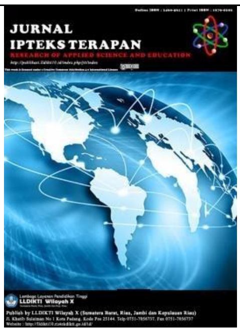

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THE DEVELOPMENT OF GAMMA RADIATION DOSIMETERS *REAL-TIME* NETWORK-BASED SENSOR WIRELESS IEEE 802.15.4 PROTOCOL

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Abstract

Several studies have been carried out on the development of real-time gamma radiation dosimeter based on the wireless sensor network (WSN) protocol IEEE 802.15.4. WSN technology can be adopted to develop a gamma radiation dose monitoring system on a large scale due to its real-time, centralized, efficient, and relatively low-cost attributes. This study aims to develop a personal radiation dosimeter that can collect data from the measurement results of several sensor nodes or multi-sensors. The measurement results of radiation dose values from many radiation workers are sent to a coordinator node consisting of the Xbee module and Arduino as a microcontroller. The system test is compared with a calibrated dosimeter reading and is expected to be one of the instruments for determining radiation dose in real-time. It can also reduce the risk of receiving a radiation dose that exceeds the threshold allowed by the ionizing control agency and a program in radiation protection. Changes in the intensity of radiation emitted by Cs-137 (gamma radiation) are carried out by varying each detector's distance to the source, which indirectly varies the value of the dose rate received by the detector. This relationship is shown from the value of $R^2 = 0.99$, which indicates a strong correlation between changes in the dose given to the detector's response being developed. The system built is efficient, inexpensive, and collecting radiation exposure data can monitor radiation exposure received by workers in real-time. This technique can help speed up reporting of radiation exposure received by radiation workers.

Keywords: Gamma radiation dosimeter, multi-sensor, real-time and WSN.

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INTRODUCTION

Wireless Sensor Network (WSN) refers to a group of spatially dispersed and dedicated sensors for monitoring and recording the environment's physical conditions and organizing the collected data at a central location. WSNs measure environmental conditions like temperature, sound, pollution levels, humidity, wind, etc. It was originally used for closed military telecommunication operations (Đurišić, et.al, 2012). Presently, its application extends to various areas such as health (Akkas, et. al., 2020), (Tuna, et.al. 2015) monitoring environmental radiation (Gomaa, et.al., 2014) as well as other industrial fields (Petersen, et. al., 2007), (Faheem, et.al., 2018). It consists of several portable stations integrated with a transducer, microcontroller, and a power source also referred to as sensor nodes (Liu, et. al., 2015), (Fardela, et.al., 2018) that are connected to form a network. The sensor node data is collected at the center via a wireless Radio Frequency (RF) module. It is a network system that focuses on minute power consumption at a cheap price (Reaz, et.al., 2008). This WSN technology is adopted to develop a radiation dose monitoring system on a large scale (multi-node sensor) in real-time, at a centralized, efficient, and relatively affordable cost (Fardela, et.al., 2019), (Magalotti, et.al., 2016). Medical staff working in the field of interventional radiology (IVR) are usually exposed to high doses of radiation emitted from the patient's body (Fujibuchi, et.al., 2019), for example, during fluoroscopy the doses from the cardiologist's site corresponds to those spread within the range of 1 to 14 mSv/hour. However, for those in planned exposure situations, the ICRP recently recommended an equivalent dose limit of 20 mSv/year for the eyepiece, at an average of over five years, and one-year exposure limited to 50 mSv. The Revised Law is based on the prevention of radiation hazards caused by radioisotopes, etc. This new exposure limit is speculated to increase the risk of cataracts in IVR staff that exceed the annual dose. Therefore, additional occupational exposure management is essential, and in order to sustain this, medical staffs need to wear protective clothing (Apron) as well as make use of passive dosimeters, such as the Glass or QuIxel Badges, for radiation exposure monitoring. This type of personal dosimeter is common among clinical practitioners, however, they do not provide direct readouts and is operated without any active means. Real-time individual monitoring helps determine radiation dose during IVR. By wirelessly displaying it on the monitor, it is easier to ascertain the dosage, avoiding the need for complicated procedures. Fujibuchi et al. (2019) researched the characteristics of the energy spectrum and the system dose rate (Fujibuchi, et.al., 2019).

This study is aimed to develop a real-time gamma radiation personal dosimeter based on a wireless sensor network. Although these dosimeters are available in the market, it tends to be extremely expensive when applied to a system with radiation staff. Furthermore, a wireless sensor network with a low power consumption radio module and a relatively distant communication range than those adopted in previous studies was utilized in this research. A personal radiation dosimeter was used to collect data from several sensor nodes referred to as multi-sensors. The results obtained from the

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measurement carried out by numerous staff are sent to a coordinator node made up of the Xbee module and Arduino (microcontroller). This research is expected to be an instrument of choice for the determination of real-time gamma radiation dose. It also aids to reduce the risks involved when it exceeds the threshold recommended by the ionizing radiation control agency as well as programs relating to its protection.

RESEARCH METHODS

Research Material Components

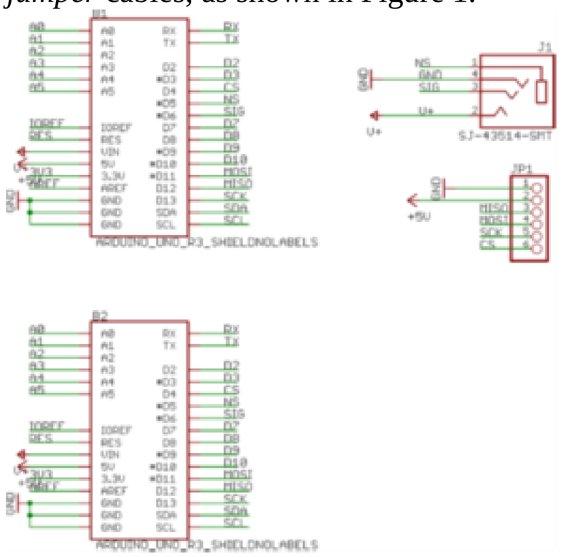
The components of the materials used and their functions are described as follows. (a) The standard gamma radiation source Cs-137 serves as one of the materials for the calibration of the sensor. It is available in a protective casing at the Atomic and Core Laboratory of the Physics Department of the Faculty of Mathematics and Natural Sciences, Gadjah Mada University. (b) The Arduino Uno is an open-source microcontroller board assembled into several systems, such as a sensor (*router*) and coordinating nodes. (c) Radio module Xbee functions as wireless data communication. It is also a telemetry module that simultaneously serves as a receiver (RX) and transmitter (TX) or tends to carry out two-way communication. This research adopted the Xbee Pro S2C with the IEEE 802.15.4 / Zigbee WPAN standard developed by the Digi international company, manufactured for low power WSN, and is ideal for building wireless sensor networks. (d) The radiation sensor used was the photodiode type *X 100-7 First Sensor*, which was connected to a circuit to form a node to determine the rate of exposure. (e) the power supply is a source of electrical energy (DC) used to operate the microcontroller, Xbee, and radiation sensors.

Software

The softwares used are as follows: (a) Arduino IDE (*Integrated Development Environment*) is a microcontroller application for writing, compiling, and *uploading* of programs and testing in serial terminals. (b) X-CTU is an official configuration and test utility program used to change or upgrade the firmware, configure and test Xbee modules, as well as its ability to send sensor *nodes* to the coordinators. (c) Visual Studio is used to design data acquisition programs centered on radiation dose measurement results and also displays the GUI.

Electronic Design

A *real-time personal* dosimeter system with a *wireless* sensor network was developed using several components namely the Arduino Microcontroller, Xbee module, radiation sensor connected to the PCB in order to minimize the use of *jumper* cables, as shown in Figure 1.



(a) (b)

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Figure 1. (a) PCB Block Diagram of the Arduino microcontroller connected to the radiation sensor, (b) Schematic design of the PCB connected to the sensor.

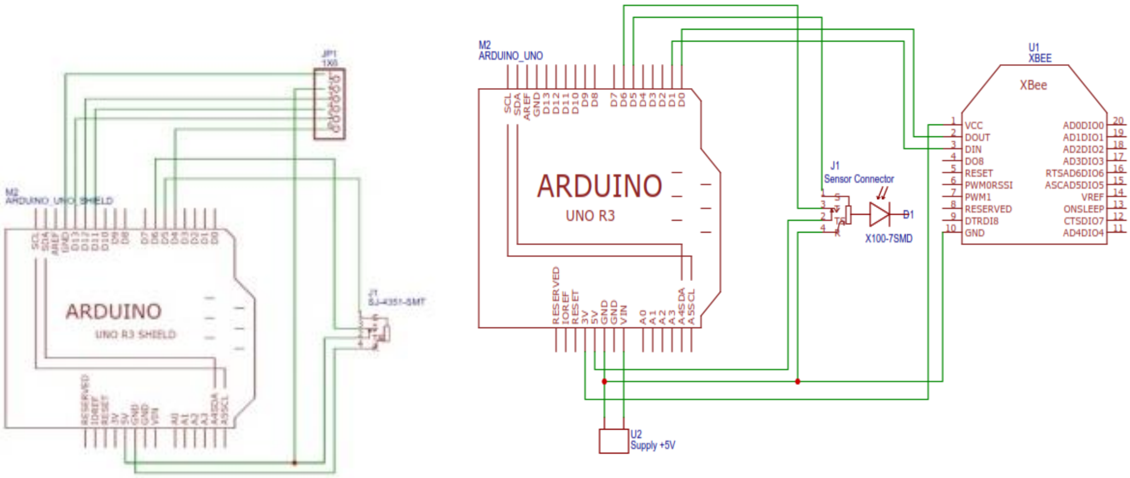

Figure 2. Schematic of WSN based *real-time* personal dosimeter circuit.

The Arduino Uno R3, Xbee module, and X100-7 SMD sensor were used as the microcontroller, wireless communication system, and detector. The entire circuit scheme is shown in Figure 2.

The X100-7 SMD sensor circuit consists of 4 pins (Ishigaki, et.al., 2013), two of them serves as the power supply, while the remaining is the data output. The power supply is connected to the + 5V *pin* and *GND* Arduino. The data output consists of signal pins connected to Arduino *D5*, *D6*, and noise pins. The Xbee wireless communication module is functional at a voltage of 3.3V, which is obtained from the Arduino Uno. The module's data line is connected to the transmitter (Arduino *D1* pin) and receiver (*D0)*. The Arduino shield battery is connected to the *Vin* and *GND* pins in order to supply power to the entire system.

Hardware and Software Integration

This stage involves the uploading of the programming language into the hardware. In addition, the integrated components include the Xbee module, X-CTU, *controller*, C+ programming language, and the Arduino IDE software for writing and *compiling* programs. The flow diagram generated using Arduino IDE is shown in Figure 3.

System Testing

This stage involves all components and data acquisition systems that have been designed and tested. The testing process for sending data is carried out using the sensor *node*, which includes the tool's characteristics and its calibration. Meanwhile, the sensor and coordinator *node systems* are used to ascertain the detection range by focusing on its sensitivity to ionizing radiation. The

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sensor node measures the radiation dose and conveys the result to the coordinator node. Furthermore, it is stored in a database or displayed in *real-time* via a data acquisition system such as a *Graphical User Interface* (GUI) and TXT data format.

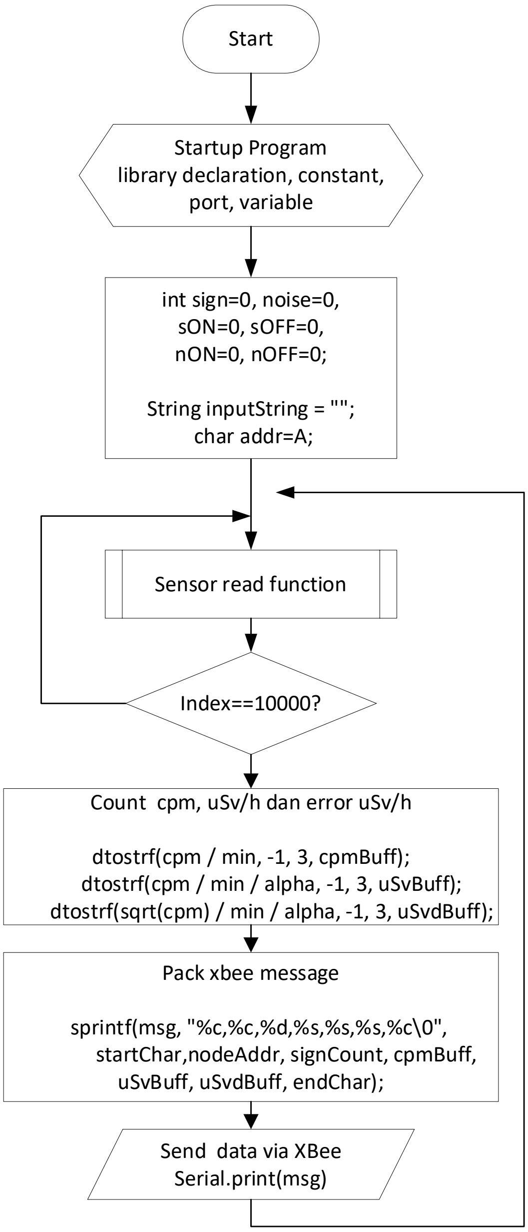

Figure 3. The flow diagram of the radiation sensor program on the Arduino IDE

The comparison between designed and calibrated dosimeters

The test phase is described as follows:

a. The detector sensitivity testing *box* is designed using Lead (Pb), available at the Atomic and Core Physics Laboratory.
b. Temperature and background radiation in the work environment is determined and recorded, using both detectors (designed (CPM) and calibrated (µSv / hour)).
c. The radioactive element used is placed in a box that has been designed and coated with Lead (Pb).
d. The detector rail is placed in a *box*, and the radiation sensor is connected to a set of sensor *nodes* placed in the actual position of the detector, as shown in Figure 4

Figure 4. Comparison testing experimental equipment set designed with a calibrated dosimeter.

e. The distance between the radiation sensor and its source is initially at a distance of 10 mm.
f. The distances vary from 5, 10, 15, 20 to 50 mm, in both the designed and calibrated detectors.
g. The output of the automatically designed detector is observed on a computer, and the results in CPM units are saved in text format.

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Furthermore, 100 data are obtained from each distance change.

h. The output on a calibrated detector needs to be observed repeatedly by recording the results of three consecutive measurements (the highest, lowest, and most frequently appeared values on the detector screen needs to be taken) in µSv / hour. The observations were carried out repeatedly for each change in distance.

System Reach Testing

This is the maximum distance for sending data related to the radiation dose measurement from the sensor *node* to the coordinator *node*, displayed in the form of a GUI or stored in a text data format. The steps for measuring system coverage using the X-CTU program are illustrated as follows.

a. The coordinator *node* is connected to the computer, after which the X-CTU program, installed *online*, is opened on the computer.
b. The *port* on the initial display of the X-CTU program is selected to find out which is connected to the Xbee radio module.
c. The connection *port* is selected, and parameters such as *Baud Rate*, *Data Bits*, and *Parity appear*. The *Baud Rate* was determined using 9600 according to the designed Arduino IDE Microcontroller program. Subsequently, the radio module is connected to the PC.
d. A display appears on the computer, illustrating the connected radio module, as shown in figure 5.
e. The next step is to configure the radio module by selecting the coordinator *node* and the module parameter update that appears.
f. A consul page appears to set several parameters such as the PAN ID 123, which is established similar to the one on the router (sensor node).

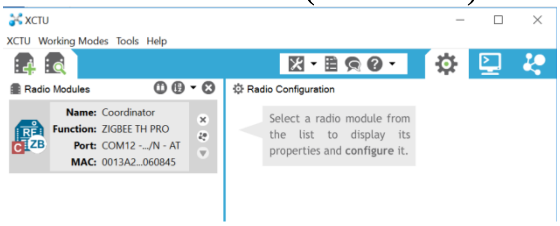

Figure 5. View of the connected radio module

g. It is extremely important to convert the coordinator *node* radio module to the API format in order to be used to measure distance and signal strength parameters.
h. Consequently, after the settings are carried out, the radio module is *updated*.
i. The sources of *power* for the five designed sensor *nodes* are turned on. The PC screen scan was clicked on to connect it to the X-CTU program, as shown in Figure 6.

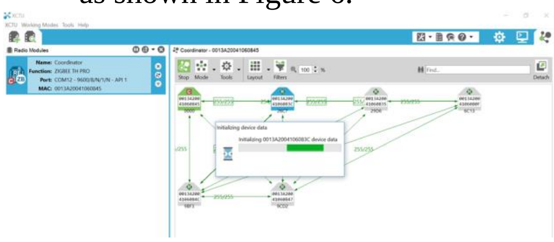

Figure 6. X-CTU Consul displaying five sensor *nodes*, one coordinator *node* that is detected or connected to the coordinator *node*.

j. In the next stage, the Xbee radio module appears attached to each sensor *node*, which is connected to the coordinator *node* to boost communication between them, as shown in Figure 7.

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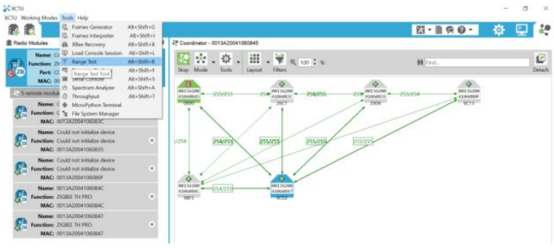

Figure 7. The *remote module* communicating with the coordinating *node*.

k. However, when tools are clicked on, an option appears, and the Range Test is selected, as shown in Figures 7 and 8.

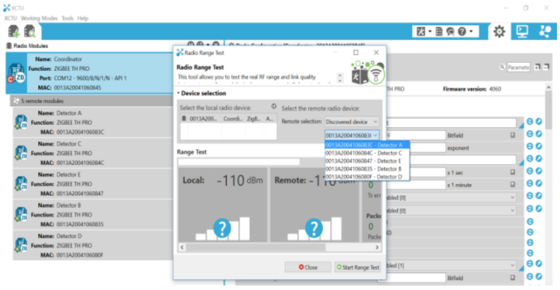

Figure 8. Display *Range Test* Consul

l. Detector A is among the range of devices being tested. Furthermore, a variation in its position is carried out in the presence of the coordinator *node*, which is kept in a particular control room, thereby displaying the results from the measured radiation dose at each radiation worker (detector) on the PC where the data acquisition system has been designed using the Visual Studio program.

m. Immediately after the testing process, changes are made to the settings in *Transparent mode* [0] format in order for the coordinator *node* to receive data in accordance with radiation dose when it is connected to the GUI in Visual Studio of the PC.

The tests were carried out to determine their characteristics, the comparison between the designed and calibrated detectors, as well as their response to the data storage time. The results obtained were processed using the Origin data processing program to determine the standard deviation, plot graphs, and the equation or relationship between the designed and calibrated dosimeters.

RESULTS AND DISCUSSION

The developed dosimeter was compared to the calibrated one under the trademark "Radiation Alert Ranger" the results from the system comparison is shown in Table 1. The background count is determined by measuring the radiation intensity in an environment lacking a radiation source, and it was obtained as 0.12 µSv. However, when the room temperature was 25^{0}C, radiation exposure after 1 mm Pb *shielding* attached to detectors obtained a value of 2.3 µSv.

Dose (µSv/hour)	Detector Response (cpm)	Standard Deviation (cpm)
375.84	1587	60
207.74	951	70
174.43	656	99
147.54	379	36
124.73	312	12
114.65	220	27
100.72	189	14
91.73	154	17
79.56	120	20
70.06	112	16

Table 1. The comparison between designed and calibrated detectors

As shown in Figure 4 (Cs-137 source), the radiation source is positioned while its exposure is confirmed to be similar to the background count to ensure there is no leakage to the work environment.

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The observation results and designed dosimeters are reported in units of µSv / hour (standard detector) and CPM, respectively, as shown in Figure 9.

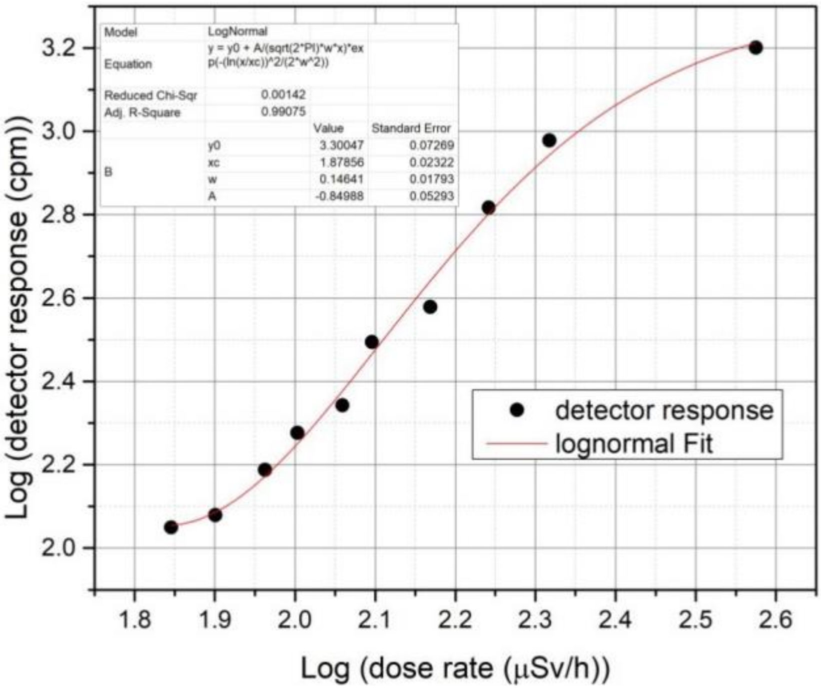

Figure 9. Log (detector response (CPM)) to log changes (radiation dose rate using a calibrated dosimeter (µSv / Hour))

Figure 9 shows the relationship between the calibrated detector dose rate log (µSv/hr) and the developed detector response log (CPM) of the Cs-137 gamma radiation source using a lognormal *fitting* curve. Changes in the intensity of radiation emitted by Cs-137 (gamma radiation) are detected by the difference in each detector's distance from its source (Cs-137), thereby indirectly generating varying values of the dose rate received. This relationship is shown in the value of R^2 = 0.99 which proves that there is a strong correlation between changes determined by the developed detector. The result from the standard dosimeter measurement is multiplied by the calibration factor of 0.94 and subtracted from the background count of 0.12. The line equation showing the relationship in Figure 9 is obtained using a lognormal fitting curve generated with the Origin *software*. This procedure is not used as a detector calibration curve because it still needs to be accredited by an institution such as *PTKM-BATAN*.

The measurement results from the detection range system using the X-CTU software (Reddy, et.al., 2017) are shown in Figure 10, which illustrates the communication test's outcome between the sensor and coordinator nodes. The sensor and coordinator node signal strengths represented both remotely and locally is -43 dBm and -31 dBm respectively, in conclusion, this signal strength is extremely strong. Approximately 100 packages, with 0 error, was sent. Additionally, 0% was obtained when the PER value is calculated using 3 measurements.

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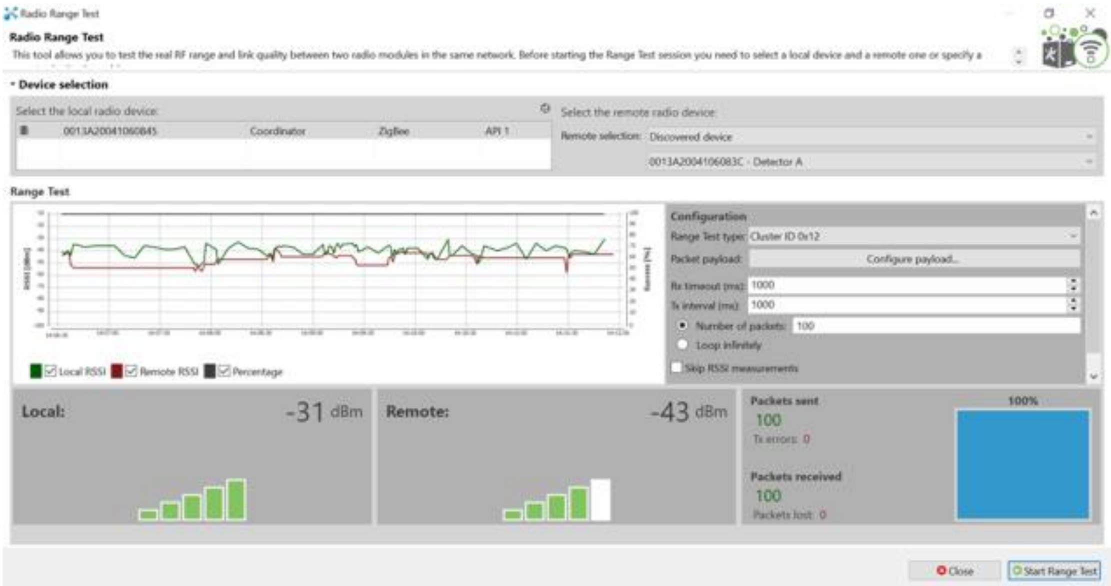

Figure 10. The display of system coverage testing using X-CTU software.

Figure 10 shows a graph of the signal strength (power) in dBm units. The signal strength (RSSI) (received signal strength indication) for the coordinator and sensor nodes are marked in green (left vertical axis) and red (left vertical axis). Meanwhile, a black graph depicts the percentage of success data transmission in units of % (right-hand vertical axis). Furthermore, the horizontal section (x-axis) depicts the time of observation. These results help to determine the extent of the communication between these devices. According to the graph, missing data is illustrated in the form of power intensity experiencing a weakening signal. Therefore, the design between the sensor and coordinator nodes' position is determined to boost the control room.

CONCLUSION

The radiation dosimeter based on the IEEE 802.15.4 protocol wireless sensor network was successfully developed. It is used to record several radiation exposures from multi-node sensors automatically connected to a PC (computer) with the help of a photodiode type radiation sensor, Xbee radio module which serves as a router, coordinating node, Arduino Uno (microcontroller) and Visual Studio (GUI). This system is efficient, inexpensive, and collecting data monitors the workers' exposure to radiation in real-time. Therefore, this technique helps speed up the reporting processes. This research development project is reported as follows: This real-time personal dosimeter based on wireless sensor networks needs to be applied in real work environments that utilize direct ionizing radiation such as nuclear installations and power plants, as well as hospitals. Further research is necessary to obtain a better radiation sensor.

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