Threat Intelligence Gathering Framework to Predict Fire on the Cell Tower Antenna: A Call for Further Research

Lateef Lanre Abdulsalam
Occupational Health, Safety, and Business Resilience Consultancy
40 Basheer Shittu Avenue, Magodo Phase 2 Lagos, Nigeria

***Abstract*—The significance of cell tower antennae and allied radio equipment in the context of mobile network infrastructure in relation to economic and security aspects which telecommunication network encompasses cannot be underemphasized in the achievement of globalization agenda. Any threat posed to this critical component of the mobile network should be identify and address with application of readily available efficient technology. Early notification with rapid response to a cell tower antennae fire incident is critical to avoid attendant consequences. Fire emergency risk assessment, and reliable detection platform at the point source of the fire constitute the most vital part of fire emergency containment. In this research, the author examines the various contributing factors of fire incident occurrence in cell tower antennae with emphases on improvement that can be driven through application of Machine learning and Artificial intelligence technologies. The author begins with examining preventive and corrective maintenance widely used today in the telecommunication industry and proceed to exploration of proactive cell tower antenna condition monitoring (Predictive Monitoring). Finally, the need for the development of machine vision technology for intelligent condition monitoring on cell tower equipment (Radio and microwave antennae, Remote Radio Unit and Base Band Unit) are suggested with intent for future research contribution.**

***Keywords*—Antenna; predictive model; algorithm; tower; radio**

I. INTRODUCTION

Reliable and timely fire emergency intervention is crucial to achieve sustainable cell tower antenna optimal performance. From the economic and security perspectives, Telecommunication infrastructures play a crucial role in global security domain and economic development activities. Human induced factors have had significant impact on cell tower antennae and allied components with resultant and/or attendant fire incident occurrence on cell tower antennae and allied components anchored on top of cell towers.

The colocation of Telecommunication infrastructures as being practiced by multiple Operators and authorized by telecommunication regulators in most part of the world especially Nigeria has served only as effective business model aimed to optimize cost and revenue generation. This business model has created service opportunities for some telecommunication engineering contractors especially in Africa (Nigeria) whose service delivery is not regulated or license to provide maintenance services in the industry. Larger percentage of all deliverables needed to provide effective telecommunication services especially in Africa (Nigeria, Ghana, Kenya, Ethiopia etc.) is outsourced. Once a contractor has been granted access to cell tower site by the site owner with the objective to execute a task on cell tower as may be assigned by the telecommunication operator (Active equipment owners). What task was approved for access to cell tower is what is understood, how the task was performed remained unknown to other stakeholders.

Unregulated maintenance engineering service provision in telecommunication industry in most part of Africa (Nigeria, Ghana, Kenya, Ethiopia etc.) has made the industry to witness an unconventional fire incident on cell tower antennae at frequent intervals in recent time. Most tasks performed on the tower are usually not vetted upon completion by the task owner, hence, installations of antennae and allied equipment, equipment upgrade and turn around maintenance on cell tower antennae are often accompanied with unprofessional and/or unethical practices with attendant unintended consequences such as fire and equipment fall from height.

Since evolution of global system of mobile telecommunication globally, the major public outcry relating to cell tower has been on health impact of radio frequency emission which has received considerable global research attention. Even though telecommunication infrastructure has supported global connectivity (Globalization). Research work needed to address major challenges facing the telecommunication industry such as cell tower antenna and allied components fire incident, compliance with health and safety standards requirement [9] and lack of clear regulatory mandates on health and safety to ensure safe system of work in the industry is scarce.

Digital strategies have started gaining relevance in fire incident anticipation, when there is a disorderliness in any system, a smart control system will automatically regulate the system structures to mitigate risk. Remote monitoring coupled with predictive control means that most break down can be anticipated, prevented, and reduce inherent or associated risk to as low as reasonably practicable. Data gathering on past event can be used to predict future recurrence. A team at Carnegie Mellon University developed fire risk assessment model that uses machine learning to predict likelihood of fire incident occurrence in each property [12].

Research on cell tower antennae fire safety has so far mainly been directed or focused on arson. Hence, the need for additional knowledge, recommendations, models, and Engineering tools has become a reality. A typical fire occurs

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in cell tower antennae due to electrical system fault- for example short circuit, partial contact, surge, and static spark due to poor earthing. Typically, electrical cable would play a vital role when it comes to fire spreading across adjacent cell tower equipment anchored on the affected tower. The risk involved in working with electricity extend beyond those working directly on it. Poor electrical installation and faulty electrical appliances can lead to fire with resultant damage to other assets, network downtime and disruption to security intelligence gathering when it involves cell tower fire incident [4].

Significant advances have been accomplished within the past two decades at both design and regulatory levels on fire prevention technology. Similarly, considerable efforts have been undertaken worldwide to implement these advances in the interest of improving fire safety at operational levels [8]. But efforts geared towards achieving similar advances specifically on cell tower antennae fire event is rarely available.

Cell tower condition monitoring encompasses identifying the components of a cell tower (Antenna, Remote Radio Unit, Base band Unit etc.) to detect unconventionalities in operations that can be a suggestive of a fault development within a component. It is obvious that fault prediction preceding occurrence via a robust condition monitoring, should lead to significant reduction in operation and maintenance costs. Condition monitoring methods have hinge on analyses of specific dimensions and certain aspects of the operations (e.g., vibration analysis, strain measurement, thermography, and acoustic emissions) [1].

Current advances in sensors and signal processing systems, big data analysis, machine learning and improvement in computational proficiencies have created opportunities for integrated and thorough condition monitoring analytics, where diverse kinds of data can facilitate informed, dependable, cost-effective, and robust decisions making in condition monitoring [1].

ROOT CAUSE ANALYSIS FOR FIRE EVENT ON CELL TOWER ANTENNAE

Fire hazards has been identified to be a major contributing factor to a plant operational safety risk [8]. Root cause analysis method has been identified as a principal elements of fire safety assessment, experience over years has shown that even minor fire incident events, when analyze with root cause analysis method, will invariably yield several insights into causative factors which other fire incident investigation method might miss. If adequate and appropriate priority attention is accorded to whatever insights generated with insights derived from root cause analysis most of which relates to people, process, and equipment, then the incident of cell tower antennae fire incidents can be reduced to as low as reasonably practicable [8].

II. CELL TOWER AND ELECTRICAL HAZARDS

Electricity has over time been recognized as the major source of industrial fire incident due to its array of application [5]; An unsafe conditions are often created by most designated maintenance engineering service providers working on cell towers antenna (Radio antennae and allied component installation) which has accounted for some of the major fire incident experienced by telecommunication infrastructure service provider in Nigeria as witnessed by the author during investigation involvement at different scene of incidents in 2021. Among the many factors that has contributed to cell tower fire incidents in recent time in Nigeria because of poor electrical installations at different heights on cell towers are as highlighted below according to [5].

1. Overheating of current carrying elements
2. Ageing of materials and /or allied components
3. Use of substandard electrical equipment
4. Poor maintenance culture
5. Ignition of flammable materials due to arcing
6. Corrosion
7. Loose connectors
8. Water ingress
9. Coax clip failure

Conversely, the three most important independent mode of electrical heating that can lead to cell tower antenna fire incident are:

1. Excessive current: System overloading may lead to unwarranted current through short circuit with resultant system protection failure.
2. Poor cable connection: Poor cable connection occur when:
   a. Lugs are not properly crimped to the cable
   b. Lugs higher than the appropriate rating and /or size is used for termination with resultant loosening of the cable against lug joint.
   c. Termination of two higher size cables at a single stud thereby leading to improper tightening (Partial contact)
   d. Formation of oxide layer or corrosion leading to higher resistance
   e. Termination of aluminum over copper without using bimetallic strip
3. Insulation failure: Deteriorated insulation materials as result of long-term exposure to climatic elements which attract leakage current may start arcing with resultant fire incident

III. FUNDAMENTALS OF POWER SUPPLY THROUGH CABLES TO CELL TOWER ANTENNAE AND ALLIED COMPONENTS

A cell tower antenna is an electrical device which transmute electric current into radio waves, and vice versa. In radio transmission, a radio transmitter supplies an electric current and oscillate at radio frequency (i.e., a high frequency alternating current to the antenna's terminals, and the antenna radiates the energy from the electric current as electromagnetic waves (Radio waves). At reception, an antenna captures some of the power of an electromagnetic wave to produce miniature amount of voltage at its terminals that applied to a receiver to be amplified [13]. To achieve optimal functionality of cell tower antennae, cable, and connector performance in conformity to standard design requirement, auditing and testing of cable and antennae system every three to six months and prompt issue resolution are highly recommended.

Proliferation occasioned by development in mobile and internet of Thin (IoT) devices, is pushing mobile network operators to progress from a typical mini cell site-based coverage topology to a denser capacity – based diverse network. Current improvements in radio technology (Improved power amplifier efficiency and better design), have empowered mobile network service providers to connect remote radio units (RRU) close to the antenna near the top of the tower. This technology enhancement has enabled mobile network service providers to improve capacity, coverage, and signal integrity, while at the same time reduce electrical, leasing, and cable costs [13].

Nowadays, cell tower power supply through coaxial cable for every transceiver path is gradually evading, mobile network service providers now use lighter and significantly fewer fiber to supply power between the remote radio units (RRU) at the top of the tower and the base band unit (BBU). The base band unit can be located at the base of the tower or remotely located. The remote radio unit converts the digital base band signal into analogue signal and vice versa for transmission and /or reception over the air. The base band unit performs the processing of the radio protocols, interfaces between the radio network and the operations management interface [13].

A. *Cell Tower Maintenance Limitation*

Cell tower maintenance service providers must physically perform all assigned tasks on tower. Various tests are performed to ensure that all cables, connectors, and other active and passive components are professionally installed and commissioned. This is done to ensure optimal cell-site performance to offer best quality of service for mobile subscribers and maximum return on investment for the network operators. Major areas of concerns associated with cell tower maintenance services which requires urgent priority attention are as mentioned below:

1. Sabotage
2. Poor cable connection
3. Over loading
4. Inappropriate cable ratings
5. Violation of original equipment manufacturer installation instruction
6. Environmental hazard (Exposure of antenna to climatic elements)

Most of the activities performed on cell towers relating to antenna and other radio equipment installations as may be assigned by the cell tower operator to the maintenance service providers are usually not verified for quality assurance after job completion which has contributed to most of the cell tower fire incidents experienced by the tower operators recently (2021) in Nigeria.

B. *Cell Tower Fire Incident Occurrence Monitoring and Detection Methods*

Portions destroyed by fires are large whenever it happened especially when not detected early enough to curtail it and fire produce carbon monoxides than the overall automobile traffic [2]. Monitoring of the potential risk involved in cell tower fire incident and an early detection of the fire ahead of emergence can significantly shorten the response time and reduce the potential damage as well as the overall impact of network failure and/or down time incurred by the network operator. Known rules apply here: 1 minute response time requires 1-cup of water, 2 minutes response time requires one hundred litres of water, 10 minutes response time requires 1,000 litres of water and vice versa [2]. The aim is to detect the fire occurrence likelihood as prompt as possible and its exact localization and early notification to the stakeholders involved is crucial. This is the deficiency that the present research attempts to address to ensure possibility to halt the fire from happening.

There are three basic fire event monitoring system used in most advanced countries like United states of America, Canada, Germany etc. [2]. These includes:

1. Optical sensor system (OSS): Each OSS rotates 360 degrees every 4 to 6 minutes in a daytime and 8-12 minutes during the night in 10 degrees steps
2. Data transfer: Optical sensor system at the tower has a wireless connection to the office computers
3. Central office: Once the sensor detects a smoke, the information is relayed to a central control room via radio transmission.

Optical sensor monitoring system can be used ubiquitously; therefore, the research interest in sensor networks is fast gaining attention. Different method of fire emergence monitoring has been proposed. Early methods were based on manned observation of towers but this method with so many other methods were ineffective

Wireless sensor network technology typically involves deployment of many small, low-cost sensor network to be used in disaster detection. The code is developed to be aware of a node's destruction threat and it can observe and influence the physical condition around them by gathering physical information, transforming it into electrical signals and sending it to a remote location for further analysis to generate a result that can be used for fire incident analysis detection. Wireless sensor technology can deliver real-time monitoring, where it can provide information at the ignition instance with less delays, depending on the node used under active and inactive schedule. For the sensors to detect fire occurrence, each node will be provided with many sensors to get the environmental parameter such temperature, smoke, and fire flickering to define a fire incident at the initial stage [2].

C. *Cell Tower Antennae Fault Detection Techniques*

Diverse categories of faults associated with cell tower antenna with resultant fire emergence may need to be treated differently. Certain unintended configuration irregularities can be fixed with the likelihood that the issue will remain resolved. Similarly, deliberate disruption such as arson may arise except certain measures are taken to circumvent external attack or mitigate its effects on cell towers. In the event of unintended disruption, it is necessary to prevent future incident occurrence through application of certain measures such as condition monitoring [3].

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IV. CELL TOWER ANTENNAE AND ALLIED COMPONENTS CONDITION MONITORING

Cell tower antenna condition monitoring is an integral part of operations and maintenance, where operations include the management of, monitoring of cell tower site, while maintenance covers intervention required to upkeep the installation. Maintenance can be corrective, preventive and /or predictive [10]: Corrective (Reactive, run-to failure) is the most expensive type and does not utilizes condition monitoring with component being replaced when defect occur or accumulate; under preventive (Scheduled) maintenance, components are replaced at the next intervention hopefully before a related fault occurs; a predictive maintenance strategy based on condition monitoring can inform maintenance about components that likely are to fail and have them replaced as and when due. Condition monitoring can be viewed along several aspects [6], [7].

Firstly, condition monitoring can be applied at different granularity, at the most coarse-grained uppermost level we can consider the complete system. The signal provided by different models can be combined to provide higher-level warning for complete system [6]

Secondly, the ways in which condition monitoring is performed can have a physical impact on the component being monitored.

Thirdly, condition monitoring can be used for fault detection in real -time or in the future, so we distinguish between: [6]

Fault detection: (Diagnosis), where we can identify a fault when it happens. Ensuring that the condition monitoring can identify the presence of failure should be a prerequisite for building a machine learning model for prognosis.

Fault prediction:(Prognosis), where the underlying model finds pattern in the signal data that predicts failure in the future [1].

When deciding which component to monitor, it is important to consider the failure rates and downtime per failure of different sub-components. Prioritized considerations are given to component that are more likely to fail or can lead to long downtimes, as they may incur the greatest impact [1].

V. MACHINE LEARNING FRAMEWORK

Machine learning involves building a model through application of artificial intelligence that enables system to automatically learn from a limited amount of data without expert involvement. This learning suggests finding basic set of patterns that are required to understand relationships in data that might not be precisely like that which learning occurred. Machine learning can be broadly classified into two; supervised machine learning algorithms which predicts an output variable using labelled input data, while unsupervised machine learning algorithms draws inferences from data without labelled inputs [1].

Steps involved in machine learning model building:

1. **Data gathering:** This involves data acquisition and initial processing for application where diverse datasets are integrated and cleaned from missing data and outliers
2. **Feature selection and extraction:** Vital indicators and features are acknowledged and mined from the data.
3. **Model selection:** An appropriate model is chosen based on relevance to this task to be performed.
4. **Authentication:** Performance appraisal is conducted to confirm the best out of the model selected in terms of accuracy, specificity, sensitivity, and predictive values.

Requirements: Digitalization of cell tower antenna equipment's condition monitoring in the aftermath of the current fire incident occurrence on cell tower antenna installed at different height on towers requires Original Equipment Manufacturers to consider integration of new technologies(Fire intelligent monitoring) on antennae manufacturing that will explore Machine learning and artificial intelligence (Hardware sensor network and automation) and software load(communication protocol datasets),including security aspects is required for the design and implementation of the digital trend [10].

Benefits of cell tower antenna condition monitoring:

1. Safety management system is enhanced by averting the development of dangerous occurrence that may be devastating to the entire business environment.
2. Avoidance of planned service provision failure through early warning signs that enable cell tower operators to prevent unintended fire incident consequences.

VI. CRITICAL SUCCESS FACTORS TO ACHIEVE IMPLEMENTATION OF CELL TOWER ANTENNAE CONDITION MONITORING

1. Establish monitoring objectives: This is to determine the condition of equipment with the aid of advance technology to potentially predict fire incident before it happened.
2. Adoption of condition monitoring program: This should be done to achieve oversight on cell tower antenna and data processing support.
3. Sensors and smart systems installation: This embraces machine learning application to learn about equipment performance patterns and hence detect any potential for fire incident occurrence on the equipment and relay timely information ahead of incident.
4. Adoption of E-monitoring management system (EMMS): This is to streamline and improve monitoring activities.
5. Data mining and warehousing: This should be done to derive useful insights for continuous improvement.
6. Develop Key Performance Indicators and Business Intelligence: This should be done to track performance progress. [10].

Cell Tower antenna condition monitoring techniques:

1. **Temperature:** Temperature monitoring is a method used to provide information about heat load on equipment during operational mode through application of thermocouple or resistance thermometers. It provides fire hazard information to equipment operator and the likelihood of fire incident occurrence.
2. **Noise assessment:** Noise generated by an equipment during operations has been customarily used to provide background information about its operational condition. The simple development can now be schematized with the aid of amplifier, microphone, and continuous recording device.
3. **Vibration monitoring:** This method involves recording and analysis of equipment vibration patterns. Unnecessary vibration is a warning sign for disorderliness in the system and by investigating vibration level at varied frequencies, precise diagnosis of the source of vibration is possible. The condition monitoring devices can be programmed to account for vibration levels at all frequencies and activate automatic alarm as early warning indicator [6], [7].

Goals of cell tower antenna condition monitoring:

1. To avoid catastrophic failure through system shut down and alarm triggers
2. To minimize system down time through early warning of potential fire incident
3. To provide basis for predictive maintenance requirements

Cell tower antenna fire incident scenario prediction:

1. **Event based fire scenario prediction:** This focused on deviated-patterns sequence of events often created by maintenance engineering service providers involved in cell tower antenna electrical components installation. Sensors can process information based on this scenario to generate data required to predict future fire occurrence.
2. **Sensor based fire scenario prediction:** The sensor will gather and process information on potential fire occurrence using machine leaning algorithms to generate prediction model applicable to predict fire incident occurrence.
3. **Model based fire scenario prediction:** This involves processing sensors and event-based fire scenario to generate predictive solution with the aid of machine learning algorithm.

VII. CONCLUSIONS AND FUTURE WORK

Various literatures reviewed in this work suggest that Cell tower antenna manufacturers will enjoin improve productivity benefit by integrating fire element detection sensor with efficient algorithm that can provide unbiased intelligent processing with higher degree of accuracy. Opportunity abounds for imminent improvement when further advance data set is utilized which includes but not limited to Cell tower antenna age, model, brands, and fault records. One of the greatest challenges faced by Telecommunication services providers is fire incident occurrence vulnerability by many of the cell tower infrastructures especially Cell Tower Antenna and allied components as it comes with attendant reputational damage, environmental hazards, and operational downtime. Thus, an urgent scientific measure that facilitate early detection to prevent fire incident occurrence can no longer be underemphasized. A review of literature on predictive maintenance models with focus on fire incident detection suggested that an optical remote sensing technologies that incorporates flame, smoke, heat, and gas detection algorithms with higher degrees of accuracy under uncertainty environment (Terrestrial, Air and space based) can serve as a remedy to fire incident on cell tower antenna [11].

Early detection of fire on Cell tower antenna will enable timely intervention in advance prior to fire occurrence if predictive maintenance is performed based on an evaluation of the cell tower antenna health status [14]. Cell tower antenna incorporated with constituent intelligent fire element detection and/or monitoring system will serve immense benefits to all global mobile telecommunication operators as it will allow early detection of fire incident occurrence which will in turn afford the service providers with opportunity to deploy early intervention mechanism.

The suggested data for Algorithms exploration could be source through the following parameters:

1. Telemetry data on Cell tower condition attributable to fire elements (i.e., heat, smoke)
2. Cell tower antenna technical parameters (Voltage, Frequency, Pressure and Vibration)
3. Cell tower antenna maintenance records (Fire incident records)

A sensor-based fire components detection which sends signal and /or activate fire emergency alarm at the network operation Centre (NOC) which further escalate the receipted information to various designated emergency responders at different locations through automated and /or online platforms such as e-mail, text messages, phone vibrations/alarm trigger with messages on what action / steps needed to be taking upon receipt of the emergency escalation. The suggested threat intelligence gathering, and analysis should reveal the severity of the hazards as either, low, medium, and high priorities with brief description of foreseeable events that may occur where there is a delay response to the emergency activation and escalation.

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