Wireless Community Networks from Routing Perspective: A Systematic Review

Safaa S. Matter*, Imad F. Al Shaikhli, Aisha H. A. Hashim, Amr Mohmed Soliman, Walaa A. Abdellatief, Abdelmoty M. Ahmed, and Mahmoud M. Khattab

***Abstract*— Recently, the internet has created a global community by connecting millions of individuals, devices, and organizations. Unfortunately, internet connectivity is still not available to many people around the world. To provide everyone with internet access, network infrastructures must be expanded, and internet connection costs must be reduced, particularly in developing regions. Therefore, Wireless Community Networks (WCNs) have emerged as a crucial alternative for individuals who lack direct access to internet services provided by traditional internet service providers. This research paper aims to investigate the routing protocols that have been widely employed in WCNs over the past decade. Specifically, it focuses on evaluating the strengths and limitations of these protocols to assess their effectiveness and reliability in establishing optimal routing paths for end-to-end message delivery across the network. A set of recommendations and future directions are proposed to facilitate further research into unresolved challenges related to WCN routing protocols.**

***Index Terms*— Wireless community networks, Routing, MPR, Babel, BMX6, OLSR**

I. Introduction

Modern information and communication technologies have the potential to significantly enhance the lifestyle of people in sparsely populated regions. This is accomplished through linking them to the international community, enhancing their access to community resources, and promoting their participation in policy decisions [1]. Unfortunately, a significant number of rural regions do not have enough access to any kind of electronic data, which puts residents, especially those living in poverty, at risk of lagging further behind the large urban world [2]. In addition, the installation of communication networks requires significant financial expenditures. Therefore, major telecommunications companies have chosen to focus their efforts on urban regions because these regions have a larger paying capacity and a higher density of population. As a result of that, WCNs were developed to enable rural communities to establish cost-effective communication networks, thereby realizing the objective of connecting all individuals to the Internet.

The International Telecommunication Union (ITU) revealed in its report on September 12, 2023, that about one-third of the global population, which is about 2.6 billion people, remains offline [3]. As efforts continue to solve this problem, the need for WCNs continues. A recent example of ongoing WCN project is the XOneFi project released on January 31, 2023, by UNICEF in Nigeria. According to the ITU, about three-quarters of Nigerians have no internet connection, and this project will help individuals and small communities get affordable, high-speed internet connections [4].

WCNs, as a decentralized commons-based not centralized commercial-based approach, can provide better services in some fields than commercial alternatives through the inclusiveness of all participants, the assurance of transparency between users, providing incentives for participation in some tasks such as management and maintenance, and supporting social goals [5]. With the emphasis on its importance in some places [6, 7] and the cost that has already been spent on establishing it in many places, many opinions call for WCNs sustainability instead of replacement [8]. Therefore, some new policy recommendations for the service providers to facilitate the spread and expansion of WCNs are suggested to overcome the gap in the current regulations used in the telecommunication system which undervalues the political, social, and economical role of WCNs in societies [9]. New community business models are also needed that grant unbiased, free, and open communication to the users and avoid the organizational and economical breakdown of the current WCNs business model [10]. Therefore, nowadays, we can find that the use of a WCNs in rural areas extends beyond just accessing the internet [11]. Especially with the move towards smart sustainable cities, the first generation of WCNs become a candidate to evolve to its smart generation to support more advanced applications such as blockchain and AI [7]. A network of this kind can be made available by the local government on a non-profit basis for the purposes of education or the collection of information, such as

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S. S. Matter is an Assistant Professor at Department of Computer Science, Applied College, King Khalid University, Abha, 61421, Saudi Arabia (Corresponding Author, Email: safaamatter2010@gmail.com).

I. F. Al Shaikhli is a Professor at Faculty of Engineering, Duzce University, Turkey (Email: imadyaseen39@yahoo.com).

A. H. A. Hashim is a Professor at Department of Electrical and Electronic Engineering, International Islamic University Malaysia, Kuala Lumpur, 50728, Malaysia (Email: aisha@iium.edu.my).

A. M. Soliman is an Assistant Professor at Special Education Dept, College of Education, King Khalid University, Abha, Saudi Arabia (Email: psy_amro@hotmail.com).

W. A. Abdellatief is a lecturer at Information Technology Department, Faculty of Computers and Information, Menoufia University, Shebin El-kom, 32511, Egypt (Email: walaaali285@gmail.com).

A. M. Ahmed is an Assistant Professor at College of Computer Science, Nahda University, Beni Suef, Egypt (Email: abd2005moty@yahoo.com).

M. M. Khattab is a Postdoctoral Researcher at Department of Computer Science, Kulliyyah of Information and Communication Technology, International Islamic University Malaysia, Kuala Lumpur, 50728, Malaysia (Email: mmkhattab2000@gmail.com).

comments on civic services [12]. Therefore, WCNs are used in many applications, such as but not limited to digital media repositories, electronic governance platforms, telecommunication services, telemedicine frameworks, communal web infrastructures, radio broadcasting systems, and as supportive networking foundations for Non-Governmental Organizations (NGOs) [13].

WCN is a wireless mesh network that is developed using a bottom-up methodology [14]. In a WCN, a particular small number of users establish an alternate, self-managed, community-based networking infrastructure for themselves and their peers [15]. WCN is often utilized for two primary purposes: facilitating inter-user communications (such as messaging, conversing, and sharing) and providing internet connection where it is not already accessible. In today's world, there is a variety of inexpensive equipment available on the market that can be used to establish wireless connections across a range of up to tens of kilometers [16]. It is also possible to share a few internet connections using a multi-hopping strategy to cover a relatively wide region.

In Fig. 1, the structure of a WCN with components needed for its setup is previewed. As seen, WCN is composed of three network entities, which are the internet gateway, access points, and mobile devices. The internet gateway is used as an end point that allows access to the wired internet infrastructure. According to the area of the network, more than one gateway can be used to provide coverage for all members of the community. The access points are considered the main backbone of the network. With their multiple communication capabilities, end-users with mobile devices are able to join the network and get access to the wired internet infrastructure. They are low-cost and easy to deploy devices with one or multiple directional antennas and wireless interface cards. The end users, on their mobile devices, such as laptops or cell phones, who need an internet connection, can join the network through access points that relay data to the internet gateway.

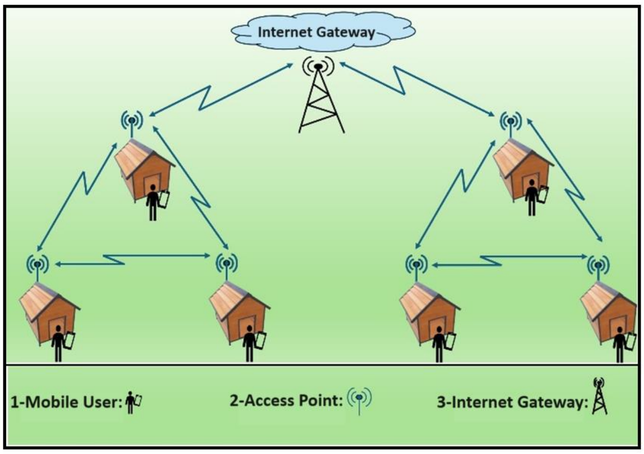

Fig. 1. The structure of the WCN with the components required to set it up.

The use of WCNs has an automatic growth nature because of the existence of many nodes that can readily use manual (decentralized) control [13]. In this research, we focus on the routing layer of WCNs. Nodes in these networks can benefit from the well-established mesh routing protocols for Mobile Ad hoc Networks (MANETs). The reason is that these protocols are able to provide self-adaptation to network changes and good determination of the routing paths for end-to-end messages delivery throughout the network [17].

This paper undertakes to investigate the currently existing routing protocols that are commonly used for WCNs. Additionally, the primary focus is placed on illustrating the essential strengths and limitations associated with these protocols, with the aim of evaluating their efficacy and reliability in facilitating optimal routing path selection for easy end-to-end message transmission across the network. Finally, a series of recommendations and future research directions have been formulated to support further investigation of unresolved challenges regarding WCN routing protocols.

The rest of this paper is organized as follows: Section II illustrates WCNs around the world. Section III describes a taxonomy of routing protocols used for WCNs. Different WCN routing protocols are represented in Sections IV–X. A detailed discussion, security and privacy aspects, some recommendations, and future work directions are offered in Sections XI and XII, and the paper is concluded in Section XIII. For the reader's convenience, the main abbreviations used in this paper are summarized in Table I.

TABLE I
NOTATIONS AND DEFINITIONS

WCNs	Wireless Community Networks
NGOs	Non-Governmental Organizations
MANET	Mobile Ad hoc Network
AWMN	Athens Wireless Metropolitan Network
B4RN	Broadband for the Rural North
FFDN	Federation French Data Network
NWNP	Nepal Wireless Networking Project
OLSR	Optimized Link State Routing Protocol
OLSRv2	OLSR version 2
ETX	Expected Transmission count metric
BATMAN	Better Approach To Mobile Ad hoc Networking
IPv6	Internet Protocol version 6
BMX6	BatMan-eXperimental version 6 protocol
RFC	Request for Comment
IHU	I Heard You message
rxcost	rating the link cost
CPU	Central Processing Unit
Babel-SFE	Babel with Spare Forwarding Entries
RP	Report messages
TC	Topology Control message
MPRs	Multipoint Relays
OGM	OriGinator messages
Cc	Closeness centrality
BGP	Border Gateway Protocol
SDN	Software Defined Networking
WMN	Wireless Mesh Network
LD-OLSR	Link Defined OLSR
OCI-OLSR	Optimized Control Interval OLSR
TLVs	Type Length Values
NHDP	Neighborhood Discovery Protocol
DSP	Dynamic Shortest Path
DAT	Directional Airtime
CBR	Constant Bit Rate
EFW	Expected Forwarding counter
MEFW	Minimum EFW
JEFW	Joint EFW
MAC	Media Access Control
ELARM	Energy-Load Aware Routing Metric
HWMNs	Hybrid Wireless Mesh Networks
WCETT	Weighted Cumulative Expected Transmission Time
D-WCETT	Dynamic WCETT
PPO	Packet Priority-Oriented
PP-QoS	PPO-Quality of Service
PSO	Particle Swarm Optimization
GA	Genetic Algorithm
ACO	Ant Colony Optimization
MP-OLSR	Multipath OLSR
ETX-OLSR	Expected Transmission count OLSR

ML-OLSR	Minimum Loss OLSR
MD-OLSR	Minimum Delay OLSR
BW-OLSR	Bandwidth OLSR
NPC	Node Performing the Computation
OPNET	Optimized Network Engineering Tools
EM-OLSR	Energy and Mobility OLSR
MBA-OLSR	Multipath Battery-Aware OLSR
L-OLSR	Localization technology OLSR
W-OLSR	Weighted OLSR
MOLSR	Modified OLSR
AOLSR	Airborne OLSR
LQI	Link Quality Indicator
RSSI	Received Signal Strength Indication

II. WCNs Around the World

Hundreds of WCNs are active all over the world, encompassing both rural and urban areas, as well as rich and poor regions. WCNs are present practically everywhere, such as in [18], which works worldwide. In the north of America, there are many WCNs, such as [19], [20], [21], [22], [23], [24], and [25]. In Europe, there are many WCNs that reach thousands of nodes, such as [26] in Denmark, Athens Wireless Metropolitan Network (AWMN) in Greece [27], [28] in Germany, [29] in the Czech Republic, [30] in Spain, Broadband for the Rural North (B4RN) in England [31], and the Federation French Data Network (FFDN) in France [32]. Additionally, there are many other European WCNs, including [33], [34], [35], [36], and [37]. In Africa, [38], [39], and [40] are examples of these networks. While the Nepal Wireless Networking Project (NWNP) in Nepal [41] and [42] in Thailand are famous WCNs in Asia. A summary of the world's most notable WCNs is concluded in Table II. Routing Protocols Commonly Used in WCNs

In a dynamic environment such as WCN, routing techniques which decide the route of each data packet to its destination are considered a crucial and challenging function. Therefore, it is insistent that community network routing protocols be able to adapt to the continuous changes of the network. These networks are built by community members, with new members always joining the network, which leads to network expansion and topology change. WCNs are also managed by its members in a decentralized fashion, where each node works also as a router that relays data to others [15].

As mentioned earlier, WCNs are a mesh of nodes, as they are probably composed of various layer 2 devices. Since the connectivity between the various nodes is not assured and the stability of links may vary over time, several WCNs employ mesh routing protocols that were previously used for MANETs to overcome this. A significant number of WCNs employ adapted versions of the Optimized Link State Routing (OLSR) protocol for their operational needs [43]. It has been expanded with the Expected Transmission Count metric (ETX) as well as some other features to be used in WCNs. Some WCNs have implemented OLSRv2, which represents the evolution of the original OLSR protocol to its second version. Furthermore, an alternative routing protocol employed in WCNs is the Better Approach To Mobile Ad hoc Networking (BATMAN), offering an enhanced methodology for mobile ad hoc network connectivity [44]. It is a routing protocol for the second layer, so it creates a bridged network. Furthermore, it ensures a simple client transition across wireless nodes without error occurrence. The Internet Protocol version 6 (IPv6) is the basis for the BatMan-eXperimental version 6 (BMX6) protocol. Moreover, BMX6 is designed to construct the underlying social architecture of WCNs [45]. Concurrently, Babel is another routing protocol employed within WCNs as a distance-vector routing protocol to avoid loops, which is documented in the Request for Comment (RFC) 6126 [46].

TABLE II
WCNs AROUND THE WORLD

WCN Name	Location	Found	Size	Env.	Internet	Network Technology
Free2Air	London, England	1999	--	Urban	yes	wired, WiFi
Consume	Clink St., London, England	2000	> 200 nodes	Urban	yes	WiFi
SeattleWireless	Seattle, Washington, USA	2000	> 80 nodes	Urban	yes	WiFi, VoIP
Djurslands.net	Djursland, Denmark	2000	> 27000 households	Rural	yes	WiFi
NYCwireless	New York, USA	2001	> 145 nodes	Urban	yes	WiFi
AWMN	Greece	2002	> 2473 nodes	Urban, Rural	yes	WiFi
Freifunk	Germany	2002	> 41000 nodes	Urban, Rural	yes	fiber, WiFi
Wireless Leiden	Leiden, Netherlands	2002	> 300 nodes	Urban, Rural	yes	WiFi
Czfree.net	Prague, Czech Republic	2002	> 2000 transmitters	Urban, Rural	yes	WiFi
Funkfeuer	Austria	2003	> 300 nodes	Urban, Rural	yes	wireless
Ninux	Italy	2003	> 352 active nodes	Urban, Rural	no	WiFi
NWNP	Nepal	2003	> 150 villages	Rural	yes	WiFi
Guifi.net	Catalonia, Spain	2004	> 37534 nodes	Urban, Rural	yes	fiber, WiFi
FON	Worldwide	2006	> 23 million hotspots	Urban, Rural	yes	WiFi
Wireless Philadelphia	Philadelphia, USA	2007	> 350 kilometer^2	Urban	yes	WiFi
MadMesh	Madison, USA	2007	> 250 nodes	Urban	yes	WiFi
Google WiFi	California, USA	2008	> 500 nodes	Urban	yes	WiFi
Rhizomatica	Oaxaca, Mexico	2009	> 700 nodes	Rural	yes	wireless
B4RN	Norfolk & Suffolk, England	2011	> 7000 homes	Rural	yes	fiber
FFDN	France	2011	28 WCNs	Urban, Rural	yes	WiFi, fiber
Cisco Meraki	California, USA	2012	> 1407 nodes	Urban, Indoor	no	wireless
TakNET	Tak province, Thailand	2013	> 2000 homes	Rural	yes	WiFi
Zenzeleni.net	Eastern Cape, South Africa	2013	> 60 kilometer2	Rural	yes	WiFi, VoIP public phone
Mesh Bukavu	Bukavu, Congo	2015	> 15 nodes	Urban	yes	WiFi
Home of Compassion	Cape Town, South Africa	2015	> 20 active APs	Urban	yes	WiFi
XOneFi	Nigeria	2023	Ongoing	Rural	yes	WiFi

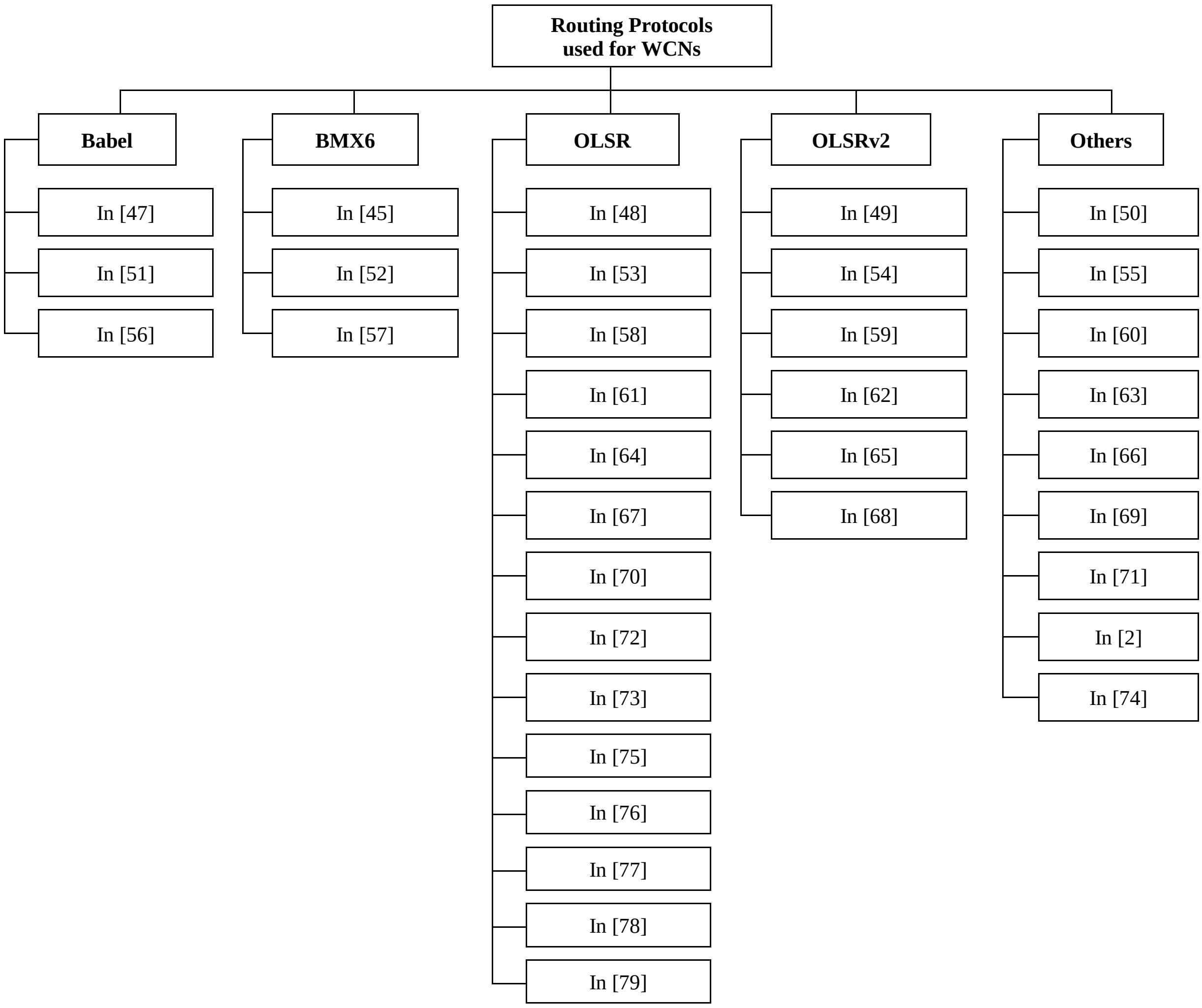

Fig. 2. A taxonomy of routing protocols used for WCNs.

In this paper, a taxonomy of routing protocols used for WCNs has been designed. The WCNs routing protocols have been classified into five classes, namely: Babel, BMX6, OLSR, OLSRv2, and other routing protocols applied to WCNs, as summarized in Fig. 2. Firstly, a review is made of the basic problems that the researchers identified in their research work. Secondly, the research methodology that these researchers use to solve these problems is presented. Finally, the strengths and limitations of every method are discussed to determine its efficiency and quality in WCNs. Thus, the above-mentioned routing protocols are presented in the subsequent sections, focusing on their underlying mechanisms, such as neighbor discovery and topology dissemination. Table III summarizes the differences between Babel, BMX6, and OLSR in terms of reducing overhead, minimizing convergence time, dissemination mechanisms, and sending data. Table IV summarizes the comparison of OLSR and OLSRv2 in terms of flexibility, packet format, neighborhood discovery, extensions for security, and selection of the shortest routes. Furthermore, the comparison between the multipoint relay selection methods based on the improved OLSR routing protocols is summarized in Table V. Additionally, Table VI presents a comprehensive overview of significant techniques, along with a thorough examination of their respective strengths and limitations.

III. Babel Routing Protocol

A. Protocol Overview

Babel is classified as a proactive distance vector routing protocol that is built upon the foundational principles of the Bellman-Ford protocol. Moreover, it focuses on limiting routing pathologies like black holes or routing loops. In order to achieve its concern, it does two functions. Firstly, it uses a good feasibility condition to filter the received routing updates and determine which ones to consider [80]. A feasible routing update for a route should have a smaller metric than any other routing update for this route. Secondly, the destination node generates a sequence number to be added to a routing update. This sequence number advertises and decides the routing changes that can be compared to the metric. The similar sequence numbers have the same information [46].

- **Neighborhood discovery**

Babel nodes exchange two different types of messages to learn about their surrounding seconds: Hello and I Heard You (IHU) messages [80]. The Hello message is a multicast message that assists nodes in neighborhood discovery as well as rating the link cost (rxcost). Its sequence number is increasing internally with every Hello message. Babel nodes exchange Hello messages every 4 seconds. The primary purpose of the IHU messages is to share the rxcost with the neighborhood, as well as identify the bidirectionality of a link. In theory, IHU messages are intended for unicast transmission. However, in practice, these messages are efficiently combined into a single packet by transmitting them to a multicast address. They are sent by default every 12 seconds [80]. Fig. 3 indicates a usual neighborhood discovery for the Babel routing protocol.

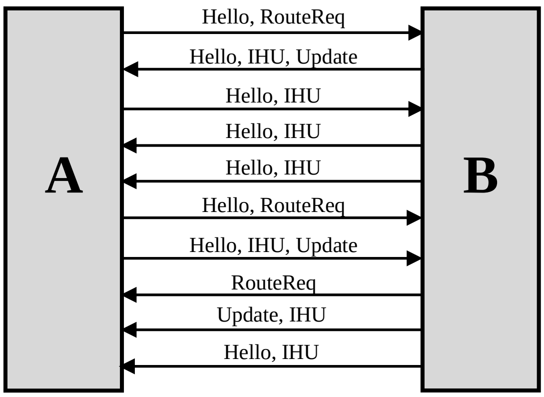

Fig. 3. A neighborhood discovery for Babel routing protocol.

- **Topology distribution**

Babel nodes exchange periodic update messages, so that they can discover their indirect neighbors in seconds [80]. The route update message carries a routing table that includes a route and its own related cost. Furthermore, Babel forces nodes to perform unscheduled route updates if any significant topology change happens, like a considerable metric change or a route retraction. On the other hand, when an update is received by any node, the node checks its feasibility. If the update is feasible, then the node calculates the cumulative metric by merging the update metric with the cost of the link that transfers the update seconds [80]. Fig. 4 shows the Babel topology distribution mechanism.

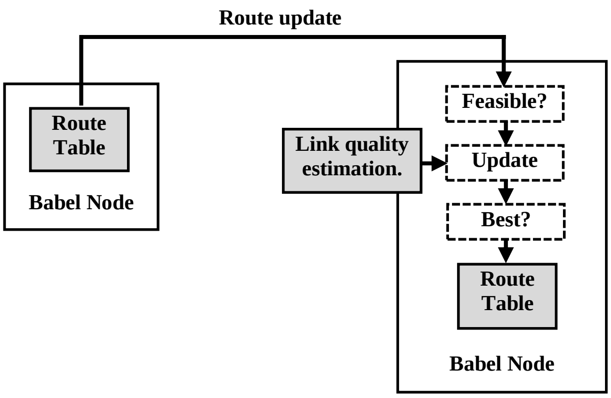

Fig. 4. Babel topology distribution mechanism.

B. Related Works of Babel

Hart et al. in [51] focused on employing the Babel protocol on robotic nodes working in uncontrollable, harsh environments. They studied the problems of the Babel protocol through seven practical tests and deduced two problems. The first was the flapping between more than one route for the same data flow, and the second was the slow route convergence time. To overcome the first problem, they suggested using a threshold for the ETX values. The main reason for that is to use hysteresis when the ETX value is the same as the threshold, which will prevent route flapping during the same data flow. They also noticed that increasing the Hello packet rate of the Bable's protocol decreased the convergence time. Both solutions helped to provide an uninterrupted connection and make the Babel protocol more suitable for real-time transmissions. Neumann et al. [47] compared the performance of the Babel Protocol with BMX6 and OLSR. The study aims to identify which one is better in which condition of the network. The scalability, the performance, and the stability of these protocols are measured through simulation and experimentation. In low-density networks characterized by few stable links, Babel emerges as the lightweight routing protocol, exhibiting minimal memory utilization, low Central Processing Unit (CPU) requirements, and low control-traffic overhead. However, in dense deployments where link changes occur frequently, both OLSR and BMX6 outperform Babel in terms of their ability to manage overhead, maintain stability, and even have self-healing capabilities. This superiority can be attributed to their consistent rate of sending topology and routing update messages. In [56], Backhaus et al. tried to add robustness to the Babel routing protocol and proposed the Babel with Spare Forwarding Entries (Babel-SFE) protocol. They added a reactive methodology to the protocol by adding entries that include backup paths that can be used when the main paths fail. And to overcome any access overhead, they disabled the regular periodic updates and relied on the reactive updates triggered in case of a link outage or topology change.

IV. BMX6 Routing Protocol

A. Protocol Overview

The principal objective of the BMX6 protocol is to minimize routing overhead while maintaining a high level of responsiveness to changes within the network architecture [81]. To fulfill this aim, BMX6 employs stateful compression techniques in communications between adjacent nodes, effectively reducing the size of periodic messages and thereby achieving a reduction in routing overhead. This stateful exchange is facilitated by the utilization of compact (16-bit) local identifiers, optimizing the protocol's efficiency. Additionally, BMX6 distinguishes itself by its strategic dissemination of information, selectively propagating data based on its context—local versus global and static versus dynamic. This approach significantly enhances the protocol's flexibility in responding to network dynamics [81].

In the classification of information, static information is that which is implausible to change, such as addresses and other details of a node. All these attributes are fully collected in the comprehensive description of the node. On the other side, link and path cost estimations are dynamic information. Moreover, global vs. local separation identifies what information is kept locally (such as local identifiers and link costs) and what information is flooded globally throughout the network (such as path costs and node descriptions) [81].

- **Neighborhood discovery**

The neighbor discovery is done in the same manner as Babel, as shown in Fig. 3. By default, transmissions of Hello messages are directed toward a designated multicast address every half-second. Furthermore, there is a sequence number that is generated with each new Hello message. In contrast, Report (RP) messages are regularly sent every 0.5 seconds to monitor the count of Hello messages transmitted and received by a node. This allows an accurate evaluation of the costs involved in link transmission and reception [81].

- **Topology distribution**

In BMX6, spreading routes through the network is done by OriGinator messages (OGM) that are flooded over the network by each node [81]. Each node sends OGM every 5 seconds, and then the node that receives it forwards it again. The OGM includes a local identifier of the sender for the originator node. In addition, the message incorporates a sequence number and a metric that represents the cost of reaching both the sender and the originator of the message. This metric is calculated by adding the metric value included in the received OGM with the cost of the link from the sender. Then, the node compares the calculated cost with the cost of other neighbors. If the calculated cost is lower than the cost associated with another neighboring node, the node proceeds to update the OGM and subsequently multicasts it to the network. On the other hand, the static information is shared only if the local identifier refers to an unknown node [81]. Fig. 5 shows the BMX6 topology distribution mechanism.

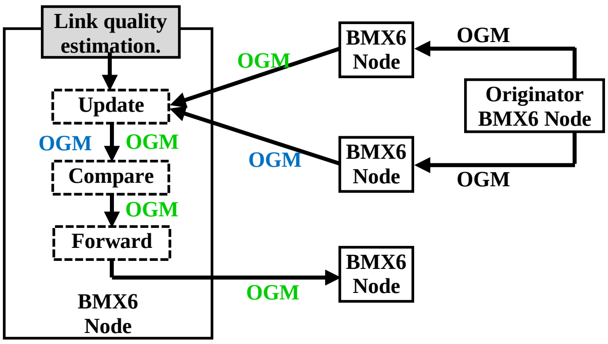

Fig. 5. BMX6 topology distribution mechanism.

B. Related Works of BMX6

Neumann et al. [45] conducted a comprehensive analysis of the scalability achieved in routing within WCNs using the BMX6 protocol. They specifically focus on evaluating the convergence time and the overhead associated with both BMX6 and OLSR protocols as the number of nodes and network diameter increase. The results obtained indicated that the performance of BMX6 surpasses OLSR when a new node is added to the network. Cerdà-Alabern et al. [52] performed experiments on real world WCN deployment to evaluate the performance of the BMX6 routing protocol. Their methodology incorporates a widely recognized conflict-graph model to derive the expected capacity estimations for various multi-hop routes. Subsequently, these estimations are compared with experimentally measured throughput values obtained from the same paths. Additionally, the capability of the BMX6 routing protocol to select optimal paths is examined. The findings reveal that, for the most part, BMX6 consistently selects the most optimal paths. However, it is noteworthy that while the conflict-graph model provides accurate information regarding the core network graph, it tends to overestimate the available capacity.

V. OLSR Routing Protocol

A. Protocol Overview

The optimization of OLSR occurs throughout the flooding process [82]. Multipoint Relays (MPRs) are the backbone of the OLSR protocol. During the flooding process, only a subset of the nodes, known as MPRs, propagate the broadcast messages. Since all nodes forward the broadcast messages, the traffic overhead becomes less than it was with the initial flooding strategy [82].

- **Neighborhood discovery**

OLSR can find neighbors by periodically sending out Hello messages. In addition to the sender's known neighbors and the link quality, the Hello message also includes an increasing internal sequence number. Every two seconds, the Hello messages are dispatched [82]. Table III summarizes the differences between Babel, BMX6, and OLSR. The OLSR routing protocol neighborhood finding process is depicted in Fig. 6.

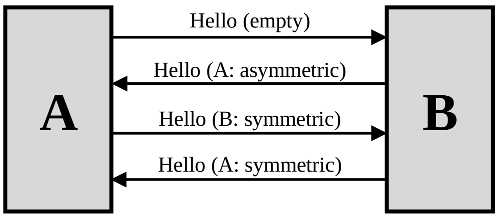

Fig. 6. Neighborhood discovery for OLSR routing protocol.

- **Topology distribution**

In line with other link-state routing protocols, the OLSR protocol operates by flooding Topology Control (TC) signals throughout the network, allowing each node to share a subset of the network's topology. TC messages, which remain unchanged, are generated periodically by all nodes within the network and propagated. These TC messages provide information regarding the nodes involved in the path as well as the quality of the links utilized for message transmission [82]. Fig. 7 shows the OLSR topology distribution mechanism.

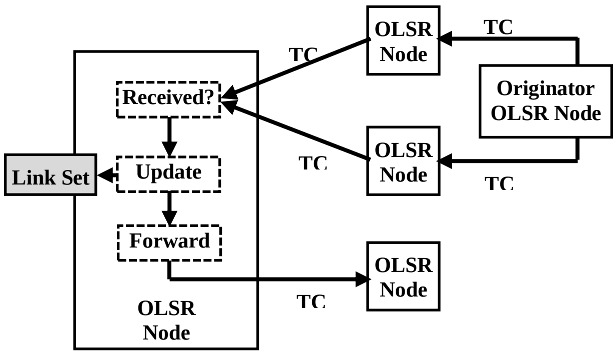

Fig. 7. OLSR topology distribution mechanism.

B. Related Works of OLSR

Maccari and Leonardo [61] performed an analysis of the Ninux [37] network to study and illustrate the impact of the routing metrics and the centrality metrics. The ETX metric, the shortest path betweenness centrality, and the Closeness centrality (Cc) are tested on this network, which uses OLSR as a routing protocol. The analysis shows that the Cc metric can be successfully merged with OLSR. Dropping the ETX metric allows reintroducing multipoint relays to save resources. However, without using ETX, bad links are chosen until the moment when they break down. Avonts et al. [64] studied the results of a survey sent to different WCN organizations. They aim to show the differences between most of these networks and index their common challenges. Regarding the routing, OLSR comes in first place as the main routing protocol used by ten networks (53%). In the second place comes the Border Gateway Protocol (BGP), used in three networks (16%), and in third place is BATMAN, used in two networks (11%). The remaining four networks use different types of routing protocols. Detti et al. [67] presented a novel proposition that integrates the principles of Software Defined Networking (SDN) with the architecture of a Wireless Mesh Network (WMN), wherein the WMN is composed of OpenFlow-enabled switches. The data traffic routing is engineered using the traditional OpenFlow controller. In [76], authors proposed the Link Defined OLSR (LD-OLSR) which determined the link quality by successful data broadcasting and successful back acknowledgments. Therefore, the ETX of links considers both packet forwarding probability and acknowledgement receiving probability. Authors in [77] and [78] proposed different methods for optimal MPR nodes selection. In their first paper, they used the min-max algorithm to select MPRs with the largest signal range. It is noted that this method increased the PDR and decreased the packet loss rate and the topology control packets. In their second paper, they suggested the construction of a preferred broadcasting group that includes the most active nodes for MPRs selection. This method helped to decrease the number of overhead messages. In [79], the Optimized Control Interval-Optimized Link State Routing (OCI-OLSR) protocol was proposed. Authors reduced the neighbor hold time to 1s instead of the maximum waiting period used in the original OLSR. This resulted in a delay reduction. They also used optimal control intervals which reflect the topology changes to constantly include fresher routes in the routing process. OLSRv2 Routing Protocol

C. Protocol Overview

The second version of the OLSR protocol is OLSRv2, which is defined in RFC7181. OLSRv2 has the same key features as OLSR, such as MPRs, as well as other improvements like modularity and flexibility. As shown in Table IV, OLSRv2 differs from OLSR in several respects:

1) Firstly, regarding packet format, Hello and TC messages in OLSR have the same packet format. However, the general MANET packet format, which is defined in RFC 5444, is used in OLSRv2. Furthermore, in the OLSRv2 protocol, Type Length Values (TLVs) defined in RFC5497 are utilized, along with message jitter mechanisms defined in RFC5148.
2) Secondly, concerning neighborhood discovery, Hello messages are used in OLSR to get information about neighbors. However, the Neighborhood Discovery Protocol (NHDP) is used in OLSRv2 for discovering neighbors.
3) Thirdly, for the shortest route selection, OLSR uses hop count, but OLSRv2 uses link metrics. The minimum hop count is not always the best metric, as it does not guarantee good link quality.
4) Finally, regarding security, OLSRv2 has extensions for security, as signatures can be attached to packet or message TLVs. However, the fixed packet/message format of OLSR brings signature problems.

D. Related Works of OLSRv2

Clausen et al. [49] found that the traffic of the binary format of OLSR is less than the traffic of the flexible RFC5444 packet format of OLSRv2. Herberg and Ulrich [54] aimed to enhance the performance of the routing by speeding up the shortest path calculation algorithm. This is achieved by decreasing the required CPU time using a Dynamic Shortest Path (DSP) calculation algorithm. Results shown that DSP requires less time to calculate the shortest paths, especially for networks with high density. Barz et al. [62] evaluated the OLSRv2 performance. In the case of an IPv6-only setup, the traffic of the routing process for OLSRv2 is less than that of OLSR for high-density networks. Barz et al. [68] added a new metric called Directional Airtime (DAT) to deal with the heterogeneity of links in WCNs. This metric is based on a proposed architecture for the node, which is called hybrid node design. This design separates the radio terminals of the node and the router terminal. The calculation of the DAT value involves determining the proportion of successfully received frames based on the link speed. The findings indicated that this approach leads to a more robust route selection process and improved throughput. The novel DAT metric consistently generates high-quality network paths, resulting in superior performance of the enhanced OLSRv2 protocol compared to OLSR in various scenarios.

TABLE III
THE DIFFERENCES BETWEEN BABEL, BMX6, AND OLSR

	Babel	BMX6	OLSR
Reducing overhead	By retaining long intervals between periodic updates.	By compacting periodic messages as much as possible.	Nearby nodes share updates more than remote nodes.
Minimizing convergence time	Unscheduled updates are sent when significant network changes.	Very frequent exchange of messages.	Update intervals are kept small.
Dissemination mechanism	Complete routing table is shared locally.	Every node periodically advertises its existence.	The MPR method is used for distributing link information.
Sending data	Uses history-sensitive route selection.	Nodes store only a basic route and forward data to the optimal next node.	Uses hop count for routes selection process.

TABLE IV
COMPARISON OF OLSR AND OLSRV2

	OLSR	OLSRv2
Flexibility	Not modular	More modular and more flexible
Packet Format	Binary packet format (fixed format)	TLV packet format defined in RFC5444 (flexible format)
Neighborhood Discovery	Uses Hello messages to gather neighborhood data	Neighbor discovery is facilitated using NHDP
Extensions for Security	Packet TLVs can include attached signatures	Fixed packet/message formatting presents signatures challenges
Selection of Shortest Routes	Hop count	Link metric

VI. OTHER ROUTING PROTOCOLS APPLIED ON WCNS

Ikeda et al. [50] evaluated the performance of the Hybrid Wireless Mesh Routing Protocol (HWMP) using the Network Simulator Version 3 (NS-3) simulator. HWMP represents an integration of two distinct routing strategies: the Ad hoc On-demand Distance Vector (AODV) protocol and methodologies grounded in tree-based routing. This protocol is described in IEEE 802.11s. There are reactive and proactive components that work together to provide efficient and optimum path selection in mesh networks. Experiments with multiple flows at a Constant Bit Rate (CBR) are carried out. According to the findings, real-time applications such as video streaming become more difficult when the transmission rate is increased to higher values and as the number of connections increases to 30. This causes an increase in the number of delays and jitters.

Paris et al. [55] studied the problem of selfish nodes in WCNs. Previous routing protocols cannot choose the network paths with the highest rate of delivery when there are intermediate nodes that have selfish forwarding behavior. Consequently, this study introduces a cross-layer routing metric called the Expected Forwarding (EFW) counter along with two alternative enhancements: the Minimum EFW (MEFW) and the Joint EFW (JEFW). These metrics help to choose the most efficient path by considering both the Media Access Control (MAC) layer quality of wireless links and the routing-layer forwarding behavior of network nodes. According to the findings, the proposed solutions significantly boost both the throughput of the network and its level of fairness.

The double shortest path routing strategy was proposed by Zhu et al. to minimize traffic congestion [60]. This was accomplished by concurrently adopting the routing technique that considers the shortest path in both the inter-modules and the intra-modules. When the tunable parameters are set appropriately, the proposed routing technique is significantly better than the conventional shortest-path routing protocol.

Boronat et al. [63] compared a variety of metrics that may be of relevance in practical WCN scenarios. Real topologies derived from a real WCN deployment are used to execute routing scenarios. The routes that were produced by applying the various metrics are compared in terms of length, capacity, and alternate paths. According to the findings, the number of routes with low bandwidth may be reduced by half, while network capacity can increase by up to 25% when using metrics based on real link bandwidth. They concluded that routing based on the shortest path is not enough. The real link capacity must also be considered.

For the Funkfeuer WCN, Millan et al. [66] performed link quality analysis and prediction. This was an important issue to be considered in routing because of the unreliability of the wireless medium. Time series analysis was employed within the routing layer to derive an accurate assessment of link quality for practical applications in WCNs. The results that are acquired from a number of different learning algorithms indicate that the link quality values that are calculated by time series algorithms produce accurate predictions in WCNs. It has been noticed that one of the most important factors for achieving high accuracy in predictions is the size of the training data set. The error rate tends to decrease over time, and this trend is inversely proportional to the size of the data set.

Kanaoka and Yoshihiro [69] studied the delay in multi-channel WMNs that use dynamic metrics. The proposed methodology integrates rapid local channel selection with dynamic metrics to reduce latency issues. The research findings demonstrated that the integration of local link switching, and dynamic metrics proved to be an effective solution for achieving improved network performance in these WMN environments.

A new routing metric named Energy-Load Aware Routing Metric (ELARM) for Hybrid Wireless Mesh Networks (HWMNs) is developed by Kiani et al. [71]. ELARM determines the ideal route based on the stability of the link and the network load conditions. In addition, the energy conditions of the receiving node are used for evaluating link stability. Several simulations are tested to build a direct comparison between the newly proposed metric and two of its most promising predecessors. These predecessors include Weighted Cumulative Expected Transmission Time (WCETT) and its Dynamic variant (D-WCETT). Scenarios are simulated with high mobility to represent the instability of links. The experimental outcomes showed significant enhancements in both the packet delivery ratio and average network latency, despite a slight increase in routing overhead.

Braem et al. [2] studied the BGP behavior of WCNs. The methodology involved analyzing BGP message dumps from two different networks. Subsequently, the obtained results were compared to data collected from the public internet. The comparative analysis showed a significant difference in stability, with WCNs demonstrating substantially lower stability, in contrast to the public internet, which exhibits a higher proportion of update to withdrawal messages. In order to offer the most effective routes for real-time applications, Zhao et al. [74] developed a model for selecting a cross-layer relay node for the routing protocols. Two routing metrics are proposed: the Packet Priority-Oriented (PPO) routing metric and the PPO-Quality of Service (PP-QoS) routing metric. Empirical results derived from a series of simulations indicated that the proposed model exhibited enhanced performance when compared against various established models.

Recent researches start to suggest the use of heuristic optimization methods such as Particle Swarm Optimization and Genetic Algorithm in [83], and Ant Colony Optimization (ACO) in [84] and [85]. In these researches, the problem of route selection between the source and the destination is formulated as an optimization problem that combines the routing metrics in an objective function. While these methods can select more optimal routes than deterministic selection methods, they suffer from higher overhead and processing time.

VII. Improved Versions of the OLSR Protocol

In this section, we focus on the previous work done on the OLSR routing protocol and how it is applied to different types of wireless networks. Table V summarizes a comparative analysis of the various MPR selection strategies as they relate to the enhanced OLSR protocols.

Yi et al. [59] proposed a Multipath OLSR (MP-OLSR) routing protocol where, it is based on OLSRv2 and it is also a hybrid multipath routing protocol. It was implemented to enhance QoS, load balancing, and energy conservation. In addition to including a significant modification to the Dijkstra algorithm, the MPR mechanism was deployed to flood control traffic information throughout the network. The inherently proactive nature of the OLSR protocol is modified to incorporate an on-demand route computation approach within the MP-OLSR protocol, which also transforms the OLSR into a source routing protocol with two cost functions that may generate several disjoint or non-disjoint paths. In terms of packet transmission, the number of hops was utilized as the link cost metric. Initially, all connections between the source and the destination were assigned a cost of "1". However, this uniform cost assignment approach can lead to potential issues such as path congestion or increased energy consumption by intermediate nodes.

Pandey and Baliyan [48] attempted to compare the three different versions of OLSR, which were referred to as ETX, Minimum Loss (ML), and Minimum Delay (MD). OLSR-ETX, as a routing metric, was designed to evaluate the link quality based on the ability to successfully send and receive Hello messages. To decide the link quality between nodes within a network, a probability calculation was performed, which involved assessing the ratio of messages transmitted from node X to node Y to the total number of messages received through Y from X. This calculation allowed for the evaluation of the ETX using equation (1). For this reason, while selecting the route with the shortest path, we take into consideration the path that has the sum of the smallest ETX.

$$\mathrm{ETX} = \frac{1}{\mathrm{P(X)}} \times \mathrm{P(Y)} \qquad (1)$$

The PLINK metric is calculated in the ML-OLSR version as the product $\mathrm{PLINK} = \mathrm{P(X)} \times \mathrm{P(Y)}$, and it was designed to discover the link with the fewest lost packets. The routing table was used to compute the transmission delay that occurs between nodes in MD-OLSR. The path with the smallest delay is the shortest path. It was clear from the comparison of these versions that ETX-OLSR provides higher levels of satisfaction in regard to end-to-end delay and throughput.

The Bandwidth OLSR (BW-OLSR) protocol proposed in [53] was an improved version of RFC 3626 [43]. The authors have refined the MPR selection algorithm by integrating bandwidth as a critical factor in the computation of paths between source and destination nodes within the network. Specifically, within the OLSR protocol, the algorithm calculates multiple potential paths via the node's MPRs associated with the Node Performing the Computation (NPC). Among these, the path chosen was distinguished not by its shortness but by its capacity to include the greatest number of nodes with the highest bandwidth availability. The simulation that was conducted on Optimized Network Engineering Tools (OPNET) for the OLSR version and the BW-OLSR version indicated that the BW-OLSR provides a number of MPRs bigger than those computed by OLSR, which resulted in a considerable increase in rate across the network.

In Energy and Mobility OLSR (EM-OLSR) proposed in [58], the determination of the willingness parameter is predicated upon an evaluation of two critical metrics: the energy and the mobility characteristic of the node, which helps the OLSR protocol reinforce its MPRs selection mechanism. Each individual node independently calculates its residual energy along with the determination of its speed, and then it deduces from these two values the value of willingness, which may be one of three different values, WillignessDefault, WillignessLow, or WillignessHigh, depending on the outcome of the following algorithm:

Algorithm 1: Willingness Calculation

if ((life_time > EnergyThreshold)**&&**(MobilitySpeed > MobilityThreshold) **or** (energy < EnergyThreshold) **&&** (MobilitySpeed <MobilityThreshold))
    willingness = WillignessDefault

if((energy < EnergyThreshold) **&&**(MobilitySpeed > MobilityThreshold))
    willingness = WillignessLow

if((energy > EnergyThreshold) **&&** (MobilitySpeed < MobilityThreshold))
    willingness = WillignessHigh

The simulation experiments undertaken utilizing the NS-2 simulator provided comparative insights into the performance metrics of throughput, packet loss, and energy consumption. Findings from these simulations indicated that the EM-OLSR version demonstrated an improvement over the standard OLSR protocol.

In [65], authors made use of the multipath Dijkstra algorithm. Nevertheless, the preliminary link cost of every link was determined depending on the remaining battery capacity of both nodes. Within the field of network protocol enhancement, particularly concerning the OLSR and its Multipath Variant (MP-OLSR), a notable modification was achieved for the integration of topological data. This revision entails the change of the existing Hello and TC messages to accommodate the inclusion of a node's residual energy metrics. This inclusion was a defining characteristic of the Multipath Battery-Aware OLSR (MBA-OLSR), which integrates energy parameters to inform routing decisions, thereby extending the protocol awareness to encompass energy conservation considerations. Additional TLV may be added for remaining battery information using the TLV method of OLSRv2. Because of these improvements, other nodes in the network were aware of the information about the amount of remaining energy of the battery energy in the local node.

Anbao and Bin [70] proposed a version of OLSR called node Localization technology OLSR (L-OLSR). This L-OLSR incorporated a novel approach within the MPR selection mechanism by considering the angular relationship between two pivotal lines: one connecting the NPC node to the node exhibiting the highest accessibility, labeled NA, and the other linking the NPC node to the prospective MPR candidate, labeled NC. The NC node is selected as the MPR for the NPC node if the angle is near 90, 180, or 270. Using the coordinates of each node, we can derive the NPC-NA, NPC-NC, and NA-NC distances, and then use this information to compute the NC-NPC-NA angle using equation (2).

$$x = \arccos\left(\frac{[(NPC - NA)^2 + (NPC - NC)^2 - (NA - NC)^2]}{2} \times (NA - NC)\right) \quad (2)$$

The simulation conducted by NS-3 demonstrated compelling results regarding the comparison between standard OLSR and L-OLSR. Specifically, it was observed that the number of transmitted packets was substantially higher in standard OLSR compared to L-OLSR. However, both versions of OLSR demonstrated similar numbers of received packets. Consequently, L-OLSR exhibited a notable reduction in the number of missing packets when compared to OLSR. As a result, this proposed solution needs a large quantity of CPU power, which is not appropriate for smart devices with limited computing capacity and battery power.

Weighted OLSR (W-OLSR) proposed in [72] was an extended version that has been created from the standard OLSR with new parameter added to the process of selecting MPRs. This new parameter was called weighted MPR, and it was derived from the residual energy of nodes, the signal strength of the transmitted data, and the latency inherent in data transmission using equation (3).

$$\text{Weighted MPR} = X \times \text{Residual Energy} + Y \times \text{Signal Strength} - Z \times \text{Transmission delay} \quad (3)$$

If the weighted MPR of the node is less than the threshold weight, then the node is regarded as having an MPR. X, Y, and Z are constants. The Hello message is transmitted together with the value of the remaining energy and the transmission time at the source node. The quality of this link (poor or excellent) was evaluated during reception by evaluating the amount of residual energy, the delay in transmission, and the strength of the signal. According to the findings of a comparison between the standard OLSR and W-OLSR, the latter was more effective than the OLSR regarding throughput and the number of lost packets. However, the average energy consumption increased with node density and node speed.

In the Modified OLSR (MOLSR) [73], OLSR was updated so that every node in the network may select its option of "Update" or "Not Update" the Hello and TC messages. This was being done to decrease the cost of borrowing a path, both in terms of the number of jumps required and the quantity of energy required. Depending on the energy capacity of the intermediary nodes, this approach chooses a different path if the threshold is reached. End-to-end delay, overhead routing, and residual energy were just a few of the metrics used to evaluate the effectiveness of this technique. According to the simulation findings, the proposed MOLSR algorithm reduced the network load and the energy consumption significantly. In addition, the average throughput is slightly reduced.

The MPR selection approach that is used by the OLSR protocol has been optimized, and this improvement served as the foundation for the Airborne OLSR (AOLSR) protocol that was presented in [75]. Initially, there are two sets of MPRs for each node: one on the right and one on the left. Then, depending on the location of the destination, the MPRs on either the right side or the left side are utilized for the further rebroadcasting of control and data packets.

VIII. OTHER DIRECTIONS FOR ROUTING MECHANISMS

Some researchers opted to use optimization and AI methods for solving the routing problem or enhancing the performance of existing protocols. For example , in [86], authors proposed the QoS-Aware Software Defined Routing (QASDN) protocol. They studied two separate problems to produce an optimal routing mechanism. The first one is the shortest path selection problem, and the second one is the data caching problem. In the optimization problem of the shortest path selection, authors considered the consumed bandwidth and the number of packets loss as the QoS metrics. The reliability of different types of physical access and the overall network utilization cost is also considered. In the second problem, they aimed to select the optimal APs for caching data along the best route. This is done to prevent memory saturation of the APs and provide more scalability in dense networks. Authors used the Lagrangian Relaxation Based Aggregated Cost (LARAC) algorithm to find all links with the minimum cost of flow between all the network links and to select the optimal APs to cache data. QASDN achieved higher resource utilization than the traditional shortest cost-based algorithm.

Another example, to minimize routes convergence, authors in [87] suggested to use nodes' centrality to formulate an optimization problem for the timer's length of the control messages generation which is selected subject to a predetermined acceptable overhead value. The proposed algorithm named Pop-Routing allows central nodes to generate more information than peripheral nodes. Authors added the Pop-Routing mechanism as an extension to the OLSRv2 and tested it on synthetic and real topologies. The proposed algorithm reduced the number of unreachable destinations and routing loops when compared with OLSRv2. Furthermore, due to the highly dynamic nature of WCNs, link quality is considered an important routing metric and predicting it is also a challenging task. Therefore, In [88], authors evaluated four famous online machine learning techniques for link quality prediction in WCNs. These techniques are the online perceptron (OP) [89], the online regression trees with options (ORTO) [90], the fast incremental model trees with drift detection (FIMT-DD) [91], and the adaptive model rules (AMRules) [92]. Evaluation experiments showed that the accuracy of OP outperformed the other techniques. According to this, they produced a hybrid online prediction algorithm that combines the baseline with OP technique which provided more accurate link quality prediction with less computational load. The testing dataset was collected from Funkfeuer Wien community network [36] with 500 nodes using OLSR routing protocol over about 2000 links between them. Another link quality prediction method was published in [93]. Authors used the deep learning mechanism through recurrent neural network (RNN) to predict the link quality accurately. They tested the proposed protocol on a dataset collected from the real deployment of the Funkfeuer Wien WCN [36]. Authors suggested two RNN variants to produce more accurate prediction than the traditional RNN. They used the long short-term memory recurrent neural networks (LSTM-RNN) version [94] and the gated recurrent unit (GRU) version [95]. LSTM and GRU are common examples of the gating units used in neural networks and have been proved to achieve high efficiency in solving time series prediction problems.

TABLE V
COMPARISON BETWEEN THE MPR SELECTION APPROACHES BASED ON THE IMPROVED OLSR ROUTING VERSIONS.

	Routing Metric	Energy Efficient	Bandwidth	Node Mobility	Link Cost	Hello Message	TC Message	Control Overhead	Simulator
OLSR	Hop Count				✓	✓	✓	✓	NS-2
ETX-OLSR	Expected Transmission Count		✓		✓	✓		✓	NS-2
ML-OLSR	Minimum Loss		✓		✓	✓		✓	NS-2
MD-OLSR	Minimum Delay		✓		✓	✓		✓	NS-2
BW-OLSR	Bandwidth		✓		✓				OPNET
EM-OLSR	Battery Energy Level and Mobility Speed	✓		✓	✓	✓			NS-2
L-OLSR	Node Localization Information				✓				NS-3
W-OLSR	Residual Energy, Signal Strength, and Transmission Delay	✓		✓	✓	✓		✓	
MOLSR	Hello messages and TC messages Expiration Timer	✓			✓	✓	✓	✓	NS-3

TABLE VI
SUMMARY OF THE WCNS ROUTING PROTOCOLS PREVIOUS WORK.

Ref.	Protocol Name	Protocol Methodology	Pros	Cons
[54]	Dynamic shortest path-based routing.	Based on OLSRv2 with the DSP algorithm for shortest path determination.	The use of DSP algorithm reduced the required CPU time, especially in large networks.	It is not efficient in small networks.
[59]	MP-OLSR	Hybrid multipath routing protocol based on OLSRv2 with modified Dijkstra algorithm.	It improved QoS metrics through load-balancing.	Energy efficiency is not considered
[50]	HWMP	Based on AODV protocol with tree-based routing mechanism.	Suitable for low transmission rate applications with small number of connections.	Not suitable for real-time applications. It achieved noticeable delay and jitter for mor than 30 connections.
[53]	BW-OLSR	The bandwidth is used as a route parameter between the source and the destination.	More MPRs nodes are discovered than OLSR.	Network load is much higher than OLSR.
[58]	EM-OLSR	Based on the node's energy and mobility metrics, willingness value is calculated for MPRs selection.	In terms of throughput, packet loss, and energy consumption, it outperforms OLSR.	Link capacity or data load is not considered
[48]	ETX- OLSR ML- OLSR MD-OLSR	OLSR with Link Quality OLSR with Minimum Loss OLSR with Minimum Delay	In terms of the evaluation parameters, ETX-OLSR provides a higher level of satisfaction	ML-OLSR shows the minimum end-to-end delay out of the four protocols.
[62]	OLSRv2 on real testbed.	Extended the implementation over the testbed with the Rician fading model.	With more nodes and IPv6 exclusively, OLSRv2 has lower total traffic than OLSRv1.	OLSRv2's RFC5444 packet format has a higher overhead than OLSRv1's binary format.
[55]	MEFW and JEFW Based Routing	The use of the minimum expected forwarding and joint expected forwarding metrics to selects network paths with the greatest delivery rate in the presence of selfish intermediary nodes.	Network throughput and fairness are greatly improved by the proposed techniques.	The link or path quality has to be considered with the traffic loads.
[61]	OLSR with -Betweenness Centrality -Closeness Centrality	The use of centrality metrics to determine core nodes with the highest betweenness centrality and periphery nodes with the lowest closeness centrality.	Betweenness centrality helps nodes to improve security and privacy features. Closeness centrality helps nodes to expose the addresses of foreign networks they are attached to.	Without the use of the ETX metric, faulty links are utilized until they break down.
[60]	Double Shortest Path Routing	The shortest path selection process considers both the inter-modules and the intra-modules to avoid traffic congestion.	The proposed routing method is better than the classic shortest path routing protocol.	Residual energy of nodes is not considered.
[65]	MBA-OLSR	It is a multipath battery aware routing protocol where the initial cost of multiple links is based on the mobile node's	It improves node lifetime and QoS metrics versus simulation time variance.	No modifications in the MPR selection mechanism are considered.

		remaining battery.		
[70]	L-OLSR	It uses a precise localization mechanism for the NPC node.	This strategy aids in the coverage holes determination in the scattered region that has not yet been covered.	Due to the difficulty of the computations, the suggested solution is not suited for smart devices with limited CPUs and batteries.
[72]	W-OLSR	Weighted-MPR is a new MPR selection parameter added to the traditional OLSR which depends on residual energy, signal strength, and transmission delay.	In terms of throughput and packet loss, it outperforms OLSR.	The average energy consumption increases with higher node density and higher node speed.
[68]	Directional Airtime based routing	The DAT metric, which is a fraction of successfully received frames and incoming bit rate, is added to deal with link speed heterogeneity.	The new DAT metric produced good network paths, and the enhanced OLSRv2 outperforms OLSRv1 in several situations.	Routing through multipaths is not supported, therefore data flow cannot be split among equivalent selected shortest paths.
[69]	Local channel selection with routing metrics	The use of combination of local link switching mechanism and dynamic routing metrics.	works well in multi-radio multi-channel WMNs. Improved stability and throughput in multi-channel WMSs.	Suffer from little overhead.
[71]	ELARM	The best route selection is based on link stability and the load conditions.	Significant improvement in packet delivery and average network latency.	A slight increase in routing overhead.
[73]	MOLSR	Depending on the energy capacity of the intermediary nodes, this approach takes a different route if it crosses the threshold.	A considerable decrease in the messages load and the energy consumption is achieved.	The average throughput is slightly reduced.
[74]	Packet Priority-Oriented (PPO) and PPO-Quality of Service based routing.	Using a cross layer approach which considers both the application priority and the channel busy level to improve the routing path selection process.	The proposed protocol achieved superiority over interference-aware-based routing mechanism.	Link quality is not considered.
[75]	AOLSR	It optimizes the MPR selection method used in OLSR protocol based on the direction of them by constructing right side MPR set and left side MPR set.	Improved PDR and average end-to-end delay.	It brings greater routing overhead.
[86]	QASDN	Formulated a QoS-based optimization routing problem and solved using Lagrangian Relaxation Based Aggregated Cost (LARAC) algorithm.	Increased resources utilization because packet loss rate, path cost, and gateway caching are considered.	Traffic control or management mechanism is needed with centralized software-defined- network-based techniques.
[87]	Pop-Routing	Formulated an optimization method for control-message-generation timer.	Reduced routes convergence time.	Only overhead is considered while determining the updating timer. Other metrics such as Time-to-Live has to be considered.
[88]	Link-Quality-Prediction-based Routing	Link quality prediction using online machine learning. A hybrid of the online perceptron method with the OLSR is introduced.	Higher prediction accuracy with low computational load	Network performance metrics such as throughput and delay are not measured or analyzed.
[93]	Link-Quality-Prediction-based Routing	Link quality prediction using deep recurrent neural networks.	Higher efficiency in predicting the varying link quality values because it uses time-series analysis.	Deep recurrent neural networks are computationally expensive to train and run.

IX. Discussion and Analysis

The systematic investigation of routing protocols within WCNs, as presented in the literature from Sections IV to IX and further explored in this discussion, offers an insightful view of current advancements, challenges, and performance metrics that define the state-of-the-art in this domain. This comprehensive analysis is aimed at demonstrating the critical dimensions of these protocols that are paramount for enhancing WCNs' efficiency, reliability, and scalability, highlighting their strengths, limitations, and broader implications for the field of wireless networking.

A. Comparative Analysis of Existing Routing Protocols

WCNs grow dynamically in a decentralized manner with an already large number of nodes. Therefore, WCNs can make use of routing protocols for MANETs. These routing protocols, including Babel, BMX6, OLSR, and OLSRv2, exhibit self-adaptive characteristics, enabling them to adjust autonomously to changes within the network infrastructure, facilitating the determination of optimal routing paths.

The exploration of Babel, BMX6, OLSR, and OLSRv2 routing protocols underscores the precise balance between overhead management, convergence speed, and adaptability to dynamic network topologies. Babel gives high performance without consuming memory or CPU and with less traffic overhead in the case of a network with steady links and low network density. Nevertheless, if the network is highly dynamic, then the Babel protocol results in high control overhead and processing overhead in order to meet the changes in topology through distributing additional route request messages and routing updates. In contrast, BMX6, with its emphasis on minimizing routing overhead through stateful compression and selective information dissemination, emerges as a robust solution for more dynamic and dense network environments. This distinction highlights the imperative of choosing a routing protocol that aligns with the specific architectural and operational dynamics of the WCN.

On one hand, OLSR protocol significantly benefits from the MPR mechanism however it causes a proportional increase in overhead as the network grows in the number of links and nodes. In contrast, the BMX6 routing protocol generally has low control overhead as it hides the state of the local nodes from widespread information as well as using compact local identifiers. Therefore, when comparing OLSR with BMX6 in terms of convergence time and overhead with network growth in nodes and distance, different results are found. Both overhead and convergence time in BMX6 do not increase with the growth of the network. However, the convergence time and control overhead grow super linearly with OLSR. As a result, BMX6 outperforms OLSR in terms of the control overhead in addition to the fast reaction for dynamic link changes. However, BMX6 requires more memory than OLSR.

OLSR suffers from convergence problems and more traffic. Therefore, OLSRv2 comes with additional features, such as increased self-configuration capabilities and dual-stack configuration, to overcome the drawbacks of OLSR. During a comparative analysis between OLSR and OLSRv2, it is observed that OLSRv2 exhibits superior performance across multiple metrics. Notably, OLSRv2 outperforms OLSR in terms of throughput, jitter, average end-to-end delay, and packet loss rate. Specifically, OLSRv2 demonstrates higher throughput compared to OLSR. Additionally, the average end-to-end delay experiences a more significant reduction in OLSRv2 than in OLSR. Moreover, regarding jitter, OLSRv2 shows better results than OLSR. Also, the loss rate of packets for OLSRv2 is always lower than for OLSR. Hence, the OLSRv2 protocol provides overall good performance as compared to OLSR. However, the traffic generated by OLSR in the IPv4-only setup is extensively lower than utilizing OLSRv2. Due to this fact, the fixed binary packet that is used in OLSR does not cause a high overhead. However, the use of the flexible TLV packet format for OLSRv2 results in high overhead. While the traffic overhead caused by the routing process is less for OLSRv2 than for OLSR in the case of an IPv6-only setup with a larger number of nodes. From this analysis, it is suggested, as a future work, to think about replacing the flexible TLV packet format used in OLSRv2 with the efficient binary packet format used in OLSR to obtain the best performance of OLSRv2.

Generally, OLSR's utilization of MPRs to optimize the flooding process is pivotal in reducing traffic overhead, yet this mechanism's scalability in larger networks prompts a deeper inquiry into OLSRv2. With OLSRv2's enhanced modularity, flexibility, and integration of the NHDP, our analysis indicates superior performance in terms of throughput and latency, particularly in IPv6-only setups and high-density node distributions.

Besides the previously mentioned routing protocols, some other routing protocols have been tested on WCNs, such as AODV and BGP routing protocols. AODV shows a high increase in jitter and delay with a high network load and more connections. While BGP shows less network stability, there is a substantially higher ratio of modified messages to withdrawal messages on the public internet.

B. Optimization Techniques for MPR Calculation

A wide variety of different optimization techniques for calculating the MPR are presented. The investigation of these approaches enables us to make some findings. The majority of existing strategies focus on energy considerations over other factors such as mobility, security, and bandwidth. The absence of mathematical models in existing research and the narrow focus on specific simulation environments suggest a gap in holistic protocol evaluation and optimization. Furthermore, the technique for selecting MPRs and the structures of Hello and TC messages are two key areas where authors most often make improvements to them. However, it is not taken into consideration to conduct studies on the dependency that exists between the parameters, regardless of the fact that modifying any one of the parameters may have an effect on the others. In addition, in comparison to other types of mobility, such as the random selection of direction, the Manhattan grid system, freeway grid points, and others, the simulation makes the most frequent use of the random way point type. Addressing this gap requires a multi-parametric approach that considers the intricate interplay between various network and protocol parameters, steering future research towards more comprehensive and practical routing solutions for WCNs.

C. Theoretical and Practical Implications

The theoretical implications of our findings suggest that the adaptability and efficiency of routing protocols in WCNs are critically dependent on their architectural underpinnings and operational logic. Practically, this translates to a decision-making framework for network administrators to select and customize routing protocols based on their network's specific requirements such as low overhead, rapid convergence, or high scalability.

Moreover, our analysis reveals a significant gap in the literature concerning the energy efficiency of routing protocols in WCNs. Given the often resource-constrained nature of devices in WCNs, future research should pivot towards developing energy-aware routing protocols that extend network lifetimes without compromising on performance metrics.

The analysis and discussion conducted in this study unequivocally highlight the need for an improved routing protocol that can effectively address the challenges associated with achieving optimal routing performance in WCNs. It is essential that this enhanced protocol take into account the heterogeneous characteristics of WCNs and focuses on developing a more efficient routing technique that ensures stability and scalability.

D. Future Directions

A notable limitation of the current study is the predominance of simulation-based evaluations over real-world deployments. While simulations provide valuable insights into protocol behavior under controlled conditions, they may not fully capture the complexities and unpredictable dynamics of live WCN environments.

Consequently, future studies should endeavor to validate these findings through extensive real-world testing across diverse geographical and societal contexts.

Additionally, the security aspect of routing in WCNs remains underexplored. As WCNs often operate in open and decentralized settings, they are inherently vulnerable to various security threats. Integrating robust security mechanisms within the routing protocol design without unduly inflating overhead or diminishing performance presents fertile ground for future research.

X. List of Open Issues

The WCN technology presents a great number of difficulties, challenges, and problems for its underlying protocols, all of which need to be resolved before it can be utilized to create communication that is both effective and dependable. From our literature review, we conclude the following points as a list of open issues in WCNs routing protocols for future research:

- **Transmission Power Level**: Current routing protocols do not match existing wireless technologies. It should not exceed the maximum allowed transmission levels of the used wireless technology. This is an important point to test the routing protocols according to real energy models.
- **Provisioning**: Current routing protocols should focus on fair distribution of the available bandwidth among the changeable number of users of WCNs.
- **Scalability**: Current routing protocols are not processing IPv4 and IPv6 address types simultaneously, which leads to high overhead.
- **Stability**: Current routing protocols do not consider the Link Quality Indicator (LQI) as a metric for controlling the routing of packets. LQI is used to measure the quality of the received packets as a combination of the Received Signal Strength Indication (RSSI) value and the signal-to-noise ratio value.
- **Efficiency of TCP Protocol**: The TCP protocol already performs poorly in single-hop networks; therefore, its performance degrades much worse in WCNs where each node acts as a router.
- **Security**: Although there are many different approaches to WLAN security, none of them are appropriate for WCNs. Current routing protocols should offer both authentication and privacy, in addition to dependability.
- **Sustainability:** Current routing protocols do not support new technologies such as blockchain which can provide sustainability instead of replacement.
- **Intelligent Routing:** Artificial intelligent techniques must be tested over WCNs topology which proved more enhancement in the routing process just like wireless ad hoc network.
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XI. Conclusion

This paper investigates the current existing routing protocols that are commonly used for WCNs. A taxonomy of routing protocols used for WCNs has been designed. The WCN routing protocols have been classified into five classes, namely: Babel, BMX6, OLSR, OLSRv2, and other routing protocols applied to WCNs. Firstly, a review is made of the basic problems that the researchers identify in their research work. Secondly, the research methodologies that these researchers used to solve these problems are presented. Additionally, the primary focus is placed on illustrating the essential strengths and limitations associated with these protocols, with the aim of evaluating their efficacy and reliability in facilitating optimal routing path selection for easy end-to-end message transmission across the network. Finally, a series of recommendations and future research directions have been formulated to support further investigation into unresolved challenges regarding WCN routing protocols. As our discussion, most of the current existing routing protocols are still suffering from stability and scalability issues. Consequently, it is still imperative to develop a routing protocol that takes into account the diverse characteristics of WCNs to establish a highly efficient routing technique that ensures stability and scalability in network operations.

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References

[1] A. Gasouma, K. Yusof, B. Bouallegue, A. Ahmed, and M. Khattab, "Route Optimization for Energy Efficiency in IoT and Software Defined RPL Heterogeneous Networks," 2023.

[2] B. Braem, J. Bergs, and C. Blondia, "Comparing Community Networks to the Internet: An Empirical Study of BGP Behaviour," in *Future Internet of Things and Cloud (FiCloud), 2015 3rd International Conference on*, 2015, pp. 788-793.

[3] I. T. U. (ITU). (February 6, 2024). *Press release*. Available: https://www.itu.int/en/mediacentre/Pages/PR-2023-09-12-universal-and-meaningful-connectivity-by-2030.aspx

[4] U. V. Fund. (February 6, 2024). *XOneFi: Equitable, affordable Internet access for remote and underserved areas*. Available: https://www.unicefventurefund.org/story/xonefi-equitable-affordable-internet-access-remote-and-underserved-areas

[5] P. De Filippi and F. Tréguer, "Expanding the Internet commons: The subversive potential of wireless community networks," *Journal of Peer Production, Issue,* no. 6,2015.

[6] L. Maccari, G. Gemmi, R. L. Cigno, M. Karaliopoulos, and L. Navarro, "Towards scalable community networks topologies," *Ad Hoc Networks,* vol. 94, pp. 101949, 2019.

[7] G. Gemmi, L. Cerdà-Alabern, L. Navarro, and L. Maccari, "Toward Smart Community Networks," *IEEE Network*, vol. 37, no. 2, pp. 128-134, 2023.

[8] M. D. de Rosnay, F. Tréguer, P. Antoniadis, I. Apostol, V. Aubrée, A. Burns, *et al.*, "Telecommunications Reclaimed: A Hands-On Guide to Networking Communities," 2019.

[9] P. De Filippi and F. Tréguer, "Wireless community networks: Towards a public policy for the network commons?," *Net Neutrality Compendium: Human Rights, Free Competition and the Future of the Internet,* pp. 261-270, 2016.

[10] A. L. Serra, F. del Águila López, J. B. Dalmau, and X. Moncunill-Geniz, "A new community business model for a free, open, and neutral network: Considering the wireless to fiber transition," *Internet of Things,* vol. 26, pp. 101157, 2024.

[11] S. S. Matter12, I. F. Al Shaikhli, and A. H. Hashim, "Theoretical Review of Routing Protocols Used for Wireless Community Networks," *J. Comput. Theor. Nanosci,* vol. 16, pp. 3656-3662, 2019.

[12] S. S. Matter, I. F. A. Shaikhli, A. H. A. Hashim, A. M. Ahmed, and M. M. Khattab, "Enhanced MPR Selection Strategy for Multicast

OLSR," *IJCSNS International Journal of Computer Science and Network Security*, vol. 22, no. 10, pp. 137-144, 2022.
[13] L. Navarro, R. B. Viñas, C. Barz, J. Bonicioli, B. Braem, F. Freitag, *et al.*, "Advances in wireless community networks with the community-lab testbed," *IEEE Communications Magazine*, vol. 54, no. 7, pp. 20-27, 2016.
[14] A. Gasouma, K. M. Yusof, B. Bouallegue, A. M. Ahmed, and S. S. Matter, "Routing Optimization for Energy Efficiency in Software-Defined IoT and RPL Networks," 2023.
[15] A. Neumann, "Cooperation in open, decentralized, and heterogeneous computer networks," 2017.
[16] Picopeer.net. (2018). *Picopeering Agreement v1.0. [online] Available at: http://picopeer.net/ [Accessed 11 Nov. 2018].*
[17] S. S. Matter, I. F. Al Shaikhli, and A. H. Hashim, "Theoretical Review of Routing Protocols Used for Wireless Community Networks," *Journal of Computational and Theoretical Nanoscience*, vol. 16, no. 9, pp. 3656-3662, 2019.
[18] Fon. (February 1, 2024). *Fon: The global WiFi network*. Available: https://fon.com/
[19] SeattleWireless. (28 June, 2022). Available: http://www.seattlewireless.net/
[20] NYCwireless. (February 1, 2024). Available: https://nycwireless.net/
[21] P. C. Wireless. (February 1, 2024). *Building community-controlled networks in Philadelphia*. Available: https://phillycommunitywireless.org/
[22] MadMesh. (February 1, 2024). *The Renewable Internet Initiative : by SupraNet*. Available: http://www.madcitybroadband.com
[23] M. Afanasyev, T. Chen, G. M. Voelker, and A. C. Snoeren, "Usage patterns in an urban WiFi network," *IEEE/ACM Transactions on Networking*, vol. 18, no. 5, pp. 1359-1372, 2010.
[24] Rhizomatica. (February 1, 2024). *Community Infrastructure Autonomy*. Available: https://www.rhizomatica.org/
[25] K. LaCurts and H. Balakrishnan, "Measurement and analysis of real-world 802.11 mesh networks," in *Proceedings of the 10th ACM SIGCOMM conference on Internet measurement*, 2010, pp. 123-136.
[26] Grenaas.net. (February 1, 2024). *Grenaas.net*. Available: https://djurslands.net/
[27] AWMN. (February 1, 2024). *Athens Wireless Metropolitan Network*. Available: http://www.awmn.net
[28] freifunk. (February 1, 2024). Available: https://freifunk.net/
[29] D. S. Portal Software. (February 1, 2024). *CZFree.Net forum Wireless community home page*. Available: https://www.czfree.net/home/index.php
[30] guifi.net. (February 1, 2024). *Open, Libre and Neutral Telecommunications Network*. Available: https://guifi.net/
[31] B4RN. (February 1, 2024). *Broadband for the rural north*. Available: https://b4rn.org.uk/
[32] FFDN. (February 1, 2024). *Federation French data network*. Available: https://www.ffdn.org/en
[33] Free2Air. (February 1, 2024). *Open Distributed Public Wireless Network Infrastructure*. Available: http://www.free2air.org/
[34] Consume. (February 1, 2024). *Consume*. Available: http://consume.net
[35] W. Leiden. (February 1, 2024). *Wireless Leiden*. Available: https://wirelessleiden.nl/
[36] Funkfeuer. (February 1, 2024). *Initiative für freie Netze*. Available: https://www.funkfeuer.at/
[37] Ninux. (February 1, 2024). *Pagina Principale*. Available: http://ninux.org/
[38] Zenzeleni.net. (February 1, 2024). *Zenzeleni Community Networks*. Available: https://zenzeleni.net/
[39] N. K. Nguyen, "(Re)Building Technology: Community Technology Fieldguide," Open Technology Institute, Open Technology Institute, AMC2015.
[40] C. Geerdts, A. Gillwald, and D. Enrico Calandro, "Developing Smart Public Wi-Fi in South Africa," 2016.
[41] NWNP. (February 1, 2024). *Nepal Wireless Networking Project*. Available: http://www.nepalwireless.net/
[42] TakNet. (February 1, 2024). *A community white space wireless network*. Available: https://blog.apnic.net/2019/07/01/taknet-a-community-white-space-wireless-network/
[43] T. Clausen and P. Jacquet, "RFC 3626," *Optimized link state routing protocol (OLSR)*,2003.
[44] D. Seither, A. König, and M. Hollick, "Routing performance of Wireless Mesh Networks: A practical evaluation of BATMAN advanced," in *Local Computer Networks (LCN), 2011 IEEE 36th Conference on*, 2011, pp. 897-904.
[45] A. Neumann, E. López, and L. Navarro, "An evaluation of bmx6 for community wireless networks," in *Wireless and Mobile Computing, Networking and Communications (WiMob), 2012 IEEE 8th International Conference on*, 2012, pp. 651-658.
[46] J. Chroboczek, "RFC 6126," *The Babel Routing Protocol. Chemistry &…. Retrieved from http://tools. ietf. org/html/rfc6126*,2011.
[47] A. Neumann, E. López, and L. Navarro, "Evaluation of mesh routing protocols for wireless community networks," *Computer Networks*, vol. 93, pp. 308-323, 2015.
[48] A. Pandey and M. Baliyan, "Performance Analysis of OLSR and Modified Version of OLSR-ETX/MD/ML in Mesh Networks," *International Journal of Computer Science & Communication Networks*, vol. 2, no. 2, pp. 268-271, 2012.
[49] T. H. Clausen, C. Adjih, C. M. Dearlove, and J. W. Dean, "Generalized mobile ad hoc network (MANET) packet/message format," 2009.
[50] M. Ikeda, T. Oda, E. Kulla, M. Hiyama, L. Barolli, and M. Younas, "Performance evaluation of WMN considering number of connections using ns-3 simulator," in *Broadband, Wireless Computing, Communication and Applications (BWCCA), 2012 Seventh International Conference on*, 2012, pp. 498-502.
[51] A. Hart, N. Pezeshkian, and H. Nguyen, "Mesh networking optimized for robotic teleoperation," in *Unmanned Systems Technology XIV*, 2012, pp. 523-529.
[52] L. Cerdà-Alabern, A. Neumann, and L. Maccari, "Experimental evaluation of bmx6 routing metrics in a 802.11 an wireless-community mesh network," in *Future Internet of Things and Cloud (FiCloud), 2015 3rd International Conference on*, 2015, pp. 770-775.
[53] D. Moad, S. Djahel, and F. Naït-Abdesselam, "Improving the quality of service routing in OLSR protocol," in *2012 International Conference on Communications and Information Technology (ICCIT)*, 2012, pp. 314-319.
[54] U. Herberg, "Performance evaluation of using a dynamic shortest path algorithm in OLSRv2," in *Communication Networks and Services Research Conference (CNSR), 2010 Eighth Annual*, 2010, pp. 376-380.
[55] S. Paris, C. Nita-Rotaru, F. Martignon, and A. Capone, "Cross-layer metrics for reliable routing in wireless mesh networks," *IEEE/ACM Transactions on Networking (TON)*, vol. 21, no. 3, pp. 1003-1016, 2013.
[56] M. Backhaus, M. Theil, M. Rossberg, and G. Schaefer, "Robustness and scalability improvements for distance vector routing in large WMNs," in *2020 16th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)*, 2020, pp. 1-6.
[57] Qmp.cat. (2018). *Home - qMp. [online] Available at: http://qmp.cat/Home [Accessed 11 Nov. 2018].*
[58] L. Fatima and E. Najib, "Energy and mobility in OLSR routing protocol," *Journal of Selected Areas in Telecommunications (JSAT)*, vol. 2012, no. 3, pp. 1-6, 2012.
[59] J. Yi, A. Adnane, S. David, and B. Parrein, "Multipath optimized link state routing for mobile ad hoc networks," *Ad hoc networks*, vol. 9, no. 1, pp. 28-47, 2011.
[60] Z.-Q. Zhu, C.-J. Liu, J.-L. Wu, and B. Liu, "The information transmission in community networks," *Physica A: Statistical Mechanics and its Applications*, vol. 392, no. 17, pp. 3827-3832, 2013.
[61] L. Maccari, "An analysis of the Ninux wireless community network," in *Wireless and Mobile Computing, Networking and Communications (WiMob), 2013 IEEE 9th International Conference on*, 2013, pp. 1-7.
[62] C. Barz, J. Niewiejska, and H. Rogge, "NHDP and OLSRv2 for community networks," in *Wireless and Mobile Computing, Networking and Communications (WiMob), 2013 IEEE 9th International Conference on*, 2013, pp. 96-102.
[63] P. Boronat, M. Pérez-Francisco, C. T. Calafate, J. C. Cano, and P. Manzoni, "Evaluating metrics for optimal path selection in large wireless community networks," in *Proceedings of the 11th ACM symposium on Performance evaluation of wireless ad hoc, sensor, & ubiquitous networks*, 2014, pp. 85-92.
[64] J. Avonts, B. Braem, and C. Blondia, "A questionnaire based examination of community networks," in *Wireless and Mobile Computing, Networking and Communications (WiMob), 2013 IEEE 9th International Conference on*, 2013, pp. 8-15.
[65] W. A. Jabbar, M. Ismail, and R. Nordin, "MBA-OLSR: a multipath battery aware routing protocol for MANETs," in *2014 5th International Conference on Intelligent Systems, Modelling and Simulation*, 2014, pp. 630-635.
[66] P. Millan, C. Molina, E. Medina, D. Vega, R. Meseguer, B. Braem, *et al.*, "Tracking and predicting link quality in wireless community networks," in *Wireless and Mobile Computing, Networking and Communications (WiMob), 2014 IEEE 10th International Conference on*, 2014, pp. 239-244.

[67] A. Detti, C. Pisa, S. Salsano, and N. Blefari-Melazzi, "Wireless mesh software defined networks (wmSDN)," in *Wireless and Mobile Computing, Networking and Communications (WiMob), 2013 IEEE 9th International Conference on*, 2013, pp. 89-95.
[68] C. Barz, C. Fuchs, J. Kirchhoff, J. Niewiejska, and H. Rogge, "OLSRv2 for Community Networks: Using Directional Airtime Metric with external radios," *Computer Networks,* vol. 93, pp. 324-341, 2015.
[69] H. Kanaoka and T. Yoshihiro, "Combining local channel selection with routing metrics in multi-channel Wireless Mesh Networks," *Journal of Information Processing,* vol. 23, no. 2, pp. 221-228, 2015.
[70] W. Anbao and Z. Bin, "Improving MPR selection algorithm in OLSR protocol based on node localization technology," *Journal of networks,* vol. 9, no. 7, pp. 1674, 2014.
[71] A. K. Kiani, R. F. Ali, and U. Rashid, "Energy-load aware routing metric for hybrid wireless mesh networks," in *Vehicular Technology Conference (VTC Spring), 2015 IEEE 81st*, 2015, pp. 1-5.
[72] L. Anandrao and J. Y. Amey, "Comparison of OLSR and Energy Conserved OLSR," *International Journal of Technical Research and Applications,* vol. 2, pp. 05-08, 2014.
[73] S. Tiwari and A. K. Jaiswal, "Modified OLSR (MOLSR) Protocol for improving optimal route selection with Dynamic MPR selection in Mobile Adhoc Network," *International Journal of Management, IT and Engineering,* vol. 6, no. 2, pp. 117-132, 2016.
[74] L. Zhao, A. Al-Dubai, X. Li, G. Chen, and G. Min, "A new efficient cross-layer relay node selection model for wireless community mesh networks," *Computers & Electrical Engineering,*2017.
[75] P. Kumar and S. Verma, "Implementation of modified OLSR protocol in AANETs for UDP and TCP environment," *Journal of King Saud University-Computer and Information Sciences,*2019.
[76] R. Jain and I. Kashyap, "An QoS aware link defined OLSR (LD-OLSR) routing protocol for MANETs," *Wireless Personal Communications,* vol. 108, no. 3, pp. 1745-1758, 2019.
[77] A. Alamsyah, I. K. E. Purnama, E. Setijadi, and M. H. Purnomo, "MPR selection to the OLSR quality of service in MANET using minmax algorithm," *International Journal of Electrical and Computer Engineering,* vol. 9, no. 1, pp. 417, 2019.
[78] E. Setijadi, I. Purnama, and M. Hery, "MPR Selection to the OLSR Quality of Service in MANET Using Preferred Group Broadcasting," *IAENG International Journal of Computer Science,* vol. 46, no. 2, pp. 192-198, 2019.
[79] J. Singh, G. Singh, D. Gupta, G. Muhammad, and A. Nauman, "OCI-OLSR: An Optimized Control Interval-Optimized Link State Routing-Based Efficient Routing Mechanism for Ad-Hoc Networks," *Processes,* vol. 11, no. 5, pp. 1419, 2023.
[80] M. von Ehren, J. Andre, and F. Wiedner, "An Implementation of the Babel Routing Protocol for ns-3," *Network,* vol. 73,2021.
[81] U. Singh, S. K. Sharma, M. Shukla, and P. Jha, "Blockchain-based BATMAN protocol using Mobile ad-hoc Network (MANET) with an Ensemble Algorithm," 2021.
[82] A. Nabou, M. D. Laanaoui, and M. Ouzzif, "New MPR computation for securing OLSR routing protocol against single black hole attack," *Wireless Personal Communications,* vol. 117, no. 2, pp. 525-544, 2021.
[83] U. K. Addanki and B. H. Kumar, "Enhancement OLSR Routing Protocol using Particle Swarm Optimization (PSO) and Genrtic Algorithm (GA) in MANETS," *International Journal of Computer Science & Network Security,* vol. 22, no. 4, pp. 131-138, 2022.
[84] R. Jain, "Ant colony inspired energy efficient OLSR (AC-OLSR) routing protocol in MANETS," *Wireless Personal Communications,* vol. 124, no. 4, pp. 3307-3320, 2022.
[85] K. Saleem and I. Ahmad, "Ant colony optimization ACO based autonomous secure routing protocol for mobile surveillance systems," *Drones,* vol. 6, no. 11, pp. 351, 2022.
[86] M. B. Attia, K.-K. Nguyen, and M. Cheriet, "QoS-aware software-defined routing in smart community network," *Computer Networks,* vol. 147, pp. 221-235, 2018.
[87] L. Maccari and R. L. Cigno, "Improving routing convergence with centrality: Theory and implementation of pop-routing," *IEEE/ACM Transactions on Networking,* vol. 26, no. 5, pp. 2216-2229, 2018.
[88] M. L. Bote-Lorenzo, E. Gómez-Sánchez, C. Mediavilla-Pastor, and J. I. Asensio-Pérez, "Online machine learning algorithms to predict link quality in community wireless mesh networks," *Computer Networks,* vol. 132, pp. 68-80, 2018.
[89] A. Bifet, G. Holmes, B. Pfahringer, and E. Frank, "Fast perceptron decision tree learning from evolving data streams," in *Advances in Knowledge Discovery and Data Mining: 14th Pacific-Asia Conference, PAKDD 2010, Hyderabad, India, June 21-24, 2010. Proceedings. Part II 14*, 2010, pp. 299-310.
[90] E. Ikonomovska, J. Gama, B. Zenko, and S. Dzeroski, "Speeding-up hoeffding-based regression trees with options," in *Proceedings of the 28th International Conference on Machine Learning (ICML-11),* 2011, pp. 537-544.
[91] E. Ikonomovska, J. Gama, and S. Džeroski, "Learning model trees from evolving data streams," *Data mining and knowledge discovery,* vol. 23, pp. 128-168, 2011.
[92] J. Duarte, J. Gama, and A. Bifet, "Adaptive model rules from high-speed data streams," *ACM Transactions on Knowledge Discovery from Data (TKDD),* vol. 10, no. 3, pp. 1-22, 2016.
[93] M. Abdel-Nasser, K. Mahmoud, O. A. Omer, M. Lehtonen, and D. Puig, "Link quality prediction in wireless community networks using deep recurrent neural networks," *Alexandria Engineering Journal,* vol. 59, no. 5, pp. 3531-3543, 2020.
[94] S. Hochreiter and J. Schmidhuber, "Long short-term memory," *Neural computation,* vol. 9, no. 8, pp. 1735-1780, 1997.
[95] J. Chung, C. Gulcehre, K. Cho, and Y. Bengio, "Empirical evaluation of gated recurrent neural networks on sequence modeling," *arXiv preprint arXiv:1412.3555,*2014.

Safaa S. Matter - Department of Computer Science, Kulliyyah of Information and Communication Technology, International Islamic University Malaysia, Kuala Lumpur, 50728, Malaysia.