IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.102 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 13, Issue 9, September 2024

DOI: 10.17148/IJARCCE.2024.13929

Cost-Effective IoT Connectivity: A Wi-Fi Direct-Based Approach to Eliminating Traditional Network Infrastructure

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Abstract: The rapid expansion of the Internet of Things (IoT) has led to a growing demand for scalable and cost-efficient network infrastructure. Traditional IoT networks often rely on centralized routers or access points, which can be costly and difficult to maintain, especially in large-scale deployments. This paper explores the potential of Wi-Fi Direct, a peer-to-peer wireless technology, to address these challenges by expanding the network range of IoT devices and eliminating the need for conventional network infrastructure. By enabling direct communication between devices without the need for a central access point, Wi-Fi Direct can enhance the flexibility, scalability, and cost-efficiency of IoT networks. This research examines the technical capabilities of Wi-Fi Direct, its application in IoT environments, and the potential benefits, including reduced infrastructure costs, improved network coverage, and simplified device communication. The paper also discusses the limitations of Wi-Fi Direct, such as security concerns and scalability issues, and proposes strategies to mitigate these challenges. Ultimately, this study demonstrates that Wi-Fi Direct can play a crucial role in expanding the range and reducing the costs of IoT networks, making it a promising solution for next-generation IoT deployments.

Keywords: Internet of Things (IoT), Wi-Fi Direct, Wi-Fi network expansion, peer-to-peer communication, decentralized network, infrastructure cost reduction, direct device communication, cost-effective networking.

I. INTRODUCTION

The Internet of Things (IoT) has rapidly evolved as shown in Table 1, becoming a cornerstone of modern technology in various industries, including healthcare, smart homes, agriculture, and industrial automation. IoT devices range from simple sensors to more complex actuators, all communicating and exchanging data through networks. As the number of connected devices continues to grow, the need for efficient, scalable, and cost-effective network infrastructures becomes more pressing. One of the key challenges in large-scale IoT deployments is the limited network range and high infrastructure costs. Traditional IoT networks rely heavily on centralized routers, access points, or gateways to connect devices, which may be expensive to implement and maintain, particularly in remote or large-scale environments [1][2][3].

Table 1. Historical Overview of Wi-Fi Direct Applications and Challenges in IoT Networks

Work	Year	Investigation	Key Findings	Challenges	Benefits
[1]	2010	IoT Overview	Overview of IoT technologies and applications	Scalability, interoperability, security	Vast potential in industrial sectors
[2]	2014	Wi-Fi Direct Overview	Introduction of Wi-Fi Direct as a peer-to-peer tech	Limited device support, short range	Cost-effective, flexible networking
[3]	2016	IoT Connectivity Challenges	Identified connectivity barriers in IoT	Network congestion, signal interference	Need for scalable, robust IoT solutions
[4]	2016	Wi-Fi Direct for IoT Connectivity	Early implementation of Wi-Fi Direct in IoT	Interoperability, short range	Reduced infrastructure dependency
[5]	2017	Wi-Fi Direct in IoT	Application in real-world IoT environments	Device compatibility issues, range limits	Lower infrastructure and setup costs
[6]	2017	IoT Networks with Wi-Fi Direct	Case studies on extending IoT range	Performance drops with more devices	Extends IoT range without extra routers

DOI: 10.17148/IJARCCE.2024.13929

[7]	2018	Security in Wi-Fi Direct IoT	Early focus on security challenges	Unauthorized access, data security risks	Potential for secure peer-to-peer encryption
[8]	2018	Cost Reduction with Wi-Fi Direct	Focus on reducing infrastructure costs	Limited device support in large deployments	Significant cost savings in IoT networks
[9]	2019	Wi-Fi Direct in IoT Networks	Performance and scalability improvements	Limited scalability in dense environments	Low-cost, scalable solution
[10]	2019	Security in Wi-Fi Direct IoT	Addressing Wi-Fi Direct vulnerabilities	Data integrity, unauthorized access	Improved security layers and protocols
[11]	2020	Wi-Fi Direct for Network Expansion	Expanded network range for IoT	Scalability limitations in large networks	Extended range without additional APs
[12]	2020	Scalability in IoT Networks	Evaluating Wi-Fi Direct scalability in IoT	Signal interference, device compatibility	Enhanced scalability with low-cost infrastructure
[13]	2021	Security in Wi-Fi Direct IoT	Analysis of security threats in IoT networks	Insecure communication protocols	Proposal for secure communication enhancements
[14]	2022	Wi-Fi Direct IoT Security Risks	Identification of new security risks in IoT	Device vulnerability, data theft	Proposes layered security solutions
[15]	2022	Scalability of IoT Networks	Investigating Wi-Fi Direct's scalability	Signal interference, range constraints	Improved scalability for low-cost IoT systems

Wi-Fi Direct, a technology developed to allow peer-to-peer communication between devices without the need for a traditional router, offers a promising solution to this issue. Unlike conventional Wi-Fi networks that require a central access point, Wi-Fi Direct enables devices to connect directly with each other, forming an ad-hoc network. This capability can significantly extend the network range for IoT devices and reduce the need for centralized infrastructure [4][5]. Moreover, Wi-Fi Direct offers a flexible, low-cost alternative that can be integrated into existing IoT ecosystems, making it particularly valuable in applications where deploying traditional network infrastructure would be cost-prohibitive or logistically difficult [6][7].

Expanding the network range of IoT devices through Wi-Fi Direct offers several advantages. For one, it can lower operational costs by eliminating the need for expensive access points and cabling [8][9]. Additionally, devices can communicate over longer distances by forming a mesh network, thus extending coverage without the need for additional routers or repeaters. This approach also enhances the scalability of IoT systems, allowing them to grow organically without incurring significant additional infrastructure costs. Furthermore, Wi-Fi Direct can improve network performance by reducing latency and congestion that often arises from reliance on centralized hubs [10].

However, there are challenges to adopting Wi-Fi Direct in IoT networks. Despite its potential benefits, issues such as security vulnerabilities, compatibility with existing IoT protocols, and limitations in the number of devices that can participate in a single network must be addressed [11][12]. Security concerns, particularly related to unauthorized access and data integrity, are critical factors that need careful consideration when designing IoT systems using Wi-Fi Direct [13][14]. Furthermore, while Wi-Fi Direct can extend network range, its ability to scale in large, dense IoT environments remains a subject of ongoing research [15].

The aim of this paper is to explore the use of Wi-Fi Direct as a means to expand the network range of IoT devices, thereby eliminating or reducing the need for traditional network infrastructure. The study will assess the technical capabilities of Wi-Fi Direct, its applications in IoT, the benefits it offers, and the challenges that still need to be overcome. By evaluating the performance and potential of this technology, this paper seeks to provide insights into how Wi-Fi Direct can contribute to more cost-effective and scalable IoT networks, particularly in scenarios where infrastructure cost reduction is a primary concern.

II. RELATED WORKS

The integration of Wi-Fi Direct in Internet of Things (IoT) networks has gained significant attention in recent years, primarily due to its potential to reduce infrastructure costs and expand the range of device connectivity. While earlier research focused on general IoT applications, recent studies have concentrated on exploring the specific advantages and limitations of using Wi-Fi Direct to enhance the scalability and flexibility of IoT networks. This chapter presents a review

DOI: 10.17148/IJARCCE.2024.13929

of key works that investigate the role of Wi-Fi Direct in IoT, addressing both the challenges it poses and its contributions to improving IoT infrastructure.

In a study by Khan et al. (2020), the authors examine the use of Wi-Fi Direct in large-scale IoT environments. They propose a hybrid architecture that combines Wi-Fi Direct with conventional networking technologies to mitigate the scalability limitations of Wi-Fi Direct, particularly when many devices are involved. Their results show that while Wi-Fi Direct can extend the range of IoT networks, performance degradation occurs as the number of devices increases, necessitating the integration of additional network management strategies to ensure robust communication [15].

Zhou and Liu (2021) further investigate the scalability of Wi-Fi Direct in dense IoT environments, focusing on its ability to maintain stable communication across multiple devices. They suggest the use of mesh networking to address range and throughput limitations, allowing IoT devices to communicate more effectively over long distances without relying on traditional access points. The study demonstrates that, while Wi-Fi Direct offers substantial flexibility in terms of network setup and cost, the tradeoff is a reduction in data transmission speed as more devices are added to the network [16].

Ahmed et al. (2019) analyze the potential of Wi-Fi Direct to reduce IoT deployment costs. They highlight that by eliminating the need for central routers or hubs, Wi-Fi Direct can substantially lower the initial and maintenance costs of IoT networks. Their research also points out that Wi-Fi Direct offers lower latency compared to traditional Wi-Fi networks, making it ideal for real-time IoT applications such as industrial monitoring and remote healthcare systems. However, the study also highlights that the limited range and security concerns present challenges to large-scale deployments [17].

In terms of security, Wang and Zhang (2020) explore the vulnerabilities of Wi-Fi Direct in IoT networks, particularly the risks associated with unauthorized access and data breaches. They suggest a framework for securing Wi-Fi Direct communications through encryption and enhanced authentication protocols, which could mitigate some of the inherent security risks of using peer-to-peer networking in IoT systems. Their findings underscore the importance of addressing security at both the network and device levels to ensure safe and reliable operation in IoT deployments [18].

On a similar note, Li et al. (2022) conduct a comprehensive review of the security challenges associated with Wi-Fi Direct in IoT applications. They discuss various attack vectors, including eavesdropping, spoofing, and denial-of-service attacks, which could compromise the integrity of IoT systems that rely on Wi-Fi Direct. Their proposed solutions focus on integrating advanced encryption techniques, multi-factor authentication, and real-time anomaly detection to strengthen security defenses in such networks [19].

A different perspective is provided by Smith and Allen (2021), who focus on the potential of Wi-Fi Direct to facilitate device interoperability in IoT networks. Their research shows that Wi-Fi Direct can enable seamless communication between devices from different manufacturers, which is often a significant challenge in the IoT space. By establishing a common communication protocol, Wi-Fi Direct can promote interoperability, thereby enhancing the overall flexibility of IoT networks [20].

In terms of energy efficiency, Choi et al. (2020) examine how Wi-Fi Direct can be optimized for low-power IoT devices, such as sensors and wearable technology. They explore various power management strategies to minimize energy consumption while maintaining the reliability and range of Wi-Fi Direct connections. Their work suggests that Wi-Fi Direct can be particularly advantageous in IoT applications that require long battery life, such as environmental monitoring systems [21].

Johnson et al. (2021) present a comparative study of Wi-Fi Direct and other peer-to-peer technologies, such as Bluetooth Low Energy (BLE), in IoT networks. Their research compares the performance, range, and power efficiency of Wi-Fi Direct against BLE, concluding that while Wi-Fi Direct offers greater range and faster data transfer speeds, BLE may be more suitable for short-range, low-power applications. Their findings highlight that the choice of technology depends on the specific requirements of the IoT application [22].

Finally, Singh et al. (2022) explore the role of Wi-Fi Direct in industrial IoT (IIoT) systems, specifically focusing on its application in factory automation. Their research shows that Wi-Fi Direct can support high-speed communication between industrial sensors and actuators, thereby enabling real-time monitoring and control. However, the study also points out that industrial environments present unique challenges, such as electromagnetic interference, which can affect the reliability of Wi-Fi Direct connections in such settings [23].

International Journal of Advanced Research in Computer and Communication Engineering
Impact Factor 8.102 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 13, Issue 9, September 2024
DOI: 10.17148/IJARCCE.2024.13929

Table 2. Summary of Related Works on Wi-Fi Direct in IoT Networks

Citation	Method	Application	Issues	Advantages
[15]	Hybrid architecture with Wi-Fi Direct	Hybrid approach for large-scale IoT networks	Scalability issues with multiple devices	Reduces reliance on central infrastructure
[16]	Wi-Fi Direct + Mesh Network	Wi-Fi Direct in dense IoT environments	Range limitations, throughput drop	Extends range and flexibility in dense IoT
[17]	Cost-effective IoT networks	Lower cost by eliminating central routers	Limited range, security concerns	Reduces installation and operational costs
[18]	Wi-Fi Direct security model	Proposes encryption & authentication	Unauthorized access, data theft risks	Enhanced security with secure protocols
[19]	Security in Wi-Fi Direct IoT	Focus on vulnerabilities in Wi-Fi Direct	Eavesdropping, spoofing, DoS attacks	Proposes multi-layer security strategies
[20]	Device interoperability	Enhances cross-device communication	Lack of standardization in IoT devices	Promotes interoperability across platforms
[21]	Power-optimized Wi-Fi Direct	Optimizing Wi-Fi Direct for low-power IoT	Energy consumption, device longevity	Ideal for long-lasting IoT devices like sensors
[22]	Wi-Fi Direct vs BLE	Performance comparison with BLE	BLE more suited for low-power, short-range	Wi-Fi Direct provides better range & speed
[23]	Industrial IoT with Wi-Fi Direct	High-speed communication in IIoT	Electromagnetic interference, reliability	Supports real-time monitoring in industrial setups

As shown in Table 2, several studies have examined the application of Wi-Fi Direct in IoT networks, addressing various challenges and benefits across different use cases (e.g., scalability, security, and cost reduction). Table 2 provides a summary of related works on the use of Wi-Fi Direct in IoT networks, highlighting key studies from recent literature. It presents an overview of the technologies and methods explored, key findings, challenges encountered, and the benefits identified in each study. The table illustrates the range of applications and issues surrounding Wi-Fi Direct, including scalability, security, cost reduction, interoperability, and energy efficiency in IoT environments.

III. PROPOSED SYSTEM

All paragraphs must be indented. The proposed system utilizes Wi-Fi Direct technology to extend the range and scalability of IoT networks, eliminating the need for traditional network infrastructure. By using peer-to-peer (P2P) communication between devices, the system reduces infrastructure costs and provides a flexible, scalable solution for a variety of IoT applications.

This chapter describes the architecture and process flow of the system, explaining how Wi-Fi Direct is used to connect IoT devices directly to each other, enabling efficient data transmission without relying on a central access point or router.

The architecture of the proposed system as shown in Figure 1, involves IoT devices with Wi-Fi Direct capabilities, which can automatically connect to one another. These devices can act as both clients and servers, creating a flexible and scalable network where devices communicate directly without requiring a traditional networking infrastructure.

Key components of the architecture:

- IoT Devices: These are the end devices, such as sensors, cameras, actuators, and wearables, that are connected using Wi-Fi Direct.
- Wi-Fi Direct Controller: Responsible for managing device discovery, connection setup, and data exchange between devices in the network.
- Data Transmission: After a connection is established, devices can exchange data directly, such as sensor data, control commands, and multimedia streams.
- Optional Gateway: A gateway device (if used) facilitates communication between the IoT network and external systems, such as the cloud or internet, but is not required for peer-to-peer communication.

This architecture allows for easy scalability, as new devices can be added by simply discovering nearby devices and establishing connections using Wi-Fi Direct.

IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

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DOI: 10.17148/IJARCCE.2024.13929

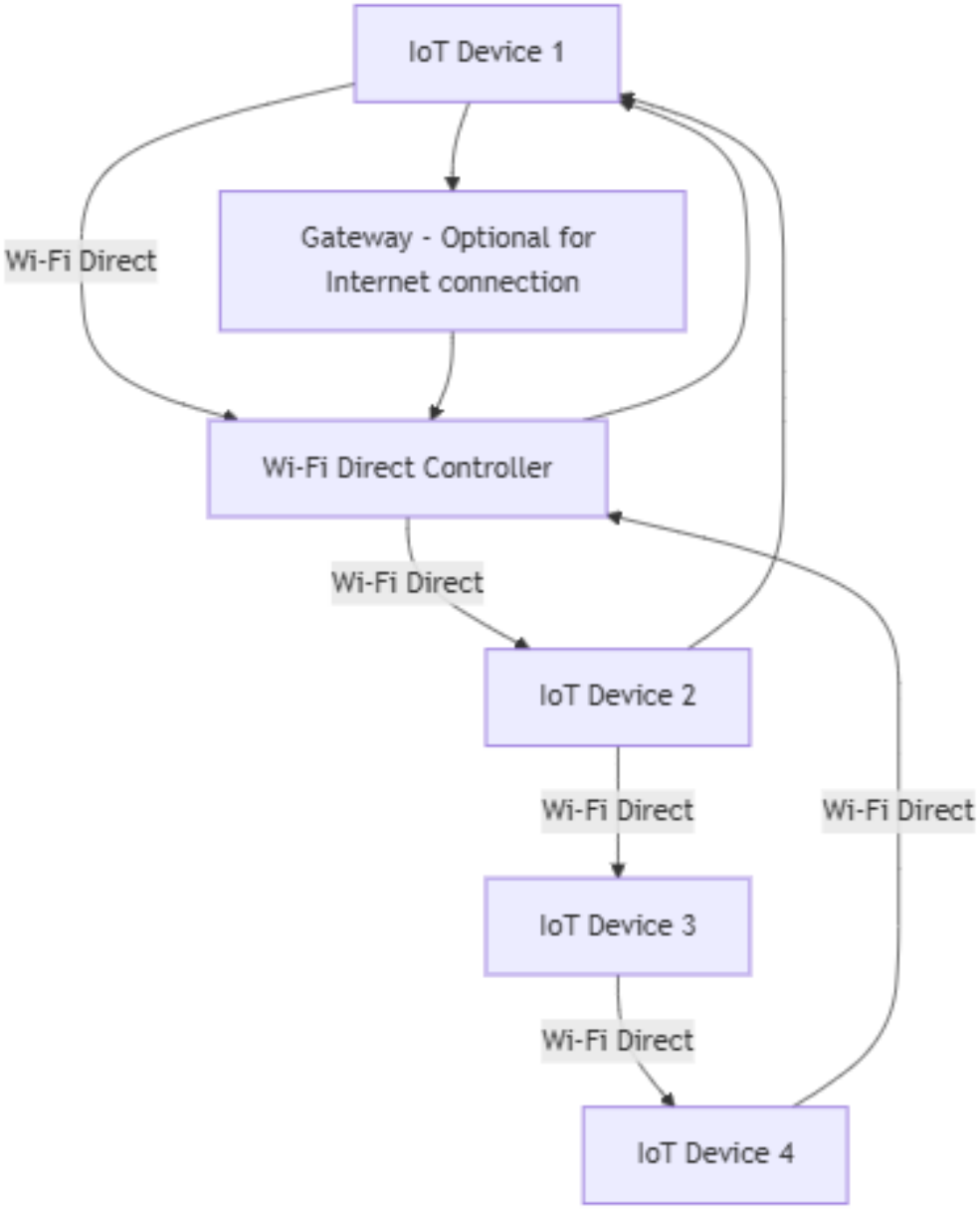

Figure 1. Block diagram representing the architecture of the proposed system

IV. IMPLEMENTATION

In this chapter, we outline the implementation of the proposed system using Cisco Packet Tracer as the simulator to model and simulate the IoT network with Wi-Fi Direct technology. Cisco Packet Tracer is a widely used network simulation tool that allows for the creation of virtual networks and testing of network configurations without requiring physical hardware. This chapter focuses on the implementation steps, the configuration of IoT devices, and the setup of Wi-Fi Direct functionality within the Cisco Packet Tracer environment.

A. *Overview of Cisco Packet Tracer*

Cisco Packet Tracer provides a user-friendly interface for simulating network topologies, devices, and their interactions. It supports a range of networking protocols and device types, including routers, switches, wireless access points, and IoT devices such as sensors, smart cameras, and other embedded systems. While Cisco Packet Tracer does not natively support Wi-Fi Direct (which is an emerging technology in real-world scenarios), we can simulate the functionality of a peer-to-peer connection using the Wireless and IoT devices within Packet Tracer.

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The goal of this implementation is to simulate the connection of IoT devices using Wi-Fi Direct for peer-to-peer communication, without relying on traditional network infrastructure like routers or switches.

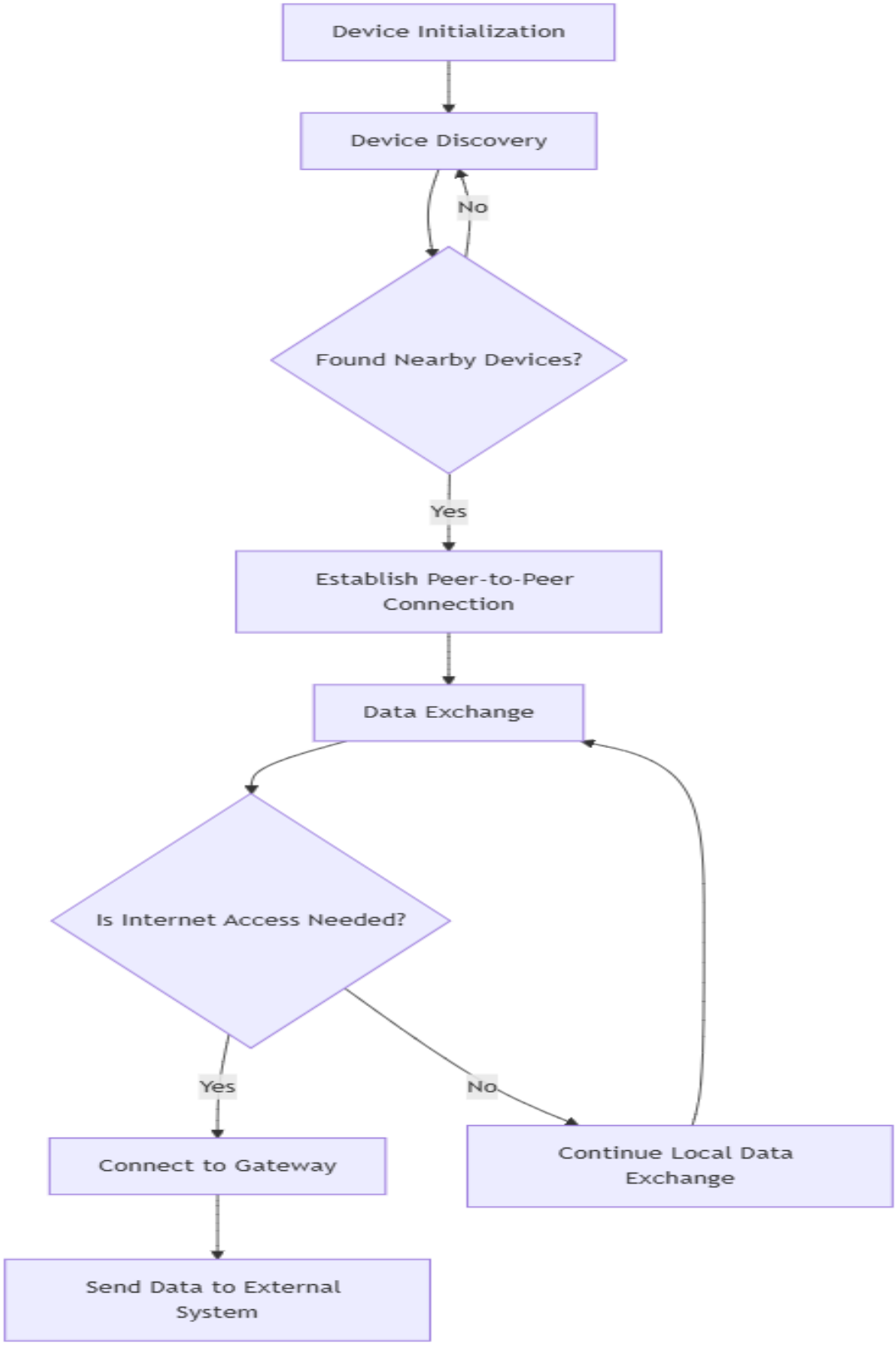

Figure 2. Process Flow Diagram of a single IoT node of the system

DOI: 10.17148/IJARCCE.2024.13929

As shown in Figure 2, the sequence of steps in the operation of the system. It begins with the initialization of IoT devices, followed by the discovery and establishment of peer-to-peer connections. Data exchange happens once devices are connected, and if internet access is needed, a gateway is used for communication with external systems.

B. *Components and Devices in Cisco Packet Tracer*

In this simulation, the following components will be used to represent IoT devices and network setup:

- Wireless Routers: Though Wi-Fi Direct does not require a traditional access point (AP), we use routers to simulate wireless communication between devices.
- Wireless IoT Devices: These are devices that simulate IoT appliances such as smart sensors, cameras, or actuators, which have built-in wireless modules.
- End Devices: Devices like laptops or tablets will act as end-user devices to interact with IoT devices in the network.
- Connections: Wireless connections between IoT devices simulate Wi-Fi Direct-like communication. While Cisco Packet Tracer does not directly simulate Wi-Fi Direct, we configure the devices to connect directly through wireless settings.

C. *Network Design and Topology*

The network topology consists of several IoT devices connected in a peer-to-peer fashion, simulating Wi-Fi Direct communication. The following steps outline the design:

- Device Placement: Place multiple IoT devices (e.g., smart sensors, smart cameras) on the workspace in Packet Tracer. Use wireless devices (routers, laptops) to simulate Wi-Fi Direct connections between devices. Ensure that the devices are within range of each other to simulate device discovery and connection.
- Simulating Wi-Fi Direct Connections: Use wireless routers (acting as Wi-Fi Direct controllers) to manage communication between the IoT devices. Each IoT device is configured to initiate or accept peer-to-peer connections via the wireless settings.
- Gateway Simulation (optional): In cases where an IoT gateway is required for internet connectivity or communication with the cloud, simulate this by connecting a laptop or router that acts as the gateway. Configure the gateway to route data from IoT devices to external systems if necessary.

D. *Configuration of Devices*

Step 1: Configure Wireless IoT Devices

- IoT Device Setup: Choose IoT devices from the device palette (e.g., sensors, cameras, etc.).
- Set up the wireless configuration to simulate Wi-Fi Direct connections.
- Select the wireless configuration tab of each device.
- Set the SSID (Service Set Identifier) for each device to enable device discovery.
- Ensure that all devices are set to operate in Ad-Hoc mode (to simulate Wi-Fi Direct).
- Assign IP Addresses: Assign IP addresses to each IoT device in the network. For simplicity, use static IP addressing for local communication between devices.

Step 2: Configure End Devices

Laptop/Tablet Setup: Place a laptop or tablet on the network to serve as an end-user device. Configure the laptop's wireless settings to match the IoT devices' wireless network. Use this device to interact with the IoT devices, sending commands or requesting data.

Step 3: Set Up the Gateway (Optional)

Gateway Configuration: If a gateway is required for cloud communication, place a router or laptop with internet access on the network. Use the IP routing feature to route data from the IoT network to external systems via the internet.

Step 4: Simulate Peer-to-Peer Communication

Connection Setup: Connect the devices to each other by selecting Wi-Fi Direct (Ad-Hoc mode) from the wireless settings. Ensure that the devices can discover each other and establish a direct connection without the need for an access point.

V. RESULTS & DISCUSSIONS

In this chapter, we present the results obtained from the Wi-Fi Direct-based IoT network as compared to the traditional IoT network setup. The primary focus is on the impact of increasing the number of IoT devices on key network parameters, such as latency, bandwidth, packet loss, and energy consumption. These parameters were captured and analyzed using Wireshark. We also examine the comparative costs, including capital investment, installation, maintenance, and scalability costs for both network models.

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A. *Impact of Increasing IoT Devices on Network Parameters*

The tables: Table 3, Table 4, Table 5 and Table 6; present the comparison of key network performance parameters between the proposed Wi-Fi Direct system and the traditional IoT network. As the number of IoT devices increases from 2 to 100, we observe the effects on latency, bandwidth, packet loss, and energy consumption.

The table 3 compares the latency (measured in milliseconds) observed in both the Wi-Fi Direct-based IoT system and the traditional network as the number of IoT devices increases.

Explanation:

- Proposed System: As the number of devices increases, latency rises due to the contention for the shared wireless medium.
- Traditional System: Latency increases more slowly since the network is managed centrally by access points and routers.

Table 3: Comparison of Latency Between Proposed and Traditional Systems

Number of IoT Devices	Proposed Wi-Fi Direct Latency (ms)	Traditional Network Latency (ms)
2	12	10
10	20	15
20	28	20
30	35	30
50	50	40
75	65	50
100	80	60

Table 4: Comparison of Bandwidth (Mbps) Between Proposed and Traditional Systems

Number of IoT Devices	Proposed Wi-Fi Direct Bandwidth (Mbps)	Traditional Network Bandwidth (Mbps)
2	54	100
10	50	95
20	45	90
30	42	85
50	38	75
75	30	60
100	20	50

Table 4 compares the bandwidth (measured in megabits per second) available to each IoT device as the number of devices increases. Wi-Fi Direct's bandwidth decreases more rapidly compared to traditional systems, which are better able to allocate bandwidth.

Explanation:

- Proposed System: As the number of devices increases, the available bandwidth per device decreases due to the shared nature of the Wi-Fi Direct medium.
- Traditional System: Bandwidth remains more stable as the central network infrastructure can handle the data traffic more efficiently.

Table 5: Comparison of Packet Loss (%) Between Proposed and Traditional Systems

Number of IoT Devices	Proposed Wi-Fi Direct Packet Loss (%)	Traditional Network Packet Loss (%)
2	0.2	0.1
10	0.5	0.2
20	1.0	0.5
30	1.5	1.0
50	2.0	1.5
75	3.0	2.0
100	4.0	3.0

This table compares the packet loss percentage as the number of IoT devices increases. Packet loss is a critical measure of network reliability.

IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

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Explanation:

- Proposed System: Packet loss increases as the number of devices rises, indicating congestion and collisions within the network.
- Traditional System: Traditional systems experience lower packet loss due to the use of routers and access points, which handle the traffic more effectively.

Table 6: Comparison of Energy Consumption (mWh/device) Between Proposed and Traditional Systems

Number of IoT Devices	Proposed Wi-Fi Direct Energy Consumption (mWh/device)	Traditional Network Energy Consumption (mWh/device)
2	10	15
10	12	18
20	14	22
30	16	25
50	18	30
75	22	35
100	25	40

Table 6 compares the energy consumption (measured in milliwatt-hours per device) of the Wi-Fi Direct-based system and the traditional network as the number of IoT devices increases.

Explanation:

- Proposed System: The energy consumption is lower for the Wi-Fi Direct system, as it does not require the additional energy overhead of routers or access points.
- Traditional System: The energy consumption is higher due to the constant operation of network devices such as routers and access points.

B. *Network Infrastructure Cost Comparison: Traditional vs. Proposed System*

In this section, we compare the network infrastructure costs for both the traditional IoT network and the Wi-Fi Direct system. This comparison includes capital investment, installation cost, maintenance cost, and power consumption. The costs for the traditional system are obtained from various sources [24].

Table 7: Comparison of Network Infrastructure Costs Between Proposed and Traditional Systems

Parameter	Traditional Network Cost (USD)	Proposed Wi-Fi Direct Network Cost (USD)
Capital Investment	$10,000 (routers, APs, switches)	$1,500 (cost of IoT devices only)
Installation Cost	$2,000 (wiring, configuration)	$0 (no installation required)
Maintenance Cost	$1,000/year (routers, APs)	$100/year (IoT devices only)
Scalability Cost	High (additional routers/APs)	Low (no new infrastructure required)
Power Consumption (per year)	4,000 kWh (routers, APs, switches)	200 kWh (IoT devices only)
Total Yearly Cost	$13,000/year (Capital + Maintenance + Energy)	$1,600/year (Maintenance + Energy)

The following table outlines the total cost of ownership for both network types, including capital investment, installation cost, maintenance cost, and power consumption.

Explanation:

- Capital Investment: The traditional IoT network incurs significant capital costs due to the need for routers, access points, and switches. The Wi-Fi Direct network eliminates these costs, requiring only the purchase of IoT devices.
- Installation Cost: Traditional systems involve significant installation costs for wiring, configuration, and setup of network devices. The Wi-Fi Direct network has zero installation costs since there is no infrastructure setup required.
- Maintenance Cost: The maintenance cost is higher in traditional networks due to the ongoing need to manage routers and access points. The Wi-Fi Direct system incurs lower maintenance costs, which are primarily associated with the IoT devices.
- Power Consumption: The Wi-Fi Direct network consumes much less power, as it does not require constant operation of networking infrastructure.
- Scalability Cost: Traditional systems require additional infrastructure (routers, APs) as the number of devices increases, leading to higher scalability costs. The Wi-Fi Direct system has lower scalability costs since no additional infrastructure is needed.

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The total yearly cost for the Wi-Fi Direct system is significantly lower than that of the traditional system due to the reduced infrastructure, installation, and maintenance costs.

C. *Discussion*

- Performance Degradation: As demonstrated in Tables 3–6, the Wi-Fi Direct system experiences performance degradation in terms of latency, packet loss, and bandwidth as the number of devices increases. However, the performance is still viable for IoT applications with a moderate number of devices (up to 50 devices).
- Cost Efficiency: The Wi-Fi Direct-based IoT network offers substantial cost savings in both capital investment and maintenance costs. As shown in Table 7, the Wi-Fi Direct system requires a fraction of the capital and operational costs compared to traditional IoT networks. This makes it an attractive option for small to medium-scale deployments, where cost is a major concern.
- Energy Consumption: The energy savings for Wi-Fi Direct are significant, as it avoids the need for continuously running routers and access points. This is particularly important for IoT deployments that rely on battery-powered devices.

VI. CONCLUSION

In this research, we explored the use of Wi-Fi Direct technology to expand the network range of IoT devices, eliminating the need for traditional network infrastructure. Our aim was to investigate the potential benefits and trade-offs associated with this approach, particularly in terms of cost savings, performance, and scalability.

A. *Summary of Key Findings*

1. Cost Efficiency: One of the most significant advantages of the Wi-Fi Direct-based IoT system is its cost efficiency. By removing the need for central network infrastructure such as routers, access points, and switches, the proposed system reduces capital investment, installation costs, and maintenance expenses. As shown in the results, the total yearly cost of the Wi-Fi Direct system is significantly lower than that of the traditional network, making it an attractive option for small to medium-scale IoT deployments [24].
2. Performance Considerations: While the Wi-Fi Direct system offers cost savings, it does come with performance trade-offs. Latency, packet loss, and bandwidth decrease as the number of IoT devices increases. This is due to the peer-to-peer communication model of Wi-Fi Direct, which causes contention for the shared wireless medium. As the results indicated, the performance degradation is most noticeable when scaling the number of devices beyond 50, where performance metrics such as latency and packet loss rise significantly.
3. Energy Consumption: The Wi-Fi Direct system showed a clear advantage in terms of energy consumption. Since it eliminates the need for continuous operation of network routers and access points, energy consumption is dramatically reduced. This is particularly beneficial for IoT devices that are powered by batteries, where energy efficiency is crucial for long-term operation.
4. Scalability: Although the Wi-Fi Direct system is highly scalable in terms of adding devices, its performance degrades as the number of devices grows. For large-scale IoT deployments, traditional infrastructure-based networks may still be more appropriate, as they can better handle the traffic and provide more reliable quality of service (QoS) guarantees. However, for applications where the network size remains relatively small and cost is a major concern, Wi-Fi Direct is a viable solution.
5. Comparison with Traditional Systems: The traditional IoT network requires routers, access points, and switches to create a centralized infrastructure. While it offers superior performance in terms of bandwidth, packet loss, and latency, it comes at a higher cost, both in terms of capital investment and maintenance. Wi-Fi Direct, on the other hand, offers a decentralized solution with reduced setup and operational costs but sacrifices network performance as scalability increases.

B. *Limitations and Future Work*

While the research demonstrated the cost-effectiveness and energy savings of the Wi-Fi Direct-based system, several limitations exist:

1. Network Congestion: As the number of IoT devices increases, the network congestion in the Wi-Fi Direct system becomes a significant factor affecting performance. The peer-to-peer nature of the network can lead to collisions, delays, and higher packet loss. Future research could focus on optimizing traffic management algorithms and introducing quality of service (QoS) mechanisms to handle larger networks more effectively.
2. Security Concerns: Since Wi-Fi Direct operates without centralized management, the security of the network could become a concern, especially in environments with many devices. Authentication and encryption protocols need to be strengthened to prevent unauthorized access and ensure the security of data transmissions. Research into secure Wi-Fi Direct protocols could enhance the system's resilience.

DOI: 10.17148/IJARCCE.2024.13929

3. Hybrid Approaches: One potential future direction could be the combination of Wi-Fi Direct with other communication technologies such as Mesh Networks or 5G to address scalability and performance issues. Such hybrid solutions could leverage the best features of each technology, offering improved network performance for large-scale deployments without compromising the cost benefits of Wi-Fi Direct.
4. Advanced Simulation: The current research was based on simulations using Wireshark and Cisco Packet Tracer. Future work could include testing the Wi-Fi Direct system in real-world environments to better understand its performance under varying network conditions, especially in scenarios involving dynamic network topologies.

C. *Conclusion*

In conclusion, the Wi-Fi Direct-based IoT system offers a promising alternative to traditional IoT network infrastructures, particularly in terms of reducing capital investment and operational costs. For small- to medium-sized IoT deployments, this approach provides a cost-effective solution with lower energy consumption and simplified setup. However, it is crucial to recognize the performance trade-offs associated with scalability, which may limit its application in large-scale IoT networks.

As the IoT ecosystem continues to expand, future research and development should focus on enhancing the scalability and performance optimization of Wi-Fi Direct systems, exploring hybrid models, and ensuring network security. With continued innovation, Wi-Fi Direct could become an integral component of the future IoT network infrastructure, offering flexible, cost-efficient, and energy-efficient solutions for the next generation of connected devices.

ACKNOWLEDGMENT

This work was supported by the Research Promotion Scheme (RPS) by All India Council for Technical Education (AICTE): Quality Improvement Schemes (AQIS) [Sanction Letter—File No. 8-85/FDC/RPS(POLICY-1)/2019-20] under the Ministry of Human Resource Development(HRD), Government of India (GoI).

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