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Determination Of Optimal Location Of Gateway In Lorawan-Based Internet Of Things Sensor Network

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***Abstract*— In this paper, the problem of locating the gateways in LoRaWAN-based Internet of Things (IoT) sensor network is presented. One of the major objectives of this paper entails maximization of the average energy efficiency of the network by placing as few gateways as possible in optimal locations within the network coverage area. In the model, IoT end devices (EDs) were divided in clusters using Gap statistics method, which results in the minimum number of clusters for a specific IoT deployment. Depending on the number of clusters, Fuzzy C-Means (FCM) method was applied for computation of gateway location based on the defined number of clusters. A heuristics approach was used for optimization of the energy efficiency in the clustering process by ensuring optimal spreading factor (SF) assignment and this Fuzzy C-means enhanced method is denoted as Fuzzy C-ADR approach. Then, the Adaptive Data Rate (ADR) approach and the Fuzzy C-means enhanced method are compared based on a simulation conducted with 36 gateways. The results show that the Fuzzy C-ADR approach performs better than the ADR approach in all the iterations. Notably, with 18 of the gateways installed, the results 2 show that using the Fuzzy C-ADR strategy increases the average Power Delivery Ratio (PDR) of the network from 0.62 to 0.753 which is about 21.5% and at the same time it increases the average energy efficiency from 265 to 330 which is about 24.5%. In addition, In the same vein, the results show that power violation in the Fuzzy C-ADR strategy is slightly lower than that in the ADR strategy.**

Keywords*— *Sensor Network, Optimal Location of Gateway, Power Delivery Ratio, Lorawan, Internet of Things, Fuzzy C-Means

1. INTRODUCTION

In a LoRaWan-based Internet of Things (IoT) sensor network, end devices (EDs) transmit their packets in a broadcast manner, while gateways listen for transmissions on all available channels and all possible spreading factors (SFs) [1,2]. If the received signal power at the gateway is higher than a minimum required Received Signal Strength Indicator (RSSI), otherwise known as receiver sensitivity, then end device's transmission is received successfully at the gateway [3,4,5]. The decoded packets are sent through the gateways to a central network server using broadband Internet connections, where repeated packets are detected and removed. An edge of broadcast transmissions is that, though a packet might not be decoded successfully by one gateway, due to collisions; there is still a chance that it may be decoded by another gateway, resulting in more successful receptions. The quantity of gateways that can listen or hear an ED's transmission depends on the communication distance of the end device, which in turn is directly related to the transmission power and the spreading factor (SF) used by the end device.

Generally, in IoT sensor network, the sensor nodes or end devices (EDs) are usually resource constrained in terms of the amount processing power, storage capacity, and power supply. In many cases, the EDs are battery powered and installed in remote locations [6,7,8,9]. In such cases, the ED battery lifespan is a critical issue in determining the network lifetime. In essence, ensuring optimal energy consumption in the EDs is key to ensuring optimal network lifetime.

Notably, one of the major objectives of this paper entails maximization of the average energy efficiency of the network by placing as few gateways as possible in optimal locations within the network coverage area. In the model, IoT end devices (EDs) were divided in clusters using Gap statistics method, which results in the minimum number of clusters for a specific IoT deployment [10,11,12,13]. Depending on the number of clusters, Fuzzy C-Means (FCM) method was applied for computation of gateway location based on the defined number of clusters [14,15,16,17]. A heuristics approach was used for optimization of the energy efficiency in the clustering process by ensuring optimal spreading factor (SF) assignment and this Fuzzy C-means enhanced method is denoted as Fuzzy C-ADR approach. Then, the Adaptive Data Rate (ADR) approach [18,19,20,21] and the Fuzzy C-means enhanced method are compared based on a simulation conducted using AnyLogic software.

2. METHODOLOGY

This paper focuses on determining the optimal location of gateway in Lora-WAN-based Internet of Things sensor network. For a regular structured sensor network, the overall performance of the network degrades if some end devices (EDs) attempt to communicate with multiple gateways by increasing their transmission power. In the context of this paper, transmission power is considered as the deciding factor that is used to determine which gateway an end device (ED) can connect and communicate with. This implies that an optimal solution must be selected such that the transmission power of an ED depends on its distance from its closest gateway along with the corresponding propagation loss associated with that distance and the spreading factor (SF) used by the end device. If this solution is obtained, then, it will successfully reduce the number of decision variables to the SF assignment for EDs, and gateway locations. Each gateway in the sensor network forms a cell in which the proximity of all EDs are close to the gateway than to other gateways. Hence, in this paper work, the term cell will be used to imply a set of EDs, subsequently. The major problem this paper seeks to address is to determine optimal location for gateway installation and then determine the energy efficiency of the network.

In order to address the problem, the number of gateways are calculated based on Gap statistics method, then depending on the number of clusters selected from the gap statistics, Fuzzy C-Means (FCM) method was applied for computation of the gateways location placement for specific IoT deployment. The algorithm for the fuzzy c-means is given in Algorithm 1.

Algorithm 1: Fuzzy C-Means

Input: The coordinates of the devices, the desired number of clusters M and the error stop criterion ε.

Output: The final fuzzy c-partitioned matrix U_{ij}^{r} , the gateways coordinates, the final Euclidean distance matrix, and the objective function jm_j.

1. Initialize variables
2. Start U matrix with arbitrary values between 0 and 1
3. **While** *convergence criterion is not reached* **do**
4. instructions
5. **for** $j \in \{1,2,\dots,M\}$ **do**
6. Calculate cluster centers according to Equation 7
7. **for** $i \in \{1,2,\dots,N\}$ **do**
8. Compute $dist_{ED_i,GW_j}$
9. **if** *the device does not have sufficient power to send packet to* GW_j **then**
10. Update $dist_{ED_i,GW_j}$ higher
11. **end**
12. Calculate objective function jm_{ji} according to Equation 1
13. Update U_{ij}^{r} matrix using the membership coefficients according to Equation 6
14. **end**
15. **end**
16. **if** *the convergence criterion in* Equation *8 is satisfied* **then**
17. Stop Algorithm
18. **end**
19. **end**

The major objective of this paper entails maximization of the average energy efficiency of the network by placing as few gateways as possible. Let EE_i represent the energy efficiency of the i^{th} end device (ED) where:

$$EE_i = \frac{\pi_i}{e_i} \qquad (1)$$

where, π_i and e_i represents the Power Delivery Ratio (PDR) and the per packet energy consumption of the i^{th} ED. Again, the PDR of ED i is expressed as shown in Equation 11

$$\pi_i = 1 - \prod_{j=1}^{M}\left(1 - \pi_i^{j}\right) \qquad (2)$$

where π_i^{j} represents the probability that ED i has successfully transmitted to gateway j. The probability of successful transmission to at least one gateway is represented by the right-hand-side of Equation 2. The transmission power p_i used by an ED and the packet transmission time t_i determines the energy consumption for transmitting one packet. Hence, this energy is given by:

$$e_i = \quad P_{t(i)}dB \times t_i \qquad (3)$$

Two conditions must be satisfied for a successful transmission to occur between an ED and gateway. (1) the communication range between the EDs and the gateway must be close enough (2) there must not be any interfering packet during transmission at the gateway. The value of t_i is obtained using online tool for computing the packet time on air for LoRa transceivers. The online tool is available at: https://www.thethingsnetwork.org/airtime-calculator.

The transmission power p_i is determined using the link budget equation for the LoRa communication link. Notably, for a LoRa wireless link with zero link margin and negligible antenna gains, the received power at end device i is denoted as $P_{r(i)}dB$ and it is given in terms of LoRa receive sensitivity, $S_{sen(k)}$, the path loss, $LP\ (dB)$ and transmitter power at end device i denoted as $P_{t(i)}dB$ as follows;

$$P_{r(i)}dB \ = \ S_{sen(k)} = P_{t(i)}dB - \ LP\ (dB) \qquad (4)$$

Hence,

$$P_{t(i)}dB = \ S_{sen(k)} - \ LP\ (dB) \qquad (5)$$

In this study, the Comit´e International des Radio-. Communication, (CCIR) path loss model [**22,23**] is used to compute $LP\ (dB)$ hence;

$$LP\ (dB) = A + B * \log_{10}(d_{(i)}) - E \quad (6)$$

Then,

$$P_{t(i)}dB = S_{sen(k)} - A - B * \log_{10}(d_{(i)}) + E \quad (7)$$

Where

$$A = 69.55 + 26.16 * \log_{10}(f) - 13.82 * \log_{10}(h_b) - a(h_m) \quad (8)$$

$$a(h_m) = [1.1 * \log_{10}(f) - 0.7] * h_m - [1.56 * \log_{10}(f) - 0.8] \quad (9)$$

$$B = 44.9 - 6.55 * \log_{10}(h_b) \quad (10)$$

$$E = 30 - 25(\log_{10}(PB)) \quad (11)$$

The degree of urbanization is denoted as PB , gateway or base station antenna height is denoted ash_b , sensor or end device antenna height is denoted as h_m, f is the frequency, $S_{sen(k)}$ is the LoRa receiver sensitivity for spreading factor k and $P_{t(i)}dB$ is the transmitter power of end device i.

3 RESULTS AND DISCUSSION

The classical configuration of the LoRa end devices is the Adaptive Data Rate (ADR) and the Fuzzy C-means enhanced method is denoted as Fuzzy C-ADR approach. The performance evaluation of the Fuzzy C-ADR and the Adaptive Data Rate (ADR) approaches are presented. The simulation is conducted using AnyLogic software.

A network which comprises of $N = 50000$ EDs is generated with arbitrary distribution in an area measuring$50 \times 50\ km^2$. Let there be $M = 36$ prospective gateway locations, distributed uniformly in the area. The packet payload size is selected as $PL = 51\ bytes$ for all EDs, resulting in different air times when different SFs are used. The bar chat in Figure 1 shows the packet air time values. Packet inter-arrival time is set to $T = 25$ for all EDs. The parameters and their values used in the experimental setup are shown in Table 1.

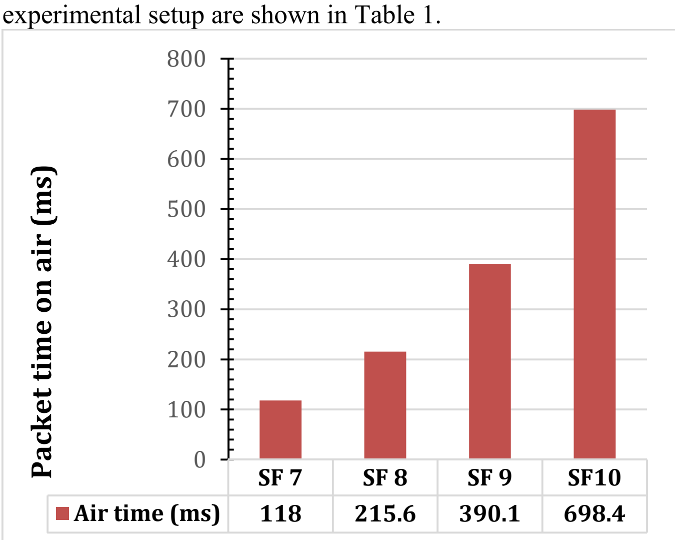

Figure 1 : Packet air times for different SFs

Table 1: Parameters and their values used in the experimental setup

Name	Value	Description
N	50000	Number of end devices
L	50	Edge of analysis area (Km)
M	36	Number of prospective cluster heads locations
PL	50	Size of the payload (in Bytes)
T	1200	Cycle time (s)
PB	16 %	Degree of urbanization
h_b	40	Gateway antenna height (m)
h_m	1	End device antenna height (m)
$P_{Max,dB}$	20	Maximum LoRa transmitter power level (dBm)

The metrics used for comparison are the average energy efficiency, the average PDR, the median of energy efficiency, the median of PDR and the power violation. The comparison of these performance metrics for the ADR and the Fuzzy C-ADR are presented in Table 2 to Table 6 as well as in Figure 2 to Figure 6.

The results of mean Power Delivery Ratio (PDR) for ADR approach and for Fuzzy C-ADR approach are shown in Table 2 and Figure 2. The results in Figure 2 show that the Fuzzy C-ADR approach performs better than the ADR approach in all the iterations. For example, if 18 of the gateways are installed, the results in Table 2 and Figure 2 show that using the Fuzzy C-ADR strategy increases the average Power Delivery Ratio (PDR) of the network from 0.62 to 0.753 which is about 21.5%. At the same time, if 18 of the gateways are installed, the results in Table 4 and Figure 4 show that using the Fuzzy C-ADR strategy increases the average energy efficiency from 265 to 330 which is about 24.5%.

In the same vein, the results in Table 6 and Figure 6 show that power violation in the Fuzzy C-ADR strategy is slightly lower than that in the ADR strategy.

Table 2 The results of mean Power Delivery Ratio (PDR) for ADR approach and for Fuzzy C-ADR approach

No of installed gateway	Mean Power Delivery Ratio (PDR) for Fuzzy C-ADR	Mean Power Delivery Ratio (PDR) for ADR
3	0.2	0.2
6	0.39	0.365
9	0.58	0.52
12	0.66	0.58
15	0.72	0.61
18	0.753	0.62
21	0.78	0.64
24	0.8	0.65

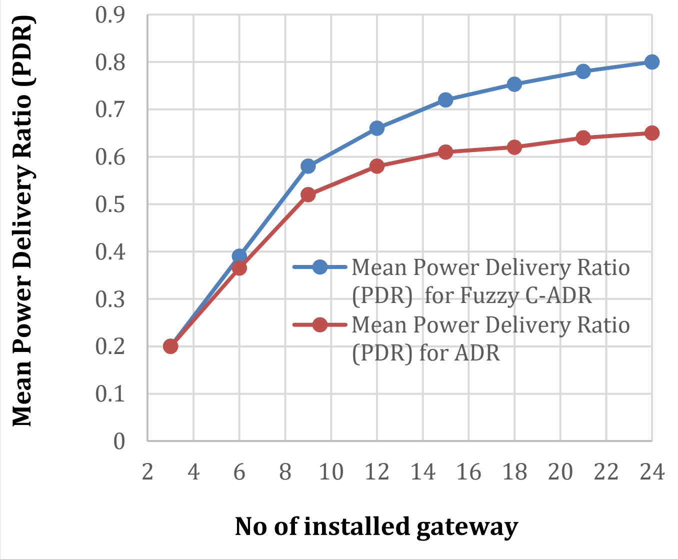

Figure 2: The graph of mean Power Delivery Ratio (PDR) for ADR approach and for Fuzzy C-ADR approach

Table 3 The results of median Power Delivery Ratio (PDR) for ADR approach and for Fuzzy C-ADR approach

No of installed gateway	Median Power Delivery Ratio (PDR) for Fuzzy C-ADR	Median Power Delivery Ratio (PDR) for ADR
3	0	0
6	0.43	0.36
9	0.58	0.53
12	0.67	0.58
15	0.71	0.64
18	0.74	0.65
21	0.76	0.66
24	0.77	0.67

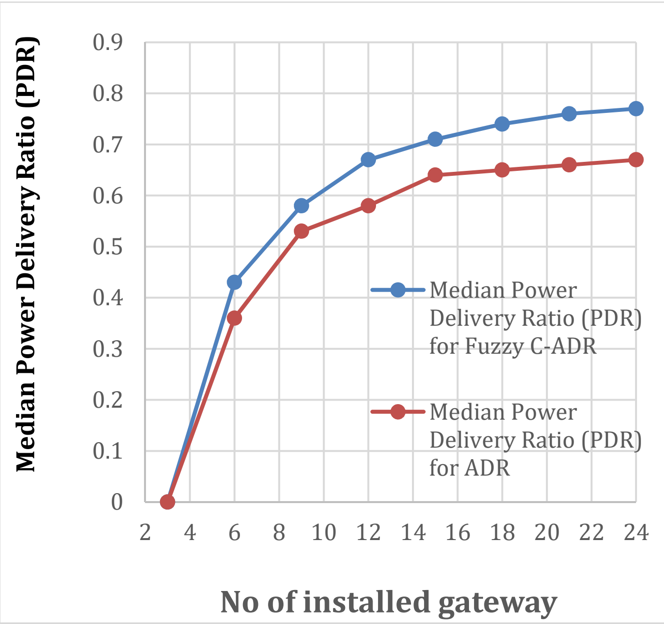

Figure 3: The graph of median Power Delivery Ratio (PDR) for ADR approach and for Fuzzy C-ADR approach

Table 4 The results of the mean energy efficiency (EE) for ADR approach and for Fuzzy C-ADR approach

No of installed gateway	Mean energy efficiency (EE) for Fuzzy C-ADR	Mean energy efficiency (EE) for ADR
3	50	40
6	100	85
9	160	136
12	220	193
15	275	235
18	330	265
21	370	292
24	395	302

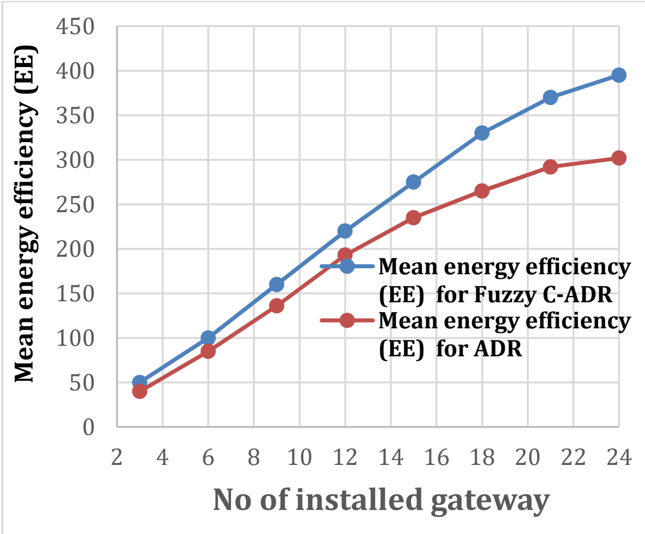

Figure 4: The graph of mean energy efficiency (EE) for ADR approach and for Fuzzy C-ADR approach

Table 5 The results of median energy efficiency (EE) for ADR approach and for Fuzzy C-ADR approach

No of installed gateway	Median energy efficiency (EE) for Fuzzy C-ADR	Median energy efficiency (EE) for ADR
3	0	0
6	10	7
9	46	36
12	78	60
15	99	80
18	118	95
21	128	105
24	134	110

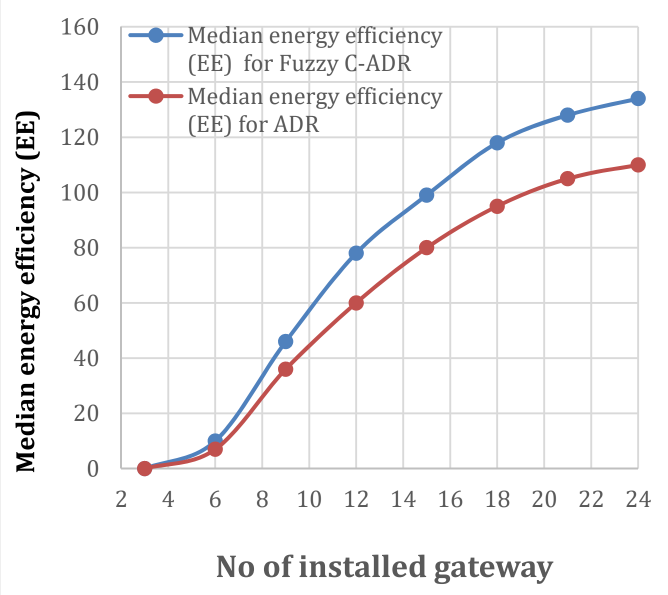

Figure 5: The graph of median energy efficiency (EE) for ADR approach and for Fuzzy C-ADR approach

Table 6 The results of power violation for ADR approach and for Fuzzy C-ADR approach

No of installed gateway	Power violation for Fuzzy C-ADR	Power violation for ADR
3	0.67	0.8
6	0.43	0.57
9	0.16	0.24
12	0	0.08
15	0	0
18	0	0
21	0	0
24	0	0

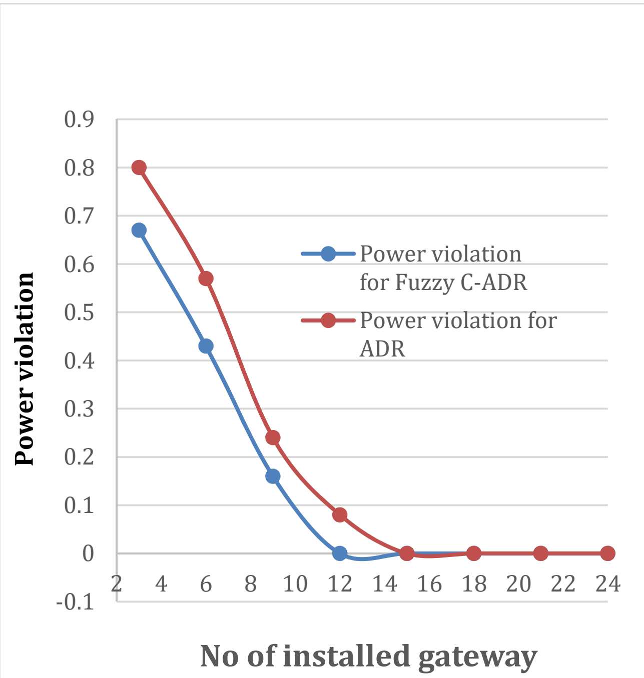

Figure 6: The graph of power violation for ADR approach and for Fuzzy C-ADR approach

4. CONCLUSION

In this paper, the problem of locating gateway in LoRaWan based internet of things sensor network is considered. The optimal number of gateway was computed using Fuzzy C-Means (FCM) based on specific IoT deployment case. A heuristics approach was used for optimization of the energy efficiency in the clustering process. Notably, the Adaptive Data Rate (ADR) approach and the Fuzzy C-means enhanced method, denoted as Fuzzy C-ADR approach are compared based on a simulation conducted with 36 gateways.

The simulation result attests that the Fuzzy C-ADR approach yields a solution with a higher mean Power Delivery Ratio (PDR) and higher mean energy efficiency (EE) without violating any constraints.

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