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# Design of an Optimal Software-Defined Network for Reducing the Greenhouse Gas Effect

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**Abstract:** Currently, the high-load transmission system uses high energy resources, and due to the utilization of high energy, greenhouse gases are polluted. High load transmission caused more resource usage, causing traffic over the communication channel, and fewer packets were transmitted in more time. So to avoid the issue mentioned above, a novel buffalo-based gossip load balancing routing protocol (BGLBRP). Initially, this research created the desired number of nodes in the software defined network (SDN) environment. Avoid high-load data transmission; the system monitored the transmission with the help of the proposed model. For that, the system identifies the high-load data; it then shares the data into a free hub and performs the load-balancing operation. However, the proposed model needs a lower rate of energy resources for performing the packet transmission operation. The proposed model consumes lower energy about 0.051J, so it reduces greenhouse gas. Moreover, the performance rate of the proposed model was calculated, and a comparison was made through the existing model. In comparison, the proposed model attains a higher parameter rate than the existing models. Consequently, the parameters were measured in terms of node lifetime, communication delay, packet drop, packet delivery rate, and energy consumption. The presented model has recorded a high PDR of 97.5%. Compared to the past works, 10% of PDR has been improved. Subsequently, the communication latency was reduced by 25% than the compared models.

**Keywords:** Greenhouse gas, Buffalo optimization, Load balancing, Energy consumption, Transmission channel, Node creation, Software defined networking (SDN).

## 1. Introduction

The software defined networking (SDN) method provides the advantages related to the programmable networking parameters through splitting and transferring the hydroplanes, effectiveness along with the optimization based steering and elasticity development while managing the networks [1]. The cost of a donation to the energy was much higher among the networks, so effective energy was considered as the major role for developing the needs related to the contemporary interacting methodologies [2]. Moreover, the scheme's design effectiveness provides better resolution at the non-trivial [3]. Subsequently, the tackles were needed to adjust the effective energy of the software and the presentation based on the interactions [4].

Here, the ideas were developed based on increasing energy efficiency by applying the SDN mechanism [5]. SDN provides the model related to attraction based on developing the attention based on the research along with important features based on the regulator phase as well as the data phase departure, and rational centralization was controlled through programming interacting procedures [6]. Through the SDN methodology, the merits like suppleness without affecting the advanced presentation [7], increased effectiveness among optimization steering, easy implementation, management, and preferred cost range [8]. The energy consumption rates of energy consuming were playing an important role in the whole evidence and the interaction method rate [9]. So many other methods were developed for improving the energy efficiency in the systems,

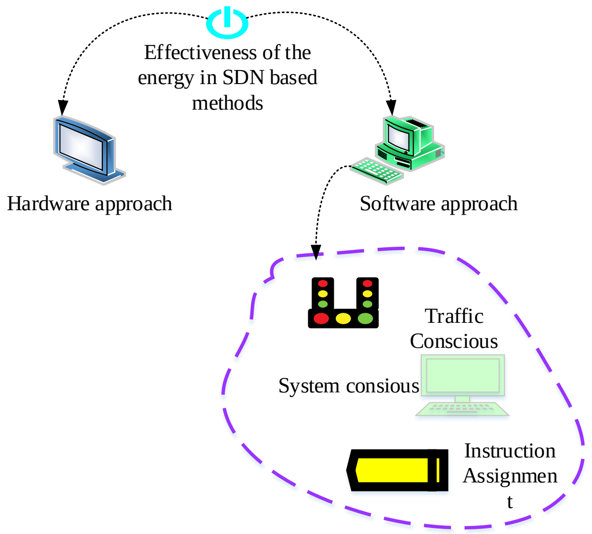


Figure. 1 Energy saving competencies in SDN

among them network function virtualization (NFV), cloud data centers, as well as wireless sensor networks (WSN) [10]. Energy optimization in the software was transmitted into different stages of the SDN model, or the SDN scheme was utilized for consuming the energies [11]. Fig. 1 illustrates the sections based on SDN energy consumption methods [12]. Energy consumption in the SDN was developed according to the algorithms and related to the development of hardware schemes [13]. The software-related resolution was provided only by the regulators [14]. The three energy-consuming methodologies addressed through the algorithm were traffic-conscious, system-conscious, and instruction-assigning [15].

Traffic consciousness having the ability to consume energy, was relative to the traffic capacity [16]. SDN uses the system conscious were saving energy through exploiting the simulated equipment assignment and relocations [17]. Many energy-conscious-based algorithms didn't accept the particular law planetary lies inside the regulators [18]. Assigning the instructions states the consuming of energy among the instructions [19], and condensing the instruction in the path user was saving the portion of the network [20].

The present work is arranged as follows; recent associated SDN works are described in section.2. Problem of the conventional SDN system is described in the 3rd section, and the solution to the described problem is exposed in the 4th section. The outcome of the presented solution is elaborated in the 5th section and section.6 concludes the research article.

## 2. Related work

Some of the recent literature related to energy optimization in the wireless network was described as follows:

M. Soltani et al. [21] suggested optimization and energy calculation in the geothermal temperature exchangers at different flowing fluids. Here the calculations were developed along with the genetic algorithm (GA). Moreover, optimizing the systems was more difficult because intention constraints on evaluating the influences were dissimilar in the flowing fluids consuming the energy of a geothermal heat pump (GHP). In this research, the coefficient of performance (COP) related to the GHP was measured with the help of these flowing fluids. However, higher installation costs were needed in GHP.

Eva Garcia Martin et al. [22] developed the approximation of energy depletion based on a machine learning technique to manage energy consumption at a low cost. The energy adaptation was considered a metric related to machine learning; the mainstream of this investigation was focused on acquiring a great range of accurateness devoid of other computational parameters. Along with some of the software equipment, the energy consumption was made, and those tolls provided the studies related to energy consumption in machine learning. But, the consumption of energy was not the same at all times. It varied according to the climatic changes.

Nassrudin et al. [23] developed an optimization of HVAC scheme energy consumption in a building using artificial neural networks (ANN) and multi-objective genetic algorithm (MOGA). For temperature optimization, the ventilating and air conditioning (VAC) scheme procedures and different construction constraints were planned to reduce the final energy consumption and develop thermal prevention. Moreover, the ANN and MOGA were provided for the optimization process in the double cooler scheme process in the construction. Ideally, the temperature variations were affecting the energy level in the buildings.

Tawfik Ismail et al. [24] presented splitting functions based on optimizing energy consumption in the virtualized radio access network (V-RAN) to maintain the constant temperature on energy optimization. Basically, the V-RAN was used to develop 5G technology and the constraints in the machine learning algorithm. New methodologies were developed based on Network Function Virtualization (NFV), and software defined radio (SDR) was considered the major factor in V-RAN that allowed the virtual double-phase presentation in every related process to the temperature-related optimization in energy consumption. Moreover, V-RAN takes more time for execution as well as analysis.

Ziwei li et al. [25] suggested building energy consumption based on the ANN forecasting methodology in the complex architecture procedure at the initial design level. Mostly, the ANN was commonly used in the presentation of optimization because of the higher level speed, high accurateness, and capacity to manage the non-linearity interactions among the constraints. Decomposition methods were developed here to reduce the difficulty of the construction shape in the initially proposed scheme. But, ANN completely depends upon the hardware system.

The key contribution of the present study is defined as follows,

- Initially, the required number of nodes is designed in the SDN environment
- Consequently, a novel BGLBRP has been introduced for optimal routing by managing the data load and optimizing the energy usage
- Here, the data load was balanced by sharing the overload data with other data-free hubs
- Moreover, the data transmission is initiated, and the communication parameters are valued
- Then the effect of energy optimization in the greenhouse has been discussed theoretically.
- Finally, the performance metrics were measured and compared with other models regarding node lifetime, communication delay, packet drop, packet delivery rate, and energy consumption.

## 3. System model and problem statement

Dealing the energy management in the wireless system is more complicated because of the movable and different user environments. In addition, the main cause of high energy utilization in the SDN system is data overloading, often caused by data loading.

Moreover, the high energy utilization has polluted the environment by increasing greenhouse gas. Hence, proper load balancing is required to balance the load between the considered users in the SDN environment. Moreover, the unbalanced data in the wireless environment has decreased the node lifetime. Hence, if the node is in the dead status, the packet drop has occurred, reducing the packet transmission rate. Fig. 2 shows the problem statement of the proposed model as well as the structure of the system. The common issues were found in the existing methodologies, such as the lifetime of the nodes being less, the system transmitting fewer packets with high time, and the greenhouse gas will be polluted due to more energy usage. The problems mentioned above were overcome through the proposed model. By using the proposed model, the system transmits more packets in less time, and the node's lifetime is improved. Subsequently, the system used less energy to process the function.

## 4. Proposed methodology

The chief reason for energy consumption and malicious events is network traffic. Hence, this network traffic is caused by high data load, so the load balancing model has been considered in this present study. Moreover, a novel buffalo-based gossip load balancing routing protocol (BGLBRP) has been introduced in this research.

Initially, the required nodes count was designed in the NS3 environment then a novel BGLBRP was designed to monitor the data loading hubs and to share the data with other free nodes. Hence, if the load is balanced, energy usage and data drop have been minimized. These have tended to reduce the communication delay time and maximize the node lifetime. Moreover, this routing scheme is tested in the SDN environment. Then finally, the reduction of energy utilization in Greenhouse gas reduction is discussed in a theoretical way. The presented model is described in Fig. 3. The proposed model was developed to monitor the amount of data load level sharing. The high load data was causing the traffic in data transmission.

### 4.1 Design of BGLBRP

This proposed model initially created the desired number of nodes in the SDN environment. Here, the proposed model was executed in the NS3 platform. Moreover, the node creation of the proposed model was expressed in Eq. (1),

$$D(n) = \{n(1), n(2), n(3) \dots\dots\dots n(n) \tag{1}$$

Where, *D(n)* defines the node creation function of the proposed model and *n(n)* represents the number of nodes that were presented in the SDN environment. After creating the nodes, the nodes were transmitted over the channel. Moreover, the data transmission of the proposed model was declared in Eq. (2) The transmitted nodes contained high load data and average load data.

$$D_t = \begin{cases} d_r > 300; & data\ overloaded\ hub \\ else; & optima\ data \end{cases} \tag{2}$$

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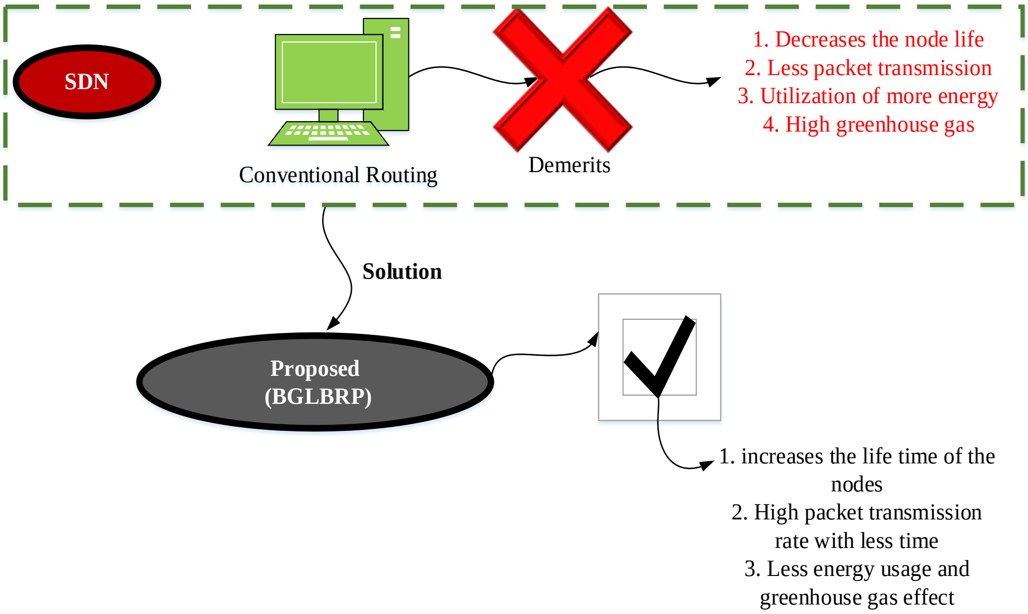


Figure. 2 System model with problem

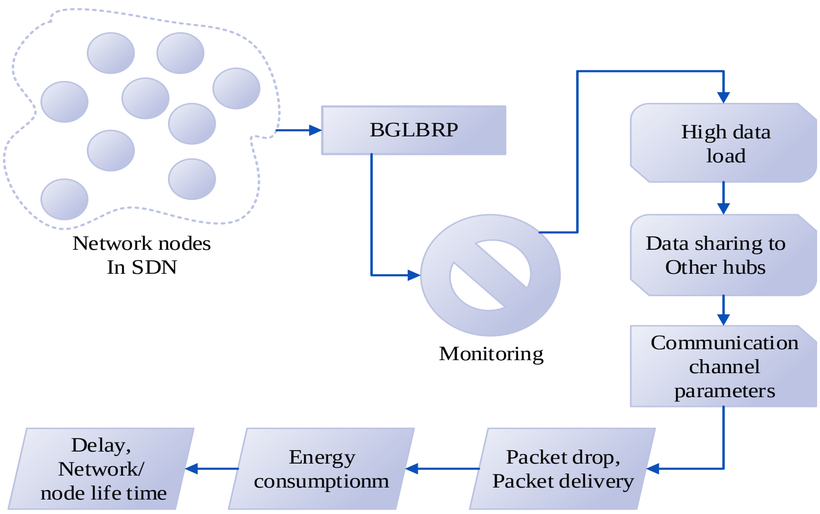


Figure. 3 Proposed architecture

At here, $D_t$ defines the data transmission parameter and $d_r$ defines the rate of data present in the transmission channel. If it is greater than 300mbps, then it is an overloaded data hub, then the half data is migrated to the other free nodes, which is less than 100Mbps. After designing the model, validating the rate of parameters presented in the proposed model is important. Subsequently, sharing of high-loaded data was declared through the Eq. (3),

$$D_s=\{(d^*) \rightarrow (h_1) \dots \dots (d^{**}) \rightarrow (h_n)\} \quad (3)$$

Where, $D_s$ defines the data sharing parameter of the proposed model, $d^*$, $d^{**}$ were considered as the high loaded data transmitting over the transmission channel and $h_1$, $h_n$ denotes the free hubs presented in the channel. Load balancing was done to develop the performance of the system. In the load balancing, the data were equally separated and given to the nodes for transmission. However, the load balancing of the proposed model was expressed in Eq. (4),

$$l_b = \{(d(h_1)), (d(h_2)) \dots \dots (d(h_n))\} \quad (4)$$

At here, the parameter $l_b$ represents the load-balancing function of the proposed model, $d$ defines the data presented in the channel as well parameter $n$ defines the number of nodes presented in the transmission medium. The high load data were balanced to avoid the traffic in the transmission channel. Due to high data transmission, the medium needs high energy. The energy was increased based

Algorithm: 1 BGLBRP

```
Start
{
   Creating node in SDN ()
   {
    D(n) = {n(1), n(2), n(3)..........n(n)  // To initialize the desired number of nodes
   }
   Data transmission ()
   {
       D_t, d*,  d_1, d**// initialize the data transmission parameters
    D_t=(d*,  d_1, d**)//While transmission, the channel contains a high load, normal parameters
   }
   Sharing high-load data ()
   {
    int D_s, d, h; // initialize the high-load data constraints
    D_s={(d*) → (h_1) ... ... . (d**) → (h_n)}// share the high-load data to the other free hubs
   }
   Load balancing ()
   {
    int l_b, d, n,;
    l_b = {(d(h_1)), (d(h_2)) ... ... . (d(h_n))   /After sharing the data  nodes were checked for  level
   }
   Energy consumption ()
   {
     int d_r, C(E) //initializing energy consumption parameters
    if d_r > 300Mbps   ;high   data_load   hub
    Else;    (normal data rate)
   }
Stop
}
```

Table.1 Simulation parameter specification

| Parameter specification | |
|---|---|
| Nodes count | 100 |
| Simulation platform | NS-3 |
| Network type | Wireless |
| Data Controller | SDN |
| Operating system | UBUNTU |
| Maximum data range | 300 Mbps |

on the amount of data and time. The greenhouse gas was polluted due to the utilization of high energy sources.

Due to high energy consumption, more toxic gases evaporate, affecting greenhouse gas. So, to avoid greenhouse gas pollution, the proposed model has optimized energy usage. The parameters were measured in node lifetime, communication delay, packet drop, packet delivery rate, and energy consumption. The working procedure of the proposed model was developed in pseudo-code format and given in algorithm.1. The workflow diagram of the proposed model is illustrated in Fig. 4.

## 5. Result and discussion

The introduced novel BGLBRP is tested in the NS-3 simulation windows, which successfully run in the Ubuntu platform. Initially, the required number of nodes was created. Then the SDN controllers are designed with the novel routing protocol. The main objective of this work is to reduce greenhouse gas emissions by optimizing the energy usage of the wireless network system. The simulation parameters used are given in Table. 1.

### 5.1 Case study

In the case study, the working procedure of the proposed model was discussed. The major aim of this present research was that greenhouse gas was polluted due to higher energy usage, and traffic arose

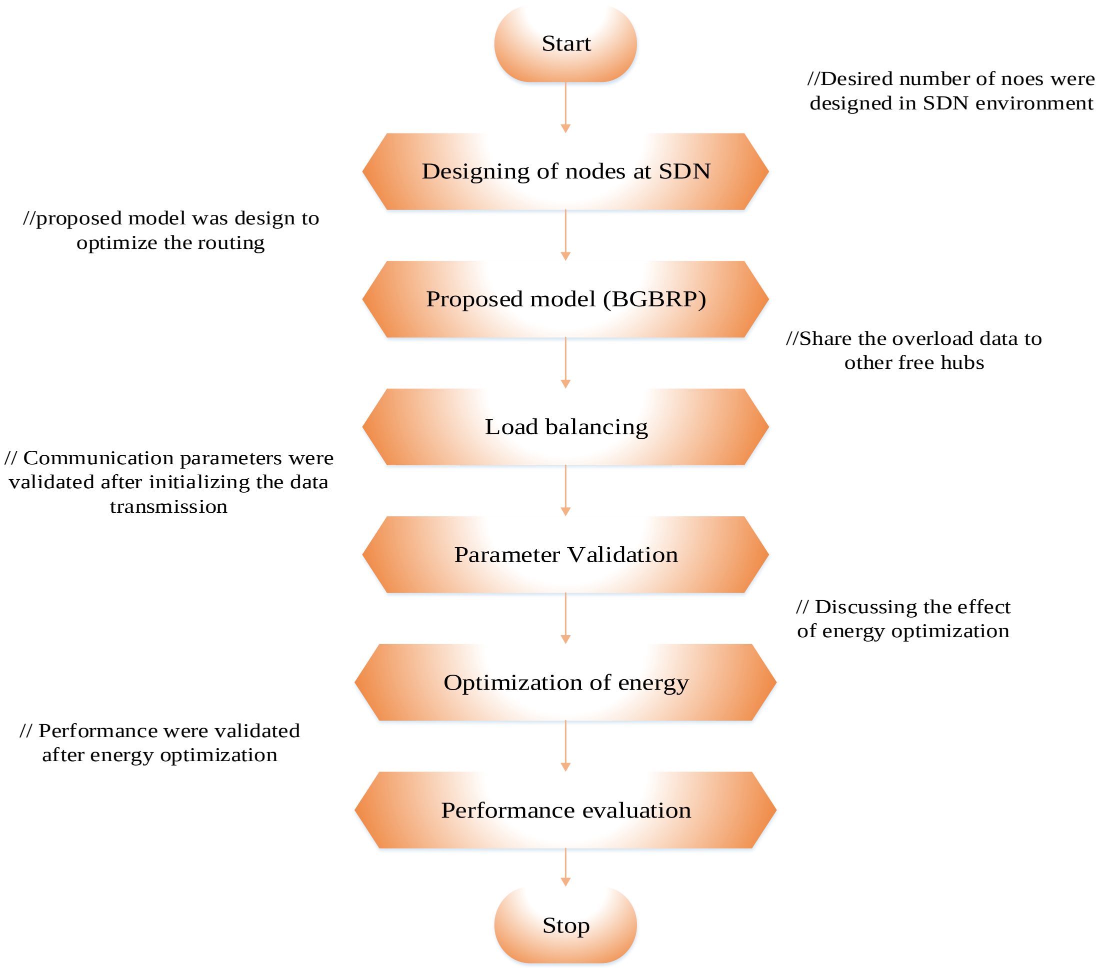


Figure. 4 Workflow of BGLBRP

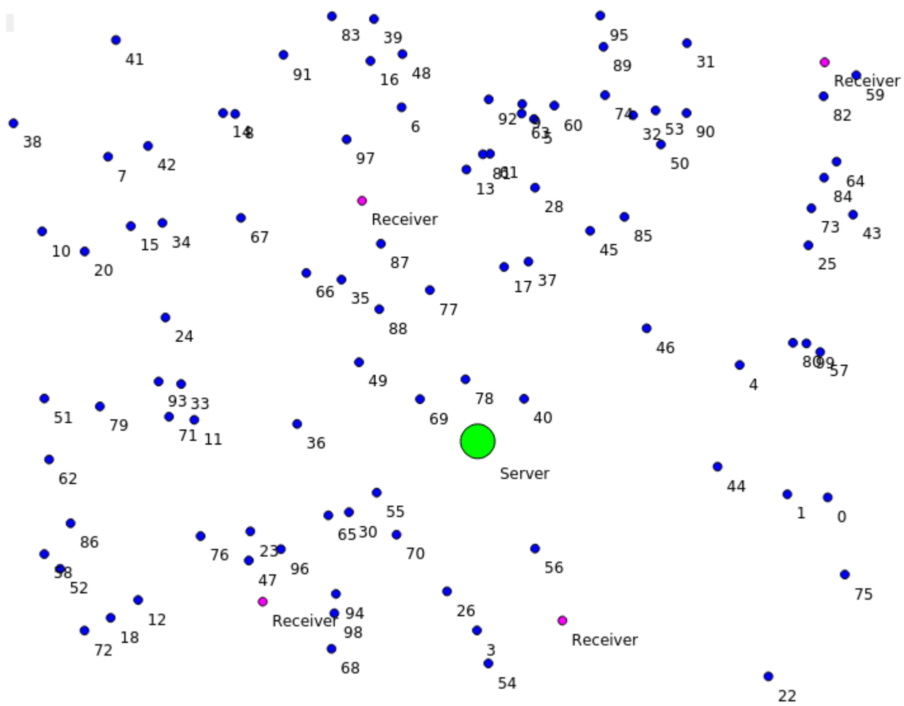


Figure. 5 Node generation in NS-3

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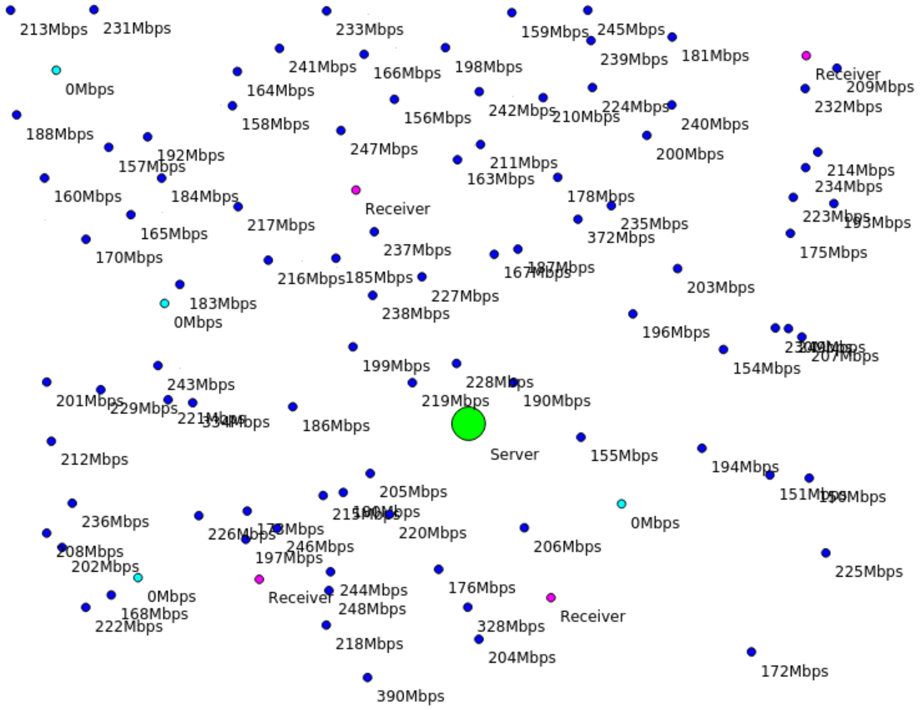


Figure. 6 Nodes data rate monitoring

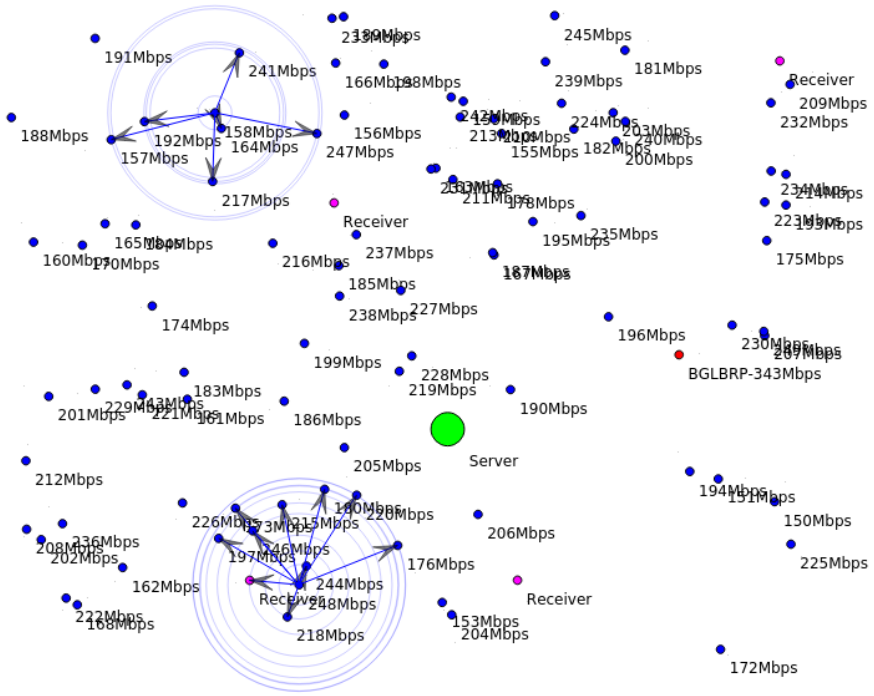


Figure. 7 Data migration

when transmitting high-load data. In the existing models, greenhouse gas was affected due to the utilization of high-consumption energy. So, the proposed model was designed to avoid high energy consumption and reduce energy usage. In this research, initially, the node was created in the SDN environment. After that, the system was monitored through the proposed model. The system was monitored to estimate the rate of data load. The high data load caused traffic in the system, and the system needed more energy to process the high data. So that the greenhouse gas was polluted. Subsequently, the proposed model data-sharing operation was presented if the system accessed the high data load.

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The node generation diagram in NS-3 is defined in Fig. 5; it contains one server and four receivers.

The data rate monitoring function was defined in Fig. 6. Here, the nodes below 100Mbps are said to be the free nodes. Also, the node's data rates of more than 300Mbps are considered overloaded.

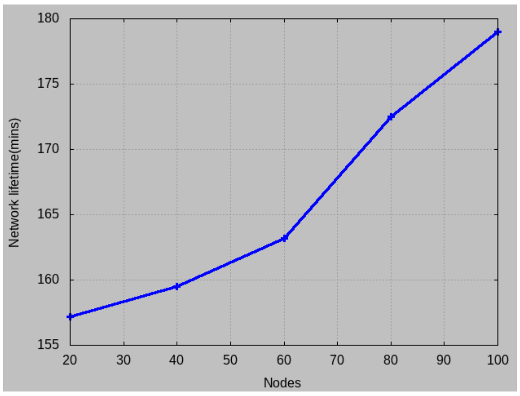
The node diagram's arrow represents the overloaded data migration to the free hubs. Moreover, the rest nodes and the condition for finding the high data load hub are executed in the African Buffalo fitness. Hence, the migration process is determined in Fig. 7. After migrating the data, the system is optimized the data is transferred through the shortest path.

To measure the performance of the designed model, the performance metrics must be measured with different nodes. Here, the calculated performance metrics with different node counts are defined in Fig. 8. Various performance metrics considered in the study are (a) Network lifetime, (b) Network overhead, (c) Throughput ratio, (d) Packet delivery ratio (PDR), (e) Energy consumption, (f) Communication delay, (g) Packet drop, and (h) Energy wastage.

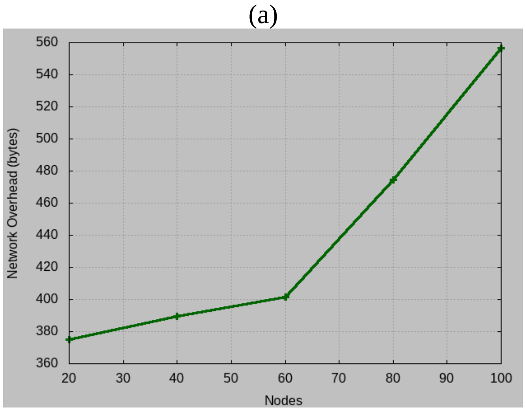
The main intention of this present research is to minimize the greenhouse effect by optimizing the SDN wireless system. Hence, the data migration function has been focused on achieving this process. This can reduce the data overhead and improve the network lifetime. Hence, the reported maximum lifetime of the developed novel BGLBRP SDN is 178 min. Also, the minimum network overhead rate is 378 bytes. Besides, the recorded energy waste rate is 0.001, which is very less and in a negligee state. Moreover, the attained maximum throughput ratio is 80Mbps, and 0.2% of packet drop has been reported. Subsequently, the gained minimum energy consumption score is 0.051J and 0.6ms communication delay. Hence, the gained performance metrics have revealed that the designed network is in optimal form.

## 5.2 Comparison analysis

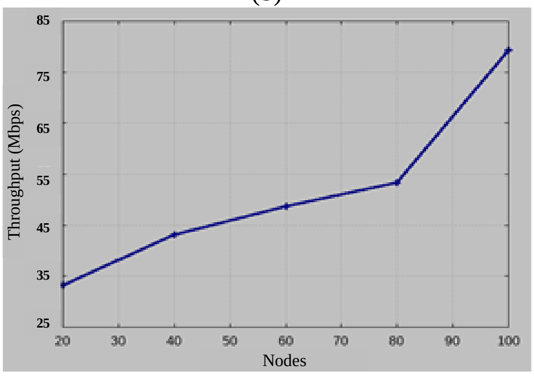
To check the necessity of the proposed design for the particular application, this comparative analysis has been performed with recent existing models implemented in the NS-3 platform. Hence, the existing models that were considered in this present research work is Mobile Broadband SDN (MB-SDN) [26], Cellular SDN (C-SDN) [27], Dijkstra-SDN (D-SDN) [28], fybrrlink SDN (F-SDN) [29], SDN Routing (SDN-R) [30], Sway-SDN (S-SDN) [31], Clustered Routing SDN (CR-SDN) [32],



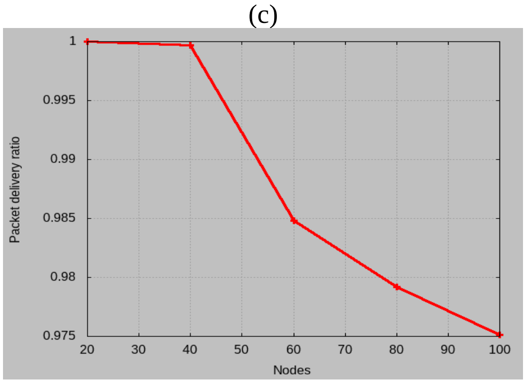
(a)



(b)



(c)



(d)

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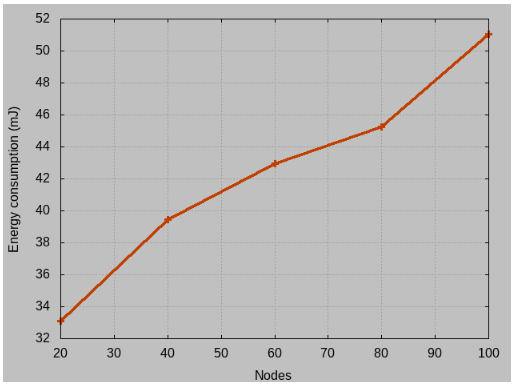
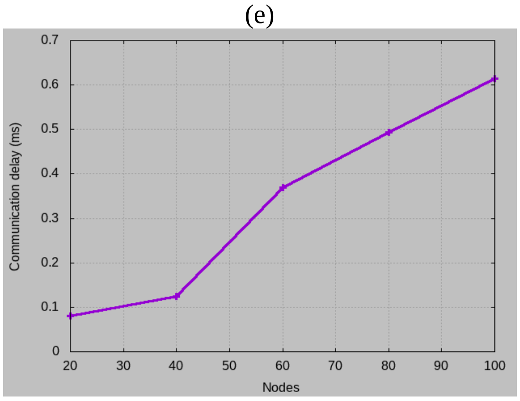
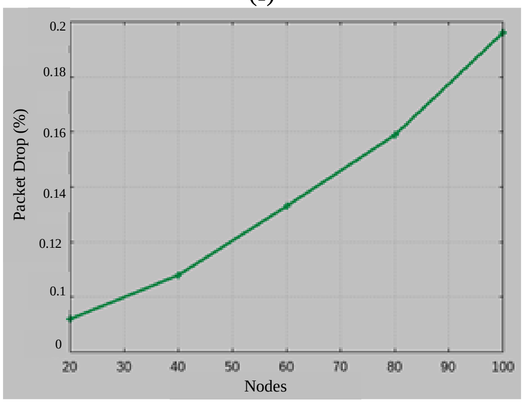


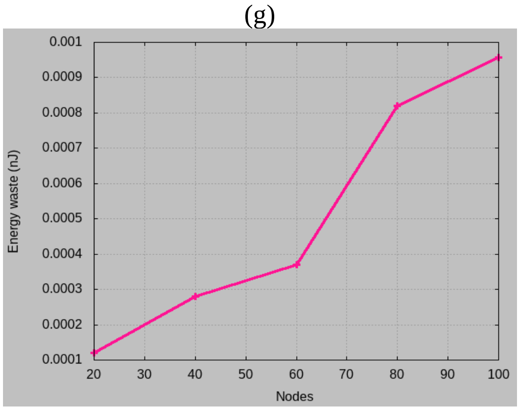

(e)




(f)




(g)




(h)

Figure. 8 Performance outcome: (a) network lifetime, (b)network overhead, (c) throughput ration, (d) packet delivery ration (PDR), (e) energy consumption, (f) communication delay, (g) packet drop, and (h) energy wastage

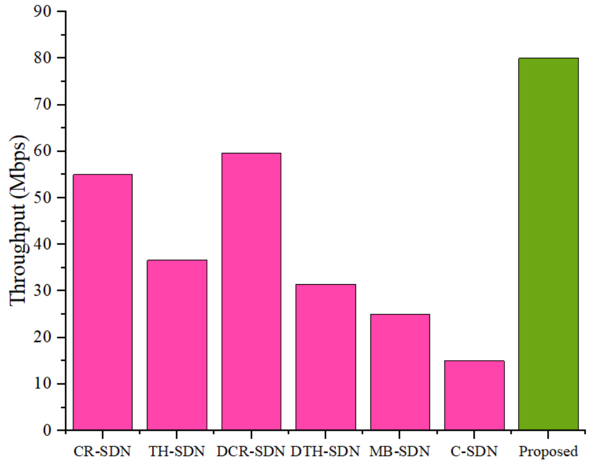



Figure. 9 Throughput assessment

Traditional hexagonal SDN (TH-SDN) [33], dynamic clustered routing SDN (DCR-SDN) [34], and dynamic traditional hexagonal SDN (DTH-SDN) [35].

### 5.2.1. Throughput

The metrics throughput has been measured to measure the data transferring capacity, which is formulated in Eq. (5)

$$\text{Throughput} = \frac{packet\ received}{time\ taken} \tag{5}$$

Here, the DTH-SDN has recorded a 31.4Mbps throughput ratio, DCR-SDN has scored 59.7 Mbps throughput ratio, TH-SDN has gained 36.6 Mbps throughput, the throughput of CR-SDN is 55 Mbps, the model MB-SDN has gained 25mbps throughput value, and C-SDN has scored 15Mbps throughput ratio. Considering all these compared models, the proposed novel BGLBRP has scored the maximum throughput score of 80Mbps. These statistics are described in Fig. 9.

### 5.2.2. Communication delay

During the data broadcasting, a collision or network overhead occurs because the data traffic can cause communication delay, which is validated by Eq. (6). Also, the high communication delay tented to cause high energy consumption and wastage.

$$delay = departure\ time - arrival\ time \tag{6}$$

The MB-SDN scored the communication delay as 18ms, C-SDN scored 23ms of communication delay, D-SDN gained 91ms of communication delay, F-

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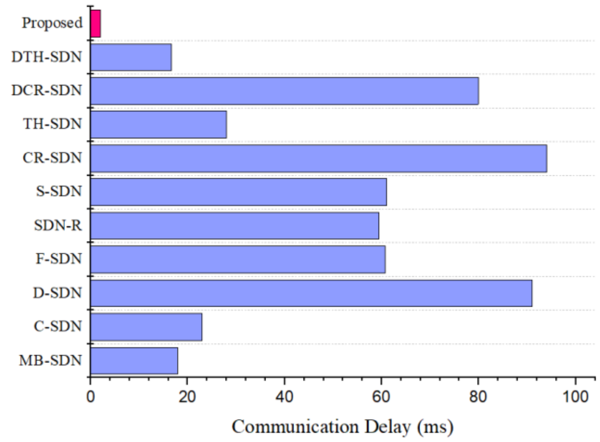

Figure. 10 Communication delay assessment

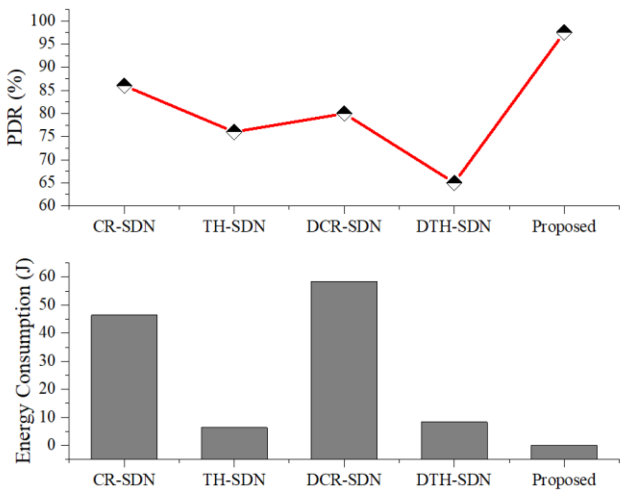

Figure. 11 Energy consumption PDR

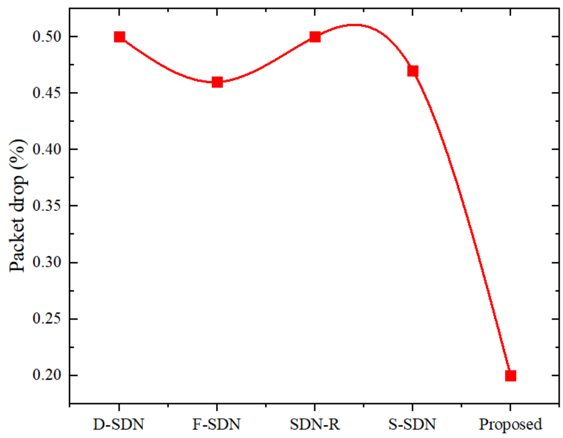

Figure. 12 Packet drop assessment

SDN recorded 60.74ms latency, SDN-R gained 59.4ms communication latency, S-SDN scored 61ms latency, CR-SDN has achieved 94ms communication latency, TH-SDN has scored 28ms latency, DCR-SDN has earned 79.9ms communication latency, and DTH-SDN has scored 16.6ms latency. Compared to these existing models, the presented model has recorded the lowest communication latency at 0.6ms. These results are shown in Fig. 10.

#### 5.2.3. Energy consumption and PDR

Less energy consumption and high packet delivery are the most required parameters to achieve the optimized greenhouse effect objective. If the technique attains less PDR and less energy consumption, it will be good for emission reduction but is not usable for the network users. Considering these, the dual chief parameters were considered. Moreover, the PDR is measured using Eq. (7).

$$\text{PDR} = \frac{Received\ Packets}{Packets\ Sent} \quad (7)$$

The energy consumption of the model CR-SDN is 46.4J, and the PDR is 86%; DCR-SDN has attained 58.33J energy consumption and 80% PDR, TH-SDN has gained the lowest energy consumption score as 6.4J and 76% PDR. Also, the DTH-SDN has reported 8.33J energy consumption and 65% PDR. Moreover, the proposed novel BGLBRP has reported the reduced energy consumption score as 0.051J; also achieved the highest PDR of 97.5%; these comparison statistics are defined in Fig. 11.

#### 5.2.4. Packet drop

Reducing the emission range is the most required task for the public environment. At the same, optimizing the packet flow rate is the chief parameter for the wireless system to enhance the data broadcasting function. Hence, the packet drop is described in Eq. (8).

$$\text{Packet drop} = \frac{received\ packet\ counts}{total\ packets} \quad (8)$$

The model S-SDN has recorded a 0.47% of packet drop, SDN-R has reported 0.5% packet loss, a 0.46% packet drop is recorded by the model F-SDN, and D-SDN has scored a 0.5% packet drop. Besides, the presented model has reported the optimal packet drop score as 0.2%, which is described in Fig. 12.

It has verified the robustness of the designed model. Moreover, the overall comparison statistics are exposed in Table. 2.

### 5.4 Discussion

In this section, the performance rate of the proposed model was discussed. Moreover, the proposed model attains an improved rate of parameters. On comparing the rate of performance in

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Table.2 Comparison assessment

| Comparison assessment | | | | | |
|---|---|---|---|---|---|
| Techniques | Throughput (Mbps) | Communication delay (ms) | Packet drop (%) | Energy consumption (J) | PDR (%) |
| MB-SDN | 25 | 18 | - | - | |
| C-SDN | 15 | 23 | - | - | - |
| D-SDN | - | 91 | 0.5 | - | - |
| F-SDN | - | 60.74 | 0.46 | - | - |
| SDN-R | - | 59.4 | 0.5 | - | - |
| S-SDN | - | 61 | 0.47 | - | - |
| CR-SDN | 55 | 94 | | 46.4 | 86 |
| TH-SDN | 36.6 | 28 | - | 6.4 | 76 |
| DCR-SDN | 59.7 | 79.9 | - | 58.33 | 80 |
| DTH-SDN | 31.4 | 16.6 | - | 8.33 | 65 |
| Proposed | 80 | 0.6 | 0.2 | 0.051 | 97.5 |

Table.3 Proposed BGLBRP Performance

| Overall performance of BGLBRP | |
|---|---|
| Throughput ratio (Mbps) | 80 |
| Communication delay (ms) | 0.6 |
| Packet drop (%) | 0.2 |
| Network lifetime (min) | 178 |
| Energy consumption (J) | 0.051 |
| PDR (%) | 97.5 |
| Energy wastage (nJ) | 0.001 |
| Network Overhead (bytes) | 378 |

the proposed model with the existing models, the proposed model attains better results. However, the proposed model attains an increased rate of network lifetime up to 178minutes, and a lower rate of communication delay reached through the proposed model was about 0.6ms. Subsequently, the system shares the data in the proposed model if a high data load is found. So traffic did not happen in the implemented design, and the packet loss also decreased. The overall performance assessment is defined in Table. 3.

The energy consumption recorded by the novel BGLBRP is 0.051J, representing that the present system is in the optimal state. Also, to reduce the effect of the greenhouse effect, the energy wastage of the designed model has been measured. Hence, the rated energy wastage score is 0.001nJ. Hence, the proposed model is utilized to reduce the effect of the emission range that has resulted in a low greenhouse effect.

## 6. Conclusion

In this research work, the novel BGLBRP was presented. Initially, the desired number of nodes was created in the SDN environment. After that, the system was monitored through the proposed model. Moreover, the high load data increases the traffic among the transmission channel and consumes more energy. So the proposed system shares the high-load data into the free hub presented over the transmission channel. Hence the system transmits the packet easily without making traffic in the channel. Subsequently, the high utilization of energy will pollute greenhouse gas. In the proposed model, less energy was used, and the greenhouse gas was not polluted. However, the proposed model obtained a higher rate of parameters, such as the implemented design reduced the energy consumption rate to about 0.051J when compared to the existing models, 10% of the Energy consumption rate was minimized. Also, it has recorded less energy wastage at 0.001nJ, which indicates that the proposed model is used to manage the greenhouse gas effect in the optimal stage. In addition, the reported packet loss score by the designed model is 0.2% compared to another model; the data loss rate was reduced by 2%. Besides, the presented model has recorded a high PDR of 97.5%. Compared to the past works, 10% of PDR has been improved. Subsequently, the communication latency was reduced by 25% than the compared models. These outcomes have revealed that the proposed model is suitable for reducing the greenhouse gas effect.

## Conflicts of interest

All the authors declare no conflict of interest.

## Author contributions

Conceptualization, Choupiri Shivakeshi and Sreepathi B; methodology, Choupiri Shivakeshi and Sreepathi B; software, Choupiri Shivakeshi; validation, Choupiri Shivakeshi and Sreepathi B; formal analysis, Choupiri Shivakeshi and Sreepathi B; investigation, Choupiri Shivakeshi and Sreepathi B; resources, Choupiri Shivakeshi and Sreepathi B; data curation, Sreepathi B;; writing—original draft preparation, Choupiri Shivakeshi; writing—review and editing, Choupiri Shivakeshi and Sreepathi B; visualization, Choupiri Shivakeshi and Sreepathi B; supervision, Sreepathi B;

## References

[1] M. G. Prina, M. Lionetti, G. Manzolini, W. Sparber, and D. Moser, "Transition pathways optimization methodology through EnergyPLAN software for long-term energy planning", *Applied Energy*, Vol. 235, pp. 356–368, Feb-2019.

[2] M. Capra, B. Bussolino, A. Marchisio, G. Masera, M. Martina, and M. Shafique, “Hardware and Software Optimizations for Accelerating Deep Neural Networks: Survey of Current Trends, Challenges, and the Road Ahead”, *arXiv*, 2020.

[3] L. Wu, X. Yan, L. Yang, S. Shen, Y. Li, S. Yang, L. He, Y. Chen, S. Yang, and Z. Zhang, “Simultaneous efficient degradation and dechlorination of chloramphenicol using UV/sulfite reduction: Mechanisms and product toxicity”, *Chemical Engineering Journal*, Vol. 452, p. 139161, 2023.

[4] M. Khanali, A. Akram, J. Behzadi, F. M. Rad, Z. Saber, K. Chau, and A. N. Pelesaraei, “Multi-objective optimization of energy use and environmental emissions for walnut production using imperialist competitive algorithm”, *Applied Energy*, Vol. 284, p. 116342, 2021.

[5] F. Palomba, D. D. Nucci, A. Panichella, A. Zaidman, and A. D. Lucia, “On the impact of code smells on the energy consumption of mobile applications”, *Information and Software Technology*, Vol. 105, pp. 43–55, 2019.

[6] Z. Yong, Y. L. Juan, Z. Qian, and S. X. Yan, “Multi-objective optimization of building energy performance using a particle swarm optimizer with less control parameters”, *Journal of Building Engineering*, Vol. 32, p. 101505, 2020.

[7] W. Yan, W. Tong, and X. Zhi, “FPGAN: An FPGA Accelerator for Graph Attention Networks With Software and Hardware Co-Optimization”, *IEEE Access*, Vol. 8, pp. 171608–171620, 2020.

[8] E. Naderi, B. Sajadi, M. A. Behabadi, and E. Naderi, “Multi-objective simulation-based optimization of controlled blind specifications to reduce energy consumption, and thermal and visual discomfort: Case studies in Iran”, *Building and Environment*, Vol. 169, p. 106570, 2020.

[9] J. Hu, W. Cao, F. Jiang, L. Hu, Q. Chen, W. Zheng, and J. Zhou, “Study on Multi-Objective Optimization of Power System Parameters of Battery Electric Vehicles”, *Sustainability*, Vol. 15, No. 10, p. 8219, 2023.

[10] S. Memeti, S. Pllana, A. Binotto, J. Kołodziej, and I. Brandic, “Using meta-heuristics and machine learning for software optimization of parallel computing systems: a systematic literature review”, *Computing*, Vol. 101, No. 8, pp. 893–936, 2018.

[11] F. Merlo, G. Vazzoler, and G. Berselli, “Eco-programming of industrial robots for sustainable manufacturing via dynamic time scaling of trajectories”, *Robotics and Computer-Integrated Manufacturing*, Vol. 79, p. 102420, 2023.

[12] P. Wang and R. M. P. Goverde, “Multi-train trajectory optimization for energy-efficient timetabling”, *European Journal of Operational Research*, Vol. 272, No. 2, pp. 621–635, 2019.

[13] O. Ekren, C. H. Canbaz, and Ç. B. Güvel, “Sizing of a solar-wind hybrid electric vehicle charging station by using HOMER software”, *Journal of Cleaner Production*, Vol. 279, p. 123615, 2021.

[14] R. Mokhtari and M. H. Jahangir, “The effect of occupant distribution on energy consumption and COVID-19 infection in buildings: A case study of university building”, *Building and Environment*, Vol. 190, p. 107561, 2021.

[15] D. K. Bui, T. N. Nguyen, A. Ghazlan, N. T. Ngo, and T. D. Ngo, “Enhancing building energy efficiency by adaptive façade: A computational optimization approach”, *Applied Energy*, Vol. 265, p. 114797, 2020.

[16] A. Ghavi, G. Bagherian, and H. R. Vahidian, “Degradation of paraquat herbicide using hybrid AOP process: statistical optimization, kinetic study, and estimation of electrical energy consumption”, *Environmental Sciences Europe*, Vol. 33, No. 1, 2021.

[17] R. Alsharif, M. Arashpour, E. Golafshani, A. Rashidi, and H. Li, “Multi-objective optimization of shading devices using ensemble machine learning and orthogonal design of experiments”, *Energy and Building*, Vol. 283, p. 112840, 2023.

[18] Y. Xie, Y. Li, Z. Zhao, H. Dong, S. Wang, J. Liu, J. Guan, and X. Duan, “Microsimulation of electric vehicle energy consumption and driving range”, *Applied Energy*, Vol. 267, p. 115081, 2020.

[19] W. Wang, G. Tian, M. Chen, F. Tao, C. Zhang, A. A. Ahmari, Z. Li, and Z. Jiang, “Dual-objective program and improved artificial bee colony for the optimization of energy-conscious milling parameters subject to multiple constraints”, *Journal of Cleaner Production*, Vol. 245, p. 118714, 2020.

[20] K. A. Osman, V. Yılmaz, H. Ö. Ünver, U. Şeker, and S. E. Kılıç, “Slot milling of titanium alloy with hexagonal boron nitride and minimum quantity lubrication and multi-objective process optimization for energy efficiency”, *Journal of Cleaner Production*, Vol. 258, p. 120739, 2020.

[21] M. Soltani, P. Farzanehkhameneh, F. Moradi Kashkooli, A. A. Haq, and J. Nathwani, “Optimization and energy assessment of

Received: May 31, 2023. Revised: June 29, 2023. 

geothermal heat exchangers for different circulating fluids", *Energy Conversion and Management*, Vol. 228, p. 113733, 2021.

[22] Y. Zhang, B. K. Teoh, M. Wu, J. Chen, and L. Zhang, "Data-driven estimation of building energy consumption and GHG emissions using explainable artificial intelligence", *Energy*, Vol. 262, p. 125468, 2023.

[23] Nasruddin, Sholahudin, P. Satrio, T. M. I. Mahlia, N. Giannetti, and K. Saito, "Optimization of HVAC system energy consumption in a building using artificial neural network and multi-objective genetic algorithm", *Sustainable Energy Technologies and Assessments*, Vol. 35, pp. 48–57, 2019.

[24] T. Ismail and H. H. M. Mahmoud, "Optimum Functional Splits for Optimizing Energy Consumption in V-RAN", *IEEE Access*, Vol. 8, pp. 194333–194341, 2020.

[25] X. Li, S. Liu, L. Zhao, X. Meng, and Y. Fang, "An integrated building energy performance evaluation method: From parametric modeling to GA-NN based energy consumption prediction modeling", *Journal of Building Engineering*, Vol. 45, p. 103571, 2022.

[26] A. Filali, Z. Mlika, S. Cherkaoui, and A. Kobbane, "Dynamic SDN-based Radio Access Network Slicing with Deep Reinforcement Learning for URLLC and eMBB Services", *arXiv*, 2022.

[27] A. Ashipala and J. A. Abolarinwa, "SDN-Enabled Data Offloading and Load Balancing in WLAN and Cellular Networks", *SSRN Electronic Journal*, 2023.

[28] R. Radito, P. H. Trisnawan, and K. Amron, "Implementasi Pencarian Jalur berdasarkan Bandwidth dengan menggunakan Algoritme Dijkstra pada Arsitektur Jaringan Software-Defined Networking (SDN)", *J. Pengemb. Teknol. Inf. dan Ilmu Komput*, Vol. 2548, No. 964X, 2020.

[29] P. Kumar, S. Bhushan, D. Halder, and A. M. Baswade, "fybrrLink: Efficient QoS-Aware Routing in SDN Enabled Future Satellite Networks", *IEEE Transactions on Network and Service Management*, , Vol. 19, No. 3, pp. 2107–2118, 2022.

[30] Y. R. Chen, A. Rezapour, W. G. Tzeng, and S. C. Tsai, "RL-Routing: An SDN Routing Algorithm Based on Deep Reinforcement Learning", *IEEE Transactions on Network Science and Engineering*, Vol. 7, No. 4, pp. 3185–3199, 2020.

[31] N. Saha, S. Bera, and S. Misra, "Sway: Traffic-Aware QoS Routing in Software-Defined IoT", *IEEE Transactions on Emerging Topics in Computing*, Vol. 9, No. 1, pp. 390–401, 2021.

[32] V. Tyagi and S. Singh, "GM-WOA: a hybrid energy efficient cluster routing technique for SDN-enabled WSNs", *The Journal of Supercomputing*, Vol. 79, No. 13, pp. 14894–14922, 2023.

[33] M. Bastami, A. E. Mousavi, and M. Abbasnejadfard, "Evaluation of Mechanical Characteristics of High-Strength Reinforced Concrete Columns with Hexagonal Chicken Wire Mesh Under Cyclic Loading", *International Journal of Concrete Structures and Materials*, Vol. 16, No. 1, 2022.

[34] P. R. Desai, S. Mini, and D. K. Tosh, "Edge-Based Optimal Routing in SDN-Enabled Industrial Internet of Things", *IEEE Internet of Things Journal*, Vol. 9, No. 19, pp. 18898–18907, 2022.

[35] S. Prabakaran, R. Ramar, I. Hussain, B. P. Kavin, S. S. Alshamrani, A. S. AlGhamdi, and A. Alshehri, "Predicting Attack Pattern via Machine Learning by Exploiting Stateful Firewall as Virtual Network Function in an SDN Network", *Sensors*, Vol. 22, No. 3, p. 709, 2022.