A guide for selection of wireless communication technology for effective and robust early forest fire detection system

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ABSTRACT

The world is facing a major ecosystem crisis due to global warming and pollution. Considering the rate at which the temperatures are rising, one must think about the causes and origins of this extreme environmental shift. Today, countries like India, have cities ranked as some of the most polluted cities in the world. Apart from vehicular traffic and industrial wastes, one of the prime components of the entire problem is forest fires. Burning forests emit tons of harmful gases into the atmosphere. This disaster also leaves drastic aftereffects on the economy and society. Therefore, an efficient system should be designed to monitor the forest fires at the earliest. Highlighting the role of wireless sensor networks in the irregular terrains of forests and considering the technical challenges, it is important to identify, first, the best technology for communication among sensors, in such complex terrains. Second, the identification of an optimization algorithm for the deployment of sensors to achieve maximum coverage This work presents an analysis of state-of-the-art wireless sensor networks to identify a reliable communication technique. Further an optimization algorithm is proposed for maximum coverage with a minimum number of sensors. The algorithm outperforms the other state-of-the-art algorithms in simulation results.

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1. INTRODUCTION

Today, most of the world is facing the issue of pollution, severely affecting the health of living beings worldwide. No doubt there are numerous sources of air pollution including vehicular, industrial and other pollution, yet one of the prominent reasons for the same is forest fires. Being recurring in nature [1], the sudden emission of abundant pollutants into the atmosphere due to the forest fire outbreak makes the situation worse. Cardiorespiratory and other health issues have increased to a very large extent due to air pollution caused by wildfires itself [2]–[4]. Forest fires are harmful in both aspects. On one end it results in emitting gases into the atmosphere affecting the environment [5], on the other end the natural air purifiers and oxygen providers, trees in forests are being destroyed. Thus, where steps are being taken to reduce pollution, one of the major sources of oxygen- forests are still being ignored. Besides being the major sources of oxygen, forests play a vital role in maintaining ecological balance, providing habitats for wildlife, fodder for cattle, pollution control, soil retention and contributing to the economy as they are major sources of timber [6]. Thus, it can be made factual that forest fires severely affect a country's social and economic aspects [7]–[9]. A forest fire can also be considered to be one of the reasons for deforestation because a large number of trees are damaged every year due to forest fires all over the world [10], [11]. There are numerous factors responsible for such outbreaks. Along with the obvious natural and human-made factors [12] resulting in forest fires, topological reasons are also very prominent, be it plains or hills, slopes or valleys everything affects the intensity and spreading of fire [1], [13]–[16]. Therefore, all such aspects should be considered while dealing with these issues. A forest fire can be summarized as one of the biggest threats to the environment at present which the world is facing today, as it endangers wildlife, flora, and fauna, leads to economic loss, species extinction, disruption of ecosystems, loss of biodiversity, degradation of soil, destruction of watersheds, emitting dangerous gases to the environment risking the health of living beings endangering human life too [17], [18].

Dealing with this issue is extremely important for the environment and society [8], and there are several good reasons why it should be given top priority. Our country is blessed with rich biodiversity and our forests are valuable in terms of economy and environment. There are around 1.7 billion hectares of conifer forests which are well defined in terms of consisting of very important commercial species of wood like chir, pine, teak, sal and fir and the estimated growth of timber in these forests is close to 60 million rupees [19]. We can imagine the severity of loss incurred by such valuable timber being burnt in forest fires along with other resources. According to a report almost 6 million km of land has already been destroyed in India over the past two centuries due to such fires. As per the analysts, the country is in a very serious crisis that requires immediate measures and actions to be taken [19], as it is assumed that around 1 million hectares of forests are affected annually due to forest fires. Approximately 300 million people, tribal or rural, directly depending on forests for their livelihood get affected. Thus, it is very clear that a few hours of fire would lead to severe damage, thus the key to avoiding such losses is to first, prevent fire in forests, and second, at least detect fire at the very early stage if unfortunately, it has occurred. For these reasons, there arises an immediate need to develop an efficient system with the best technology capable of detecting forest fires at the earliest stage.

There have been several solutions proposed regarding this previously too. Earlier forest fire monitoring could be achieved through surveillance by human beings, satellite monitoring, or monitoring by optical sensors/cameras. Although, forest fire detection by human surveillance has proved to be the most reliable system in terms of confirmation of fire, at the same time to cover vast forest areas a very large number of human resources is needed which is impractical. Most of the time the terrain is not very convenient to work upon. Overall, this technique doesn't prove to be very efficient and practical. Another approach lies with cameras and satellites. There are two types of cameras used for early fire detection, namely optical cameras and IR cameras that can capture data ranging from low resolution to ultra-high resolution for different fire detection scenarios [20]. These cameras are to be connected to some communication systems to collect and process information. This kind of system suffers medium latency as images are to be processed and analyzed to confirm fire, also the system is not very efficient in case of false alarms also. In the case of satellite systems, images are captured and then fire is to be detected based on these images. Generally, it takes considerable time for these data to reach the satellite which becomes a very significant. Also, the resolution of these satellites is nearly 375×375 m which again becomes an issue. With this resolution, a fire would only be detected once it has spread to a huge area of approximately 7 ha [21]. Thus, the fire is discovered only when it has already spread to an extent where it becomes very difficult to contain it and also significant damage has been done. Not only this, clouds, fog, or other environmental factors may interfere with receiving clear images. Therefore, this approach again doesn't seem to be a very reliable method. All these traditional approaches are not efficient enough as neither the information is very reliable in the case of optical cameras nor it can be detected early in the case of human surveillance. Also, it is not very cheap, easy to install, or modify the technique if using satellite specifically for forest fire monitoring. Keeping in mind all the challenges one can face in forest terrains new technologies have to be considered.

It has been observed in the last few years that ad hoc networks have proved to be very helpful in disaster management systems [22] and real-time monitoring, where sensors or in other words things are interconnected globally. Therefore, wireless sensor networks are generally employed while monitoring natural disasters including fires, especially in remote areas that mostly are inaccessible [23]–[26]. Sensor technology enables the creation of an environment for interlinking with the physical and virtual worlds [27]. Sensors not only gather signals but also transform them into digital information and further process them. Sensors precisely process messages about the current state of the physical environment into valuable knowledge [10]. The forest terrains are generally not easy to work on and therefore the idea of carrying and installing big infrastructures for setting up a system for fire detection and communication to the authorities is not feasible, as most of the terrains are not even approachable through proper roads (usable by vehicles). In such a scenario choosing wireless sensor networks can prove to be an effective choice in forest fire monitoring. Deploying wireless sensors is easier as compared to other devices as sensors are comparatively smaller and easy to install. However, as every technology has, even wireless sensor networks face some issues and due to these deploying such networks becomes a challenge [28]. One of the challenges that would be faced is connectivity or communication among the sensors or with the base station especially for complicated terrains like forests.

Thus, forest fires pose a potential hazard to the environment and society. The traditional methods used to detect forest fires present their kind of challenges. Although technical advancements have been made in this field like using Ad hoc or wireless sensor networks, but researchers may still face challenges in opting for an efficient communication technique. Also, the state-of-the-art work does not incorporate the obstacles present in forests while considering communication techniques. Hence, the study presented in this paper is of utmost importance. It provides a glimpse of the best possible technique and method to solve this problem to save our environment and economic losses. Keeping all the aspects of forest fires, causes, damages, facts, and figures in mind, the idea is to use wireless sensor networks in forests to collect data and crucial information to manage forest fires in a developing country like ours. Further, the same is communicated through a feasible communication technology long range (LoRA) as a solution to the communication problem in forest terrains. At last, an enhanced artificial bee colony algorithm is identified and compared with the state-of-the-art optimization algorithms. The simulation results indicate that enhanced ABC provides the maximum coverage with the minimum number of sensors under same simulation conditions and environment. This work therefore contributes in: i) providing detailed insights on rich resources of forests and forest fires: causes, severe after affects, the need of early forest fire detection system and potential solutions; ii) identifying the drawbacks of traditional forest fire detection systems and the advantages of wireless sensor networks over traditional systems; iii) highlighting the different communication techniques and their key features (advantages/disadvantages) by analyzing various state-of-the-art articles from reputed journals; iv) identifying the most successful communication technique (LoRa) to be used in forest terrains alongside wireless sensor networks; v) presenting the advantages and future scope of LoRa in forest terrains; and vi) identifying an optimization algorithm for maximum coverage with the minimum number of sensors.

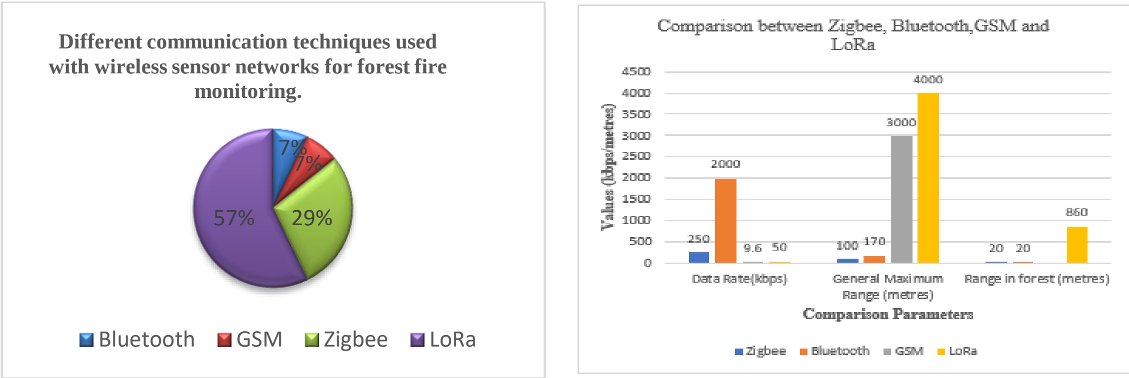
The findings of this paper will help the researchers to shortlist the communication techniques suitable for complex and vast forest terrains. Further, the work helps the researchers in choosing a suitable optimization algorithm for the deployment of sensors. Since the algorithm is proven to be capable of providing maximum coverage with minimum number of sensors, it is best suited for such applications. Also, the detailed knowledge of forest fires will help the researchers in managing all the forest related facts for this system. Thus, this work helps the researchers from start to end in designing an efficient and reliable earlt forest fire detection system. The analysis and results are presented in the form of tables and statistical diagrams for the best understanding of the reader.

2. METHOD

To identify various aspects of forest fire detection systems a comparative analysis has been conducted on various articles from reputed journals. The most preferred and successful technique is identified based on this analysis. The journals considered are indexed in SCI, Scopus and Web of Sciences. The time scale has been selected as of the last seven years. The analysis has been presented in the form of a table, Table 1 (in Appendix) ([17], [21], [29]–[47]) and the results of the analysis are presented in Table 2, Figures 1(a) and (b), for the convenience of readers.

Table 2. Analysis of different wireless communication techniques

Techniques	Standard	Maximum speed/data rate	Frequency	Energy consumption/ module	General range	Range in forest/dense vegetation	Major drawbacks
Zigbee	IEEE 802.15.4	250 Kbps	902 to 928 MHz or 868 to 868.6 MHz or 2.4 GHz	Low	50-100 m	20 m	Limited range
Bluetooth	IEEE 802.15.1	2,000 Kbps	2.4 GHz to 2.483 GHz	Medium	170 m	20 m	Limited range
GSM	GSM standard	9.6 Kbps	GSM450,480,750,850,900.1800, 1900 Mhz	High	Up to 3 km	Depending on infrastructure	Network coverage is mandatory and affected by climatic conditions
LoRa	IEEE 802.15.4 g, LoRa Alliance	50 Kbps	169 MHz, 433 MHz (Asia), 868 MHz (Europe) and 915 MHz (North America)	Low	4 km with a single gateway	860 m (very high vegetation) 2,050 m (not so dense vegetation)	Sensitive to obstacles



(a) (b)

Figure 1. Results of analysis: (a) percentage of wireless communication technologies preferred for communication by the researchers and (b) comparative analysis of communication techniques in terms of data rate, general range, and range in forests/high vegetation

The table lists reference numbers of articles, year in ascending order, different communication techniques (T_z indicates Zigbee, T_b is Bluetooth, T_g is global system for mobile communication (GSM), T_l is LoRa, T_{al} is various algorithms, and T_{ar} is architecture) and sensors addressed in articles along with major findings. A '-' in the table indicates data not available.

3. RESULTS AND DISCUSSION

This study looked into the techniques used in forest fire detection. While previous state-of-the-art works investigated the success of using wireless sensor networks in forest fire monitoring they did not explicitly address the effects of forest terrains in the communication techniques used along with wireless sensor networks. Collecting data by suitable sensors would further require aggregation and communication of this data to the sink to alert the concerned authorities. Connectivity of devices or sensors among themselves as well as to the sink is a challenge itself, especially in uneven, rough and full of obstacles terrain, like forests. The trees, dense vegetation, and many other factors hinder connectivity and communication. We prefer wireless communication technologies for our application due to our longing for minimum infrastructure and smooth communication. Such techniques have a very diverse range. These require to be considered when designing the solution, together with other factors such as data rate, power consumption, communication protocols, or costs [48]. Therefore, Table 1 accounts for the most opted communication techniques by the researchers to provide connectivity between different sensors. Considering the application of detecting fires in the harsh terrain of forests it is important to identify a successful technique for such situations. The results have been compiled in the form of a Pie diagram in Figure 1(a). The pie diagram indicates the percentage of wireless communication techniques preferred as per the comparative analysis. According to the analysis, LoRa is the most preferred choice of researchers with 57%. Zigbee stands second with 29% and the least preferred are GSM and Bluetooth both sharing 7% each of pie space. The following sections highlight the reasons why LoRa is most preferred and why LoRa stands to be the best among these techniques for rough terrains like forests. The general features and limitations of other compared techniques are also presented in the form of a table, Table 2, for the ease of understanding of the readers. Also, the deployment of sensors in such complicated forest terrains presents a challenge. Due to the non-uniformity of the vast terrains of forest, coverage of the target area becomes tedious task. Hence an optimization technique to provide maximum coverage by using the minimum number of sensors in these regions is compared with state-of-the-art optimization techniques. The simulations are performed under same conditions as mentioned in Table 3. The results of the comparison are shown graphically in Figure 2 for the ease of understanding.

3.1. Comparative analysis of different wireless communication techniques used in forest terrains (adapted from [10], [29], [40], [42])

Among various challenges encountered in wireless sensor networks communication or range is one of the most prominent ones for forest based application. We are developing a system which would be used in forest terrains. Such terrains would consist of several obstacles and other sources of attenuations due to flora and fauna. Therefore, we would focus on a wireless communication technique with the longest-range coverage in forest terrains or wildlife. In the study conducted, wireless sensor networks have been used to sense the environment attributes using different wireless communication techniques. Hence, a comparison has been made between Zigbee, Bluetooth, GSM, and LoRa in terms of various attributes as presented in Table 2. Table 2 therefore, presents an analysis of the techniques addressed with various parameters like standard, data rate, frequencies used, energy consumption, general range, range in vegetation and major drawbacks. The results have also been depicted in Figure 1(b).

The low power consumption of Zigbee makes it a suitable choice but its short range makes it less practical in the case of forest fire monitoring. Not only this, Zigbee also lacks analytics performing at the gateway node [10] making it less acceptable for such applications. Devices with a lower range always tend to increase, the overall cost of the system as the infrastructure expands in terms of the number of devices to cover a certain area [35]. In the case of general scenarios or no obstacle regions, the maximum range provided by Zigbee is about 100 meters (maximum) thus the number of devices increases when more than 100 meters of the area is to be covered which automatically increases the network head and the overall implementation cost [49].

Further, the range is reduced to 20 meters in dense vegetation like forests and the areas of forests are not only more than 100 meters, instead cover kilometers of land resulting in a very higher number of Zigbee nodes involved which seems quite costly and thus impracticable. Although Bluetooth provides a data rate of about 2 Mbps, the power consumption is not as low as Zigbee and the range is 170 meters maximum in case of no obstacle scenarios. Again, when we need to cover kilometers of forest terrain this range is not very practical. Moreover, it also reduces to 20 meters in high vegetation or dense forest areas like Zigbee which again offers the same hurdles in terms of deploying the cost-effective practical network.

Communicating information through GSM would have been the best case if not for forest terrains. Upgradation in GSM modules may provide very good data rates and very long ranges of communication. But in applications involving forests, it is not always possible to receive GSM coverage. Such areas are generally not approachable to deploy GSM infrastructure and even not populated enough to use GSM or any other telecommunication service. Also, the signal quality is affected by environmental factors such as temperature, humidity, pressure, and other air conditioning effects in the case of GSM [50].

LoRa provides a low data rate comparatively but a very good communication range of about 4 km with a single gateway in a rural environment can be observed [35]. Also, the power consumption is low compared to other techniques. Both of these factors are equally desirable in our system. The long range would mean a lesser number of devices and hence a cost-effective system and low power consumption would mean a greater lifetime of the system making it more reliable. Although the range has decreased to 860 meters when tested in dense vegetation and 2,050 meters in not-so-dense vegetation [42] but still, it marked the longest among all the wireless communication techniques in the comparative analysis, as can be seen in Figure 1(b).The comparative analysis thus proves that if the range is to be considered as a primary requirement and data rate as secondary for applications to be used in forests, LoRa would be the best. These reasons also account for the fact that out of all the techniques of communication to be used in wireless sensor networks LoRa has been preferred most of the time.

3.2. Analysis of enhanced artificial bee colony algorithm with respect to other state-of-the-art optimization algorithms

The most prominent state of the art algorithms used for coverage-related optimization problems are genetic algorithm (GA), particle swarm optimization (PSO), gray wolf optimization (GWO), monarch butterfly algorithm (MBO) and enhanced artificial bee colony algorithm (enhanced ABC). The ABC algorithm comprises of three phases, the employed bee phase, the onlooker bee and the scout bee phase. By modifying the scout bee phase we have enhanced the performance of ABC algorithm. To verify the performance these optimization algorithms are compared based on coverage rate and number of sensors under a set of simulation conditions as tabulated in Table 3. Figure 2 indicates the performance of EABC and other the state of the art algorithms in terms of coverage and number of sensors.

Table 3. Simulation environment

Environment details	Value
Simulation software	MATLAB R2017a
Simulation dimension	100×100 m^2
Sensor nodes	50
Iterations	500
Sensor’s coverage shape	Circular
Sensor’s radius	20 metres

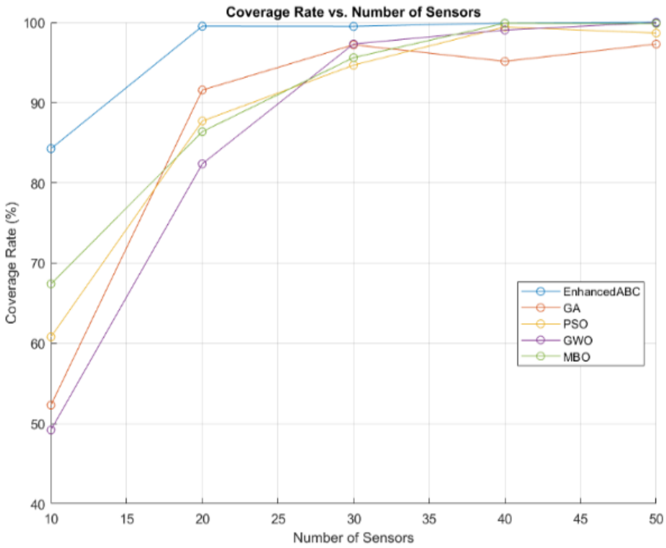


Figure 2. Graphical analysis of enhanced ABC and state of the art algorithms in terms of coverage and number of sensors

As can be seen from the Figure 2, the enhanced artificial bee colony algorithm out performs all other algorithms in terms of coverage. It provides almost 100% coverage with only 20 sensors as compared to other algorithms. This contributes to an important aspect while designing the efficient forest fire monitoring system. Considering the vast terrains of forests providing this level of coverage with minimum number of sensors is very beneficial.

3.3. Long range

Various applications in the field of environment, technology, and disaster management instigate the need for wireless sensor networks which further require strong and reliable connectivity between the devices and low power consumption. Therefore, communication technologies based on radio frequencies and various modulation techniques are in demand. One such very successful technique is the low power wide area network LPWAN [41]. In recent years LoRa technology has been gaining popularity due to its open standard specifications and architecture in academia as well as industry. Apart from this, it offers many advantages like simplicity, easy maintenance, most importantly wide coverage, and low power consumption which are considered very important parameters for green communication [51]. LPWAN also allows the reuse of frequencies making it more desirable [41]. As compared to its competitive technology Sigfox, LoRa has an open protocol where it's not required to depend on the operator [35]. The basic architecture in LoRa WAN would consist of LoRa devices, gateways or sinks, and an internet backbone connected to the server. To obtain optimized link performance and energy consumption LoRa allows its devices to be configured using different transmission powers, a wide range of spreading factors, bandwidth, and coding rate [52]. Thus, the best combination of parameter values can be used for optimum utilization. The performance of LoRa greatly depends on the choice of parameters in operation as well as architecture or deployment strategies [42]. As LoRa is still a new technique there is a wide area to explore and thus some challenges to be faced at present as well. For instance, large areas can be covered by LoRa but the link quality is greatly affected by the environmental variations. Especially in cases of applications in forests where the system is to be deployed in the open environment. There is a scope of improvement in such terrains as the areas would be hostile consisting of dense vegetation, non-line of sight conditions, major climatic variations, obstacles, and reflectors presenting a variety of interferences [41]. Not only this since the technology is new enough the gateway required would also be comparatively costly [49]. Hence, the field of LoRa can be further explored as a future scope.

4. CONCLUSION

Forest fires have been proven to be one of the major disasters happening across the world in recent years. This work emphasizes on the requirement of a reliable system for detecting forest fires early, sighting all the causes, effects, losses, facts and figures regarding forest fires and their impact on society and environment, in detail. Recent observations indicate that, there are significant challenges in this field specifically in communication among sensors, which need to be addressed. Moreover, deploying sensors in such complicated terrains that achieve maximum coverage is also very challenging. This work therefore highlights the limitations and key features of various communication techniques in forest terrains. Further it presents a solution to researchers aiming to design a reliable and efficient forest fire monitoring system by identifying the best wireless communication technology, LoRa to be used in forest terrains. The analysis concluded that LoRa outperformed the other technologies in three parameters. Although LoRA has lower data rates than other technologies, yet the data rate offered by LoRA is sufficient for forest fire applications. Also, the data rates can be further improved in future. The final phase of the problem i.e an optimization algorithm is also proposed to deploy sensors. The simulations conclude that Enhanced ABC proves to be the best among the state-of-the-art algorithms for deploying sensors with maximum coverage rate. We recommend incorporating LoRa and enhanced artificial bee colony algorithm in early forest fire detection systems to achieve higher reliability and efficiency.

APPENDIX

Table 1. Analysis of related works on wireless sensor networks based forest fire detection systems using various wireless communication techniques

Ref. No.	Year	Communication techniques						Sensors used	Key findings
		Tz	Tb	Tg	Tl	Tal	Taz		
[29]	2017	✓	✓	X	X	X	X	-	High-frequency signals face more attenuation in foliage, low frequency signals should be preferred in dense foliage.
[30]	2018	X	X	X	X	X	✓	-	Using multiple gateway nodes delay can be reduced and the lifetime of the network can be increased.
[31]	2019	X	X	X	✓	X	X	Temperature, relative humidity, and smoke sensors.	Using LoRa WAN, power consumption can be reduced. The status of nodes can be monitored on a web map in real-time.
[32]	2019	X	X	X	✓	X	X	Environment sensors along with the sound sensor.	Sound analysis is more effective than optical analysis in forest fire detection. Fire types are differentiated based on sound frequencies. Bioenergies can be harvested from trees.
[17]	2019	X	X	X	X	✓	X	Wisense nodes.	Fog cloud computing technology is used for predicting forest fires making the system more efficient.
[33]	2020	✓	X	X	X	X	X	Carbon monoxide sensor along with other sensors.	Using Zigbee a low-cost, less power-consumable system is made.
[34]	2020	X	X	X	✓	X	X	Humidity, temperature, barometric pressure, and other sensors (HTW). Flame ignition, humidity, and temperature sensors (5FTH).	Successful data acquisition is achieved through LoRa WAN also no packet losses were observed for short distances. Low power consumption of the system is observed.
[35]	2020	X	X	X	✓	X	X	Temperature, relative humidity, wind speed, and CO2 sensors.	The rate of spread of fire is studied on the Haines index. A single LoRa gateway could cover around 4 Kms of area. Graphical visualization on websites is possible.
[36]	2020	X	X	X	X	✓	X	BME280 SDS011 MH-Z14A-CO2 ZE07-CO	Artificial intelligence, and deep learning are used for the prediction of fire. The internet of things is used for connecting sensors and other objects. The model showed an accuracy of 99.8%.
[37]	2020	X	X	X	X	✓	X	-	Predicting ignitions should be the priority and predicting the behaviors of fire, is the second. Artificial neural networks and logistic regression models have been the most successful among all in forest fire detection systems.

Table 1. Analysis of related works on wireless sensor networks based forest fire detection systems using various wireless communication techniques *(continued)*

Ref. No.	Year	Communication techniques Tz	Tb	Tg	Tl	Tal	Taz	Sensors used	Key findings
[38]	2020	X	X	✓	✓	X	X	MQ2, BME280 (temperature, humidity, pressure), Nova SDS011 (particles in suspension), MH-Z14A-CO2 (carbon dioxide gas), ZE07-CO (carbon monoxide).	Better than traditional methods. Authorities can be alerted immediately via SMS. The limitations faced are, node carrying GSM module would consume more energy and network coverage in forests is mandatory.
[39]	2020	✓	X	X	X	X	X	Tilt sensor to monitor the tilting of trees, Fire sensor, Sound sensor.	Low power consumption and low-cost system for forest monitoring. The authorities are alerted by an alarm.
[40]	2020	✓	X	X	X	X	X	DH22 (temperature and humidity).	User-friendly web application is implemented. 80% throughput achieved even during heavy traffic. Zigbee offers less range and reliability.
[21]	2020	X	X	X	X	X	X	Temperature, humidity smoke, and flame sensors.	Coverage holes are reduced using satellite communication. The resolution is a limitation, fire is detected only when it extends roughly to 7 ha. Latency of transmission is also a limitation.
[41]	2020	X	X	X	✓	X	X	-	The communication range of LoRa was reduced when the device - device connectivity was done instead of device-base station connectivity.
[42]	2021	X	X	X	✓	X	X	-	Lora is sensitive to obstacles in forest vegetation. 860 m of range in dense vegetation. 2,050 meters for not so dense vegetation. Lower frequency performs better than higher in terms of coverage.
[43]	2021	X	X	X	✓	X	X	Cameras	The system is fault-tolerant and consumes very less power as compared to a system using 5G or wi-fi.
[44]	2021	X	X	X	X	✓	X	Humidity, temperature, UV, and flame sensor.	Overlapping of sensors' positions/coverage can be avoided using this algorithm. Nodes are allocated at high-hazard areas using this algorithm.
[45]	2021	X	X	X	X	✓	X	-	Performs better than the state of the art techniques.
[46]	2022	X	X	X	X	✓	X	DH22 (temperature and humidity0 LDR (light intensity), MQ9 (CO level).	Solar panels are used as secondary power sources. Text messages are sent as alerts. Delay is reduced due to tree topology.
[47]	2023	X	X	✓	X	X	X	Temperature, humidity, windspeed and carbon dioxide sensors.	The system is useful in efficient monitoring of large areas using LoRa. This also includes inapproachable remote regions specially without telecommunications infrastructure.

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