Towards an Efficient Fog-Based Forest Fire Management Architecture

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ABSTRACT

Forest fires cause significant human losses and natural damage and threaten the biodiversity on our planet. Several researchers have studied the potential of wireless sensor networks (WSNs) to manage a forested area and have proven the real potential of this paradigm. Such systems generate a large amount of heterogeneous data in a short time, which may lead to network congestion and delay in data transmission. Processing such data in a short time frame is challenging for a traditional WSN. This article presents a multi-layered architecture for wildfire prevention, detection, and intervention based on WSN, IoT, cloud, and fog computing technologies. The proposed architecture is validated using the iFogSim simulation tool. Two models are compared, cloud-only and fog-cloud-based scenarios. The experimental results show that the cloud-fog model minimizes latency and significantly reduces bandwidth consumption compared to the cloud-only model. To bring fast fire extinguishing ability to the system, the authors recommend the employment of drones equipped with fire extinguishing balls.

KEYWORDS

Cloud Computing, Data Processing, Drones, Fog Computing, Forest Fire Detection, iFogSim, IoT, WSN

INTRODUCTION

Forest fires, wildfires, or even firestorms are all terms that describe the existence of a fire in a forested area. Every year forest fires cause significant losses of environmental systems, infrastructures, biodiversity, and even human lives around the world. According to the 2020 Global Forest Resources

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Assessment report (FAO, 2020), an estimated 7.20 billion hectares of land were burned between 2001 and 2018, with an average of about 29% of the area covered by trees.

In Algeria, the year 2021 has seen many devastating wildfires. The most important ones, which caused the most natural damage and especially human losses, were during August. The newspaper "le monde" (A, 2021), reports that August's wildfires in Algeria caused at least 90 deaths. The Algerian minister of agriculture and rural development revealed that August's fires destroyed 89,000 hectares of forest in 35 Wilayas (municipalities) (Le Monde & AFP, 2021).

Forests occupy a large part of the northern part of Algeria. That makes these places very susceptible to fires. Additionally, the lack of modern fire detection systems and methods and reliance on purely traditional methods had a significant impact on the fight against fires and their spread. Therefore, the constant development and implementation of forest fire detection and prevention systems are crucial.

There are two types of forest fire detection systems (FFDS), traditional and modern. Traditional systems encompass old detection methods where human presence in all detection, localization, and extinction operations is indispensable. The full dependence on the human factor may lead to the unreliability of forest fire monitoring due to climatic conditions that hinder the surveillance operation like clouds, mists, etc. Moreover, human characteristics like fatigue, omissions, and negligence may lead to system disruption (Barmpoutis et al., 2020). Throughout the world's forested areas, implemented fire detection approaches still use traditional methods. Besides, many modern FFDS based on technological and information systems have been developed. Satellite-based image processing systems are one of these methods. Characterized by their wide geographic coverage, NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) (Barnes et al., 1998) and Visible Infrared Imaging Radiometer Suite (VIIRS) (Murphy et al., 2006) satellites have been widely used to monitor large forest areas. However, their interval time between detecting fire and alarming the concerned departments is relatively high (Grover et al., 2019). In addition, climatic conditions such as the presence of clouds and mists and other obstacles to satellite vision proved the limit of this type of system. An emerging trend in forest fire detection is camera-based image processing systems deployed on unmanned aerial vehicles (UAVs). This type of system is relatively inexpensive and can cover multiple types of terrain (Kalatzis et al., 2018). However, limited resources and processing capabilities, UAV's limited battery life, and privacy preservation are some issues that need to be addressed to achieve better results in such processing systems.

Wireless Sensor Networks (WSNs) have been widely employed for environment perception and monitoring. WSN based systems are suitable for forest fire detection and have proven their efficiency in terms of detecting, localizing, and tracking forest fires in many applications (Grover et al., 2019; Bouabdellah et al., 2013; Saoudi et al., 2016). The vast geo-distribution of environmental sensor nodes (such as temperature, humidity, precipitation, and wind sensors) in a forest area allows better monitoring and an effective detection of forest fires in an early stage. However, WSN based systems present some limitations. A WSN environmental perception system deploys many sensor types, which generate a vast amount of heterogeneous data in a short lap of time (Smys, 2019). Processing such data very quickly is challenging in traditional WSNs. Sensor node limited battery life is another limitation that every WSN system has to overcome.

The paradigm of connected objects or the Internet of Things (IoT) is a trend that is very appropriate to the field of forest fire detection, prevention, and management. In combination with the cloud computing paradigm, for efficient and fast data processing purposes, several researchers have proposed "real-time" FFDS such as (Tomar et al., 2019) and (Sungheetha & Sharma R, 2020). Data processing and transmission of results in real-time are crucial requirements in such systems. Nevertheless, cloud-based forest fire detection implementations have high network usage and latency rate in data acquisition, data processing, and results transmission due to the distance between the source and the data processing center, which is not suitable for time-sensitive applications.