Analyzing the Connectivity of the Wireless Sensor Networks

1st Maryam Ayad Gabbar
[1]*college of Information Technology*
University of Babylon
Babylon, Iraq
maryam.net.msc@student.uobabylon.edu.iq

2nd Saad Talib Hasson
[2]*college of Information Technology*
University of Babylon
Babylon, Iraq
saad aljebori@itnet.uobabylon.edu.iq

***Abstract*— Wireless Sensor Networks (WSNs) are utilized to communicate the collected information wirelessly. A wireless network can be represented as a graph composed of nodes and links. Such graph is known as connected graph if it has at least one path from any node to any other nodes, otherwise it will be indicated as a disconnected graph. A graph is considered a connected graph if for any two vertices x1 and x2 belong to a graph, there is a path whose ends at x1 and x2. The connectivity problems in wireless sensor networks is representing a crucial issue in all the WSNs applications. The network connectivity is an indication for a connected graph, it can be lost by removing certain number of the nodes from the network. This number of nodes can be used as one of the network connectivity threshold values. Sensors in a WSN can communicate and exchange information with neighbors based on their communication radius. This paper to model the connectivity and the connectivity probability problems in WSNs. The effects of varying the number of the deployed sensors and their communication radius (range) on the network connectivity are analyzed and evaluated. To evaluate the developed model in this study, different rates are used in transmitting messages during the proposed WSNs. These rates are implemented as random values with different rates to model the connectivity probability. The number of the generated messages are created based on a Poisson distribution with different means. The connectivity probability is estimated based on the binomial probability distribution. Another approach is used to estimate the network connectivity based on an exact sent message rate. Different network performance metrics are calculated to evaluate the network behaviors.**

Keywords—WSN, random deployment, connectivity, connectivity probability, message rate, simulation.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) are composed of sensor nodes which are deployed to perform sensing tasks. WSNs are commonly used for numerous applications. Wireless Sensor Networks are utilized to communicate the collected information wirelessly [1]. Several challenges must be addressed and considered before implementing any WSN. These challenges are: connectivity, localization, channel access, coverage, quality of service, energy, security and scheduling [2]. Network connectivity represents the essential problem in WSNs. A network can be considered as a connected network if a communication link is existing between every couple of the nodes, so theses nodes can communicate with each other [3]. Graph representation can be used to model the network connectivity. Usually a link between any two neighbor nodes is created if they are within the communication range of each other [4]. A wireless sensor network is considered as a connected graph if for any two vertices x1 and x2 belongs to a graph, there is a path whose ends at x1 and x2 [5]. Radio signal is usually used to achieve the communication between any sensor node and the base station either directly (single-hope) or through intermediate nodes (multi-hope). Any data can be disseminated between two sensors through a communication link. The delivery of these data is based on certain probability [3]. A quantitative measure of the quality of communications between particular nodes in the network represent an important issue. Providing reliable communications in a remotely monitored deployment of WSNs is one of the most challenging tasks [6]. A sensor node is having an ability to sense, converts the physical value of the sensed quantity into a suitable signal form. One of the important metric to measure the quality of the WSNs, is how to communicate the sensory data of the target to the sink. The deployed sensor nodes can affect the process of sensing or monitoring the given area [7]. Sensors are powered by the batteries. It is important to reduce the energy consumption of the sensor nodes during their connectivity operation [8]. Deployment approaches and power allocation with network topologies must be carefully considered. Enhancement of the network connectivity and optimization of the energy consumption has been previously attempted and still requires re-consideration [1].

II. CONNECTIVITY IN WSN

A. connectivity

WSN connectivity represents the connections between sensors. Connection among sensors and sensors to a Base Station (BS). The essential problem with the WSNs is how to discover a small set of intermediate nodes (relays) to assist the data routing. Multi-hop WSNs is a way to implement an effective route. It is useful to find small connected set of sensors to create a path of routing from the designated sensor to the BS [2].

The WSNs connectivity is defined as the ability of each sensor node to find a path to reach the sink. If there are no available path from a sensor node to the sink, the data collected by that sensor node cannot be processed or transmitted [3]. The connectivity in the graph can be guaranteed [4] by setting the value of threshold to (radius /(2 $*$ cos 30$\circ$)), where radius represents the radio range. Computing the connectivity ratio of WSN can be estimated by the following Equation (1):

$$\text{connectivity} = \left(\frac{\sum_{i=0}^{n}\sum_{j=0}^{n} c_{ij}}{n^2\text{-}n}\right)*100 \qquad (1)$$

Where n is a total sensors number and C_{ij} is a connectivity matrix element that have value 1. Any two sensors are considered as a connected if they have an ability to communicate with each other (there is a path between each two sensors) in single-hop (directly) or in multi-hops (indirectly). Tracking a specific area is not enough to provide coverage without connectivity. When an event is sensed, a BS must be informed. Different sensors applications require full connectivity to achieve their goals. the full connectivity is either being 1-connectivity or k-connectivity [5].

B. *connectivity and probability*

WSNs are composed based on either random or predefined deployment approach. Sensors can be failed in all or some of their functions. Such failures are probable. Certain probability distribution can be utilized to model the sensors behavior [6]. Network Connectivity can be modeled as a binomial probability distribution. In this study, a Binomial probability distribution [7] is utilized to test the connectivity as indicated in equation (2).

$$B(n,k) = \sum_{k=0}^{n} \binom{n}{k} P^k (1-P)^{n-k} \quad (2)$$

Where n is the number of deployed sensors, k is the number of the connected nodes effectively with probability (p) and;

$$\binom{n}{k} = \frac{n!}{k!(n-k)!} \quad (3)$$

The first step in this paper is to check if the network is connected with probability P or not with a probability of (q = 1-P). P can be estimated by equation (4).

$$p = \pi R^2 / S \quad (4)$$

Where :

R is the transmission range and S is the deployed area.

The mathematical expectation (mean) is:

$$E(x) = np = n\,\pi R^2 / S \quad (5)$$

When the number of nodes n increases and its probability P decreases to small value, this binomial distribution can be approximated to a Poisson distribution [7].

The Poisson distribution density function is shown in equation (6).

$$\Pr(X = k) = \frac{e^{\lambda} \lambda^k}{K!} \quad (6)$$

Where $\lambda = nP$, Equation (7) can be simplified:

$$\Pr(X = k) = \frac{e^{NP} (NP)^K}{K!} = \frac{(N\frac{\pi R^2}{S})^2}{K!} e^{-N\frac{\pi R^2}{S}} \quad (7)$$

It can be seen from equation 6 that the number of nodes and the communication radius are affecting the network connectivity probability value P. the number of nodes must be increased or the communication radius must be increased or both increased to achieve certain accepted value for P. Number of the deployed sensors is playing an important role in improving the probability P of a network connectivity. In a disconnected network this probability is reduced. Optimum number of the deployed nodes in each area represents the ideal case, any increase in sensors number will produces resources waste and redundant nodes. Reducing this number. When the number of the deployed sensors are less than the required optimal number, the network connectivity is affected and a disconnected network may appear continuously [7].

III. PROPOSED SIMULATION MODEL

In this paper, the following sequence of steps is followed to implement, analyze and evaluate the suggested network scenarios:

1. Select the environment area shape and size.
2. Create and deploy the similar (homogenous) static sensor nodes in the network area.
3. The sensor nodes are deployed either randomly or in predefined manner in the suggested area.
4. Creating the sink node (base station) and select its location.
5. Suggest the transmission radius based on the power as shown in equation ( ).
6. Create the links among the sensor nodes (based on the transmission radius).
7. The transmission is done in single hop or multi-hops.
8. If the sink node is within the sending node range the message can be transmitted directly (in a single hope), and in multi hops if the sink node is extreme from the source node (out of the source node range).
9. The time of generating each message (Tx) in each sensor is randomly estimated based on an exponential probability function. Counting these messages will indicate the total generated messages (transmitted messages).
   a. Generate a random number (0-1) based on the number of deployed sensors.
   b. Transform this random number into a random variable based on the following equations:
      R = Random (Number of deployed sensors)
      Tx = (- 1/ message rate)* log R

IV. SIMULATION RESUILT

TABLE I. PRESENT SIMULATION SETUP.

variable	**value**
Number of sensors	100
Area	500*500
Routing protocol	Shortest path
MAC protocol	CSMA-802.11-DCF
Message rate	Random with rate of (0.1 and 0.5) Exact with (10 and 30 per sec)
Simulation time	Estimated

Net logo as an agent based modeling approach is utilized in simulating the proposed model scenarios [8]. Figure 1 presents a simulation program snapshot for the initial deployment of 100 sensors in an area of 500*500 m.

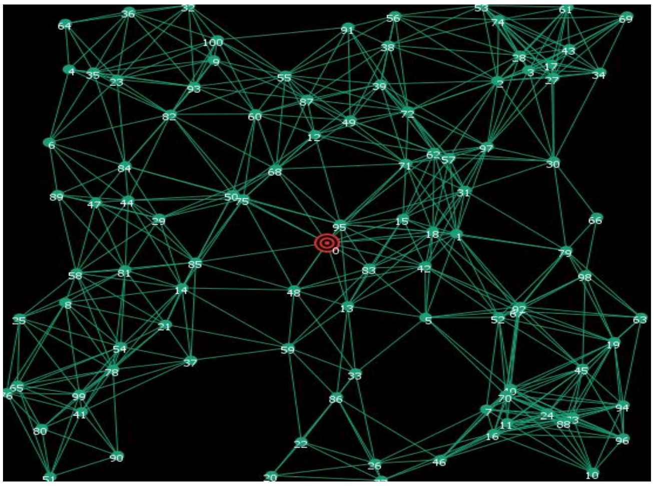


Fig. 1. sensors creation and deployment

Different Parameters are estimated and analyzed to observe the performance of the suggested WSN. These parameters are:

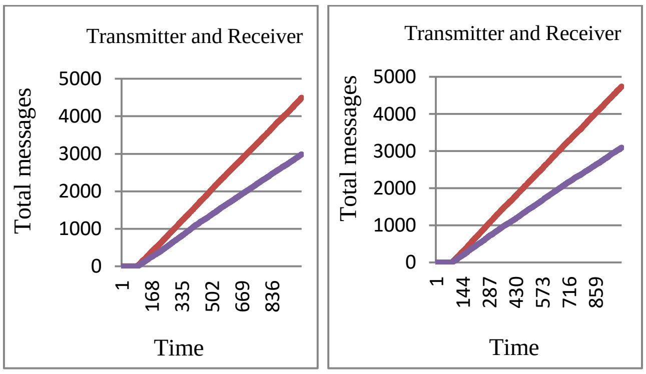
A. Transmitted and received messages

The total transmitted messages (totaltx) are calculated based on the number of messages sent form all sensors during the simulation run. The total received messages (totalrx) are calculated based on summing the number of received messages (Rx) by the sink from each sensor during a simulation run.

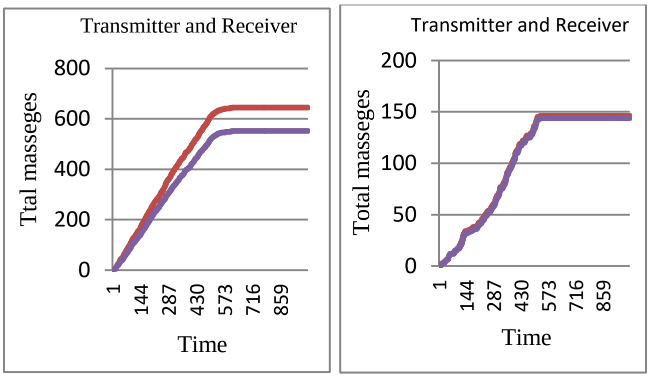
$$\text{Totaltx} = \sum_{i=1}^{n}(\text{Tx}(i)) \qquad (8)$$

$$\text{Totalrx} = \sum_{i=1}^{n}(\text{Rx}(i)) \qquad (9)$$

Figure 2 shows the relation between the transmitted and received packets during the simulation time. In (a and b) an exact packet rate of 10 and 30 packets per sec are respectively implemented. Figure 2 in (c and d) random packets generation are utilized with rate of (0.1 and 0.5 packets per sec).



(a) exact rate=10 (b)exact rate=30



(c) random rate=0.5 (d) random rate=0.1

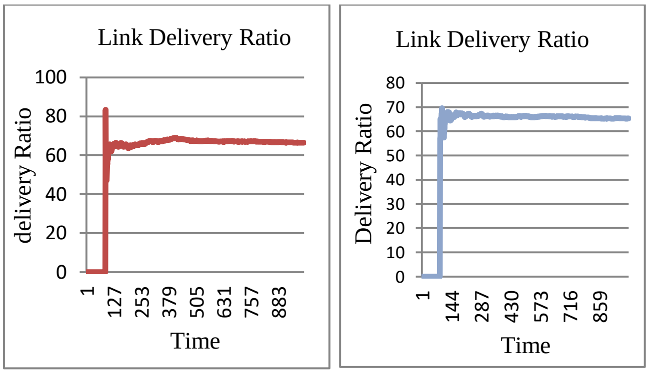
Fig. 2. transmitted and received packets

B. Delivery ratio

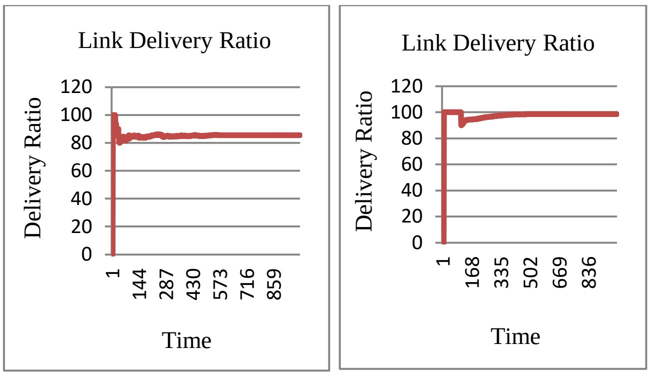
The link Delivery Ratio is calculated based on the total number of received messages to the total number of transmitted messages. The delivery ratio is calculated by equation (10).

$$\text{Delivery ratio} = \frac{\text{totalrx}}{\text{totaltx}} \qquad (10)$$

It is desired to maximize the number of data packets that reached to the destination. Figure 2 shows the link delivery ration in different generated message rates during the simulation time. In figure 2 (a and b), the delivery ratio is presented with the simulation time in exact message rate of (10 and 30 packets per sec respectively). Figure 2 (c and d) shows the delivery ratio with random message rate of (0.5 and 0.1 per sec respectively).



(a)exact rate=10 (b) exact rate=30



(a) random rate=0.5 (d) random rate=0.1

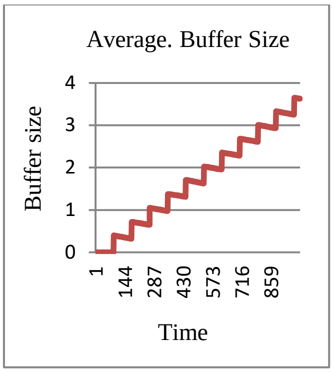
Fig. 3. Link Delivery Ratio

C. *Average Buffer Size*

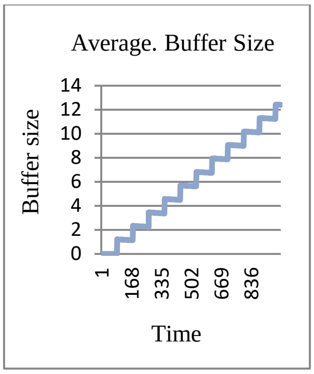
Buffer is used to get enhanced performance in a WSN. Buffer size is suggested based on the arrival rate (message rate) to reduce the failed or lost packets. It can be used when an arriving packet is reached to a busy node or in the case of many transmissions toward a certain node at the same time. The average. Buffer Size (in Kbytes) is calculated in this study based on the ration between the total number of sent messages and the number of sensors multiplied by the size of the message in bytes. Equation (11) is suggested to calculate the average buffer.

$$\text{Average Buffer Size} = \frac{\sum_{i=0}^{n} \text{txbuffer of sensors}}{\textit{number of sensor}} * \text{message\_size\_bytes} / 1024$$

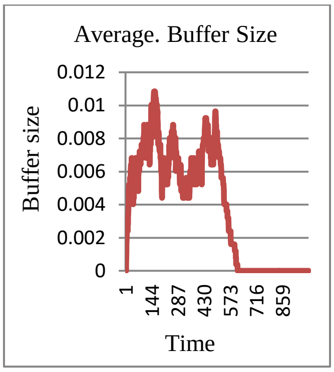
Figure 3 shows the Buffer Size during the simulation time. In figure 3 (a and b), the buffer size is presented with the simulation time in exact message rate of (10 and 30 packets per sec respectively). Figure 3 (c and d) shows the buffer size with random message rate of (0.5 and 0.1 per sec respectively).



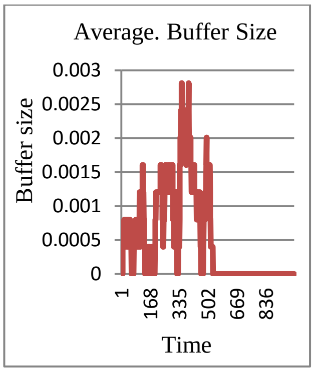
(a) exact rate=10



(b) exact rate=30



(c) random rate=0.5



(d) random rate=0.1

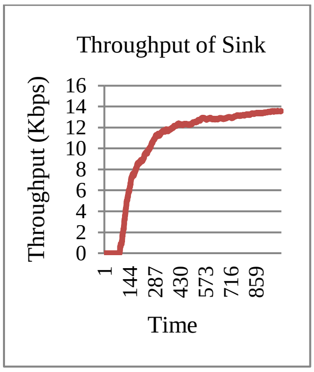
Fig. 4. Average Buffer Size

D. *Throughput*

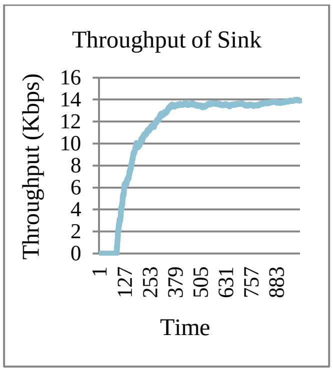
The network throughput represents the amount of data transferred from one sensor to a sink in a given period of time. Throughput is measured by bits per second (bps) [9]. Throughput in WSNs represent the rate of successful delivery of messages through a communication channel. The throughput rate is usually measured in bits per second and is the speed of the communication channel. The Throughput of Sinks is calculated based on the sum of the number of data received with in the sink multiplied by the size of the messages in bytes. Each byte is composed of eight binary digits [10]. Throughput can be calculated by equation (12).

$$\text{Throughput} = \sum_{i=1}^{n} \frac{\text{totalrx (sink)}}{\text{simtime}} \quad (12)$$

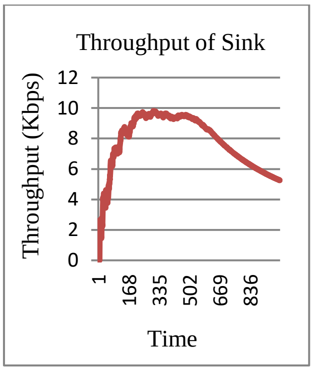
Figure 4 presents the Throughput during the simulation time with exact and random message rates. In (a and b), the relation between the Throughput in Kbps and the simulation time with exact message rates of (10 and 50 message per sec respectively) are presented. While (c and d) presents the relation between the Throughput and the simulation time with random message rates of (0.5 and 0.1).



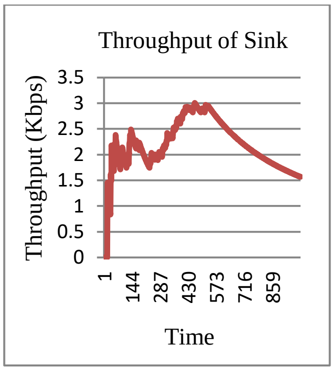
(a) exact rate=10



(b) exact rate=30



(c) random rate=0.5



(d) random rate=0.1

Fig.5. Network Throughput

E. *Sink delivery ratio*

The end- to-end delivery ration is calculated based on the sum of the number of data received with the sink divided by the total of new messages which can be calculated through equation (13).

$$\text{Delivery ratio at sink} = \frac{\text{total (sink rx)}}{\sum_{i=1}^{n}(\text{all nodes messages})} \quad (13)$$

Figure 5 presents the sink delivery ration during the simulation time. In (a and b), the relation between the sink delivery ration and the simulation time with exact message rates of (10 and 50 message per sec respectively) are presented. While (c and d) presents the relation between the sink delivery ration and the simulation time with random message rates of (0.5 and 0.1).

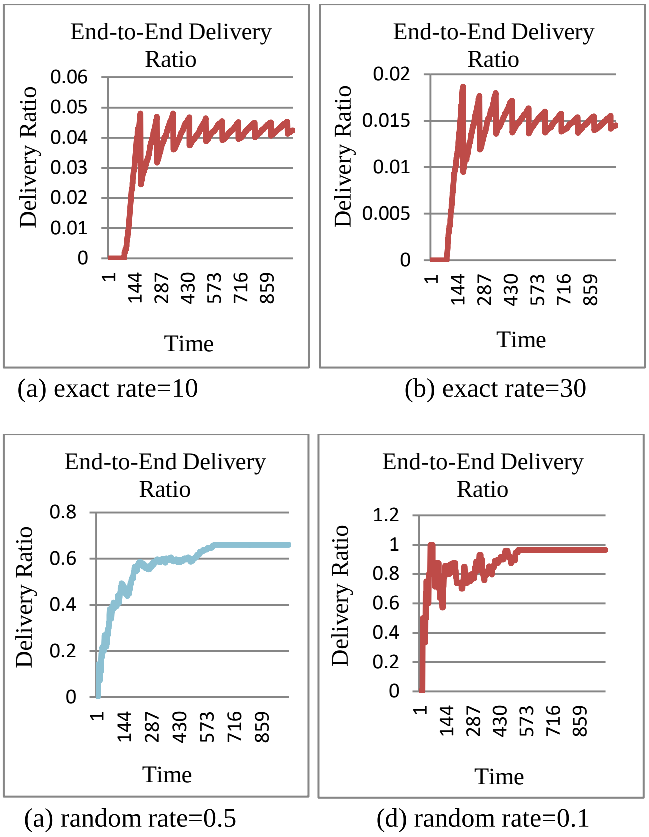


Fig.6. Sink Delivery Ratio

V. CONCLUSIONS

This paper models the connectivity of WSNs. Several simulation scenarios are suggested to analyze and evaluate the WSN performance based on certain number of deployed sensors, random deployment in a certain square area. The effect of connectivity on the WSN behavior is modeled by different types of transmitted messages. The transmitted messages are generated in two different random rates (0.1 and 0.5 message per sec). Two different exact rates (10 and 30 message per sec) are also tested and evaluated. The simulation results reflects a similar and stable behavior for the different exact rates while predictable results are indicated from the resulted figures. These results can be extended in future works to develop the performance of the WSNs in their planning, designing and implementing.

References

[1] M. Miyashita, "Evaluation of Wireless Communication for Maintenance of Underground Power Transmission Lines," *7th Int. Conf. Smart Grid, icSmartGrid 2019*, pp. 81–86, 2019, doi: 10.1109/icSmartGrid48354.2019.8990732.

[2] A. Tripathi, H. P. Gupta, T. Dutta, R. Mishra, K. K. Shukla, and S. Jit, "Coverage and Connectivity in WSNs : A Survey , Research Issues and Challenges," *IEEE Access*, vol. 6, no. January, pp. 26971–26992, 2018, doi: 10.1109/ACCESS.2018.2833632.

[3] Y. Li, G. Jiang, M. Wu, and Y. Song, "Methods to Measure the Network Path Connectivity," vol. 2020, 2020.

[4] L. F. M. Vieira, M. A. M. Vieira, and L. B. Ruiz, "Efficient incremental sensor network deployment algorithm," no. May, 2004.

[5] A. A. N. R. Finjan and S. T. Hasson, "Distance based deployment approach to improve the WSNs coverage and connectivity," *J. Telecommun. Electron. Comput. Eng.*, vol. 9, no. 2–12, pp. 147–150, 2017.

[6] A. M. Attia, "Simulation and Analytical Comparison between Load Management Techniques," *2020 8th Int. Conf. Smart Energy Grid Eng. SEGE 2020*, pp. 128–132, 2020, doi: 10.1109/SEGE49949.2020.9182010.

[7] L. Wang, J. Yan, T. Han, and D. Deng, "On Connectivity and Energy E ffi ciency for," 2019.

[8] T. T. Guingane, D. Bonkoungou, E. Korsaga, E. Simonguy, Z. Koalaga, and F. Zougmore, "Modeling and Simulation of a Photovoltaic System Connected to the Electricity Grid with MALTAB/Simulink/Simpower Software," *8th Int. Conf. Smart Grid, icSmartGrid 2020*, pp. 163–168, 2020, doi: 10.1109/icSmartGrid49881.2020.9144807.

[9] B. Almasi and S. Szilagyi, "Throughput performance analysis of the multipath communication library MPT," *2013 36th Int. Conf. Telecommun. Signal Process. TSP 2013*, pp. 86–90, 2013, doi: 10.1109/TSP.2013.6613897.

[10] S. T. Hasson and H. A. Al-Kadhum, "Developed clustering approaches to enhance the data transmissions in WSNs," *Int. Conf. Curr. Res. Comput. Sci. Inf. Technol. ICCIT 2017*, pp. 99–106, 2017, doi: 10.1109/CRCSIT.2017.7965541.