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Enhancing Performance of Wide Area CIoT SDN by US-ML Based Optimum Controller Placement

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Abstract: It is a critical area of study for enhancing the effectiveness of wide-area Cellular Internet of Things (CIoT) networks. One solution is to merge Software Defined Networking (SDN) with Internet of Things (IoT) network to boost efficiency. The main challenge is determining the best location for the SDN controller and evaluating SDN clustering. This paper proposed an Un-Supervised Machine-Learning (US-ML) approach based on silhouette distance along with gap statistic for finding the optimum number of controllers for network under consideration. In addition, the Partition Around Medoids (PAM) approach is opted for allocation of controller locations. Apart from SDN, another approach is to create efficient Low-Power Wide Area Networks (LPWAN). As a result, this research contributed to the study of various LPWAN design approaches and offered a method of optimal controller location for IoT-SDN cellular networks in industries. Several outstanding research challenges are noted, and prospective research objectives for LPWAN are offered. For the case study of wide area networks (WAN), a graphical representation of the SDN controller positioning method is presented. It is determined that effective placement can improve SDN performance in worst-case network scenarios.

***Keywords*:** IoT, LPWAN, cellular network, SDN, clustering, positioning of controller, LoRaWAN

1. Introduction

Sensing devices are deployed in the Internet of Things (IoT) network in a widespread range. The requirement of improving the performance of cellular IoT-based wide area networks (WANs) had grown dramatically in recent years. This challenge can be met by combining Low-Power WAN (LPWAN) and Cellular IoT (CIoT) networks [1]. Another strategy is to implement a hybrid combination of Software Defined Networking (SDN) and IoT networks [2], for improving the system effectiveness. The SDN-IoT network has recently become popular in industrial uses for control engineering and modeling of autonomous management. This paper proposed to test the Un-Supervised Machine-Learning (US-ML) based SDN controller's allocation problem. Figure 1 depicts the most common uses of SDN-IoT. The SDN is increasingly being employed for sensors interface and constrained monitoring of IoT for WAN implementations. These networks deployment has recently become popular in the industrial uses for control engineering

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and modeling of autonomous management. The network applications as mentioned in Figure 1 include production control, smart cities, automation of smart homes, inventory management, etc. Each of these applications needs to communicate a huge amount of information.

Figure 1. Applications of SDN-IoT in industries

1.1 *Contributions*

The main design problems are appropriate SDN controller location and adoption of low-energy devices for LPWAN applications. It has been discovered that better controller arrangement can reduce the communication distance between sensor nodes, resulting in improved performance. This paper will offer a case study of these two difficulties. The effectiveness of several LPWAN technologies is initially compared and assessed. The validation results of the US-ML based on method of silhouette and gap statistics optimal allocation of controller location for enhancing the WAN performance consideration are then shown, depending on latencies and cluster selection.

2. Classifications of WAN protocols

The broad classification of the WAN performance enhancement methodologies is given in Figure 2. The LoRaWAN as well as Narrowband IoT (NB-IoT) seem to be the most attractive long range communication techniques worldwide, and they are generating a vast IoT networks.

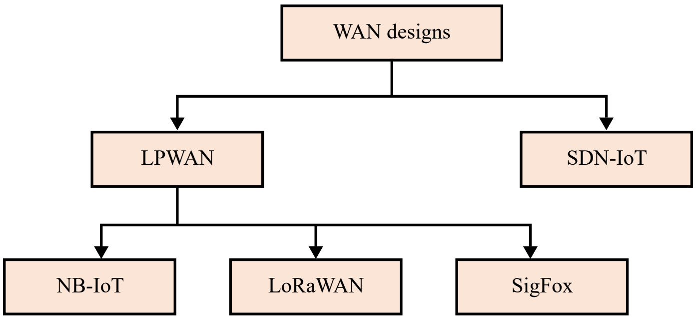


Figure 2. IoT-based WAN technology classification

The energy efficiency, longevity, quality of service (QoS) and long range coverage of these networks are all important variables to consider when evaluating their WAN performance. The 3rd Generation Partnership Project (3GPP) created the NB-IoT idea for cellular networks. NB-IoT offers the features of a fourth generation (4G) mobile network, such as worldwide coverage and long range, also with energy efficiency using LPWANs to enhance energy savings. NB-IoT is also intended to improve interior coverage and enable a variety of low devices [3, 4]. It's designed to cater to the high-value IoT sector, which values low latency and great service quality [3-6]. LoRaWAN, on the other hand, is aimed for lower-cost devices with long range (high coverage), intermittent communication needs, and long battery life. LoRaWAN and SigFox are examples of LPWAN technologies that use upgraded physical layer (PHY) technologies for achieving long range. Narrowband (NB) cellular networks, such as NB-IoT and Long-Term Evolution in the Machines (LTE-M) provide decreased capacity and simpler node and networking management measures.

3. Comparison of LPWAN methods

This section of the paper evaluates the NB-IoT, SigFox and LoRa approaches of LPWAN implementation [7-10]. The comparative evaluation is based on a survey of the literature for coverage and energy. Figure 3 depicted an overview of the performance evaluation of LPWAN techniques. The figure clearly illustrates that NB-IoT outperforms overall in regard to coverage and energy performance.

Over existing network topologies, NB-IoT offers a longer life of batteries and much more flexible energy management, with an operational lifespan of far more than 15 years. This is beneficial for small-footprint gadgets such as smart watches. Although LoRa has optimal maximum range up to 20 km, it is extremely challenging to adjust and install.

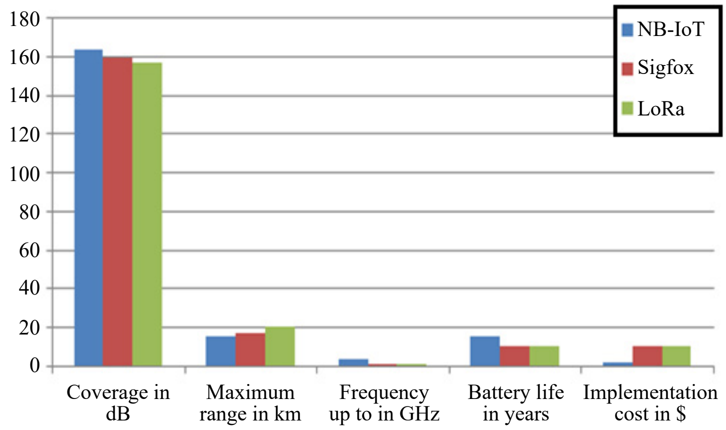


Figure 3. Performance summaries of LPWAN technologies

4. Related works

A great deal of effort has gone into improving cellular IoT networks. Adopting the SDN-IoT framework is one option. The segregation of the data and control planes in the SDN paradigm has been the technical platform, where network nodes in the data plane conduct forwarding activities under the administration and control of SDN controllers within the control plane. As a result, many SDN-enabled devices used in modern IoT networks might provide variable network architectures at a cheap capital cost. This section provides a comprehensive review for LPWAN as well as SDN-based techniques. A summary of the review work is given in Table 1.

Table 1. Summary of the clustering based routing protocols for WAN

Authors	Methodology	Approach
Onumanyi et. al. [1]	Based on an universal network infrastructure as well as a PHY layer concept.	Cognitive radio (CR) solutions in an LPWAN network must be installed at the gateway (GW) rather than the LPWAN end nodes.
Sebastian et al. [2]	The unlicensed LPWAN systems performed well at distances of up to 10 km, with SigFox having the highest coverage in the LPWAN section.	A single testbed for measuring and comparing the performance of LPWAN as well as NB-IoT devices.
Ballerini et al. [3]	Evolves the effectiveness of LoRaWAN as well as NB-IoT accurate field measurements in the same application system for fair energy efficiency evaluation.	Based on experimental information gathered at a LoRa, a wireless power sensor was created to assess fractures in reinforced concrete constructions.
Nair et al. [4]	It is dependent on the technology, which was examined using several key performance indicators (KPIs).	Addresses the huge scale of IoT installations as well as other essential needs like low power, low cost, extensive coverage, and long battery life.
Jiang [5]	Introduces the LoRa and NB-IoT testbeds that were utilized in the studies, as well as the technique for evaluating the performance benefit of protocols.	The purpose of this study is to compare the effectiveness of LoRa and NB-IoT in respect of connectivity quality.
Ugwuanyi et al. [6]	The effectiveness of LoRaWAN as well as NB-IoT employing one Evolved Node B (eNB) and two user equipment (UEs) was examined.	Aims to provide long-term potential for IoT growth in underdeveloped nations by comparing LoRaWAN with NB-IoT in regard to power consumption, privacy, latency, and throughput.
Maurya et al. [7]	Have designed a multiple-input multiple-output (MIMO)-cognitive relaying network.	Designed an energy-efficient cognitive radio network with a relay precoder.

Table 1. *Continued*

Authors	Methodology	Approach
Ismail et al. [8]	LPWANs are a cutting-edge technology that allows applications.	Identifies the important LPWAN prospects and suggests future research topics for LPWAN.
Chen et al. [9]	Wireless communication as well as heterogeneous devices, such as smart buildings and greener IoT artificial intelligence (AI) applications for smart homes, health monitoring, self-driving, and emotional engagement.	Concentrate on modern wireless communication technology, notably cellular communications.
Tran et al. [11]	SDN controller positioning.	For controller placement, this paper used the optimized submodular dependent approach.
Hans et al. [12]	SDN controllers with optimization algorithm placement.	Developed strategy for improving SDN-IoT network applications.
Jain et al. [13]	Presented deep learning based algorithm.	This method is presented for wearable devices.

4.1 *Review of SDN control*

Mobile devices are used to build WAN networks. As a result of deploying SDN in combination with an IoT network, Song et al. [14] advocated software-defined (SD)-IoT networks. Their study concentrated on recognizing spatial events and splitting challenges among several flow paths. Kobo et al. [15] created a novel SD wireless network election and effective controller placements. It allows to quickly and easily spread-ing SD network communication control over your IoT network. Rahman et al. [16] used SDN-IoT during the COVID-19 epidemic to offer robust data connection on the surfaces and devices required for Industry 4.0. Li et al. [17], Tran et al. [11] and Hans et al. [12] offered different techniques for SDN controller placement to optimize performance. Similar literature is presented in [13, 18, 19].

5. Optimum allocation of controller in SDN network

The goal of this part is to test and asses the effectiveness of the existing map graph comprising nodes in WAN-SDN under the modified worst case of latencies. Additionally, it is proposed to analyze the performance of controller smart placement in SDN. The effectiveness of SDN-IoT is proposed or predicted to improve by adopting optimal allocation of controller locations, since controllers serve as the system’s heart. Figure 4 depicts the major sequential processes of the proposed controller placement technique utilized for WAN application.

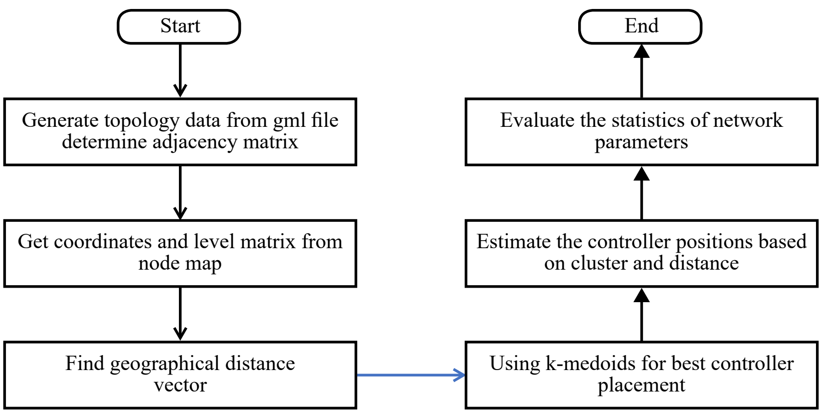


Figure 4. Design steps of SDN controller optimum placement

The topological data or information is created utilizing the MATLAB environment from an input example of a gml file. The network node coordinates and the level matrix generated from the node map. Estimate the controller placements using cluster and distance information. Based on silhouette techniques, the paper analyzed the worst-case latency and clustering counts. To find the best placements for all of these controllers, the proposed method uses a location-allocation approach called the Partition About Medoids (PAM) algorithm clustering using propagation delay. The k-medoids are employed for the allocation of the controller locations. In the foundation of controller placement, we use these techniques to detect the number of controllers that minimizes total network transmission latency.

The algorithm of the proposed controller placement using PAM based clustering is given in Algorithm 1.

Algorithm 1. The proposed PAM based clustering

The proposed PAM based clustering

1. Input data set D and, the number of medoids K = 4
2. Determine the weight matrix based on ← distance of edges K m
3. Calculate the shortest distance matrix using Johnson's algorithm
4. Find the minimum sum of distances and select initial medoids
5. If N medoids < K
    repeat 2, 3
   end if
6. Perform clustering: Find the minimum sum for all clusters
7. If N medoids < K
    Update medoids
    repeat 5
   end if
8. Calculate worst case and average latencies ← O, T, V, P, L_{avg}, $L_{worst1,2,3,4}$
9. Finally, find optimum controller location using the silhouette method. And gap statistic.

6. Results and discussions

Various proposed results are presented based on US-ML based modified latencies calculation. Table 2 displays simulation settings used to assess the best SDN controller placement strategy. For the study, four controllers for 14 WAN application sites are considered. It can be seen that latency is evaluated for the worst-case network conditions, which follow the same pattern as real latency.

Table 2. SDN based on the study using approximate parameters

Parameters	Description, range or value
Nodes	14 cities' default locations
Methodology	Cluster formations and latency improvement
Nc	The number of controllers is set to 4
S	The silhouette values range from -0.5 to 1
C	Cluster number

Figure 5 depicts the hierarchical data information extracted from the gml file, as well as the levels and coordinate plot of the WAN network. The proposed approach is used to assess cluster quality by calculating the shortest distance between data points.

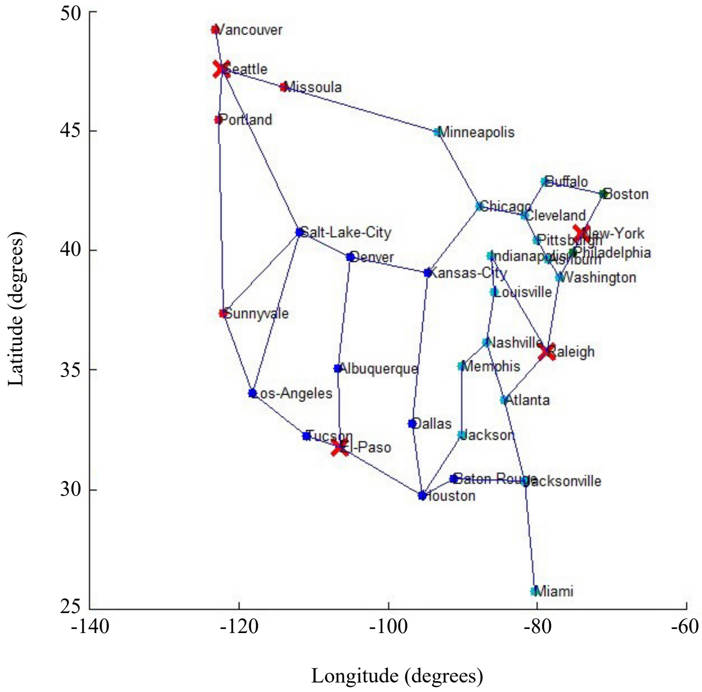


Figure 5. Representation of input collected node locations topological knowledge from the gml file

In the scope of controller placement, we use these techniques to determine the number of controllers which minimize total network propagation delay (i.e., switch-to-switch latency)

The general latencies for the network are defined as

$$L_{avg} = \sum_0^m \sum_0^n dist / (length(graph.node)) \tag{1}$$

$$L_{worst} = \max_{0\, toy} dist \tag{2}$$

In this paper, the modified calculation of the worst case of latencies for four controller locations are defined as

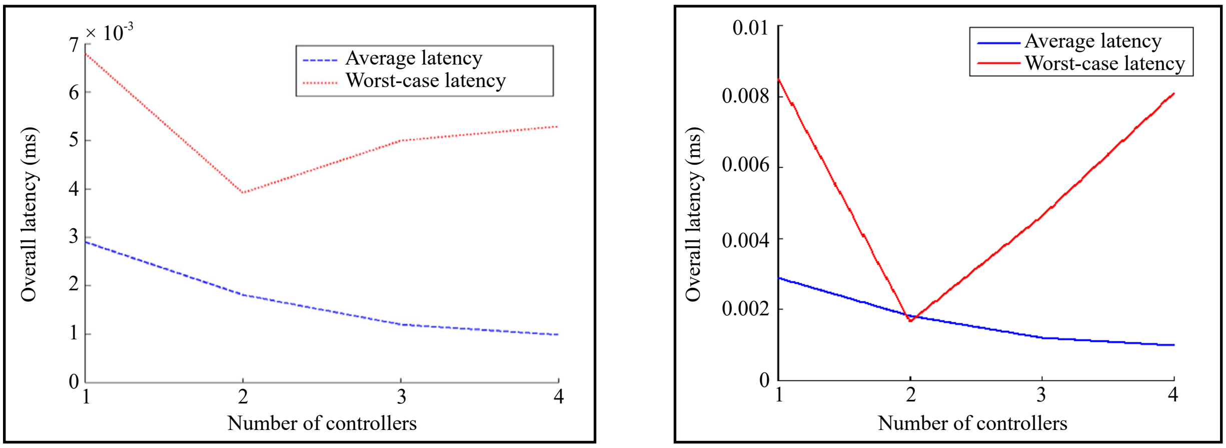
$$L_{avg} = \sum \frac{O+T+V+P}{(length(graph.node)) * 2 * 10^5} \tag{3}$$

where corresponding to four controller clusters

$$O = sum(dist_{avg1}); T = sum(dist_{avg2}); V = sum(dist_{avg3}); P = sum(dist_{avg4}) \tag{4}$$

The modified worst-case latencies for four distances are defined as

$$L_{worst1} = \frac{\max(dist_{avg1})}{2*10^5}; L_{worst2} = \frac{\max(dist_{avg2})}{2*10^5}; L_{worst3} = \frac{\max(dist_{avg3})}{2*10^5}; L_{worst4} = \frac{\max(dist_{avg4})}{2*10^5} \tag{5}$$



(a) Validated latencies (b) Proposed modified distance based worst latencies

Figure 6. Results of the validation and proposed average and worst-case latency vs. number of controllers

In Figure 6 (a) and (b), the experimental findings of computed average latency and worst-case latencies are shown. It is clear that the proposed modified distance based latency calculation (Equations (3) to (5)) performs better under worst case and worst latencies are much closer to the average required latencies.

Figure 7 presented a much better representation of the worst-case latencies with the proposed method and existing approach. It can be observed that the modified latencies even for the worst case are less for around 50% of cases of controllers.

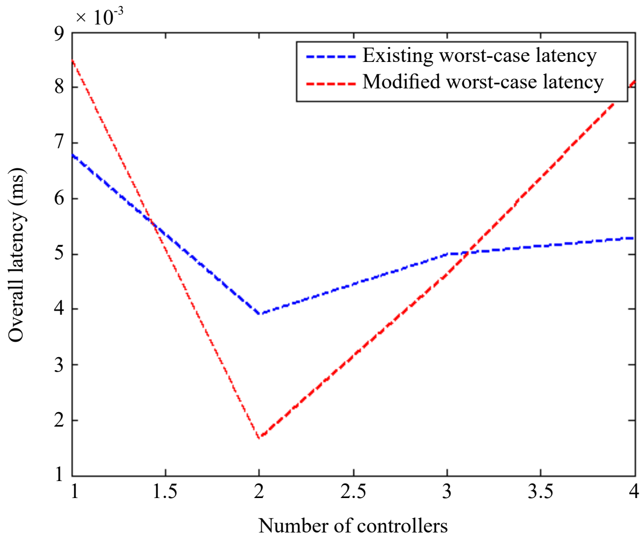
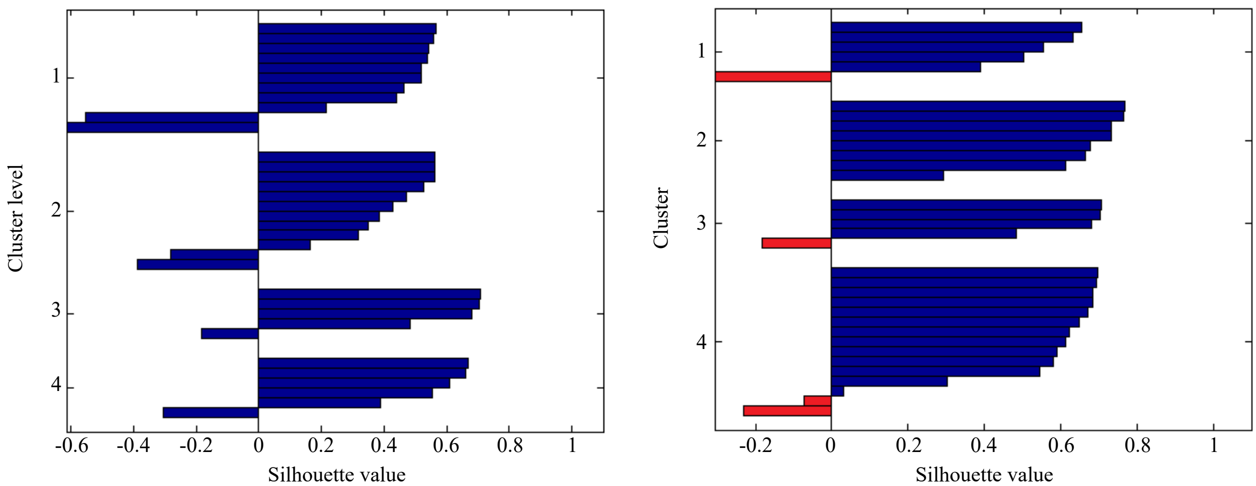


Figure 7. Results comparison of modified worst-case latency performance

Using the unsupervised silhouette distances based method to obtain the highest k percent of the values of the measures for silhouette, bend, and gap. Figure 8(a) depicts the cluster levels vs. the silhouette values. The silhouette values range from -0.5 to 1. It is required to minimize negative values for better network performance.

It is obvious from Figure 8(b) that for the proposed approach the majority of silhouette values are positive, indicating a better distribution of clusters in the network, with less than of around 10% of clusters having an incorrect distribution having negative silhouette values (shown by red color) with modified latencies calculation.



(a) Validation of silhouette values (b) Silhouette values with our proposed worst-case latency

Figure 8. Comparison of cluster count effectiveness for silhouette value for proposed four controller system

7. Conclusions and discussions

The report presents a research on the performance of LPWAN systems. Furthermore, the US-ML based silhouette PAM method-based optimal placement of the SDN-IoT controllers on WAN networks is investigated. The coverage performance of WAN networks is studied and compared for the NB-IoT, LoRa, and SigFox technology specifications. It is found that, when compared to current network topologies, NB-IoT appears to have a longer battery life and more effective energy management, with a functional lifetime of significantly more than 15 years.

It is concluded that although the maximum recommended distance for LoRa to be utilized in WAN architecture is roughly 20 km, implementing it is a difficult task at hand. SDN controller placement is tested and simulated, and it is determined that effective positioning might better redistribute clusters in the network and lower the likelihood of incorrect cluster formation.

It is found that for the proposed approach the majority of silhouette values are positive, indicating a better distribution of clusters in the network, with less than of around 10% of clusters having an incorrect distribution having negative silhouette values with modified latencies calculation. The method uses random distance measures, thus outcomes are probabilistic and expected to change a bit. Limitation can be eliminated by simulation using a fixed set of distances measured for network formation.

Overall, it is concluded that combining SDN with IoT networks can improve the overall effectiveness of the WAN network by increasing data control. In future, it is expected to test and design the performance of the LoRaWAN for the WAN performance enhancement. In the upcoming future, the effectiveness of a NB-IoT network at reduced power consumption must be tested.

Conflict of interest

Authors declare that the current work does not have any conflict of interest.

References

[1] Onumanyi AJ, Abu-Mahfouz AM, Hancke GP. Towards cognitive radio in low power wide area network for industrial IoT applications. In: *2019 IEEE 17th International Conference on Industrial Informatics (INDIN)*. Helsinki, Finland: IEEE; 2019. p.947-950. https://doi.org/10.1109/INDIN41052.2019.8972333

[2] Sebastian JE, Sikora A, Schappacher M, Amjad Z. Test and measurement of LPWAN and cellular IoT networks

in a unified testbed. In: *2019 IEEE 17th International Conference on Industrial Informatics (INDIN)*. Helsinki, Finland: IEEE; 2019. p.1521-1527. https://doi.org/10.1109/INDIN41052.2019.8972256
[3] Ballerini M, Polonelli T, Brunelli D, Magno M, Benini L. NB-IoT versus LoRaWAN: An experimental evaluation for industrial applications. *IEEE Transactions on Industrial Informatics*. 2020; 16(12): 7802-7811. https://doi.org/10.1109/TII.2020.2987423
[4] Nair KK, Abu-Mahfouz AM, Lefophane S. Analysis of the narrow band internet of things (NB-IoT) technology. In: *2019 Conference on Information Communications Technology and Society (ICTAS)*. Durban, South Africa: IEEE; 2019. p.1-6. https://doi.org/10.1109/ICTAS.2019.8703630
[5] Jiang L. *Comparision of LoRa and NB-IoT in terms of connectivity*. Degree project. KTH Royal Institute of Technology; 2020. https://www.diva-portal.org/smash/get/diva2:1453316/FULLTEXT01.pdf
[6] Ugwuanyi S, Paul G, Irvine J. Survey of IoT for developing countries: Performance analysis of LoRaWAN and cellular NB-IoT networks. *Electronics*. 2021; 10(18): 2224. https://doi.org/10.3390/electronics10182224
[7] Maurya S, Bansal M. Energy efficient relay precoder design for MIMO-cognitive relay network. In: *2016 11th International Conference on Industrial and Information Systems (ICIIS)*. Roorkee, India: IEEE; 2016. p.749-752. https://doi.org/10.1109/ICIINFS.2016.8263038
[8] Ismail D, Rahman M, Saifullah A. Low-power wide-area networks: opportunities, challenges, and directions. In: *Proceedings of the Workshop Program of the 19th International Conference on Distributed Computing and Networking*. New York, United States: ACM; 2018. p.1-6. https://doi.org/10.1145/3170521.3170529
[9] Chen M, Miao Y, Jian X, Wang X, Humar I. Cognitive-LPWAN: Towards intelligent wireless services in hybrid low power wide area networks. *IEEE Transactions on Green Communications and Networking.* 2018; 3(2): 409-417. https://doi.org/10.1109/TGCN.2018.2873783
[10] Mane SY. LPWAN's–Overview, market scenario and performance analysis of Lora, Sigfox using NB-Fi range calculator. In: *2021 International Conference on Smart Generation Computing, Communication and Networking (SMART GENCON)*. Pune, India: IEEE; 2021. p.1-4. https://doi.org/10.1109/SMARTGENCON51891.2021.9645902
[11] Tran AK, Piran MJ, Pham C. SDN controller placement in IoT networks: An optimized submodularity-based approach. *Sensors.* 2019; 19(24): 5474. https://doi.org/10.3390/s19245474
[12] Hans S, Ghosh S, Kataria A, Karar V, Sharma S. Controller placement in software defined Internet of Things using optimization algorithm. *Computers, Materials & Continua.* 2022; 70(3): 5073-5089. https://doi.org/10.32604/cmc.2022.019971
[13] Jain R, Semwal VB, Kaushik P. Deep ensemble learning approach for lower extremity activities recognition using wearable sensors. *Expert Systems.* 2022; 39(6): e12743. https://doi.org/10.1111/exsy.12743
[14] Song C, Wu J, Chen X, Shi L, Liu M. Towards the partitioning problem in software-defined IoT networks for urban sensing. In: *2018 IEEE International Conference on Pervasive Computing and Communications (PerCom)*. Athens, Greece: IEEE; 2018. p.1-9. https://doi.org/10.1109/PERCOM.2018.8444597
[15] Kobo HI, Abu-Mahfouz AM, Hancke GP. Efficient controller placement and reelection mechanism in distributed control system for software defined wireless sensor networks. *Transactions on Emerging Telecommunications Technologies*. 2019; 30(6): e3588. https://doi.org/10.1002/ett.3588
[16] Rahman A, Chakraborty C, Anwar A, Karim MR, Islam MJ, Kundu D, et al. SDN–IoT empowered intelligent framework for industry 4.0 applications during COVID-19 pandemic. *Cluster Computing*. 2022; 25: 2351-2368. https://doi.org/10.1007/s10586-021-03367-4
[17] Li Y, Su X, Ding AY, Lindgren A, Liu X, Prehofer C, et al. Enhancing the internet of things with knowledge-driven software-defined networking technology: Future perspectives. *Sensors*. 2020; 20(12): 3459. https://doi.org/10.3390/s20123459
[18] Mamushiane L, Mwangama J, Lysko AA. Given a SDN topology, how many controllers are needed and where should they go? In: *2018 IEEE Conference on Network Function Virtualization and Software Defined Networks (NFV-SDN)*. Verona, Italy: IEEE; 2018. p.1-6. https://doi.org/10.1109/NFV-SDN.2018.8725710
[19] Maurya S, Bansal M. Energy efficient precoder design for non-regenerative MIMO-CRN. *IEEE Wireless Communications Letters*. 2017; 6(5): 646-649. https://doi.org/10.1109/LWC.2017.2726533