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Exploring the Role of Wi-Fi Direct's Service Discovery Protocol in Forming Wireless Collaboration Networks: A Scoping Review

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ABSTRACT

The increasing ubiquity of mobile devices and the Internet has become a hallmark of modern society, yet challenges persist in ensuring reliable communication networks during unforeseen disruptions, such as pandemics, war, or natural disasters. Despite the advancement of Wi-Fi technology, the development of a comprehensive model for temporary communication networks based on Wi-Fi interfaces during these disruptions remains inconclusive. The temporary and infrastructure-less wireless network created by mobile devices is referred to as a Wireless Collaboration Network (WCN). To assess the extent to which wireless protocols have been leveraged in forming Wireless WCN, a scoping review was conducted. This review aimed to provide a comprehensive overview of the existing literature, specifically focusing on the Service Discovery (SD) protocol of Wi-Fi Direct within the Mobile Ad Hoc Network (MANET) domain. Our investigation delved into solutions developed by researchers in this domain and the various metrics employed to evaluate the performance of these solutions. The scoping review protocol encompassed nine distinct steps, ranging from formulating research questions to synthesizing results. The review process involved examining three major databases: IEEE Xplore, ACM Digital Library, and Scopus, with the assistance of Mendeley for data organization and filtering. In total, our search identified 186 records across these databases. After rigorous screening, which included removing duplicates, irrelevant articles, and inaccessible content, we selected 35 articles for comprehensive review. These reviewed articles were then summarized and presented in a table, offering valuable insights into article titles, objectives, measurement parameters, techniques employed, and the noteworthy contributions of each work. The table serves as an invaluable resource for researchers in the field, facilitating a deeper understanding of the research landscape and enabling easier access to the collective knowledge within this domain.

1. Introduction

On 11th March 2020, the World Health Organization declared COVID-19 as a pandemic. The pandemic has drastically changed the lifestyle of almost everyone around the world. Social activities

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are mostly conducted online, leading to an increased demand for communication and collaboration over networking platforms. According to Beech, [1] the pandemic has pushed up global Internet usage by 70% and streaming by more than 12%. Telecommunication equipment producer Nokia also reported that most countries' telecom networks have experienced increased Internet usage, with peaks being around 20 to 40 percent higher [2]. Due to the peak network usage and network instability, end-users might face network connectivity problems, such as slow network bandwidth or even loss of network connection [3]. Furthermore, major disaster such as the earthquake in Haiti (2010), Japan (2011) and Nepal (2015) have impacted millions of people. During such disasters, a stable communication network is of utmost importance, as it serves as the only way for the crisis management team to reach the victims. However, the breakdown of communication network is widely known to occur in almost all extreme conditions [4,5]. Although there has been effort where game-based mobile application was developed to teach young children about disaster awareness [6], what is more important is a stable communication system during a catastrophic situation. Statistics have revealed a continuous and significant increase in mobile network usage over the years. However, the current infrastructure-based communication network is facing persistent challenges in maintaining uninterrupted availability. Hence, it is very important to have an alternative communication platform that serves as a backup for people to stay connected, especially during critical moments. Gomes *et al.,* [7] and Khaled & Mcheick [5], reported that forming a temporary communication system is challenging due to physical destruction, lack of compatibility between technologies, and communication system congestion. Therefore, more efforts are needed to establish an alternative communication platform. In recent years, IoT has become one of the emerging research areas, where the technology allows communication between devices through the Internet [8]. Researchers have implemented IoT for monitoring purposes. In the monitoring system, a stable network connection plays an important role for consistent data exchange [9-11]. An infrastructure or infrastructure-less network has become an important utility for the success of IoT devices as the network allows continuous connection for the IoT devices at the edge.

Due to the increasing usage trend of mobile devices such as smartphones, tablets, or phablets, researchers have been exploiting the networking functionalities of these devices to form alternative networks [12-16]. The alternative networks formed by mobile devices without prior infrastructure setting is known as Mobile Ad-hoc network (MANET). According to Bellavista [17], achieving an alternative network with inter-network connectivity at all times is possible by maximizing the wireless technology of underutilized mobile devices. Examples of wireless technology include Wi-Fi, Bluetooth, Zigbee, NFC, and RFID. Compared to other wireless technologies available in mobile devices, Wi-Fi supports longer range and higher signal transmission speeds [13,14]. Therefore, the potential of leveraging the Wi-Fi interfaces of mobile devices has emerged as a promising solution for creating a MANET. The ubiquitous nature of mobile devices, coupled with their widespread usage, makes them valuable resources for forming a Wireless Collaboration Network (WCN) [20]. By utilizing the Wi-Fi interfaces of these devices, it is possible to create a dynamic and flexible communication network that can adapt to changing network conditions and provide seamless connectivity to users.

A typical use-case scenario of the Wi-Fi infrastructure mode would be a mobile device with the tethering function enabled, acting as an AP to share the Internet connection with another smartphone [21]. In ad-hoc mode, a mobile device with ad-hoc mode enabled can connect directly to another wireless device over the Wi-Fi medium for data exchange. However, a Wi-Fi connection in ad hoc mode is platform dependent. For example, not every Android smartphone provides the functionality of ad-hoc mode for peer-to-peer communication [22]. Despite that, the Android system introduced Wi-Fi Direct (WFD) as an alternative for peer-to-peer communication.

WFD, formally known as Wi-Fi Peer-to-Peer and certified by the Wi-Fi Alliance, is a wireless mode that builds upon the Wi-Fi infrastructure mode [23]. However, unlike the common infrastructure mode, the WFD mode does not require an Access Point (AP). The participating devices will negotiate to designate a device to take over the AP-like role. The device with the AP-like role is referred to as the GO, and the devices connected to the GO are referred to as clients. The clients that connect to the GO could be legacy clients or P2P clients based on the WFD standard. The fundamental operation of a P2P connection is depicted in **Error! Reference source not found.**. The steps preceding GO selection encompass device discovery and service discovery (SD). Device discovery is a mandatory step for devices to identify nearby peers. However, the service discovery procedure is optional. Generally, this protocol provides a framework that allows a host or server device to register services to announce the available communication services. This approach will result in a more effective and target-oriented communication system, enabling client devices' applications to directly identify and communicate with the relevant source providing the required service. The details about WFD were explained in the article by Lee *et al.,* [20].

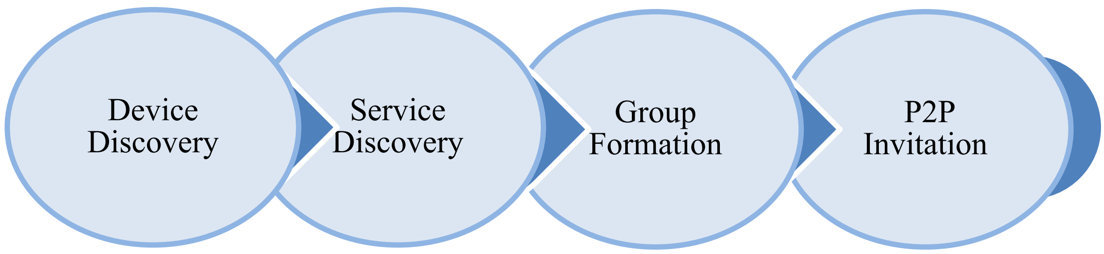

Fig. 1. The process before group formation in a P2P connection with WF

This article explains the details of the scoping review conducted as part of our long-term research on exploiting wireless technologies in mobile devices to form WCN. The concept of WCN was elaborated in another article [22]. Due to the high potential of the Wi-Fi probing mechanism in forming WCN, this scoping review narrows its focus to the SD protocol. It's important to note that this research specifically targets the Android system as its platform. These criteria were incorporated when forming the search string for the a priori protocol of the scoping review. To the best of our knowledge, this is the first scoping review article that delves into the use of SD in WFD to create WCNs. The next section explains the relevant literature in the field, followed by methodology applied in the scoping review, and finally, the results and conclusions.

2. Literature Review

In terms of the relevant literature in the field, researchers have been utilizing Wi-Fi protocols to facilitate data exchange and communication in WCN. Some researchers have also employed WFD protocol procedures to enable data dissemination. For instance, Sha *et al.,* [24] created a mobile application that distributes tasks to stream a video to peers via a WFD network. The software works by assigning peers the task of downloading videos and then combining the downloaded segments to compile the complete video. Links *et al.,* [25] and El Alami *et al.,* [26] have created a data exchange framework for a mobile device capable of transmitting data to an internet server even when there is no internet connection. Pan and Wang [27] proposed a data exchange scheme by modifying the source code of the device discovery procedure of the WFD protocol. The device name field of the probe request and response packets has been modified to carry the message to be transmitted between devices.

Some researchers utilized Wi-Fi's probe frames for various purposes, primarily related to network analysis, performance optimization, and security research. For instance, Rusca *et al.,* [28] focused their research on non-intrusive and independent datasets for user localization, introducing the concept of bounded locations to infer users' trajectories over time. The study provides insights into localization errors and proposes a new method for estimating user trajectories. Hou *et al.,* [29] and Wan *et al.,* [30] utilized Wi-Fi probe data to study human flow. By capturing and analysing the probe messages, the proposed model generated visualizations of the movement and patterns of pedestrians in an open area. Gebru *et al.,* [31] and Jundee *et al.,* [32] employed commercial sensors and devices like Raspberry Pis equipped with a Wi-Fi interface to capture Wi-Fi probe data. Chang *et al.,* [33] and Jundee *et al.,* [32] demonstrated the potential of Wi-Fi probe data for analysing mobility and travel behaviour in different scenarios, such as campus networks and public transit. The literature has highlighted the increasing importance of Wi-Fi probe data in studying human behaviour and movement patterns in various settings, ranging from urban environments and shopping malls to public transit systems. Additionally, the literature provides insights into the potential of the probe, or at least similar types of management frames, to play additional roles in data exchange. Hence, it is believed that the dissemination of probe messages, such as in the SD procedure of the WFD protocol could be utilized to contribute to the forming of a WCN.

Furthermore, some researchers have applied the concept of multi-layer operations and abstraction on top of WFD protocols to facilitate communication and data exchange operations. Li *et al.,* [34] developed an intergroup and intragroup communication model by utilizing WFD at the application layer. The proposed model adopted the role-switching mechanism, which is similar to findings reported in other literature [11,30]. The authors proposed the handover procedure for GO and Group Member (GM) roles in a WFD group, using a fuzzy-logic-based normalized quantitative decision algorithm. Khawaja *et al.,* [36] introduced the ad-hoc collaboration space framework, which offers an API abstraction layer atop the WFD protocol. This API allows developers to integrate a data communication model into their mobile applications.

Based on the literature, it can be observed that there have been numerous efforts by researchers in the research area over the years. However, research on developing a comprehensive model for WCNs based on WFD protocol is still inconclusive. There is a need for in-depth investigations and rigorous studies to design an efficient and standardized model that can be successfully implemented in mobile devices. Hence, a scoping review was conducted to comprehend the extent to which the WFD protocol has been exploited in the formation of WCNs. The following section explains the methodology implemented for the scoping review process.

3. Methodology

In general, there are several types of literature research methods to discover research related to a chosen topic. Some of the common techniques include traditional literature reviews, scoping reviews, and systematic reviews. The purpose of a scoping review is to provide a thorough and systematic overview of the existing literature on a particular research topic. The review technique was introduced by Arksey and O'Malley in 2005 through an article published [37]. In the article, Arksey and O'Malley proposed the first scoping review framework, comprising six procedures. The framework was then enhanced by Levac and colleagues in 2010 [38]. The enhanced version of the scoping review framework includes a more comprehensive process for each procedure. In 2015, the working group of the JBI produced a detailed manual for conducting scoping reviews. The manual has been updated, and the original framework has been revised to encompass nine procedures [39]. The approach introduced by JBI aligns with the PRISMA-SCR checklist. Therefore, the checklist has been incorporated into this research to serve as a standard reporting guideline for a scoping review. It is important to note that only a portion of the checklist items were introduced, as the checklist covers a wide array of components for a more comprehensive literature review, which may not be necessary for the current stage. The primary goal of the scoping reviews conducted in this research was to study an overview of the literature, focusing on WFD and SD protocols under the MANET domain. The review also aimed to investigate the solutions developed by researchers in the relevant field and the measurements involved in evaluating the performance of these solutions.

3.1 Priori Protocol of the Scoping Review

The PRISMA extension for scoping reviews (PRISMA-ScR) was published in 2018 [40]. As explained by Tricco *et al.,* [40], scoping reviews can be conducted to “examine the extent, range, and nature of the evidence on a topic or question”. **Error! Reference source not found.** lists the procedure for the conducted scoping reviews, adapted from the JBI manual [39] and PRISMA-ScR checklist . The following section demonstrates the execution of procedures 1-6 for this research, while procedures 7-9 are presented in the results section of this article.

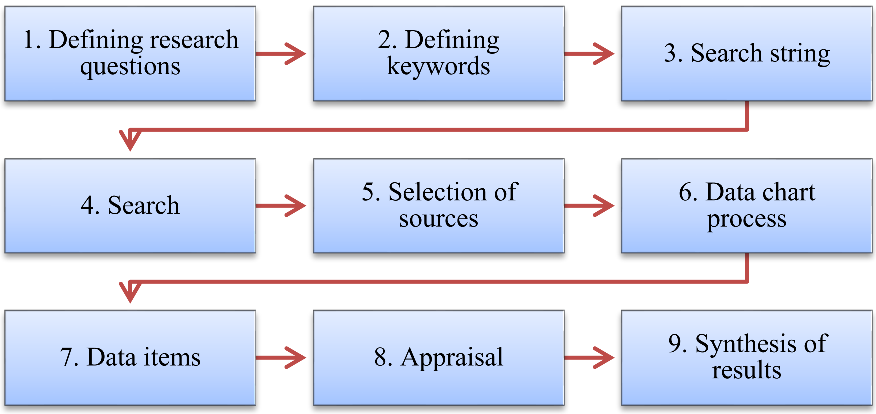

Fig. 2. Process of conducting scoping reviews

i. Defining research questions
RQ1: How are the WFD and SD protocols of Android phones utilized in the research area?
Inclusion criteria, concept: Utilization of WFD protocol
RQ2: What are the techniques and parameters to measure the performance of the solutions?
Inclusion criteria, concept: Performance measurement techniques
RQ3: What performance metrics are being measured?
Inclusion criteria, concept: performance metrics
ii. Defining keywords and context
Keywords: D2D communications; peer-to-peer network; MANET, Wi-Fi Direct; service discovery, performance, measurement, Android
Context: Android platform, Wi-Fi Direct Protocol, from 2009 to 2023 (this is because, according to the Wi-Fi P2P Technical Specification, the first version was released on 2009-12-09, and the scoping review was conducted in the second quarter of 2023)

iii. Search string

The relevant keywords are D2D communications; peer-to-peer network; MANET, Wi-Fi Direct; service discovery, performance, measurement, and Android.

Filter the keywords:

The relationship between the keywords listed is illustrated in **Error! Reference source not found.**. The full term for D2D is “device-to-device”; it is similar to the term P2P. Some researchers use P2P and D2D interchangeably. D2D or P2P networking is a sub-domain of MANET. Using the terms D2D or P2P automatically covers the MANET domain. Therefore, MANET can be excluded from the keyword list. The focus of the scoping reviews is to explore relevant research that utilized WFD and SD protocol. The WFD protocol is a type of P2P network in the Android OS. Hence, the keywords “P2P network” and Android can be omitted. For performance measurement, there is no one standard term to be used, and usually, the measurement methods will be reported to evaluate the proposed solution. Therefore, the keywords "performance" and "measurement" were not included in the search string. Lastly, the final keywords related to the aim of the scoping reviews were, "Wi-Fi Direct", and "Service Discovery".

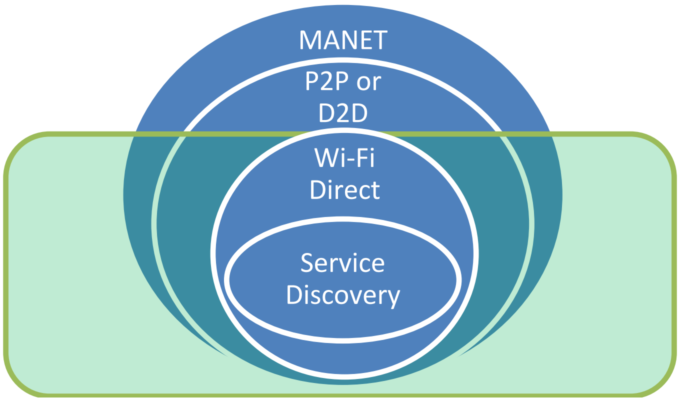

Fig. 3. The relationship between the keywords identified for scoping reviews

iv. Search

The search was conducted on three well-established information technology databases, which are IEEE Xplore, ACM digital, and Scopus. The detailed search strings for each database are reported in the next chapter. The search results’ bib text was downloaded and imported into Mendeley for the filtering and screening processes.

v. Selection of sources

a) An article was included if it met the following criteria:
- The article reported on the application of peer-to-peer service discovery.
- The article evaluated the performance of the peer-to-peer discovery or service discovery protocol.
- The article was available in English.

b) An article was excluded if it met the following criteria:
- The article did not implement Wi-Fi P2P
- The article did not focus on the Wi-Fi protocol for P2P network formation (e.g., Bluetooth, NFC, Zigbee)
- The full text of the article was not available (e.g., conference abstracts)

vi. Data charting process
The data charting process was conducted independently. The collected literature data was filtered, tabulated, organized, and presented in table form.

4. Findings and Results

This section discusses the findings of the scoping review, covering steps 7-9 of the priori protocol. At the beginning of the search, the literature search engine yielded numerous irrelevant results. It was also noted that researchers used different spellings for the term "Wi-Fi." After multiple attempts and filters, the search strings "Wi-Fi direct," "Wi-Fi direct," or "Wi-Fi direct," and "service discovery" were employed to gather only articles describing Wi-Fi Direct. Table 1 lists the search strings used for three databases: IEEE Xplore, ACM Digital Library, and Scopus. The search results were exported as BibTeX and imported into Mendeley for filtering and screening.

Table 1
Search string used for individual database

Database	Search string
IEEE Xplore	(“Full Text & Metadata”:”wifi direct” or “wi fi direct” or “wi-fi direct”) AND (“Full Text & Metadata”:”service discovery”) 2009-2023
ACM digital library	“query”: {Title:(“wi-fi direct” OR “wifi direct” OR “wi fi direct”) AND “service discovery”} OR Abstract:(“wi-fi direct” OR “wifi direct” OR “wi fi direct”) AND “service discovery”} OR Keyword:(“wi-fi direct” OR “wifi direct” OR “wi fi direct”) AND “service discovery”} OR Fulltext:(“wi-fi direct” OR “wifi direct” OR “wi fi direct”) AND “service discovery”}} “filter”: {Publication Date: (01/01/2009 TO 07/31/2023)}
Scopus	ALL ((“wifi direct” OR “wi-fi direct” OR “wi fi direct”) AND “service discovery”) AND PUBYEAR > 2008 AND PUBYEAR > 2008

As depicted in **Error! Reference source not found.**, the search string returned a total of 186 records. Mendeley was utilized to filter out the 21 duplicate articles. The screening process then involved reading the titles and abstracts. Only 39 articles were deemed relevant to the research based on the abstract explanations. Among these, 38 full texts were downloaded, and 1 article was inaccessible. The 38 full-text articles were skimmed, and three were excluded—one due to its irrelevance to the research topic, and two for having duplicate content.

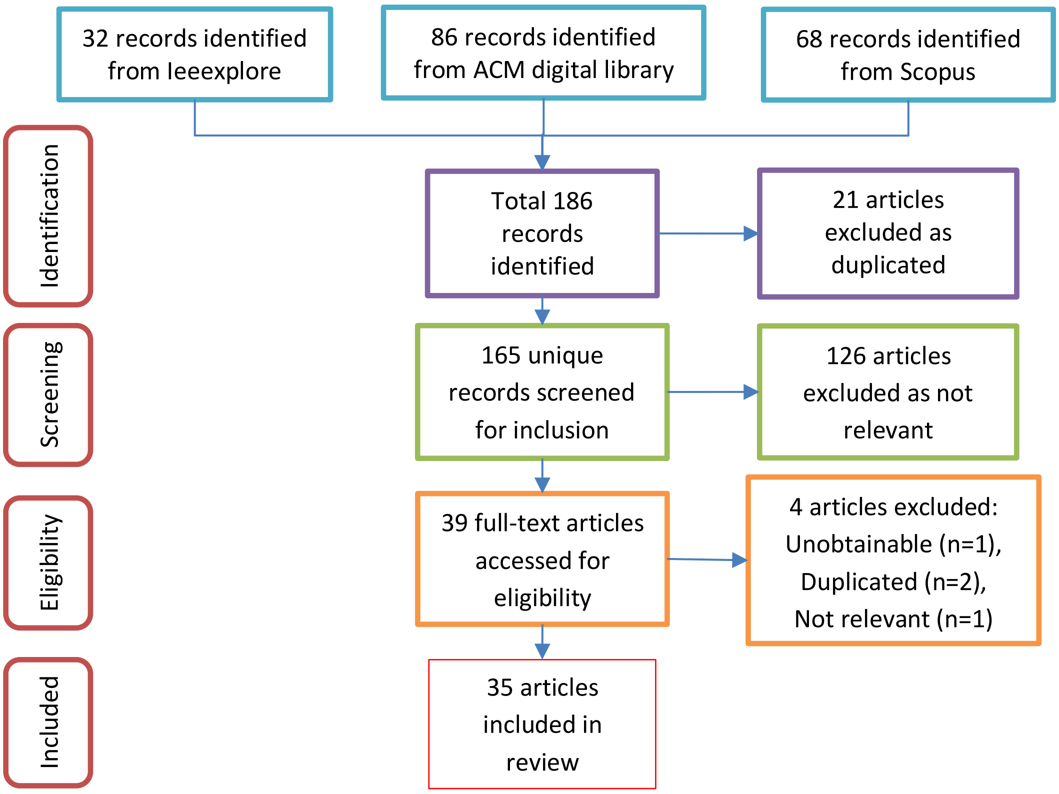

Fig. 4. PRISMA-SCR flowchart of study selection process for scoping review

Ultimately, 35 articles were reviewed, and the findings were tabulated, as shown in Table 2. The table provides a comprehensive summary of the research work, encompassing the aims and findings of the papers, parameters measured for result verification, and observations regarding limitations or shortcomings of the work.

Table 2
A summary of the tabulated information based on the collected literature

Title	Paper's Aim and Findings	Parameters Measured	Limitations Based on Observation
A Collaborative Video Download Application Based on Wi-Fi Direct [24]	A protocol to offload the video download task to peers and combine the downloaded chunks with the group owner. Broadcast video chunk download service request through SD in WFD. Peers around performed the download task and transferred it to the GO through the WFD protocol.	Video Data Rate (KBps), Downlink Rate (KBps), WFD Transferring Rate (KBps), Connection Period (s), Disconnection Period (s), Number of Group Members, Buffered Playback time (s), Playback duration of a Video Chunk (s), Rounds for the GO Receiving Video Chunks from the Group Members n, Total Number of Chunks, Time for Playing Video in, The Extra Buffered Video Content	The protocol modelled was applicable for video download operation only and not supporting other resources or data exchange.

Ad-Hoc Collaboration Space for Distributed Cross Device Mobile Application Development [36]	Introduced an Ad hoc collaboration space for the developers who are developing apps that require interaction and synchronization with other devices in Ad-hoc mode. The framework simplified the existing Wi-Fi Direct protocol by introducing abstraction and three classes to manage services, events, and socket connections. A drawing app was developed and used as the testing application to measure performance. The app demonstrated synchronization on UI updates when users on different devices performed various operations (e.g., drawing).	-SD and Group formation time -Synchronization time across devices connected -Impact of distance on data synchronization -state synchronization time on device joined later -state update synchronization time on device rejoined -memory overhead, memory used during collaboration activities	The framework introduced was limited to the local area with a restricted number of devices only. Limited info about how the time was recorded.
A Framework for Enabling Internet Access Using Wi-Fi Peer-To-Peer Links [41] & A Framework for Hotspot Support Using WFD Based D2D Links [42]	Introduced a protocol that allows users to send data to the Internet without requiring Internet access to be enabled on the smartphone. SD was used to disseminate the message to the server through gateway nodes with an Internet connection.	GPS coordinates, actual time for peer to discover the service (n), waiting time for peer to rebroadcast or forward message (m), propagation time Tpr, transmission time Ttr, computation time Tc, n=Tpr+Ttr+Tc Tpr = Distance/wave speed (3.10x10^8 speed of light) Ttr= packet size/bit rate overhead = generated messages/successful messages Simulation with WiDiSi	The protocol introduced supports one-way communication to the server and there is no mechanism to guarantee the successful transmission of data.

A Framework for P2P Networking for Smart Devices Using WFD [43]	Introduced a framework to support the formation and management of groups of communication devices. Used the WFD protocol to establish communication between peers via GO. Utilized SD to broadcast uniqueID, device name, and user name to propagate the service. Assuming N=500, M=20, alpha=1, beta=5, bandwidth by GO = 11.5Kbps, and bandwidth by the client = 2.5Kbps—significantly lower than the standard WFD speed of 54Mbps—so overhead can be ignored. Adding a new peer takes 1 and 6 seconds for the GO and clients to process, respectively. Removing a peer takes 30 and 55 seconds for the GO and clients to handle, respectively.	N= max length(bits) of heartbeat msg M=max number of group members including GO N*M=max length of peers' list msg total number of messages around GO (in and out) =(M-1)/alpha+1/beta messages per sec total number of messages around a client =1/alpha + 1/beta messages per sec Bandwitdh by GO = ((M-1)/alpha x N) + (1/beta x N x M) = ((M-1)/alpha + M/beta) x N bps Bandwidth by client =(1/alpha x N) + (1/beta x N x M) = (1/alpha + M/beta) x N bps	The framework supports communication within group and the devices are associated to an individual group only.
A Group-Less and Energy Efficient Comm Scheme Based on WFD Tech for Emergency Scenes [27]	Proposed a communication scheme to enable message delivery during emergencies. Modified the Android source code's device discovery procedure. Utilized only the find phase and omitted the scan phase. The search and listen operations in the find phase were employed for data exchange. Modified probe request/response packets to include a device name field (32 bytes) for carrying the information. The grid-quorum concept was implemented in scheduling the device to ensure that the search and listen states of the devices avoided overlapping.	Simulation with self-developed Python simulator	Although the proposed communication scheme has successfully reduced message delivery latency, developers must recompile the Android source code for implementation, and this might not be practical.

A Local Comm. System Over WFD: Implementation and Performance Evaluation [34]	Introduced intergroup and intragroup communication methods with WFD at the application layer. Intragroup Communication: GO periodically broadcasted GM list information (IP) to all GMs in the group, ensuring that all members receive a copy of the other members in the group. GO-GM communication outperformed GM-GM communication. A fuzzy logic-based, formalized quantitative decision algorithm was applied to the self-adaptive GO and GM mobile-controlled handover (MCHO) mechanism for the handover procedure. The MCHO mechanism with fuzzy logic has reduced handover decision delays.	Intragroup -average throughput (Mbps), Packet loss rate(%), over load (Mbps 0-100) average throughput(Mbps), Packet loss rate(%), delay(ms) over distance (0-42m) Intergroup -average throughput (Mbps), Packet loss rate(%), delay(ms) over 0-9 interference group (2 devices)	The methods introduced might introduce additional overhead with the implementation of the fuzzy logic algorithm. Moreover, handover execution requires disconnection, discovery, and formation (average 7.8 seconds).
A Measurement Study on D2D Comm Tech For IIOT [44]	Measured the performance and energy consumption of WFH, WFD and BT. BT in the working state consumed almost the equal power compared to WFH and WFD in the idle states. The power consumption of WFH was the same as WFD. File sending showed a higher current than file receiving for BT, WFH, and WFD. At 5 GHz, consumption of power is higher than at 2.4 GHz. WFD in the scanning state showed the lowest current consumption. The average transmission rate of BT between two devices was 1.6 Mbps, compared to 50 Mbps for WFH and WFD.	-power consumption -transmission performance -TCP/UDP performance Iperf was used to measure TCP/UDP performance.	The measurement was conducted based on smartphones only and no other IOT devices used. Furthermore, only BT,WFH and WFD were compared and other important wireless protocols such as Zigbee and NFC were not included.
Alert Dissemination Protocol Using SD in WFD [45]	Proposed a protocol that utilizes the SD mechanism in WFD to disseminate alert. Introduced a local alert management and remote alert management scheme. Embedded the alert data in SD records. -Tp = 120/(speed of light) = 120/(3x10^8)=0.4 ms -Tt(depended on transmission rate&length of frame) Tt= 5000x8(bit)/(5.4x107)= 0.7ms T = 0.4microS + 0.7ms ~ 0.7ms	-assumed transmission speed 54mbps(standard54-600Mbps), distance 120m(indoor 70m,outdoor 250m) -assumed discovery request and response frames have same size -T(time needed to deliver a service discovery frame), Tp(propagation delay) & Tt(transmission time)	Assuming SD request and response frames have the same length of L bytes, which might not be true. Limited devices involved in the protocol testing.

Benchmarking Wireless Protocols for Feasibility in Supporting Crowdsourced Mobile Computing [46]	To study D2D multimedia content dissemination with Wi-Fi Client server, Wi-Fi Mobile server, Wi-Fi direct and Wi-Fi TDLS. h1-file retrieval could be accelerated through D2D comm. h2-D2D can help in reducing congestion or load on Access Point / server side. h1 not true, h2 true, decentralized D2D technique reduce 65% traffic at the access points.	-file download time over number of devices -traffic (MB) handled by the AP over number of devices for each protocol -download time clients over number of servers for each protocol -traffic (MB) handled by the server for each protocol	Most of the testing results did not cover the WFD protocol and network overlay which is also important to achieve a more comprehensive evaluation.
BWMesh: Multi-Hop Connectivity Framework on Android For Proximity Service [47]	Introduced a heterogeneous network scheme (BT+WFD) to facilitate multi-hop networking. WFD as the additional communication interface other than BT. Device A connected to device B via BT while concurrently connecting to device C via WFD. A prototype was developed to enable chatting among users in proximity in a multi-hop way without an internet connection.	ability to pass message to peers	The scheme which required switching between BT and WFD might impose overhead. The proposed schema requires user interaction during device pairing.
Content Sharing Using P2PSIP Protocol in WFD [48]	Applied the P2PSIP protocol on top of the WFD network for multimedia sharing. Typical WFD formation operations: create a group, and client devices joined the group. Then, the application leveraged the P2PSIP protocol for sharing operations.	number of participants over transmission duration in ms	The content sharing model required the user's manual operation.
Context-Aware Configuration and Management of WFD Groups for Real Opp Networks [49]	Introduced a WFD-GM protocol to enhance network connectivity and the message dissemination process. The protocol leveraged SD to exchange context information (computational resources and battery status) to elect the GO. GO exchanged its credentials with nodes to skip the manual WPS provisioning process. Devices periodically exchanged context to update group configuration. The WFD-GM protocol improved network connectivity and message dissemination compared to the baseline protocol in low- and medium-mobility environments. Performance was the same as baseline in a high mobility scenario.	-frequency of the messages exchanged. -the percentage of success message dissemination, -battery consumption. Simulation with one simulator	The evaluation and testing were conducted on simulator and not on real devices.

Development of MANET Over WFD With Off-The-Shelf Android Phones [16]	Introduced an algorithm for multihop communication by leveraging WFD's GO and client connection procedures. Focused on the GO and client connection models. All devices were programmed to be GO when there was no transmission, so that all devices were discoverable and ready to be connected. When devices were discovered, routing tables were generated based on the MAC addresses exchanged.	no measurement involved, only demonstrated interface of routing table formation and message delivery process	Routing table formation time and message delivery time were not measured
Development of Offline Chat App Framework for Resilient Disaster Management [50]	Developed a framework for communication during disaster. Wireless SD of WFD was used for peer to discover the service available. Then connect to the network in Wi-Fi infrastructure mode with router.	likert's scale in terms of functionality, reliability, usability, efficiency, maintainability, and portability	Framework requires additional hardware to work.
Efficient Multigroup Formation and Communication Protocol for Wi-Fi Direct [51]	Introduced a protocol for multi-group communication. Leverage SD protocol for peers to exchange rank (calculated based on battery info, device with higher rank to become GO) and Soft AP credential. GO then used the information to choose and appoint a GM to be a proxy member to forward messages between groups.	no measurement involved, only demonstrated interface of a chat app	Altering the system’s source code may not be practical. No mechanism in place to keep the network running when a Group Owner (GO) or client with a specific role left the group.

Device to Device Communications With WFD: Overview and Experiment [14]	Experimental evaluation of the WFD's performance in real scenarios, in terms of the delays to be expected in practice when WFD devices discover each other and establish a connection. Evaluated the performance of the WFD power-saving protocol known as the Notice of Absence. Standard and persistent group formation used the same baseline for discovery, but persistent used an invitation mechanism and standard used GO negotiation; persistent used past recorded data for WPS provisioning. In autonomous mode, the device announces itself as "GO" and sets up a group for clients. Initial scan delayed all procedures by at least 3 seconds. The CDF graph showed randomness in the discovery delay (1-7s) for three different group formations. The discovery time in autonomous mode was constant (3s). Autonomous and standard showed similar delays because GO negotiation took less time than WPS provisioning, so the overall time taken for formation was equal.80% of the time, autonomous group formation took less than 5s; persistent and standard took about 8–9s.	-group formation delay -performance-energy -trade-offs of NOA energy saving protocol -Simulation with event-driven simulator (ns3 from reference)	The experiment was conducted only on laptops and could not represent all mobile devices. Connections formed for experiment were established in a controlled environment.

Efficient Data Dissemination for Wi-Fi P2p Networks by Unicasting Among Wi-Fi P2p Groups [52]	Reduce the load of (GO) in the Working Flow Diagram (WFD) group by dividing the main WFD group into several smaller groups. Then, use store-carry-forward mechanisms to disseminate data. SD protocol to exchange information for group formation and repair procedures. Switching between GO and client to disseminate data with store-and-forward algorithm. In simulation, average network formation time increased when the number of devices increased and reduced when the maximum number of devices in a group at higher value. SD Discovery Time Experiment >8 devices provided 1-4 kinds of services; a device was asked to find a service from a service provider. Run for 20 times. SD times varied; longest = 15.2s, average = 4s	-network formation time -data dissemination time -network repair time -SD discovery time -Simulation with even-based Wi-Fi p2p network simulator	In SD implementation, a peer might not be able to identify the correct service in time, or conflicts between services might occur and hence delay the dissemination process.
Efficient Multigroup Formation and Communication Protocol for Wi-Fi Direct [51]	Introduced a protocol for multi-group communication. Leverage SD protocol for peers to exchange rank (calculated based on battery info, device with higher rank to become GO) and Soft AP credential. GO then used the information to choose and appoint a GM to be a proxy member to forward messages between groups.	no measurement involved, only demonstrated interface of a chat app	The source code of the existing protocol was altered to enable devices to be on different subnets and to allow static assignment for validation-related devices. This might not be practical.
Enhancing The QOS of Mobile-Based SW Over WFD [53]	Introduced a model for choosing the primary GO (Group Owner) and backup device in a P2P (Peer-to-Peer) network. The model was used to identify a backup node to replace GO during group formation. Service information was injected into a probe request to reduce the time and procedures of the service discovery phase. group reformation time with ERRM reduced by 80% compared to standard group formation time	group formation (conventional method) and reformation time with 2,3,4 devices	The mobile devices' state is dynamic most of the time, so the backup device that would replace GO might not be available by the time it needs to replace GO, or when it needs to replace GO, there might be another device with a more potential value for the parameters.

Hychat: A Hybrid Interactive Chat System for Mobile Social Networking In Proximity [54]	Introduced a hybrid interactive chat system that enables p2p communication. Switching between offline communication with WFD and online over the Internet. Profile matching occurred prior to building connections among devices. Profile (username and interest) information was encoded into the device name field of the WFD. During the group forming stage, profiles were exchanged and a decision to form a connection was made based on the interest fields in the profiles. When the Wi-Fi Direct was disconnected, the application switched to online mode.	no measurement involved, only demonstrated interface of a chat app	The periodic detection time might affect the efficiency of mode switching.
Inter-Cars Safely Communication System Based on Android Smartphone [55]	Introduced a system to alert nearby vehicles via SMS or WFD when an emergency occurs nearby. Standard WFD connection formation and exchanging alert and coordinate information through the connection formed.	no measurement involved, only demonstrated interface of a chat app	The system introduced required manual user intervention and may not be suitable for VANET.
Multi-Group Message Communication on Android Smartphones Via WFD [56]	Introduced a model that enables multi-group message communication by exploiting the group formation capabilities of WFD to exchange information between multiple groups. Each device generated an identifier and holds a server socket that constantly listened for any mode to be activated. Modes: register, update, transfer, and scatter. Register, the peer must register itself to GO. Devices moved into a listening server socket after registration. In update mode, GO forwarded a hash table with to all peers in the group. In transfer mode, GO operated as the middleware to forward data. In scatter mode, peers disconnected from GO and connected to another GO, then went back to the original GO.	delay over size of file transferred (image 1-40mb), audio & video (1-100mb)	The model might experience device identifier duplication issue upon the growing number of mobile devices in the communication environment.

Network-Assisted D2D Comm: Implementing A Tech Prototype for Cellular Traffic Offloading [57]	Introduced a model to offload cellular traffic to D2D connection. When the peers were at proximity, data exchanged over WFD. Cellular networks were used to exchange mobile information (to the server) to assist the D2D device discovery and connection establishment stages. Therefore, the GO negotiation was skipped, and the GO was elected by the server.	-sustainable rate -stream latency -signalling latency -activation delay Simulation with system-level simulations with a self-designed simulation tool	The model requires an active connection to the cellular network. Root access is required on Android devices, and this may not be practical.
Nextcontact: Neighbour Discovery Mechanism for OppNet And Node Movement Based Neighbour Discovery in Opp Net [58]	Introduce a node discovery scheme called "NextContact" for neighbour discovery, based on an equation used to calculate the probing interval. An equation to calculate the probe interval and tested the idea in ONE simulator. Result showed peer detection of more than 80% with a coEff value of 0.4 and above. When compared with the PISTON v2 algorithm, NextContact showed better performance in terms of a higher percentage of peer discovery, lower energy consumption, and a higher message delivery ratio.	Tprob = 2R/(coEf*~V). R=communication range of device (wifi range), 0<coEf<1, ~V = ~D/(T+Tpause) ~D=accumulative distance travelled T=total time travel Tpause=time paused during ~D parameters for ONE simulator: simulation area, number of nodes transmission range, transmission rate, movement speed , mobility model, message, generation rate, size of messages	Device discovery cannot guarantee message delivery ratios, as there are other effects that need to be considered in the WFD protocol.
Performance Evaluation of The Dynamic Multi-Hop in Proximity Radio Access Network [59]	Proposed a model for multi-hop communications networks based on the WFD protocol. Introduced the theoretical P-RAN (Proximity Radio Access Network) mechanism in a simulator to simulate multihop communication. Data was offloaded to the neighbouring devices and then relayed to the cellular network to reach its destination.	-throughput rate (Mbps) -energy consumption J -Simulation with 5G toolbox and WLAN toolbox in MATLAB R2021b	The experiment on the multihop model was conducted in the MATLAB simulation platform.

Privateshare: Measuring D2D User Behaviour and Transmission Quality [60]	Developed a prototype called PrivateShare for D2D content sharing. Real-time data and usage behaviour were recorded for the use of other researchers. Applied QR or NFC to exchange credentials for a D2D connection. Used standard WFD connection procedures to form D2D connections and data exchange. After connection was formed, the device automatically synchronized content to be shared with peers.	-duration of device being in range -time available to communicate -signal strength -upstream and downstream bandwidth -success of D2D content transmissions -number of errors encountered while using the app	The prototype utilized the existing WFD protocol and only worked for intragroup data exchange.
Quality-Aware Traffic Offloading in Wireless Network [61]	Introduced a framework called QATO which offloads network tasks to peers with better service quality over cell stations. DNS-SD was used to exchange network information. The network task was sent to the offload engine module. The offload engine compared information from the local and neighbouring networks before making an offload decision. Evaluation showed energy savings and less delay in task completion. Evaluation of SD showed that devices took an average of 2 seconds to discover a peer.	-uplink and downlink throughput of different carrier -power consumption when using carrier connection. -Simulation with Trace-driven simulation	NA
Seamless Group Reformation in Wi-Fi P2p Network Using Dormant Backend Links [62]	Proposed a concept of seamless WFD group reformation to reduce group disruption time by implementing the Dormant Backend Link method. In the GO negotiation request/response frame, an extra field was added with the existing GO Intent value for EGO. When group reform was required, the peers in the group have access to the EGO list and automatically know, which GO to connect to next. Experiment conducted with 3, 7, and 10 devices show that more than 90% of group reformations using the SGR+DBL model were completed in less than 1 sec, while group reformations without the model took more than 1 sec.	group formation time	The concept was tested on a laptop, and the findings could not accurately represent the real behaviour of all mobile devices.

Social-Aware D2D Offloading Based on Experimental Mobility and Content Similarity Models [63]	Introduced a model for D2D content sharing that considers mobility parameters, content-related parameters, and social network relationships when identifying potential D2D peers for connection. A model was proposed to identify the optimal D2D connection for data sharing by considering the social network relationships between users, their content interests, and the frequency and duration of contacts between paired users over time and space.	-number of contacts between users -contact duration between users -inter-contact duration -content-related parameters -social network relationships, -social relationship strength -the number of mutual friends between participants -correlation between mobility parameters, -content similarity, -social network links	Privacy could be a concern, for example, user authentication to a personal social network account is required for the system to collect information such as a user ID and friends list to evaluate the level of trust for seamless content sharing.
Testing Nearby P2P Mobile Apps At Large [64]	Introduced a test framework for developers to conduct reproducible and automated tests on P2P apps, which are installed on physical or virtual devices connected to the testing framework environment. Physical mobile devices were connected to the development environment, along with virtual emulators. Experimentation demonstrated that the framework was capable of detecting bugs in the apps installed on these devices. The framework could also assess whether an app was capable of detecting peers, determine the number of peers detected, establish connections, and send messages to the maximum number of users. Furthermore, the framework allowed testers to fine-tune the discovery delay and connection strategy for both Wi-Fi (1:M) and Bluetooth (M:M) scenarios.	-the number of bugs detected (permission bugs, scalability bugs, protocol bugs, pervasive bugs) -number of users that received a message sent	Limited measurements have been taken on wireless performance parameters.

Towards Cloudless Co-Located Social Media On Android [65]	WFD for intragroup, BT for intergroup connections. WFD protocol was utilized for SD and GO negotiation. Connection was formed either with a WFD or BT connection. Gradient-routing GR algorithm was used for unicast message dissemination. The flooding algorithm and GBS algorithm were compared for evaluation. In 1:M broadcast scenario. Delivery ratios with flooding and CBS were about 90% in 300, 600, and 1200 messages. CBS generated 40% of messages generated by flooding. In the M:1 scenario. Delivery ratios with GR and CBS are about 97%, in 300, 600, and 1200 messages, respectively. GR generated 40-50% of messages generated by CBS. In both scenario flooding algorithms created broadcast storms.	-delivery rate -message load	BT limits intergroup connection distance. Interconnectivity between peers not maintained. Disconnections are not automatically detected or repaired in BT.
Usable - A Communication Framework for Ubiquitous Systems [66]	Introduced a multihop framework with carry-and-forward routing algorithms for developers. The connection-aware layer was responsible for neighbour discovery, connection, message exchange, and neighbour disconnection. The network layer had the responsibility of routing messages to destinations via BT or Wi-Fi, using the multi-hop algorithm such as flooding or AODV. The Application layer managed application instance operations, message sending and receiving procedures. message in JSON structure. It was found that RTT for AODV was around 750 ms for 3 hops. For each additional hop, the time increased by around 250 ms. The standard deviation was around 200ms.	-RTT of the message using AODV -The number of messages lost -The number of messages received -The ratio between the total number of messages sent and received	The experiment did not consider group formation time and the mobility of devices.

WD2: An Improved WFD Group Formation Protocol [67]	Introduced a group formation protocol based on the WFD protocol designed for larger groups of devices. The RSSI values collected from peers during the device discovery were used for calculating the intent value that was then encoded in the probe request frame before forward. The device with the highest IV become the GO. The average throughput of the group, determined by the GO elected by WD2, exceeded that of Android's default random GO selection mechanism. The group formation time on Android was longer than WD2. The simulator replicates the behaviour of WFD on Android using the WFD API, which includes wifiP2pmanager, NodeP2pinfo, and eventListener.	-Throughput -Group formation time	The protocol has not been integrated into a practical application and hence no real-time performance measurement was conducted.
WiDiSi: A WFD Simulator [68]	A WFD simulator on top of PeerSim was built for the Android platform. The simulator replicated the behaviour of WFD on Android using the WFD API of Android, which includes wifiP2pmanager, NodeP2pinfo and eventListener.	-package drop rate -delay for package transfer	The simulator only supports Bonjour SD. Channels and channelListeners are not available. Listener callbacks for the 'success' method are not implemented. Implement listeners only to inform the app that the required information is ready to be picked up.

Wi-Fi Direct Performance Evaluation for V2P Communications [69]	Proposed a solution to increase connection time in WFD. The proposed method of stuffing the beacon involved overloading fields in the beacon to carry information. A string of bytes containing the message identifier, fragment number, flag (indicating the presence of more fragments), and message contents was embedded into the beacon. The information was embedded into the 32-byte device name, following the structure: device name + device ID, coordinates, speed, and travel direction. Testing the proposed method resulted in a packet delivery rate of 99% and an inter-reception time of 1 second for packets.	-communication range, -Packet Delivery Rate -Packet Inter-Reception Time -Simulation with OMNet, INET	The total amount of information to be transmitted is limited to only 32 bytes.
Wi-Fi Direct Research - Current Status and Future Perspectives [70]	A review article about Wi-Fi Direct. Focused on speeding up Group formation. The author proposed to encode the IV&Peer list in IE for Probe request and respond so devices can use it to decide GO without going through the GO negotiation stage. Simulation finding 1. standard group formation time: average device discovery time required 1070 ms >negotiate GO took 850ms-9000ms, average 2198ms (50% time spent to form a group) >group forming took 903ms (median 873ms) 2. implement proposed scheme Group formation time: 2devices- overall Group formation delay improved by 20% 5devices- Group formation average 8000ms (almost 3x faster)	-delay of standard Group Formation scheme presented in normalized CDF -Simulation with mac80211_hwsim	The proposed solution was theory-based, with no real devices involved in testing.

5. Conclusions

This article demonstrated the scoping review process and its results. The purpose of the scoping review conducted in this research was to provide an overview of the literature, with a focus on the SD protocol of the WFD within the MANET domain. The review aimed to investigate solutions developed by researchers in this relevant field and the measurements used to evaluate the performance of these solutions. The priori protocol for the scoping review, as explained in the methodology section, encompassed steps 1 through 9, which range from defining the research questions to synthesizing the results. The search was conducted in three databases: IEEE Xplore, ACM Digital Library, and Scopus. Mendeley was utilized for organizing and filtering the articles. Initially, a total of 186 records were identified across these databases. After removing 21 duplicates, 127 irrelevant articles, 1 unobtainable article, and 2 duplicated content articles, 35 articles were selected for a thorough review. These reviewed articles were then summarized and presented in table form. The table included information, such as the article title, objectives, measurement parameters and techniques, as well as the findings and contributions of each work. This table will serve as a valuable resource for researchers in the same field, helping them easily understand the work conducted by other researchers in a similar area.

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