A device to device driven approach towards optimizing energy efficiency for 6G networks

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ABSTRACT

Our study aims to develop more energy-efficient mobile communication systems through the exploration of the 6th generation (6G) technology that is expected to be implemented in 2033. We focus on the impact of device-to-device (D2D) communication on power efficiency, which is a crucial need in this domain. To achieve this, we conducted a pioneering experiment using an in-house testbed and K-means clustering to classify locations as D2D enabled or disabled. Our findings show that there is a dynamic clustering mechanism that enables certain nodes to sustain D2D functionality around temporary base stations, resulting in a remarkable 5% improvement in network lifetime per second. This research not only enhances our understanding of 6G networks but also provides a practical methodology for optimizing energy consumption, which holds significant implications for society in advancing sustainable and efficient communication.

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1. INTRODUCTION

In the fast-paced realm of mobile communication, the impending deployment of 6th generation (6G) technology in 2033 accentuates the critical challenge of optimizing energy efficiency [1]. The surge in data demand and the evolution from 5G to 6G networks underscores the pressing need for innovative solutions to manage power consumption effectively [2]. Building upon the foundation laid by pioneering researchers in mobile communication and 6G technology, this paper draws inspiration from innovative proposals and investigations. Noteworthy contributions from researchers employing D2D networks, game theory techniques, machine learning (ML) approaches, deep learning and swarm optimization, to enhance energy-efficient cellular device-to-device communication in 5G/6G networks has provided the backdrop for our study [3]-[6]. These contributions have explored novel architectures, cooperative networks, and advanced spectrum access, signalling a paradigm shift in how coverage and communication are managed [7].

The literature in mobile communication (MC) and its evolution into the 6G technology is rich with innovative proposals and investigations [8] put forth a groundbreaking architecture that divides the total coverage area of an evolved NodeB (eNB) into logical regions or clusters, showcasing a fundamental shift in the way coverage is managed. Kalogridis and Georgiou [9] contributes the CreD2D framework. A multi-hop D2D heterogeneous routing system propelled by a credit based mechanism.

Tsiropoulos *et al.* [10] investigates cooperation in 5G D2D-assisted communications and improved spectrum access in heterogeneous networks (HetNets), envisioning a network where different sized cells and radio access technologies are present together. Simplifying the computation complexity of these algorithms emerges as a crucial factor in enhancing overall network performance and energy efficiency. Notable contributions also came from Wen *et al*. [11], indicating the continuous and evolving nature of research in this dynamic field.

Sedeek *et al*. [12] delves into game theory techniques, particularly the graph coalition formation game, demonstrating promising results in 5G D2D uplinks. The focus on lower complexity approaches stands out in their work. These advancements in D2D networks have catalyzed extensive research, acknowledging major obstacles that must be addressed for their full potential to be realized in emerging 5G networks. Ioannou *et al*. [13] advocates for a distributed intelligent approach in controlling the generation of D2D networks, aligning with the expectations of decentralized solutions and sophisticated networking methods in beyond 5G networks. Coll-Perales *et al*. [14] contributes by integrating device centric wireless networks, including D2D communications, and the next generation of opportunistic networking (NGO), aligning with the evolving vision of beyond 5G networks.

Ioannou *et al*. [15] shifts the focus to the performance evaluation of transmission mode selection in D2D communication, conducting an extensive literature review on related transmission mode approaches. Hossain *et al*. [16] presents a innovative layer based HetNet architecture that divides work in an ideal manner related to different ML approaches across network layers and entities. This HetNet integrates multiple access schemes and D2D communications, leveraging collaborative learning and communications to enhance energy efficiency.

Despite the advancements, challenges persist in balancing performance and energy optimization, especially in the context of 6G networks. The proliferation of data and higher data rates necessitate a nuanced approach to power efficiency [17]-[20]. Our manuscript addresses the gap in current solutions by focusing on the impact of D2D communication, aiming to optimize energy consumption dynamically.

The literature reveals a diverse range of contributions, from architectural innovations to cooperative network strategies and advanced spectrum access models, all aimed at addressing the challenges posed by the evolution from 5G to 6G networks. The focus on lower complexity approaches, intelligent decision-making, and adaptability in D2D networks underscores the dynamic nature of research in this field [21]-[26]. Areqi *et al*. [27] in their recent work systematically reviewed and categorized the latest solutions in D2D communications, addressing the increasing importance of unloading networks, reducing data access time, and enhancing overall performance, particularly in the context of growing internet of things (IoT) services.

In this pursuit, our research introduces a dynamic clustering mechanism leveraging the K-means algorithm to classify locations as D2D enabled or disabled. This novel approach allows certain nodes to sustain D2D functionality around temporary base stations, resulting in a more than 5% improvement in network lifetime. The subsequent sections will unfold the comprehensive exploration of our D2D-driven approach, detailing the methodology employed, presenting results that showcase the superior performance of our proposed method, and discussing the broader implications for the future landscape of wireless communication. Figure 1 delineates the concept of D2D communication within a cellular network.

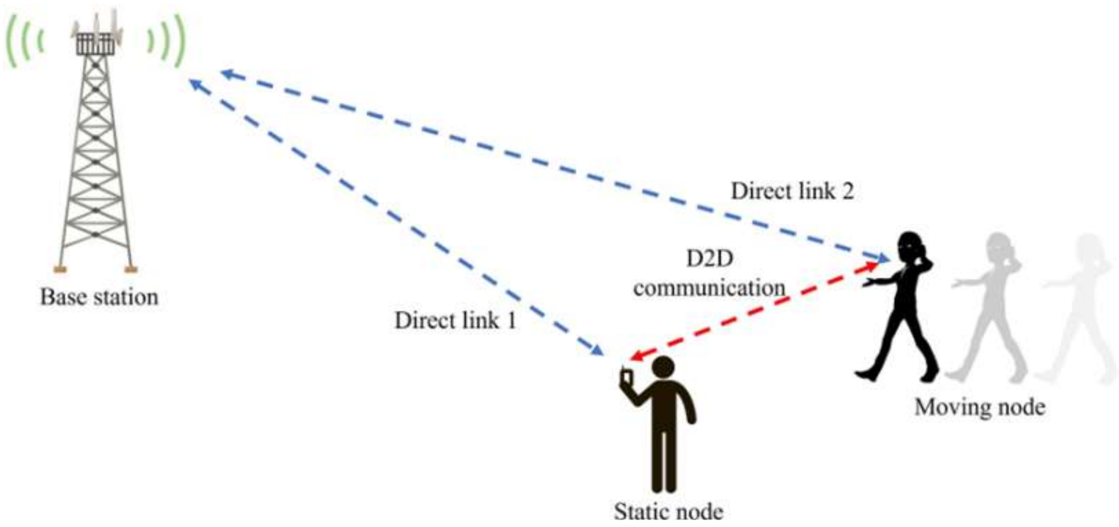


Figure 1. Concept diagram illustrating dynamic D2D communication in a wireless network

The base station can be depicted as receiving information from both direct link 1 and direct link 2. With the proposed D2D communication link, power conservation becomes feasible. When a moving node approaches a static node, communication occurs through the static node, utilizing direct link 1, and subsequently leveraging direct link 2. This strategic approach optimizes power usage, particularly in scenarios where the proximity of the moving and static nodes allows for efficient communication through intermediate nodes, hence increasing the network's overall efficiency.

2. METHOD

The research employs a methodological framework meticulously crafted to underpin its robustness, addressing the inquiries raised in the introduction while bridging the gap between exhaustive research and our contributions. Each step is meticulously chosen to facilitate a thorough analysis of the network's performance. With a focus on optimizing the potential introduced by D2D communication.

First, critical simulation parameters such as base station and device coordinates, data rate, battery power, and energy consumption metrics are meticulously initialized to capture the realistic dynamics of the communication environment. Subsequently, network lifetime for each device is calculated, employing a methodology that divides battery power by the product of data rate and energy consumption, thereby establishing a solid theoretical foundation for assessing system longevity. Distance between devices and the base station is determined using the Pythagorean theorem, ensuring accurate spatial representation crucial for communication dynamics.

Energy consumption calculation involves an algorithmic approach multiplying distance by the energy consumed per bit per second per kilometer, effectively quantifying energy requirements over varying distances. The minimum network lifetime among all devices is selected, acknowledging the interconnectedness of network elements and considering the complex dynamics of communication systems. Mapping network lifetimes through iterative steps yields a 2D visualization aiding in interpretation and optimization identification.

K-means clustering is justified to classify the network lifetime map into two clusters, enhancing system adaptability by designating devices for D2D communication or communication with the base station. Implementing clustering results configures devices for dynamic network structures, optimizing power usage. Rigorous evaluation involves recalculating network lifetimes with the clustering algorithm to identify regions favoring D2D communication, distinctly delineating existing and potential improvements. This systematic execution ensures a comprehensive analysis of the network’s performance, specifically considering D2D communication optimization potential.

3. RESULTS AND DISCUSSION

Figure 2 shows the positioning of the dynamic node and static device in a wireless network. The green circles represent the positions of the dynamic node, the blue dot represents the position of the static device, and the red star represents the base station. Since the person is not moving, the static device is positioned at (0.01, 0.011). This means that the static device is located 0.01 units to the right and 0.011 units to the top of the origin.

The dynamic node, on the other hand, is constantly moving around. The green circles in the figure represent the different positions that the dynamic node can occupy i.e. brute force. The base station is the central node in the network. It is responsible for coordinating communication between the dynamic nodes and the static nodes. The positioning of the dynamic node and static node is important for ensuring reliable communication in the wireless network. By knowing the positions of the nodes, the base station can route traffic more efficiently and avoid interference between nodes.

Figure 3 illustrates the decision-making process for choosing between direct communication and D2D communication. The figure is divided into two parts: (a) and (b). Figure 3(a) shows the original image that represents each pixel value on a grayscale spectrum from black to white. Black signifies scenarios where D2D communication is not preferred, and direct communication should be chosen instead. Conversely, white represents situations where D2D communication is essential for maximum power saving. The gray levels indicate cases where a decision needs to be made.

Figure 3(b) shows the decisions made based on K-means clustering. For all black pixels, direct communication with the base station is preferred. For all white pixels, D2D communication is the better choice. In D2D communication, all signals from the moving device are sent to a static device, which then relays the information to the base station. This method is employed to optimize power usage and enhance communication efficiency.

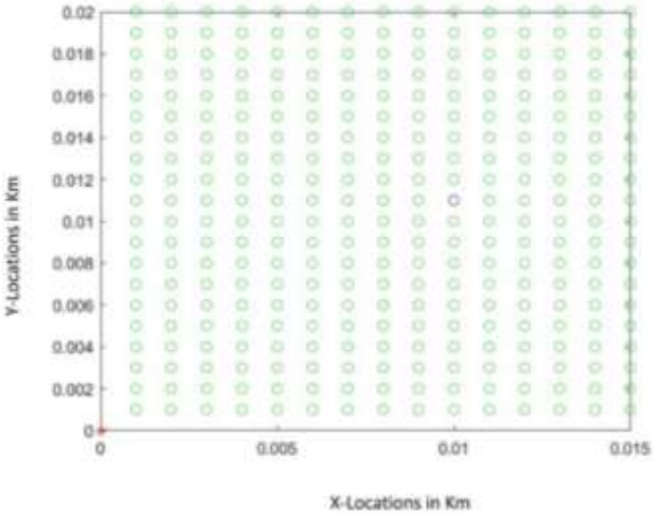
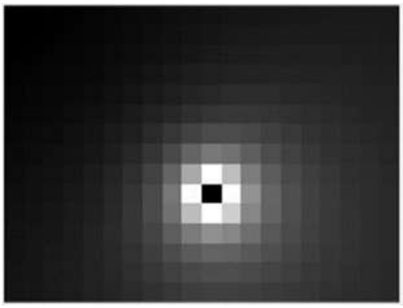


Figure 2. Positioning of the dynamic node and static device



(a)

(b)

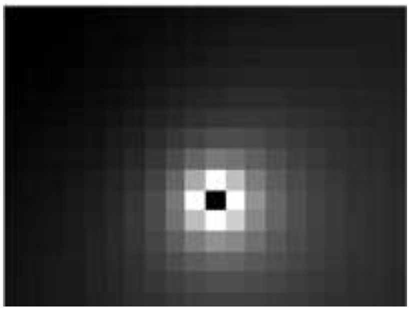
Figure 3. Decision-making process for selecting communication mode, (a) the original image reveals preferences for direct communication versus D2D transmission and (b) derived decisions from K-means clustering

Figure 4 illustrates the D2D decision-making process employing the K-means algorithm. In Figure 4(a), the probability data is presented in an image format for improved comprehension, offering a visual representation that spans pixel values from black to white. Here, black pixels signify a preference against D2D communication, favoring direct communication, while white pixels indicate the imperative use of D2D for optimal power conservation. The grayscale levels represent instances where a decision needs to be made.

Figure 4(b) showcases decisions derived through K-means clustering: black pixels advocate for direct base station communication, while white pixels endorse D2D communication for superior power savings. In the D2D scenario, signals from mobile devices are transmitted to static devices, which then relay this information to the base station. This delineates a dynamic and informed approach to choosing the communication mode based on the K-means algorithm, enhancing overall energy efficiency in the network.

Observably, after each iteration of the K-means algorithm, the mapped area for D2D communication varies, primarily contingent on the seed point. This dynamic decision-making process ensures adaptability, rendering the system consistently prepared for real-time data. The outcomes are, therefore, dynamic, reflecting the system's responsiveness to changing conditions.

The Figure 5 shows a graph of the average network lifetime of three different methods: without D2D, with D2D, and the proposed method. The proposed method outperforms both other methods, with a network lifetime of 101.2%. This is due to the dynamic allocation of resources using K-means clustering, which allows the proposed method to adapt to changing network conditions.



(a)

(b)

Figure 4. D2D decision-making with k-means algorithm (a) probability data in image format enhances comprehension and (b) K-means clustering results: black pixels suggest direct base station communication and white pixels endorse D2D for power savings

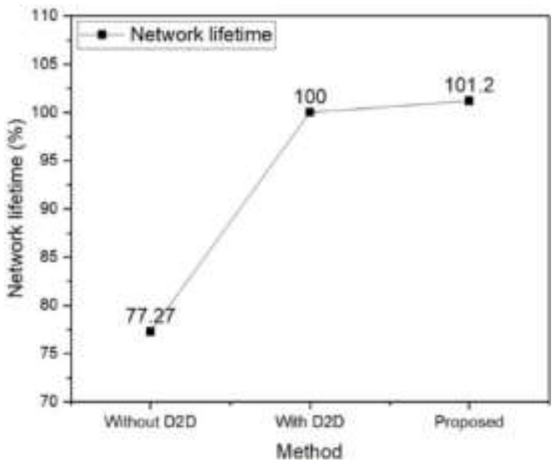


Figure 5. Network lifetime comparison of proposed method with D2D and without D2D

The proposed method outperforms both without D2D and with D2D in terms of network lifetime. The proposed method uses dynamic allocation using K-means clustering to achieve its superior performance. The proposed method is a promising approach for improving network lifetime in D2D networks. It can outperform both without D2D and with D2D, and it is adaptable to changing network conditions.

The research embarks on a pioneering exploration into the optimization of energy efficiency in 6G networks through a D2D driven approach. The findings present a compelling case for the efficacy of D2D communication in enhancing the network lifetime, showcasing a dynamic clustering mechanism that allows certain nodes to sustain D2D functionality around temporary base stations. This adaptability is crucial for real-time data processing and reflects the system's responsiveness to changing conditions.

The K-means clustering algorithm emerges as a pivotal component, offering a nuanced decision-making process for selecting communication modes. The dynamic application of K-means clustering not only categorizes locations as D2D enabled or disabled but also influences the strategic decision between devices functioning as nodes or base stations. The visual representation of this decision-making process, as illustrated in Figures 3 and 4, underscores the efficiency gained through intelligent and adaptive communication strategies.

As shown in Table 1, various methods for optimizing energy consumption in 6G mobile communication networks have been assessed, each with its distinct outcomes. Marta and Cardei [28] approach demonstrated a 4.86% improvement with an execution time of 3 units. Hoang *et al*. [29] showcased a notable 11.1% improvement, with unspecified execution time but utilizing a single node. Ansari *et al*. [30] method resulted in a modest 0.5% improvement across 2 nodes. Shaikh *et al*. [31] achieved a 5.2% improvement, remarkably efficient with an execution time of 1 unit. Hong *et al*. [32] recorded a 3.33% improvement over 5 units of execution time, involving 2 nodes. In comparison, the proposed approach achieved a commendable 5% improvement with an execution time of 1.157 seconds, demonstrating efficiency with 2 nodes. These findings underscore the diversity in approaches and highlight the potential of the proposed method in balancing improvement, execution time, and the number of nodes.

Table 1. Comparison of proposed work with existing work

Method	% improvement	Execution time	Number of nodes
Marata *et al*. [28]	4.86	3	-
Shaikh *et al*. [29]	5.2	-	1
Hong *et al*. [30]	3.33	5	2
Hoang *et al*. [31]	11.1	-	1
Ansari *et al*. [32]	0.5	-	2
Proposed	5	1.157 sec	2

Moreover, the comprehensive methodology, as outlined in the methods section, stands as a testament to the systematic approach employed in this research. From the initialization of parameters to the evaluation of improvement, each step contributes to a thorough analysis of the network's performance. The results, as depicted in Figure 5, demonstrate the superiority of the proposed method over scenarios without D2D and with D2D, with a notable network lifetime improvement of 101.2%.

4. CONCLUSION

This research significantly advances our understanding of energy-efficient mobile communication, particularly in the context of impending 6G networks. The proposed D2D-driven approach, with its dynamic clustering and intelligent decision-making processes, showcases a tangible improvement of 5% in network lifetime per second. This not only attests to the feasibility of D2D communication but also positions it as a key player in shaping the future landscape of wireless communication. The adaptability introduced by the K-means clustering algorithm is a noteworthy contribution, enabling the system to dynamically respond to changing conditions. The visual representations of the decision-making process provide clarity on the preferred communication modes, offering practical insights for network optimization. Furthermore, the superior performance of the proposed method, as evidenced by the network lifetime comparison, underscores its potential for practical implementation. The adaptability and efficiency introduced by dynamic allocation using K-means clustering position this approach as a promising avenue for improving network lifetime in D2D networks. This research not only addresses the immediate challenges of energy efficiency in 6G networks but also sets the stage for further advancements in the dynamic field of wireless communication technologies.

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