.485 GHz. The Bluetooth connection is designed to replace the data cable for mobile devices and computer peripherals. It can connect several devices and overcome synchronization problems
- ZigBee (IEEE 802.15.4) is a wireless technology standard that provides low data rate, consumes minimal power and is good for short range communication. This standard is suitable for control, monitoring, sensing and tracking applications for medical, home and industrial environments. ZigBee specification is much simpler and less expensive than Bluetooth or Wi-fi. The low power consumption restricts the range of transmission to 10-100 m line of sight. Distance depends on the characteristics of the environment and power output. Generally, ZigBee is applied for low data rate applications that need long battery life and secure networking. It can transmit a 250 kps data rate from an input device and sensor. Table 4 shows the comparison between Wi-Fi, Bluetooth and ZigBee

Wireless sensor network based on ZigBee was used in the article[65] and reported designing a greenhouse wireless monitoring system. A WSN with a star topology is recommended due to the structure of the greenhouse. The low power consumption and low cost make this wireless standard suitable to create a monitoring system. Kim *et al.*[66] designed the optimal fertilization systems using wireless sensor LAN IEEE 802.11 protocol (WiFi) and a GPS server. The sensor was applied to detect the soil moisture, conductivity, temperature, PH value, air temperature and humidity.

CONCLUSION

The agriculture industry is applying WSN in their systems for surveillance and monitoring the environment. For plantation applications, the WSN is used for control and protection, providing real-time system and control communication with the physical world, such as detecting soil conditions such as moisture content, pH and nutrients. However, the complicated geographical environment of plantation areas must be considered to create reliable wireless link communication. The received signal strengths degrade due to propagation loss. This situation happens because the presence of vegetation along a radio path acts as an obstruction. The incident electromagnetic field is attenuated and scattered. There are many factors that contribute to the extent scattering, such as tree canopy size, the height of the trees and the density of their leaves. The propagation link in that area was reviewed. Several vegetation attenuation models were presented. The structure of WSN was discussed in terms of the type of antenna, frequency selection and the transceiver location. From the studies reviewed, insight on how to design the wireless sensor network in canopy area for plantation application in future is obtained.

SIGNIFICANCE STATEMENTS

Setting up a wireless sensor network (WSN) for use in plantation areas with tree canopies is challenging due to various types of obstacles. Important aspects including propagation link issues, the antenna radiation, frequency selection and configuration of the transceiver are discussed in this paper to provide a clear picture of setting up WSNs in canopy areas. As such, this review assists researchers in evaluating the best setup concerning WSN installation in agriculture fields.

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