DOI: 10.15849/IJASCA.230720.08

Int. J. Advance Soft Compu. Appl, Vol. 15, No. 2, July 2023
Print ISSN: 2710-1274, Online ISSN: 2074-8523

Improved energy efficiency in D2D healthcare communication

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Abstract

This paper addresses the minimization of energy consumption in device-to-device (D2D) communications in the healthcare logistics domain. Given the vital importance of actions in this field for patients' lives, it is crucial to reduce the energy consumed by the devices used. This study aims to propose a fuzzy approach to predict the energy consumption induced by different protocols in D2D communications to minimize the energy consumption of healthcare logistics devices. A fuzzy supervisor is developed to evaluate and forecast the energy consumption of the devices in D2D communications. This approach allows for obtaining more accurate predictions and a better understanding of how device energy consumption can be reduced. Numerical simulations were conducted to validate the proposed method. The results show the efficiency and sustainability of D2D communication systems and a significant reduction in energy consumption when a classical method is applied.

KEYWORDS: *D2D COMMUNICATION, FUZZY LOGIC, ENERGY CONSUMPTION, HEALTHCARE LOGISTICS.*

1 Introduction

Since the previous century, various sectors have adopted novel technological solutions. These innovations have been particularly prominent in the communications sector [1]. Initially, the communication landscape was dominated by the traditional bell tool, but over time, new and surprising communication technologies emerged, introducing innovative communication modes [2]. The concept of communication has expanded beyond individual users and now

Received 3 April 2023; Accepted 26 June 2023

encompasses their surrounding environment. This expansion has led to the emergence of a new communication mode called Device-toDevice (D2D) communication, which is simple, easy to use, and highly useful [3]. Although initially developed for industrial applications, D2D devices are now widely deployed in various settings, including critical domains like healthcare [4].

In the medical sector, e.g., hospitals, rapid and effective information sharing among different departments and healthcare professionals is essential. D2D communication offers a wireless communication solution that allows devices such as smartphones, tablets, and medical devices to communicate directly without relying on a central network [5]. This capability is particularly vital in environments like surgical units where the patient's well-being is of utmost importance. Leveraging D2D communication for medical needs can significantly enhance routine tasks, including patient tracking processes and the management of inventory and medical equipment [6]. For instance, medical devices can communicate directly with each other to exchange patient health information, while doctors and nurses can use their smartphones to share and forward relevant requests, leading to real-time and accurate data inventory [7].

In the healthcare sector, every healthcare professional must have access to real-time and updated information, enabling more streamlined and efficient actions by doctors. In critical applications, such as the responsible pharmacist administering care, any deficiencies or failures must be avoided. D2D communication facilitates improved information exchange, thus enhancing healthcare professionals' capabilities [8]. Moreover, D2D communication can foster increased collaboration between different departments in hospital logistics, resulting in higher-quality patient care [8]. Besides, D2D communication has the potential to reduce costs for both patients and hospital administration by enabling more effective resource management [9]. This goal aligns with the industry's constant pursuit of cost reduction and improved efficiency [10].

However, when considering the implementation of D2D communication in healthcare settings, it is essential to address the challenges associated with energy consumption and related factors [11]. Medical devices and smartphones used in D2D communication consume significant amounts of energy to operate continuously, leading to increased electricity fees for hospitals. Moreover, optimizing the energy consumption of these devices becomes crucial to mitigate the environmental impact. This energy optimization challenge can be tackled by adopting technologies that offer energy consumption management within devices [12], utilizing longer-lasting batteries [13], and optimizing data processing to minimize energy usage [14].

In this paper, a fuzzy supervision is synthesized to minimize energy consumption in D2D communication to ensure the sustainability and continuity of wireless communication systems in sensitive environments, such as healthcare logistics.

2 Related Work

In this section, we give the existing work concerning the energy efficiency in D2D communication.

Chevillon and al. [23] focused on energy optimization of D2D communications by incorporating relay devices and exploiting data entropy. Their work highlighted the impact of relying on energy consumption and proposed a topology based on conditional entropy to minimize data relayed by the relay device, thereby reducing energy consumption. In [24], Yin and al. addressed improving energy efficiency in multimedia content dissemination through adaptive clustering techniques and D2D broadcasting. Their work aimed to ensure the quality of service (QoS) for different users with varying quality of experience (QoE) requirements, while enhancing energy efficiency. In order to analyse the energy efficiency of D2D direct connection systems in 5G networks, Bulashenko and al. [25] demonstrated improved performance of 5G networks with D2D direct connections compared to Long Term Evolution (LTE) systems, offering higher data transfer rates and better energy efficiency. Xu and al. [26] studied the design of energy-efficient mechanisms for D2D communications. They proposed a contractual approach based on contract theory to determine the price of user contributions in data transmission and used matching theory to achieve optimal matching between data requesters and users willing to relay. Their simulation results demonstrated the effectiveness of the proposed algorithms. In [27], Sultana and al. investigated resource allocation for healthcare data transmission using D2D communication in the context of the Narrowband Internet of Things (NB-IoT). Their work aimed to ensure QoS while maximizing data rates for priority healthcare data. They developed an optimization framework using non-integer multi-objective linear programming for fair resource allocation, resulting in higher data delivery rates and reduced data delivery latency. Khalaf and Abdulsahib [28] proposed an energy-efficient routing and reliable data transmission protocol for wireless sensor networks (WSN). Their protocol, HEESR, used fixed time slot assignments and combined one-way and multi-way routing techniques to minimize data transmission and improve energy efficiency in WSNs. Elijorde and Lee [29] focused on achieving reliability and energy efficiency in cloud data centers through workload profiling and SLA-aware virtual machine (VM) assignment. Their approach involved clustering similar VMs based on workload profiles and using an SLA-aware assignment strategy to optimize resource provisioning, resulting in improved performance and energy efficiency. Cao et al. [30] proposed a Group-based D2D (GD2D) clustering model for multi-recipient D2D communication, considering physical and social constraints. They developed a relay selection mechanism based on social links and formulated a resource allocation problem to maximize system energy efficiency. Their results showed significant improvements in energy efficiency compared to traditional user-centric schemes at cell edges. In [31], Muthukumar et al. worked on the average potentiality approach for a decision-making problem based on soft intuitionistic fuzzy sets in the medical domain. This approach offers a balanced solution to this problem using soft fuzzy sets of level. They implemented this average potentiality approach in medical diagnosis using a hypothetical case study.

3 PROBLEM FORMULATION AND SYSTEM MODELING

Minimizing energy consumption in D2D communication used in healthcare must be properly understood. In what follows, we will present the problem formulation and describe the system model used in this study.

3.1 Problem formulation

Energy use is a significant challenge in healthcare logistics when using D2D communication. Mobile devices such as D2D communication terminals are frequently used for long periods, requiring minimizing battery consumption and extending battery life. Otherwise, the quality of patient care may be compromised, as terminals may switch off unexpectedly or become unavailable when needed [10-11]. To minimize the impact of energy consumption on D2D communication, it is necessary to select optimized communication protocols over listening time reduction, reducing the number of transmissions and using larger capacity batteries. Therefore, implementing power management strategies to conserve energy will be convenient. One can also use artificial intelligence techniques to minimize energy consumption, which could be done by considering contextual parameters, such as signal quality, transmission distance, and battery charge level, as shown in [12-13]. To this end, we must reply to this question:

How can we reduce the energy consumption of devices used for D2D communication in healthcare logistics while ensuring communication quality and maximizing battery life?
This question will be answered once the system model is known to see what parameters must be managed for that goal. Consequently, we will try to give such system descriptions in our study as it will be underlined in what follows.

The mathematical model below depicts the formal representation of the problem under study:

- Variables:
  - Q: Signal quality, measured in dBm.
  - D: Transmission distance, measured in meters.
  - B: Battery charge level, measured in percentage.
  - P: Transmission power, measured in dBm.
- Objective:
  Minimize the energy consumption of devices used for D2D communication in healthcare logistics, while ensuring communication quality and maximizing battery life.
- Constraints:
  - Communication quality constraint: $Q \geq Qmin$, where Qmin is the minimum required quality.
  - Battery life constraint: $B \geq Bmin$, where $Bmin$ is the minimum required capacity to ensure proper functioning.
  - Distance constraint: $D \leq Dmax$, where $Dmax$ is the maximum transmission distance.
- Objective function:

$E = f(Q, D, B, P)$, where f is a function that measures the energy consumption based on signal quality, transmission distance, battery charge level, and transmission power.
The overall mathematical model can be formulated as follows: Minimize E
Subject to:

- Communication quality constraints:
  - If Q is low, then $P \geq Pmin(Q)$.
  - If Q is high, then $P \leq Pmax(Q)$.
- Transmission distance constraint: $D \leq Dmax$.
- Battery charge level constraints:
  - If B is low, then $P \leq \mathrm{Pmax}(B)$.

- ○ If B is high, then $P \geq Pmin(B)$.
- Transmission power constraint: $Pmin \leq P \leq Pmax$.

3.2 System Model

The proposed system model aiming to minimize energy consumption in D2D communication used in hospital logistics consists of several interconnected components. The primary components include D2D communication terminals for exchanging information between medical staff and patients. These terminals are equipped with sensors that measure medical data and wirelessly transmit them to other ones. The system also includes an energy management module responsible for monitoring the energy consumption of the D2D communication terminals and taking measures to optimize their usage. This module can adjust communication parameters such as listening time and transmission power, ensuring energy efficiency without compromising communication quality. Finally, the system uses fuzzy logic techniques to process data collected during the D2D communication process. This approach allows uncertain variables to be taken into account and optimal solutions found for minimizing energy consumption while maintaining communication quality. The entire system is designed to optimize D2D communication efficiency while minimizing energy consumption. It must also ensure patient care quality and mitigate the environmental impact of hospital logistics. These objectives can be achieved using a fuzzy analysis approach, which will be explored further in the upcoming section.

The flowchart (Fig 1) represents the system model. It depicts the workflow and the decisions made to minimize the energy consumption of devices used for D2D communication in healthcare logistics while ensuring communication quality and maximizing battery life.

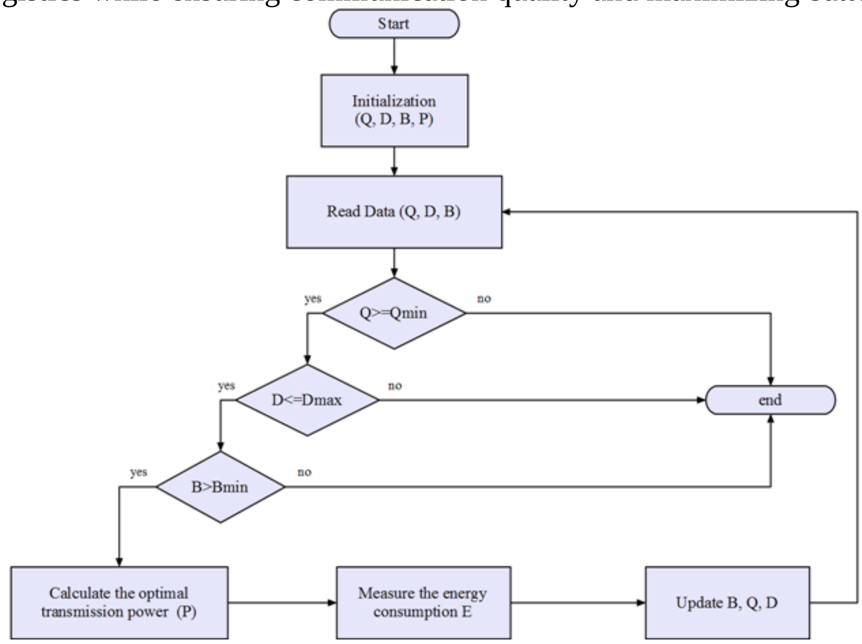

Fig 1 –System model flow chart.

4 FUZZY SYSTEM

In the context of D2D communication used in hospital logistics, we aimed to examine how a fuzzy logic approach could be used to model variables such as signal quality, transmission distance, and battery level [14][15][16]. By defining fuzzy membership functions, it would be possible to represent these variables more accurately. The analyst can take uncertainties and data variations into account [17]. Thanks to the relationships defined between variables, one can make decisions based on those relationships, as is usually the case. For example, to minimize energy consumption, a fuzzy rule could be defined to adjust the transmission power of the terminal based on signal quality, transmission distance, and battery level while maintaining reliable communication [14][15][16]. Hence, using fuzzy logic analysis, it is possible to develop a smart energy management system for D2D communication in hospital logistics that will consider uncertain variables and provide optimal solutions for minimizing energy consumption while ensuring prescribed communication quality [18].

5 Model Implementation

The EAS system incorporating fuzzy logic is generally composed of three stages: Fuzzification, Inference, and Defuzzification [19][20][21]. The block diagram of the proposed EAS is shown in Fig 2.

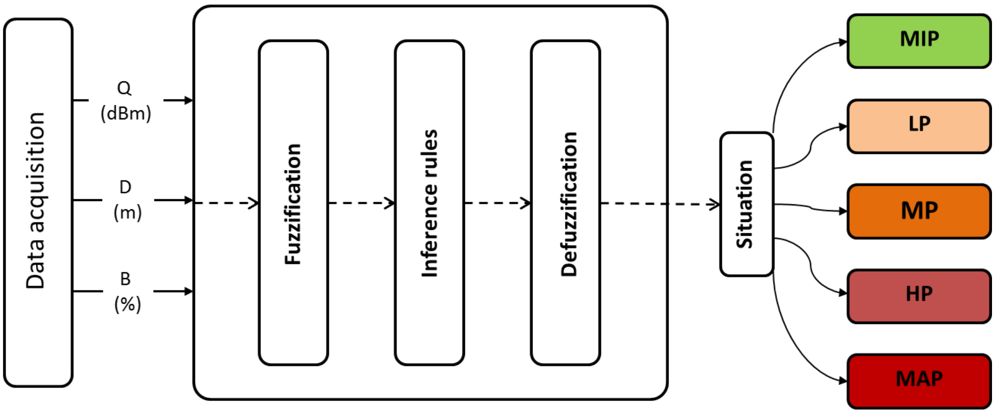

Fig2 – Schematic System Diagram (SSD).

With reference to the above diagram, the studied systems will correctly operate based on the following information set.

Input variables:

- Signal quality (*Q*): measured in dBm, with values ranging from 0 (Very Weak signal) to 45 (Very Strong signal).
- Transmission distance (*D*): measured in meters, with values ranging from 0 (very close) to 1000 (Very Far).
- Battery level (*B*): measured in percentage, with values ranging from 0 (Discharged Battery) to 100 (Fully Battery).

Output variables:

- The range for the transmission power (*P*) is from -30 to 30 dBm, where the former corresponds to a power of 1 µW (Minimum Power) and the latter corresponds to a power of 1W (Maximum Power).

Membership functions:

Figures 3, 4, and 5 depict the membership functions for the input variables, namely Signal Quality (*Q*), Transmission Distance (*D*), and Battery Level (*B*), respectively, whereas Fig 6 depicts the membership functions for the output variable, i.e., the Transmission Power (*P*) [22].

Signal Quality (*Q*):

To represent Signal Quality as a fuzzy variable, we define the following membership functions:

- Very Weak: Triangular, with a base of (0, 10) and a peak of 5.
- Weak: Trapezoidal, with a base of (5, 20) and peaks of 10 and 15.
- Medium: Trapezoidal, with a base of (15, 30) and peaks of 20 and 25.
- Strong: Trapezoidal, with a base of (25, 40) and peaks of 30 and 35.
- Very Strong: Triangular, with a base of (35, 45) and a peak of 40.

Fig 3 represents the input variable *Q*, i.e., signal quality in dBm.

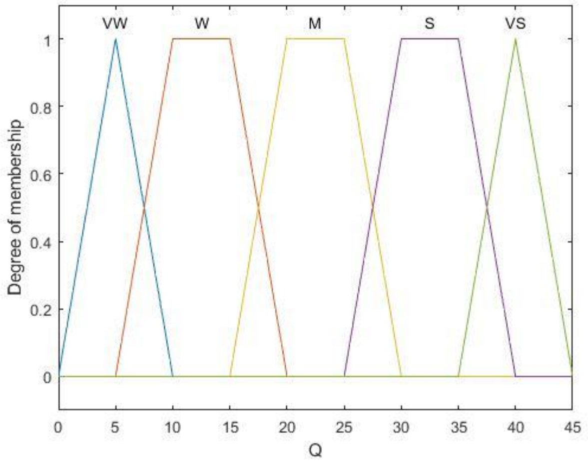

Fig 3. Input variable *Q* (dBm).

Transmission distance (*D*):
The input variable "Transmission distance (*D*)" represents the transmission distance in meters. To model this variable in fuzzy logic, we can define the following membership functions:

- Very Close: Triangular, with a base of (0, 100) and a peak of 20.
- Close: Trapezoidal, with a base of (0, 200) and peaks of 50 and 100.
- Medium: Trapezoidal, with a base of (50, 500) and peaks of 150 and 300.
- Far: Trapezoidal, with a base of (200, 1000) and peaks of 400 and 700.
- Very Far: Triangular, with a base of (500, 1000) and a peak of 800.

Fig 4 represents the input variable *D*, i.e., transmission distance in meters.

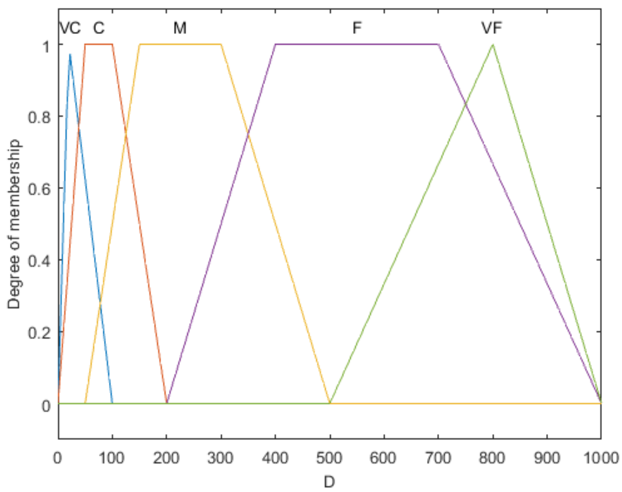

Fig 4. Input variable *D* (m).

Battery level (*B*):

The input variable 'Battery level (*B*)' represents the battery charge level. To model this variable in fuzzy logic, the following membership functions can be defined:

- Discharged Battery: Triangular, with a base of (0, 20) and a peak of 10.
- Low: Trapezoidal, with a base of (0, 40) and peaks of 20 and 30.
- Medium: Trapezoidal, with a base of (20, 70) and peaks of 40 and 55.
- High: Trapezoidal, with a base of (50, 100) and peaks of 70 and 85.
- Full Battery: Triangular, with a base of (80, 100) and a peak of 90.

Fig 5 depicts the membership functions for the input variable *B*, which represents the battery level.

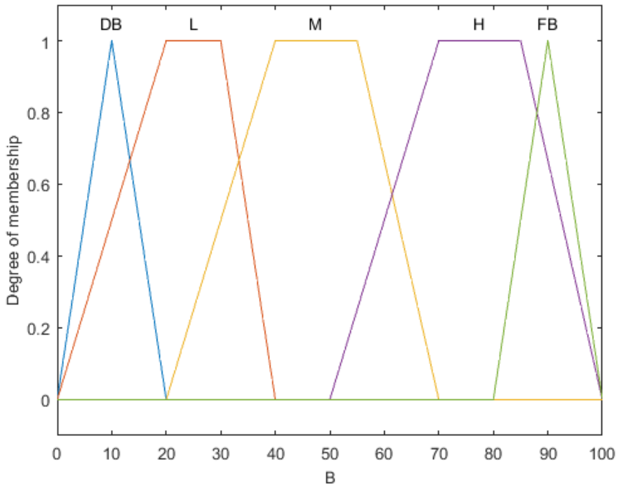

Fig 5. Input variable *B* (%).

Transmission power (*P*):

The input variable *P*, which represents the transmission power, can be modeled in fuzzy logic using the following membership functions:

- Minimum Power: Triangular, with a base of (-30, -15) and a peak of -22.5.
- Low: Trapezoidal, with a base of (-25, -5) and peaks of -15 and -20.
- Medium: Trapezoidal, with a base of (-15, 15) and peaks of -5 and 5.
- High: Trapezoidal, with a base of (5, 25) and peaks of 15 and 20.
- Maximum Power: Triangular, with a base of (15, 30) and a peak of 22.5.

These membership functions are depicted in Fig 6.

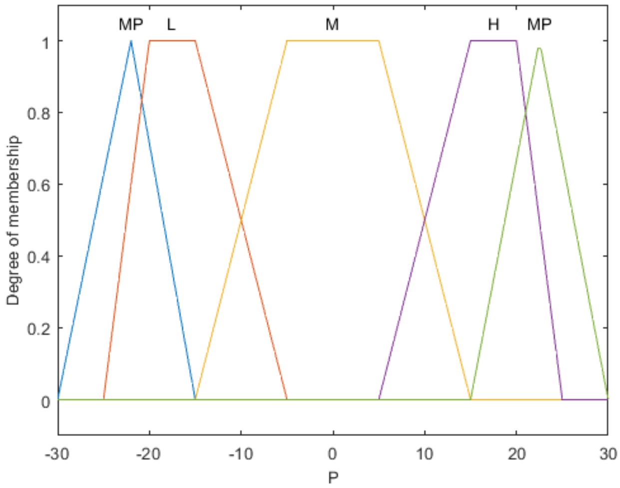

Fig 6. Output variable *P* (dBm).

Fuzzy rules:

Fuzzy rules are defined to relate the input variables to the output variable. For example:

Here are the rules for transmission power (*P*) based on signal quality (*Q*), transmission distance (*D*), and battery level (*B*):

- If the signal quality is very weak (VW) OR the distance of transmission is very close (VC) OR the battery level is drained (DB), then the transmission power should be at minimum power (MP).
- If the signal quality is weak (W) AND the distance of transmission is close (C) AND the battery level is low (L), then the transmission power should be at low power (L).
- If the signal quality is moderate (M) OR the distance of transmission is moderate (M) OR the battery level is moderate (M), then the transmission power should be at moderate power (MP).
- If the signal quality is strong (S) AND the distance of transmission is far (F) AND the battery level is high (H), then the transmission power should be at high power (H).
- If the signal quality is very strong (VS) AND the distance of transmission is very far (VF) AND the battery level is full (FB), then the transmission power should be at maximum power (MAP).

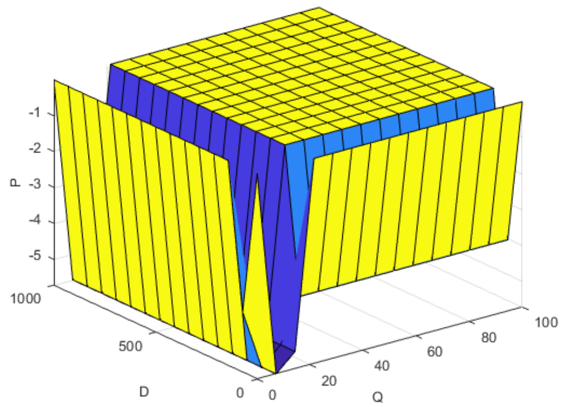

Fig 7. Fuzzy Rules (3D).

Fig 7 depicts the fuzzy rules for determining the optimal transmission power in D2D communication for hospital logistics in a 3D plot. The plot illustrates the relationship between the three input variables (signal quality, transmission distance, and battery charge level) and the output variable (transmission power). Each rule is represented by a surface, where the x and y axes correspond to the input variables (signal quality and transmission distance), and the z-axis corresponds to the output variable (transmission power). The height of each surface corresponds to the degree of membership of the output variable for that rule. The overlapping regions between the surfaces represent the combination of conditions that trigger more than one rule, and their height represents the degree of membership of the output variable for those combined rules. By using these rules, the optimal transmission power can be determined based on the current values of the input variables.

System Control:

The fuzzy rules are aggregated using a deduction method to determine the value of the output variable (*P*) [23]. Different rules contribute to different values of *P*, which are then combined to obtain a final value. Using this fuzzy model, the energy management system can adjust the terminal transmission power in real time based on measured data to minimize energy consumption while maintaining reliable communication. Examples of input parameters for adjusting the transmission power are shown in Figures 8 and 9.

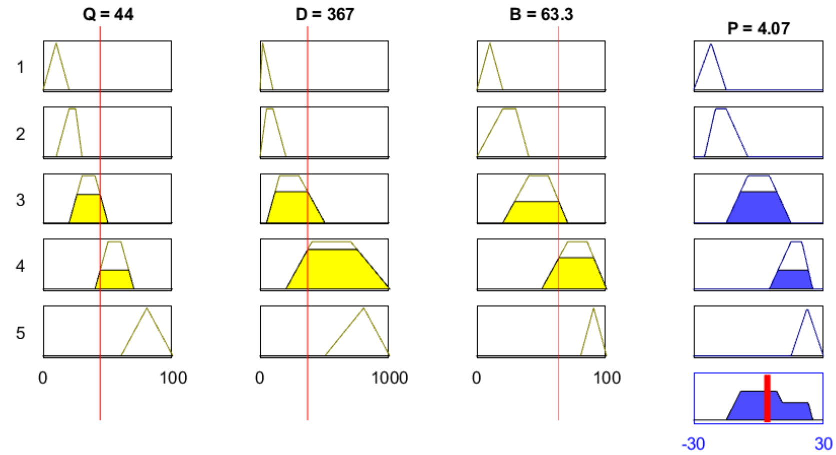

Fig 8. Example 1 of fuzzy rules.

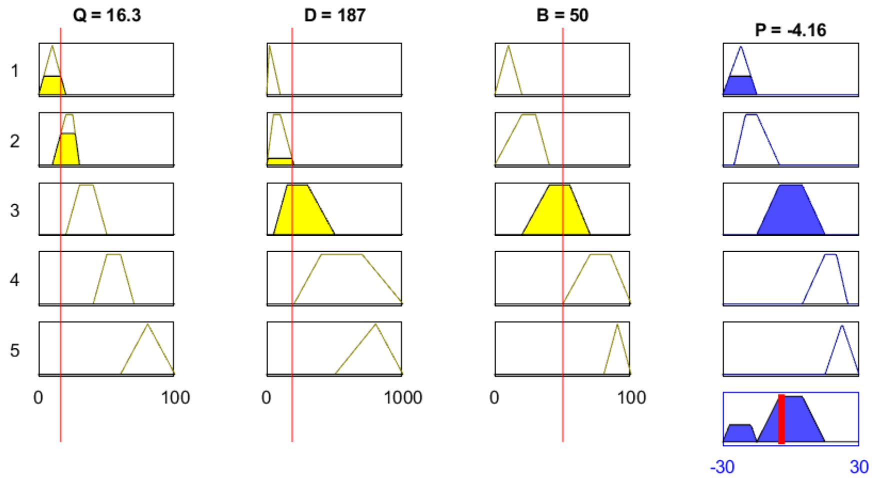

Fig 9. Example 2 of fuzzy rules.

6 RESULTS, ANALYSIS AND DISCUSSIONS

The curves in Figures 10 and 11 show that using a fuzzy system to optimize transmission power can significantly reduce the total energy consumption in a wireless communication network.

In the case of 5 UEs (Fig 10), the total energy consumption is reduced by about 5.48% when the fuzzy system is used.

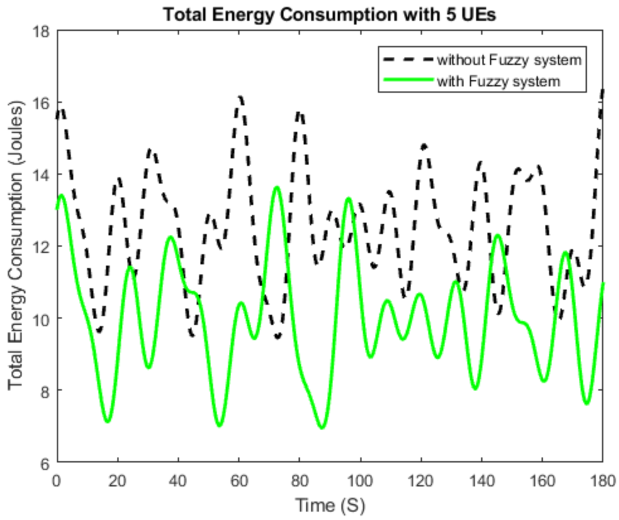

Fig 10. Total Energy consumption in 5 UEs case.

For example and in 8 UEs case (Fig 11), both curves are similar in trend, but the total energy consumption with fuzzy system guidance is still slightly lower than without one, implying that the fuzzy system is also effective in larger networks.

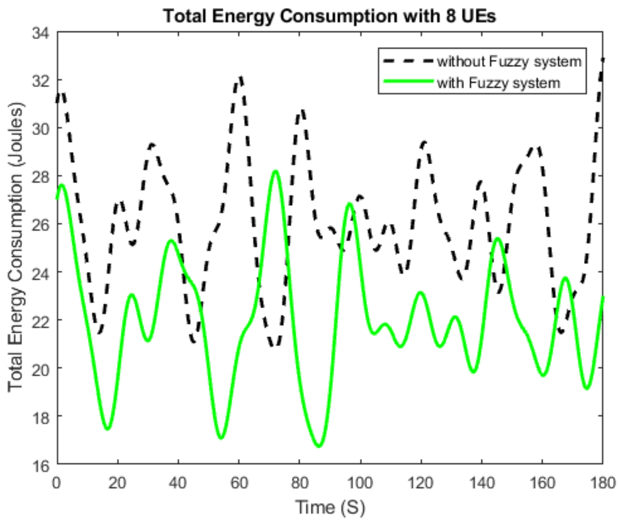

Fig 11. Total Energy consumption in 8 UEs case.

In order to assess the impact of increasing the number of users (UEs), Table 1 summarizes the total energy consumption with and without the fuzzy system for different scenarios (20, 30 and 50 users):

Table 1. Summary of Total Energy Consumption.

umber of UEs	Without fuzzy ystem analysis (J)	With fuzzy ystem analysis (J)
5	181.54	171.59

8	202.28	190.92
20	596,12	370,12
30	693,22	431,11
50	1915,40	1008,9

As shown in the table, using the proposed fuzzy system reduces significantly the total energy consumption in all cases. For 8 user equipment (UEs), the reduction is by about 6%. Furthermore, for 50 UEs, the reduction reaches approximately 48%. These results confirm the effectiveness of the fuzzy system in optimizing energy consumption in larger-scale wireless communications.

The results show that without the fuzzy system, energy consumption increases with the number of users. However, with the introduction of the fuzzy system, intelligent energy management is achieved, resulting in a significant reduction in average energy consumption.

The Fig 12 shows the average energy consumption in the two cases where the fuzzy approach and the proposed method in [30]. For example, for 20 users, the average energy consumption it is reduced by about 37%. This figure highlights the effectiveness of the proposed fuzzy system in energy optimization. This is particularly important in the current context where energy efficiency has become a major concern in communication networks.

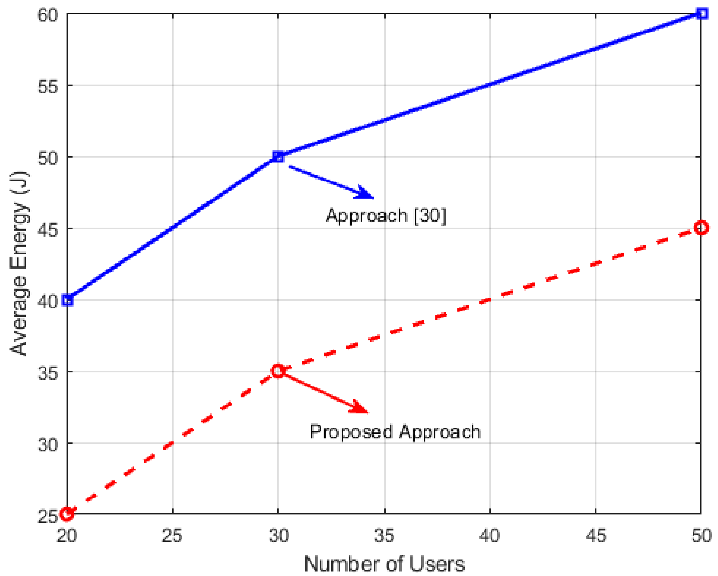

Fig 12. Average energy as a function of the number of users.

7 CONCLUSION

As a new technology approach, D2D communication is a crucial element. It could particularly help in healthcare logistics. Indeed, the energy consumed is a major concern for the sustainability and operational continuity of the planned systems. In this paper, we suggested and explored using a fuzzy analysis approach to minimize energy consumption in D2D communications. The results showed that protocol optimization can significantly reduce energy consumption and extend a device's lifespan.

When comparing the energy consumption curves for D2D communications with and without the fuzzy system, a slight reduction of 5.47% and 5.62% was observed for five and eight users respectively. These results confirm the effectiveness of our strategy, which could be further

improved. However, in the case of larger networks with 20, 30, and 50 users, the reduction reached up to 47%, demonstrating that the fuzzy system is particularly effective in larger networks.
It is important to emphasize that this approach can contribute to designing more efficient and sustainable communication systems, providing continuous energy assurance in sensitive environments such as healthcare logistics. By reducing energy consumption, not only can the device's autonomy be improved, but also the operating costs be reduced.
Using a fuzzy analysis approach to optimize energy consumption in D2D communications can be an effective way to ensure the sustainability and continuity of wireless communication systems in sensitive environments such as healthcare logistics.

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