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WIRELESS SENSOR NETWORK FOR ILLEGAL LOGGING APPLICATION: A SYSTEMATIC LITERATURE REVIEW

[1]GIVA ANDRIANA MUTIARA, [2]NANNA SURYANA, [3]OTHMAN BIN MOHD

[1]Telkom University, Department of Applied Science School, Bandung, Indonesia

[1,2,3]Universiti Teknikal Malaysia Melaka, Department of FTMK, Melaka, Malaysia

E-mail: [1]giva.andriana@tass.telkomuniversity.ac.id, [2]nsuryana; [3]mothman{@utem.edu.my}

ABSTRACT

Wireless Sensor Networks (WSN) is a technology available for outdoor area application. The characteristic of illegal logging application is suitable to apply WSN-based application. Because the illegal logging application is implemented in a wide range area, supervised the environment forest, and consists of hundreds of sensor nodes. This paper aims to review and summarize as systematically the contribution of WSN Technology in illegal logging area research as a long-range network application especially in detection and identification method, timber tracking methods, data exchange, and transmission method. A Systematic Literature Review (SLR) were outlined in this paper as a standard methodology of predefined research strategy to solve the problems by tracing the previous research. By defining the Research Question (RQ) to guidelines the SLR process and inserting the search string in the database reputation journal, the previous research can be configured. There are 42 previous studies applied WSN to used it in the illegal logging application. The result stated that WSN has biggest contributions since 33% researcher using WSN to tracking application, 41% use the WSN as a data exchange in their system, and 48% used WSN as data transmission between sensor nodes. This paper is expected to give a contribution to the researcher who wants to build the system to tackle illegal logging since the illegal logging has been hot issues in the world.

Keywords: *Wireless Sensor Network, Illegal Logging, Long-Range WSN, Data Exchange*

1. INTRODUCTION

Illegal logging is a global problem that is owned by every country that owns a large forest with a variety of logging activities [1]. Solving the problem of illegal logging is quite difficult considering the many different illegal activities like macro level (practice as a corruption, irregularities of licenses), logging in restricted or prohibited areas, illegal logging activities within legal concessions, illegal reporting activities, and illegal transport activities [1]. Besides, the position of the forest that located far from the urban and rural areas, rarely accessed by the human, and having an area covered up to thousands of hectares are an obstacle to be able to supervise the forest from logging process [2].

Various techniques of problem-solving approaches to tackle illegal logging are carried out with various methods that currently available. Previously, they use old techniques to monitor the timber. They used barcode [3] and chemical paint to tag the timber [4]. Radio Frequency Identification (RFID) then replace the use of barcode and chemical paint since the data in RFID can be renewed or update electronically [5][6][7]. Monitoring and Log-tracking systems also offer the ability to monitor forest crimes over a long period [8].

Wireless Sensor Network (WSN) is a set of a large number of mobile or static sensor nodes as an actuator that can sense the environmental information. The WSN formed a wireless network using a self-organization sensor network methods or multi-hop sensor network methods that functionated to collaborate monitoring in the term of detecting, processing, and sending object monitoring information in areas where the network is coverage [9]. WSN is suitable to use in outdoor environment applications, remote area locations that are rarely accessed by a human has long maintenance period, and can monitor and object in large areas [2].

Many application using Wireless sensor network to monitoring the system. WSN has been implementation in agriculture environment to determine pollination readiness of oil palm flower. By using an actuator node like temperature and humidity, the WSN can controlled pollination

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process [10][11]. In other fields, WSN is used in the health sector such as smart health monitoring [12]. This application is a kind of telemedicine application that can help doctors and nurses to observe the patient's health condition continuously by collaborating WSN with IoT technology and offers patient protection in remote condition [13]. WSN is also used in the monitoring power meter since there are a lot of places with shared power sources. The use of electricity in shared power sources must be monitored so that, the calculation of power usage can be evenly distributed according to the usage of each user [14].

The previous review on Wireless Sensor Network has discussed the use of WSN in the agriculture field [15]. This review discussed the potential wireless communication protocol and the taxonomy of power consumption problem in agriculture. Another survey discussed the review of a simulation framework for WSN [16]. This study reviewed the network simulator or programming language to evaluating the WSN's localization algorithm. Besides, there is a lot of review in the WSN area focused on synchronization protocol [17,18]. This study discussed the difficulties of the synchronization in WSN [17], while [18] discussed the method of synchronization in the WSN area. Another review of WSN and its application also conducted, based on the analysis of typical WSN in various application [9].

Regarding those previous reviews, however, it requires the review of WSN as Systematically Literature Review (SLR), especially in the illegal logging domain. Based on that, this research purpose to review and summarize as systematically the contribution of Wireless Sensor Network Technology in illegal logging area especially in long-range network and data exchange communication. This paper is expected to give contribution to the researcher who wants to build the system to tackle illegal logging using Wireless Sensor Network (WSN) since the illegal logging has been hot issues in the world.

2. RESEARCH METHODOLOGY

Systematic literature review (SLR) used as a predefined research strategy for performing research methodology [19,20]. By using this SLR, it is expected that the literature review can produce research studies that contribute to systematic reviews derived from previous studies.

In order to have a guideline to conduct the research. The research question is conducting for the all the research that related to illegal logging area between the year 2013 – 2018. The research questions are extracting and describing in table 1.

Table 1: Research Question for Literature Review

RQ	Research Question	Motivation
RQ1	What kind of WSN based application that used in illegal logging?	Identify the application that used to tackle illegal logging
RQ2	What methods are often used in detecting and identifying timber?	Identify the most often method that used to detect and identify the timber
RQ3	What method is often used in timber tracking?	Identify the most used method in timber tracking
RQ4	What methods are often used in exchanging timber location data?	Identify the most used method in data exchanging timber location
RQ5	What technology is often used as a timber data transmission?	Identify the most used technology in a timber data transmission

By generating a sophisticated search string strategy using the library of the reputation journal or conferences proceeding database, the list of literature research studies can be found. The search string strategy can be concatenated using Boolean AND's and OR's. But, before doing formulated the search strings, the term of the search string word should be defined.

Based on the research questions, the search string word can be defined as shown in table 2.

Table 2. Search String of The Research

Topic	Activities	Technology
Illegal Logging	Identification	Long Range Wireless
Logging Track	Tracking	Wireless Sensor Network
	Detection	Data Exchange Protocol

Besides applying the search string, the selection of the previous studies is defined to filter out the unrelated research journal and proceeding conference. The criteria are as follow:

1. IF ('the search result is a general article') THEN DISCARD, ELSE GOTO Step 2

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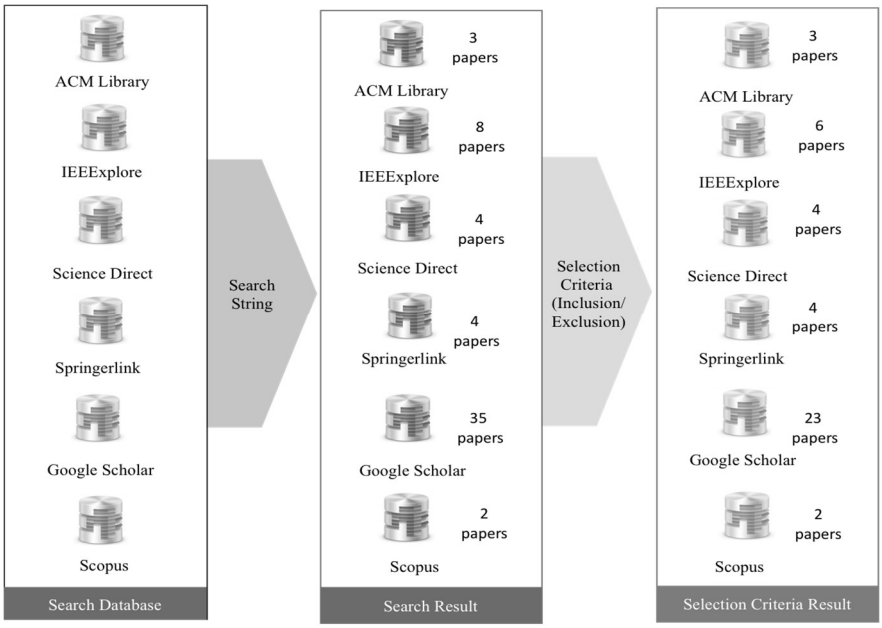

Figure 1: SLR Execution Process

2. IF('duplicate or have multiple publication from same study") THEN DISCARD, ELSE GOTO Step 3
3. IF('sensor network applied for indoor") THEN DISCARD, ELSE GOTO Step 4
4. IF ('written in English') THEN GOTO Step 5, ELSE DISCARD
5. IF ('written as thesis or dissertation') THEN DISCARD

The result of the previous studies can be seen in figure 1.

3. RESEARCH RESULT

In this section, based on the SLR execution process, it can be defined 42 of research studies as a previous study that discusses the long-range network or wireless sensor network in illegal logging area research. This section will describe the 42 research studies based on the research question on table 1. The subsections are WSN application in illegal logging, detection and identification component, tracking method, data exchange method and transmission methods.

3.1 WSN-based Application in Illegal Logging

According to the 42 previous studies, the distribution of the used of WSN-based application in illegal logging can be seen in figure 2. WSN-based application in illegal logging defined in four concerning research. Detection and identification, tracking method, data exchange method, and transmission method.

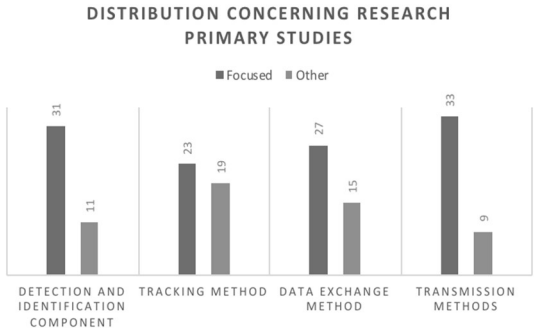

Figure 2. Distribution Concerning Research of WSN-based Application

There were 31 previous studies discuss the use of WSN in detection and identification component, 23 research studies discuss in tracking methods, 27 research studies discussed in data exchange, and 33 research studies discuss transmission methods. The term of others in the graph appears since the research did not mention the methods of that categories but mention of other categories. In the graph also explain the possibility multiple discuss research.

The application which is applied WSN for their system in term of detection and identification usually used to detect timber, detect the changes of the forest

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environment, and to detect the sound of the chainsaws.

The implementation of the WSN as a tracking method used for tracking the timber from logging area into log yard. While the data exchange method for application WSN-based is sometimes happened between nodes and their protocol or from the protocol into the cloud computing or middleware layer.

Meanwhile, the data transmission in WSN-based application in illegal logging area usually used to communicate between sensor nodes to the gateway, or sensor nodes to Base Station or gateway to Base station.

3.2 Detection and Identification Method

This is the section where the research studies are compiling to answer the research question 2 (RQ2). Identification of timber and trees is the beginning step of a study in the illegal logging domain. As shown in Figure 3, various detection and identification methods have been used by many researchers and practitioners in identifying timber and trees. Statistically, the use of audio sensors or sensor nodes gets the greatest consideration from researchers, and it is still used in research published in 2018. It is because the characteristic environment of the forest and logging is related to logging sounds and chainsaw sound. The same phenomenon also occurs in the use of the gravity sensor. The selection of timber and tree identification methods tend to use a combination of certain sensors.

The mapping of previous studies for detection and identification methods can be seen in table 3.

Table 3. Mapping Publications for Detection and Identification Methods

Detection and Identification Component	Research Studies
Gravity Sensor	[21], [22]
CCTV	[10], [11], [23], [22]
Climate Sensor	[24], [25]
GPS	[26], [27], [28], [29], [25]
RFID	[6], [7], [13]
Magnetometer	[29]
Satellite	[27], [30]
Sensor Nodes	[31], [32], [33], [23], [34], [35], [36], [37], [38], [39], [22], [40], [41], [42], [43], [44], [45]

According to table 3, there are several research studies using a certain sensor in their research. It can be seen that the emerging of the previous studies in some component detection and identification was repeated. The previous studies that use multiple sensors are using combine sensor nodes as an audio sensor, gravity sensor, and CCTV [22], while the other research studies are using combine climate sensor and GPS [25]. The magnetometer only appeared to use in the year 2013, and none of the researcher using that sensor again in recent years. Gravity sensor and audio sensor are still used until now by the researcher.

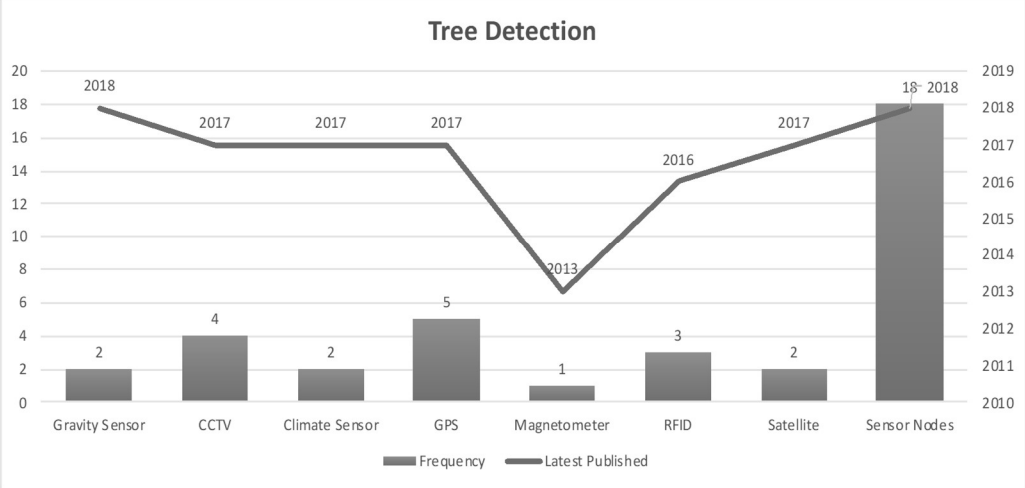

Figure 3. Illegal Logging Research for Tree Detection

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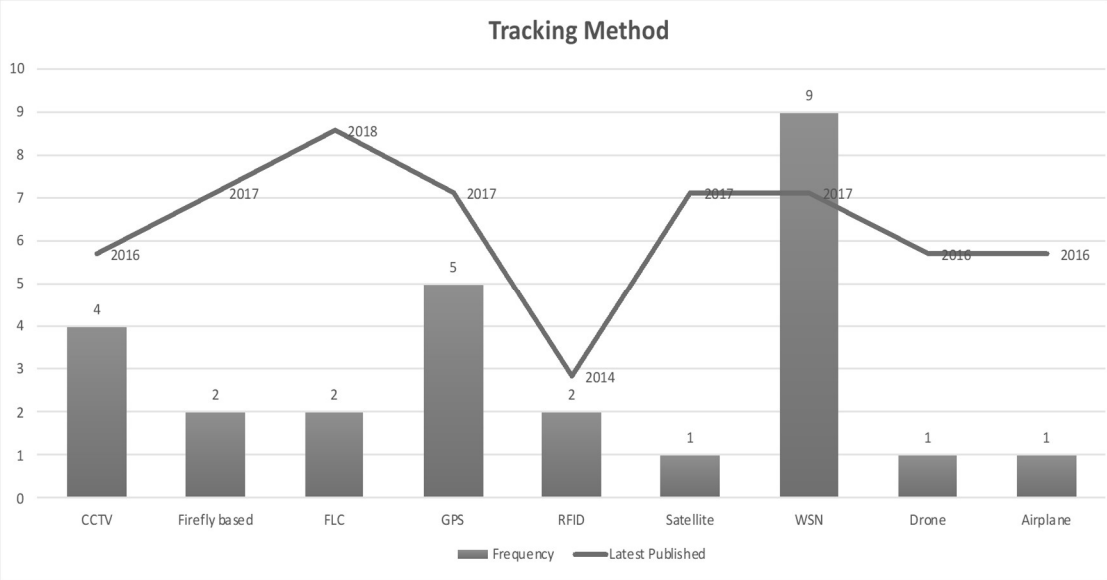

Figure 4. Illegal Logging Research for Timber Tracking Method

Moreover, not all the research studies showed the methods for detection and identification. There are eleven research studies [46], [47], [48], [49], [50], [16], [51], [52], [53], [54], [14] did not mention the detection and identification method since they had different focused in each research in the term of illegal logging. Some of the research studies focused on optimization strategies in the form of graph strategies or team search optimization. Other previous studies lead to a synchronization algorithm or power optimization used by WSN in the illegal logging area. Based on mapping the previous studies in table 3, the research studies can also be distributed as shown in Figure 4. The use of audio sensor nodes to detect logging in the forest is carried out by 49% of the previous research that concern in the detection and identification of the forest environment.

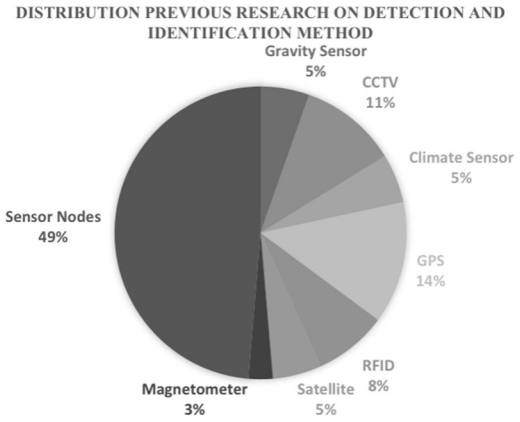

Figure 5. Distribution Previous Studies Based on Detection and Identification Method

3.3 Timber Tracking Method

After identification and detection method of timber and forest environment, the next research question is how the tracking mechanism of timber and trees will be identified. To answer the research question 3 (RQ3), as shown in Figure 5, statistically, WSN is the most commonly used tracking method and has a positive trend from year to year. In addition to WSN, Global Position System (GPS) and Closed-Circuit Television (CCTV) technology rank second and third in the order of frequency studies in the illegal logging domain that uses wireless technology. An interesting phenomenon arises in the use of Firefly-based algorithms, FLC (Forward Link Channel), and satellite, although they have limited study frequencies, they are present in recent studies. These methods deserve more attention because they have current factors.

According to Table 4, there is one previous study that using multiple timber tracking method. It is combining technology of WSN, drone and airplane to do the timber tracking [25] . Meanwhile, there are 19 research studies that did not exactly explain the timber tracking methods since they have other focuses method in illegal logging area. The research studies are [46], [47], [33], [32], [13], [29], [50], [55], [16], [36], [51], [52], [53], [54], [14], [41], [42], [43], [44].

The use of CCTV is a trend to applied by the researcher since the CCTV can deliver a motion figure that captures as sensing nodes and also can track down the movement of the logs in the forest [10], [11], [26], [22]. Drone and airplane were

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applied embed with WSN in order to have a good combination of monitoring system [25]. RFID, sensor network, vibration network, embed with WSN is also the trend that most of the researcher used them as timber tracking methods [6], [7], [31], [34], [24], [35], [37], [38], [39], [40]. Since the Forward Link Channel and the Fire-fly based is an algorithm used by a researcher to detect timber tracking [48], [49], [21]. GPS and Satellite also conducted to do timber tracking [26], [27], [28], [56], [23], [30].

Table 4. Mapping Publications for Timber Tracking Methods

Timber Tracking Method	Research Studies
CCTV	[10], [11], [26], [22]
Fire-Fly Based	[48], [49],
FLC	[21]
GPS	[26], [27], [28], [56], [23]
RFID	[6], [7]
Satellite	[30]
WSN	[31], [34], [24], [35], [37], [38], [39], [40], [25]
Drone	[25]
Airplane	[25]

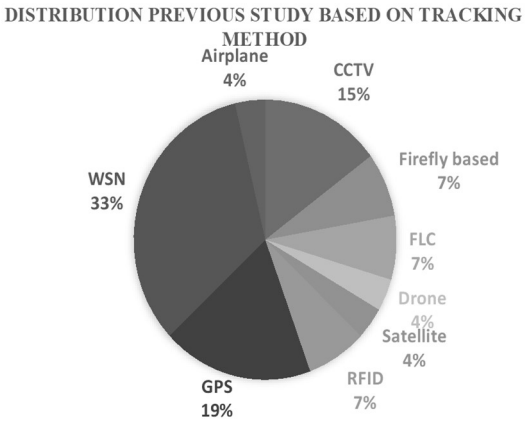

Figure 6. Illegal Logging Research for Tracking Method

The percentage distribution of the tracking method can be seen in Figure 6. Based on the figure, it can be seen that the contribution of WSN to the illegal logging research is achieved by 33%. WSN's tracking capabilities and timber monitoring play an important role so that WSN is very suitable for timber tracking applications application in the illegal logging area. The used of Global Positioning System (GPS) in the tracking system also simplify the researcher to do timber tracking which can be tracked down the timber position based on coordinate position. 19 % previous study used GPS as a tracking system.

Meanwhile, 15% previous study uses CCTV as a tracking system, since the timber can be tracked down by the moving image which is delivering and recording by the CCTV. Firefly based known as Firefly Universal Synchronization (FUSA) Protocol was used by 7% of previous research. The tracking system using the mechanism of synchronization protocol which can be tracked down the timber by the communication between sensor nodes in the networks. Besides FUSA, there are RFID and FLC which also used to track the timber by 7% of previous research. The used of RFID as a tracking system should be integrated with RFID reader meanwhile FLC is using forward link channel as hop to hop communication between nodes to tracking the timber.

3.4 Data Exchange Method

In order to answer the research question 4 (RQ4). The data exchange here discussed as a mechanism to exchange the data in the previous studies. It is shown in Figure.7 the previous research studies that discuss data exchange and transmission method in illegal logging area research.

Various mechanisms for exchanging data have been investigated by researchers and practitioners. Based on illegal logging review literature that utilizes wireless technology, the frequency of using data exchange mechanisms found that WSN and Zigbee are used most by researchers and even used up to research in 2018. Cloud Computing technology, FLC-SDN (FLC-Software Define Network), FPGA-STP (Field Programmable Gate Array-Short Term Processing), and GSM are rarely used but has a contemporary factor that can be considered in subsequent illegal logging studies.

According to Table 5 and Figure 7, there are one research studies that combine GSM and WSN as data exchange in the research [32], while about 15 previous studies did not mention the data exchange method in their research. The deployment of WSN as a data exchange increasingly established the WSN's position on illegal logging. Meanwhile, the implementation other methods are used by researchers as a certain specification. Cloud computing and middleware used as a data exchange since the system discusses the interface and the IoT

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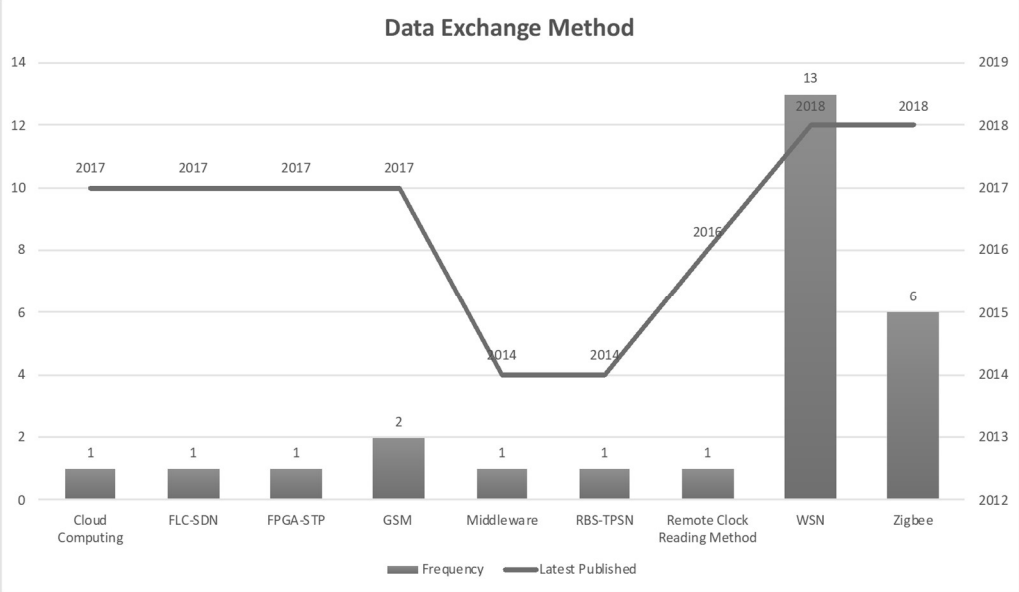

Figure 7. Illegal Logging Research for Data Exchange

for their system. Meanwhile Fuzzy Logic Control-Software Defined Network used Wi-Fi network to do data exchange, FPGA-Signal Tap Files, Reference Broadcast Synchronization-Timing-sync Protocol Sensor Network and Remote Clock Reading Method is another technique that used to do data exchange in the system which correlated with protocol clock synchronization.

Table 5. Mapping Publications for Data Exchange Methods

Data Exchange	Research Studies
Cloud Computing	[41]
FLC-SDN	[22]
FPGA-STP	[42]
GSM	[32], [33]
Middleware	[26]
RBS-TPSN	[48]
Remote Clock Reading Method	[39]
WSN	[6], [14], [56], [32], [49], [21], [55], [24], [35], [36], [51], [37], [38],
Zigbee	[10], [11], [31], [23], [34], [43]

Based on the Figure. 8 it can be concluded that the most used method for data exchange is WSN (48%) followed by Zigbee while another method is reached less than 7%.

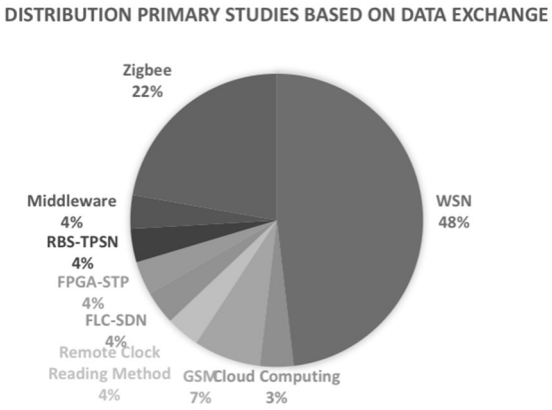

Figure 8. Distribution Research Studies Based on Data Exchange

3.5 Data Transmission Method

Meanwhile, to answer the research question 5 (RQ5), data transmission is an essential factor in supporting illegal logging solutions that ensure that the data collected in each sensor can communicate with each other. The data transmission method is focusing on what kind of transmission used in data exchange. WSN technology appears most frequently in various illegal logging studies in the period 2013 to 2018. GSM, Internet, Long-term Evolution, and Zigbee also have present factors that can be counted as data transmission technology in subsequent illegal logging research. ISM 2.4 GHz also the same with LTE but has the frequency to do data communication in the 2.4 GHz, while Gossip sleep protocol can be applied for data transmission method as a novelty to

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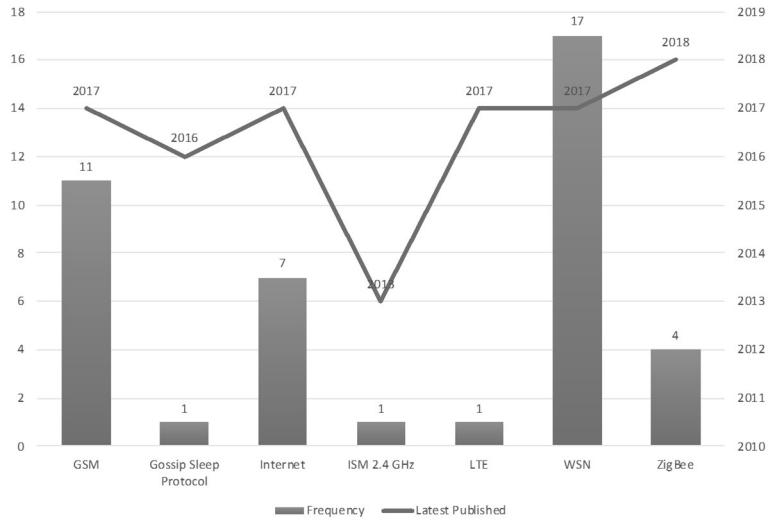

Figure 9. Illegal Logging Research for Data Transmission

have an application WSN-based saving power consumption. The graph can be shown in Figure 9.

Based on table 6, there are several previous studies that used multiple data transmission method. It is combining, GSM with internet data transmission method [23], GSM and WSN method [31], and internet and WSN [11]. The last is combining three data transmission between GSM, Internet and WSN method [27], [32]. Meanwhile, there are nine previous studies did not mention the use of the data transmission methods since they had another focus area in the illegal logging domain research.

The deployment of LTE used by the research focused on monitoring for narrow band cellular networks [42], while ISM 2.4 GHz was used by Karpis et al. to have a monitoring power supply for the sensor nodes [29]. Gossip Sleep Protocol was conducted by Alexandru et al. in order to use for data transmission method with flooding transmission communication [39]. GSM and internet were conducted by the researcher who used a middleware or IoT to enhanced better application [6], [7], [11], [13], [26], [27], [31], [28], [56], [32], [23], [55], [24], [25], [41]. In the meanwhile, Zigbee still conducted in the recent year.

Table 6. Mapping Publications for Data Transmission Methods

Data Transmission	Research Studies
GSM	[6], [31], [56], [32], [28], [27], [23], [55], [24], [25], [41]
Gossip Sleep Protocol	[39]
Internet	[7], [11], [13], [26], [27], [32], [23]
ISM 2.4 GHz	[29]
LTE	[42]
WSN	[10], [11], [14], [27], [48], [31], [32], [33], [49], [34], [36], [51], [37], [38], [52], [25], [41]
Zigbee	[21], [22], [54], [43]

Figure 10. shown that the WSN reach 41% as the most used data transmission by the researcher based on previous studies. Then followed by GSM about 26%, internet 17%, Zigbee 10% while the rest reach less than 2%.

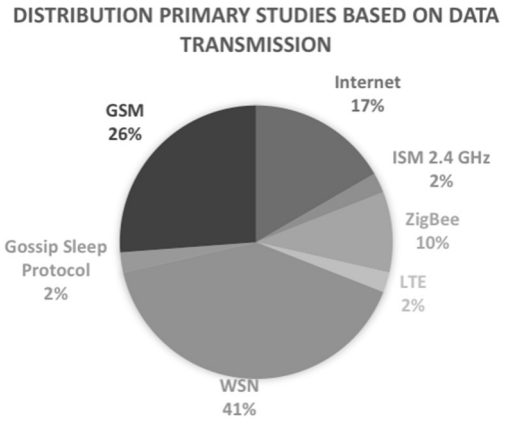

Figure 10. Distribution Research Studies Based on Data Transmission

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4. DISCUSSION

According to the systematic literature review above, the Wireless Sensor Network took the crucial part of the system in the illegal logging domain since the supervised environment is wide and in open area landscape. The application will need more than a hundred nodes as a sense node that connected each other within the communication module embedded in each node. Based on the SLR, it can be stated that the WSN in illegal logging domain should be supported by the robust communication protocol network such as zig-bee or Lo-Ra.

The limitation of WSN application should be considered by many factors such as the number of nodes, the distance between nodes, the landscape of area supervised, the long-range data communication that used to supervised the environment, and the energy efficiency.

5. CONCLUSION

This literature review aims to find the contribution of a long-range WSN technology in the research studies by identifying and analyzing the research trends, methods and technology in detection and identifying the process, tracking process, data exchange, and data transmission of WSN research between years 2013 until 2018. Based on the criteria of the selection of the research studies, it was found 42 research as a research study of long range WSN in illegal logging area published from January 2013 until July 2018. These 42 research studies were investigated in the stages of systematic literature review like the planning stage, conducting stage, and reporting stage in order to provide available evidence to answer the defined research questions.

According to the defined research question, the trend of the studies in illegal logging area focused on the number of researches that generated year by year. An increasing trend illustrated that the needs and challenges based on this phenomenon have a positive trend in developing the research that supports long-range WSN in the illegal logging area. Distribution research studies are various depend to discuss research studies in detection, identification, tracking methods, data exchange method, and transmission methods. There are 31 research studies mention the detection and identification component, 23 research studies mention tracking method, 27 research studies mention data exchange method, and 33 research studies mention transmission methods.

There were nine components and methods mentioned by 31 research studies. Sensor nodes use an audio sensor reach 49% as the most used component to detect and identify the logging. While there were 11 methods used by 23 research studies to do tracking the timber. The most used tracking method was using long-range WSN. About 33% of the research studies using long-range WSN for tracking timber system.

Meanwhile, the data exchange methods used by the researchers mention in 27 research studies. The same with data tracking timber, WSN had the most useful technology that used in data exchange with 48% of research studies using WSN for data exchange. The last, similar with the timber tracking and data exchange, about 33 research studies mentioned data transmission in their research in order to do data transmission, 41% of research studies, used WSN as data transmission in their system. Based on this phenomenon, Long Range WSN is the most useful technique in illegal logging area to do tracking, data exchange and data transmission. The use of WSN in these domain areas because of the characteristic of illegal logging research. This system needs implementation at the outdoor environment in the remote area, need supervised the environment since the area is covered up to thousand-meter squares, and has a long life duration to do supervised. Besides that, the system also has an environment that inaccessible by the human, so the implementation of WSN become the most required in this illegal logging domain research [2].

6. FUTURE WORK

Finally, there is also future work that can be explained from this literature review. In the study of tree detection, the trends of studies an using audio sensor have received great attention from researchers. However, the development of sensor nodes which is using the multiple sensors to detect the trees rise a positive tendency and still in research published in the year 2018. The tendency to use multiple sensor nodes in order to have more data actuator has the potential to be developed in the next illegal logging research, considering the selection of sensor combinations requires configuration parameters that are suitable for forest environment.

In the term of the use of long-range wireless sensor network, the combination of Zigbee and WSN are a suitable couple technology in Illegal Logging. A lot of researchers tends to conduct the combination of Zigbee, GSM, internet and WSN to detect, identify, data exchange and data communication in the system of illegal logging domain. However, with the enhancement of the innovation in the internet

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field area, the using IoT can be enhanced to the next illegal logging research especially in tracking and monitoring the timber. Other than that, the used of other long-range WSN such as Long-Range (LoRa) Wireless Communication, would be a great combination for the novelty

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