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Application of MANETs as a communication system for sustainable mobility

Aplicación de MANET como sistema de comunicación en la movilidad sostenible

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Abstract

This paper presents an architecture based on the MANET (Mobile Ad Hoc Network) paradigm as an emergency communication system between users of electric bicycles. The solution consists of 4 mobile nodes representing the users and a main fixed node, which emulates a bicycle docking station. This architecture allows multi-hop communication between the nodes, using the proactive routing protocols OLSR (Optimized Link State Routing) and BATMAN (Better Approach to Mobile Ad Hoc Networking). The study was divided into 3 main stages. First, an analysis of the wireless medium was performed to determine the maximum transmission distance and the maximum bitrate between 2 nodes. Subsequently, the throughput behavior was characterized in a multi-hop configuration consisting of 4 nodes in order to establish the network capacity in terms of bandwidth. Finally, a web application was implemented for the transmission of audio and text traffic. Regarding the evaluation of the proposal, two scenarios were designed to emulate the integration of a new cyclist to the network and the communication between two users in motion. The results reveal that OLSR provides a better system operation, with a throughput of 2.54 Mbps at 3 hops and a PRR (Packet Reception Rate) higher than 96%. In addition, it guarantees a delay within the ITU-T (International Telecommunication Union-Telecommunication) G.114 recommendation for bidirectional communication.

Keywords: BATMAN, BSS, Emergency communication system, ITS, MANET, OLSR

Resumen

En este artículo se presenta una arquitectura basada en el paradigma MANET (Mobile Ad Hoc Network) como un sistema de comunicación de emergencia entre usuarios de bicicletas eléctricas. La solución consta de cuatro nodos móviles que representan a los usuarios y un nodo fijo principal, que emula una estación de anclaje de bicicletas. Esta arquitectura permite la comunicación multisalto entre los nodos, utilizando los protocolos de enrutamiento proactivos OLSR (Optimized Link State Routing) y BATMAN (Better Approach to Mobile Ad Hoc Networking). El estudio se dividió en tres etapas principales. Primero, se hizo un análisis del medio inalámbrico para determinar la distancia máxima de transmisión y el bitrate máximo entre dos nodos. Posteriormente, se caracterizó el comportamiento del throughput en una configuración multisalto conformada por cuatro nodos con el fin de establecer la capacidad de la red en términos de ancho de banda. Finalmente, se implementó una aplicación web para la transmisión de tráfico de audio y texto. En cuanto a la evaluación de la propuesta, se diseñaron dos escenarios que emulan la integración de un nuevo ciclista a la red y la comunicación entre dos usuarios en movimiento. Los resultados revelan que OLSR proporciona una mejor operación del sistema, con un throughput de 2.54 Mbps a 3 saltos y un PRR *(Packet Reception Rate)* superior al 96 %. Además, garantiza un delay dentro de la recomendación G.114 de la ITU-T *(International Telecommunication Union-Telecommunication)* para una comunicación bidireccional.

Palabras clave: BATMAN, BSS, ITS, MANET,OLSR, sistema de comunicación de emergencia

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1. Introduction

The bicycle is a vital mode of transportation for the development of sustainable mobility systems. As highlighted in [1], it offers users numerous advantages, including affordability, efficiency, safety, and environmental sustainability. Consequently, many cities have implemented Bike Sharing Systems (BSS) to promote cycling as a viable transportation option. Nevertheless, despite these benefits, users remain exposed to challenges such as traffic congestion, accidents, environmental pollution, and noise pollution, among other adverse conditions [2].

In this context, Bike Sharing Systems (BSS) have undergone significant technological advancements and are now in their fourth and fifth generations. These iterations include enhancements to streamline sharing processes, integrate electric bicycles, and implement communication systems among users [3]. As part of Intelligent Transport Systems (ITS), BSS have been widely adopted in cities worldwide, contributing significantly to reducing CO_2 emissions [4–8].

On the other hand, considering that a BSS involves multiple users, ITS systems have incorporated hybrid communication architectures based on the Ad Hoc paradigm, particularly leveraging ANET (Mobile Ad Hoc Network) and VANET (Vehicular Ad Hoc Network).

In MANET-type networks, each node functions both as a terminal device and as a router, enabling the rapid establishment of communication links without relying on centralized network infrastructure. As a result, they present a valuable technological solution for scenarios requiring resilient communication systems, as highlighted in [9,10]. However, their implementation poses several challenges, including the management of dynamic topologies due to node mobility, energy limitations in battery-powered devices, and the variability of the wireless medium, particularly in multi-hop configurations [11,12].

In this context, the literature has proposed various routing mechanisms to address the challenges associated with diverse applications and scenarios, including MANETs, VANETs, FANETs (Flying Ad Hoc Networks), and SANETs (Sea Ad Hoc Networks), among others [13]. Notably, prior studies emphasize the superior functionality of proactive protocols compared to reactive or hybrid approaches, even in environments characterized by highly dynamic topologies [14,15].

It is important to note that most proposals have been evaluated within simulation environments and under controlled conditions, highlighting the additional challenges and complexities associated with experimentation in real-world scenarios and applications [14]. The most relevant studies available in the literature are discussed below, with a particular focus on applications requiring resilient or emergency communication systems.

Emergency communication systems play a vital role in scenarios where conventional telecommunication infrastructures are non-operational, such as during earthquakes, floods, accidents, or in remote and low-coverage areas [12,16].

In [17], an evaluation of routing protocols in emergency applications using FANETs is presented. The results highlight the performance of AODV (Ad Hoc On-Demand Distance Vector), DSDV (Destination Sequenced Distance Vector), and OLSR (Optimized Link State Routing) mechanisms. Conversely, [18] emphasizes that proactive protocols in emergency applications exhibit lower end-to-end delays, as their routing tables are continuously updated to reflect changes in network topology. However, this advantage introduces additional challenges, including increased bandwidth and energy consumption requirements [19].

In [20], the performance of the OLSR and BATMAN protocols is evaluated across the 2.4 GHz and 5 GHz frequency bands. The results show that OLSR outperforms BATMAN in terms of throughput, achieving 0.91 Mbps at 2.4 GHz and 0.82 Mbps at 5 GHz over a distance of 50 meters. Additionally, OLSR exhibits superior performance in packet loss ratio (PLR), with 11% for 2.4 GHz and 20.4% for 5 GHz.

Similarly, in [21], a comparative analysis of the OLSR and BATMAN protocols is presented, defining two distinct scenarios. The first involves a multi-hop topology with four static nodes, where OLSR demonstrates higher throughput (10 Mbps at two hops and 6 Mbps at three hops), while BATMAN exhibits lower delay (6 ms at two hops and 8 ms at three hops). The second scenario involves an evaluation using a mesh topology, where both protocols achieve a 100% packet reception rate.

Multimedia content currently dominates internet traffic. In this context, a comparative analysis of various video codecs over a multi-hop Ad Hoc network is presented in [10]. Key performance metrics such as Packet Reception Rate (PRR), delay, and throughput are evaluated for real-time audio and video transmission. The study concludes that the VP8 video codec is the most suitable for the proposed scenario.

Other studies propose innovative protocol adaptations to ensure the efficient transmission of multimedia traffic. For instance, [22] describes the RTMC (Real-Time Multi-Cast) protocol, which enables receivers to specify their real-time constraints, thereby optimizing multicast trees to meet delay requirements while reducing energy consumption. This solution operates without relying on network topology information or link maintenance mechanisms, offering a reactive routing approach.

On the other hand, [23] introduces the Multi-Parameter Fuzzy Logic Resource Management (MP-FLRM) approach, which leverages request, download, and upload time data to dynamically update the resource list in real time. This methodology enhances resource management efficiency in VANET scenarios.

Finally, [24] explores the use of the OLSR protocol as a routing mechanism for VoIP (Voice over IP) services in a VANET, aiming to maintain an acceptable quality of service for voice calls. The results indicate that OLSR achieves delay, jitter, and packet loss values of 102.48 ms, 10.675 ms, and 0.07%, respectively. However, limitations are observed as the number of hops increases, resulting in delays that exceed the thresholds recommended by ITU-T standards [15, 25].

Regarding energy constraints, [26] introduces a mechanism known as EARVRT (Energy-Aware Virtual Relay Tunnels), which proposes the establishment of virtual tunnels for route selection based on the available energy in nodes and the number of hops. Additionally, [27] describes the EEE-SR (Enhanced Energy-Efficient Secure Routing) protocol, which integrates security policies, authentication, and energy thresholds into routing decisions.

In [28], a mechanism called ACEAMR (Adaptive Congestion and Energy-Aware Multipath Routing) is introduced, aiming to balance quality of service and energy consumption by discovering stable routes. Simulation results indicate that ACEAMR outperforms existing schemes in throughput (0.2 Kbps at a speed of 15 m/s and 7.2 Kbps at 60 m/s), packet delivery ratio (PDR) (81% at 15 m/s and 63% at 60 m/s), delay (rising from 0.003 ms to 0.0093 ms), and energy efficiency (7.2 J of energy consumption).

Motivated by these considerations, this study proposes a communication system based on a MANET for transmitting emergency informational messages in text and audio formats among BSS users. The system was implemented and evaluated in a real-world scenario, consisting of four mobile nodes and a main node, which facilitates the execution of experiments across all nodes. For the experimental evaluation, the OLSR and BATMAN protocols, highlighted in previous studies, were selected. A comparative analysis of these protocols was performed, focusing on throughput, delay, and packet reception ratio (PRR). Additionally, energy consumption and node autonomy during audio communication operations were analyzed. The primary contribution of this work lies in the experimental analysis and the development of a communication system for BSS utilizing the MANET paradigm in a real-world setting.

The article is organized into several sections, each addressing distinct aspects of the study. The Materials and Methods section outlines the methodology employed for system evaluation, which comprises three key components: the characterization of the Ad Hoc network, the analysis of throughput in a multi-hop topology, and the development and evaluation of a web application. At each stage, tables and figures are included to enhance clarity and comprehension. In the Results and Discussion section, evaluation metrics such as throughput, delay, and packet reception ratio (PRR) are analyzed and interpreted across two scenarios. The Conclusions section summarizes the study's primary contributions, discusses its practical implications, and provides recommendations for future research directions. Finally, the References section offers the necessary citations to substantiate the work and its findings.

2. Materials and methods

Figure 1 illustrates the coupling of a node with the bicycle, highlighting its main components. Each node is specifically implemented using a Raspberry Pi platform, a wireless card compliant with the IEEE (Institute of Electrical and Electronics Engineers) 802.11 standard and compatible with Ad Hoc mode, as well as a current sensor.

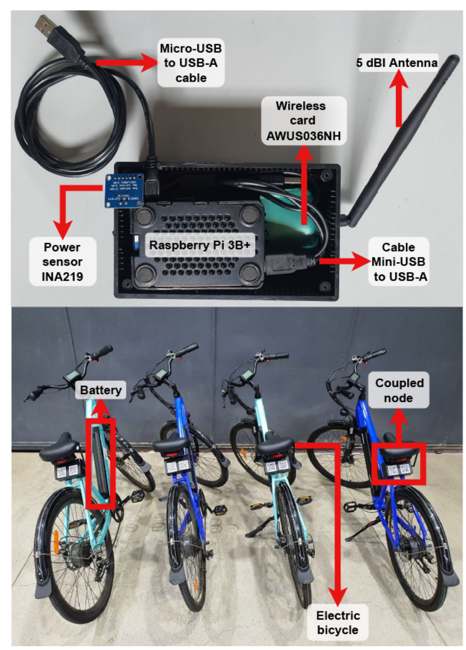

Figure 1. Electric bicycles with the coupled nodes

Figure 2 illustrates the methodology developed to perform the comparative evaluation of routing protocols in the MANET network. Initially, a series of experiments were conducted to characterize the maximum transmission distance and the wireless channel capacity in a two-node configuration. Subsequently, the bandwidth performance was assessed in a linear topology comprising four nodes (three hops). Following this, a mobile web application was developed, enabling both subjective and objective analyses of audio traffic quality. These analyses facilitated the adjustment of audio encoding parameters, tailored to the specific characteristics of the network.

Finally, real-time audio transmission was conducted to verify communication between the nodes, and the system's performance was objectively assessed using metrics such as delay, PRR, and throughput.

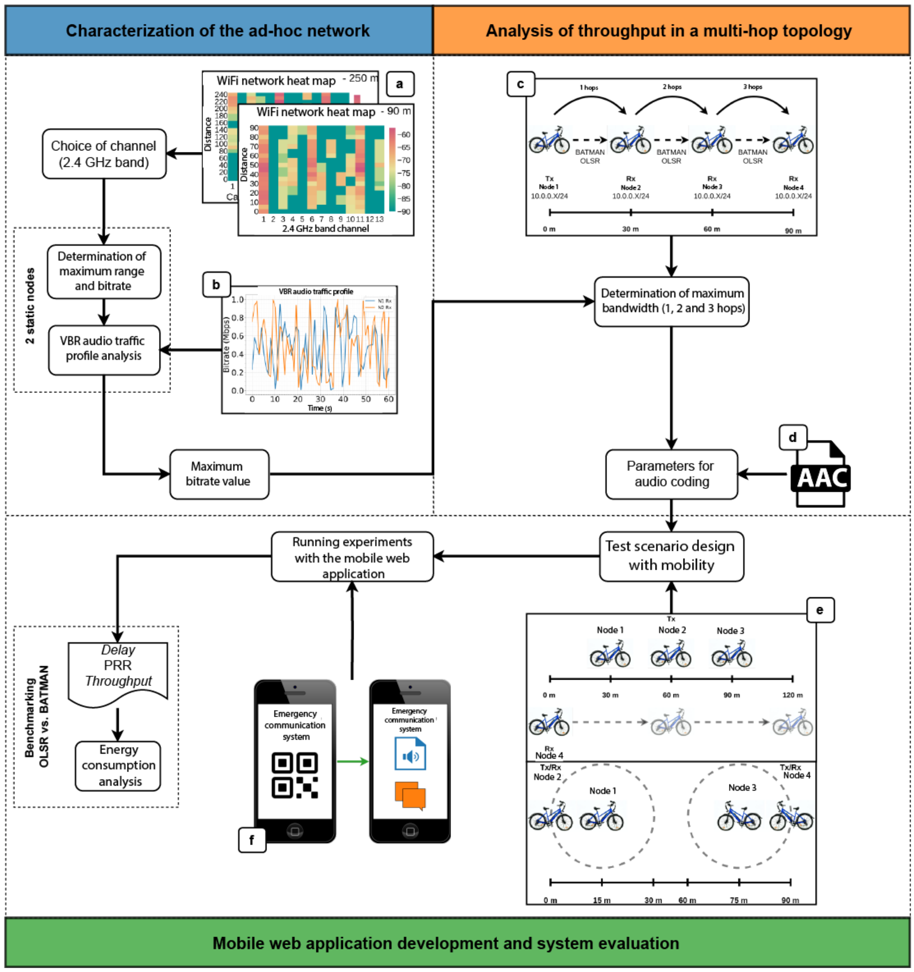

Figure 2. Methodology for evaluating the proposed system: (a) Heat maps of WiFi networks foreach channel in the 2.4 GHz band. (b) Graphs representing the Variable Bit Rate VBR audio traffic profile. (c) A multi-hop network topology consisting of four nodes. (d) Advanced Audio Codec (AAC). (e) Test scenarios incorporating mobility to assess network performance and the mobile web application. (f) A mobile web application capable of scanning QR codes and providing audio and text transmission functionalities.

2.1. Characterization of the ad hoc network

The characterization of the Ad Hoc network was conducted to determine the maximum transmission distance and the maximum bitrate for a two-node configuration. The experiments were carried out at the facilities of the Scientific, Technological, and Research Center Balzay (CCTI-B) at the University of Cuenca. Specifically, the paths highlighted in Figure 3 were selected, with lengths of 90 meters and 250 meters.

The first experiment involved transmitting UDP (User Datagram Protocol) traffic between two nodes, with one node remaining stationary while the other was moved away in 10-meter increments. At each distance, the traffic rate was maintained at a constant 200 Kbps and repeated ten times. In the second experiment, the nodes were positioned at an intermediate distance, and the UDP traffic rate was incrementally increased from 200 Kbps to 6 Mbps in steps of 100 Kbps. The experiments were conducted using the Iperf tool [29]. Table 1 provides a summary of the main parameters configured for each routing protocol.

Table 1. Default time intervals for the OLSR and BATMAN protocols

OLSR	(s)	BATMAN	(s)
HELLO_INTERVAL	2.0	ORIG_INTERVAL	1.0
REFRESH_INTERVAL	2.0	ELP_INTERVAL	0.5
TC_INTERVAL	5.0		
MID_INTERVAL	TC		
HNA_INTERVAL	TC		

Figure 3. Paths defined for conducting experiments at the CCTI-B.

An additional experiment was conducted to analyze the characteristics and traffic profile generated by audio transmission. For this test, two nodes were positioned 10 meters apart. The AAC (Advanced Audio Coding) codec was employed, configured with an average compression rate of 200 Kbps. The wireless card was set to a transmission speed of 54 Mbps and a power output of 20 dBm. Notably, the FFMPEG (Fast Forward MPEG) tool [30] was utilized for this process.

2.2. Throughput analysis in a multi-hop topology

In this scenario, throughput behavior was analyzed in a multi-hop configuration. This setup is particularly relevant as it enables bicycle users to communicate over extended distances (e.g., between distant nodes or with the anchor station).

The bitrate was varied to assess channel performance across one-hop, two-hop, and three-hop configurations. The experiments involved four nodes arranged in a linear topology, with each node configured to receive traffic exclusively from its directly adjacent node.

Figure 4 illustrates the topology employed in the experiment, where Node 1 serves as the transmitter (TX), and Nodes 2, 3, and 4 function as receivers (RX). The Iperf tool was utilized to regulate UDP traffic in 100 Kbps increments until a threshold value was reached at each hop, following the parameter values outlined in Table 1.

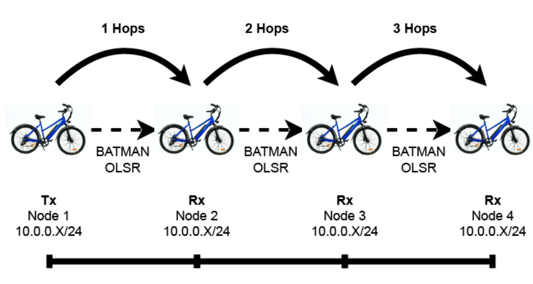

Figure 4. Multi-hop network topology

Based on the results obtained, the audio traffic encoding parameters were adjusted and are presented in detail in Table 2.

Table 2. General parameters for audio transmission and reception

Parameter	Value
Audio codec	AAC
Bitrate	64 kbps
Probesize	50000
Samplerate	48000 Hz

2.3. Development of the mobile web application and system evaluation

At this stage, a mobile web application was developed to support the remote management of the nodes and to evaluate their performance.

The application functions as a DHCP (Dynamic Host Configuration Protocol) server using Hostapd and Dnsmasq, enabling the management of the local network and the assignment of IPv4 (Internet Protocol version 4) addresses to devices connected through a Raspberry Pi.

Additionally, two scenarios were designed to evaluate the MANET network alongside the mobile web application. These scenarios are detailed in the following section.

To enhance user experience, two QR (Quick Response) codes were integrated one to facilitate wireless network connection and the other to launch the mobile web application. These codes enable users to conveniently access the desired functions by scanning them. In cases where scanning capabilities are unavailable, the required information for manually establishing the connection is also provided.

The evaluation was conducted using key metrics, including delay, PRR, throughput, and energy consumption.

3. Results and Discussion

Figure 5 illustrates the bitrate behavior as a function of the number of hops, based on the routing protocol utilized. For the experiments, a linear topology was configured with nodes spaced 30 meters apart. As observed, the throughput decreases as the number of nodes increases, which in turn raises the number of required hops.

This behavior can be attributed to data flow contention at each hop, a phenomenon known as intra flow interference. Additionally, signaling mechanisms, such as acknowledgment (ACK) messages, further limit data transfer speeds, as discussed in [31].

Figure 5a depicts the bitrate performance for the OLSR protocol. For the 1-hop configuration (blue), the channel exhibits a highly favorable response, demonstrating linear behavior up to 6 Mbps. In the 2-hop scenario (orange), linear behavior persists up to 3 Mbps; however, beyond this point, the channel begins to show variability, with a maximum bitrate of 3.2 Mbps. Lastly, in the 3-hop configuration (green), the behavior remains linear up to 2.4 Mbps. Beyond this threshold, the received bitrate exhibits notable variability, fluctuating between 2.3 Mbps and 2.8 Mbps. The experiment achieved a maximum traffic transmission of 3.3 Mbps.

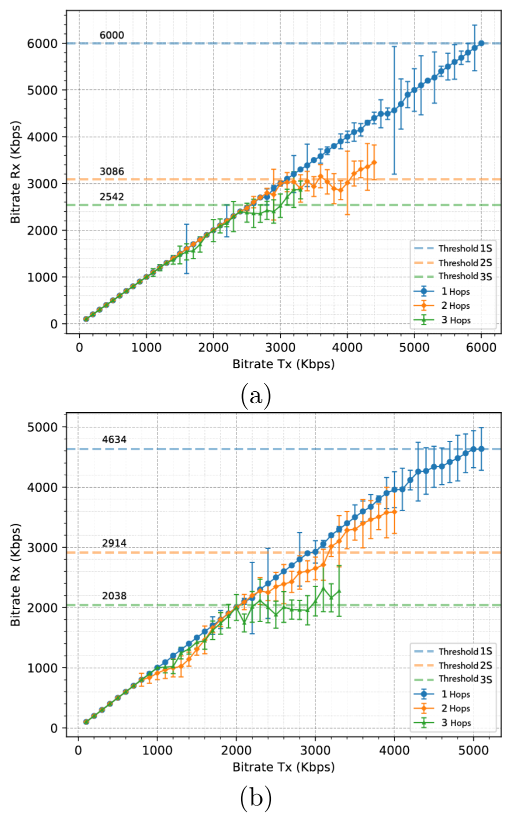

Figure 5. Behavior of the bitrate according to the number of hops. (a) With OLSR. (b) With BATMAN

Figure 5b illustrates the bitrate performance for the BATMAN protocol. For the 1-hop configuration (blue), the channel exhibits a favorable and nearly linear response, achieving 4.63 Mbps when traffic is transmitted at 5.1 Mbps. In the 2-hop scenario (orange), the response remains nearly linear up to 2.2 Mbps. Beyond this point, the channel begins to exhibit variability, reaching a maximum of 3.6 Mbps. Lastly, for the 3-hop configuration (green), the bitrate initially maintains linear behavior up to 1 Mbps. Beyond this threshold, the graph displays some variability, with the received bitrate stabilizing around 2 Mbps. However, when traffic exceeds 2 Mbps, the received bitrate fluctuates between 1.8 Mbps and 2.3 Mbps.

Based on the results, the threshold values corresponding to the maximum throughput achieved at each hop were identified and are presented in Table 3.

The results presented in Figure 5 align with the findings in [31], which indicate that multi-hop flows tend to compete for access to the medium at each hop on their path to the destination node. Consequently, packets transmitted along longer routes are more likely to be discarded compared to those traveling shorter routes, thereby explaining the reduction in throughput observed at 2 and 3 hops.

Table 3. Maximum throughput achieved in the multi-hop network topology

Protocol	1 hop	2 hops	3 hops	Unit
OLSR	6.00	3.08	2.54	Mbps
BATMAN	4.63	2.91	2,038	

3.1. Selection of scenarios for network evaluation

Two scenarios were designed to evaluate the MANET network in conjunction with the mobile web application. Specifically, the area depicted in Figure 6 was designated for the tests, encompassing a 120-meter path within the CCTI-B facilities at the University of Cuenca.

Figure 6. Selected location for conducting the experiments within the CCTI-B

The experiments involved the transmission of voice traffic. The first scenario, illustrated in Figure 7, simulates the integration of a new node (node 4) into the MANET network. This node, serving as the data destination, moves along the defined path, while the remaining three nodes remain stationary, with node 2 functioning as the transmitter. Nodes 3 and 1 serve as intermediate hops to maintain communication when node 4 is positioned at the ends of the path.

The second scenario, illustrated in Figure 8, emulates communication between two moving cyclists (nodes 2 and 4), while nodes 1 and 3 remain stationary, serving as anchor stations to enable communication via hops. The fixed nodes are separated by a distance of 60 meters, while the distance between the mobile nodes ranges from 30 to 90 meters. The results for each metric and scenario are detailed below.

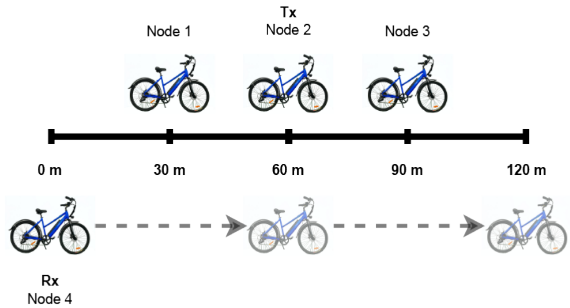

Figure 7. First scenario for the evaluation of the system and the mobile web application

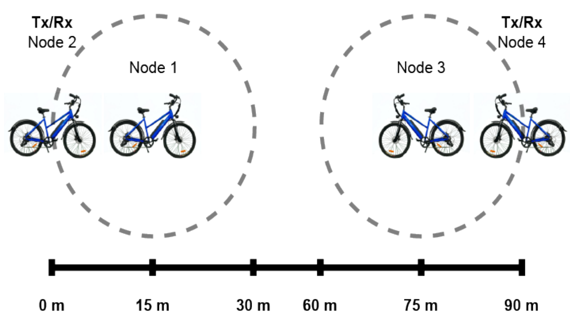

Figure 8. Second scenario for the evaluation of the system and the mobile web application

3.2. Delay

Figure 9 presents the results for the average delay observed with each protocol, analyzed with 95% confidence. Notably, the OLSR protocol exhibits a higher delay compared to BATMAN, with values of 49.5 ms versus 43.5 ms in the first scenario, and 20.9 ms versus 20.2 ms in the second scenario. This behavior can be attributed to the additional delay introduced by the exchange of signaling messages required for route establishment (e.g., Hello Interval, Orig Interval), as outline din Table 1.

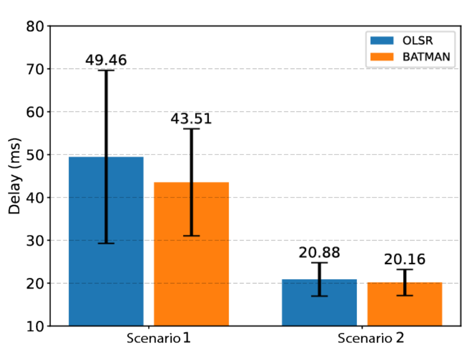

Figure 9. Average delay

3.3. PRR

Figure 10 presents the PRR percentages for scenarios 1 and 2. In the first scenario, the OLSR protocol achieves a PRR of approximately 96%, while the BATMAN protocol achieves 97%. Conversely, in the second scenario, OLSR records a PRR of 99%, outperforming BATMAN, which achieves 97%.

These results underscore the robust packet reception performance of both evaluated protocols. In the first scenario, both solutions achieve a reception rate exceeding 95%, while in the second scenario, this value rises to over 96%. Collectively, these findings highlight the effectiveness of both protocols in the evaluated scenarios.

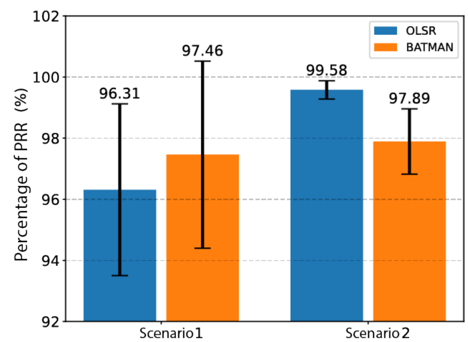

Figure 10. Average PRR

3.4. Throughput

Figure 11 illustrates the throughput results for each protocol. For the OLSR protocol, node 2 achieves a throughput of 68.21 Kbps, while node 4 records 65.7 Kbps. In the case of the BATMAN protocol, throughput values of 69.1 Kbps at node 2 and 65.82 Kbps at node 4 are observed.

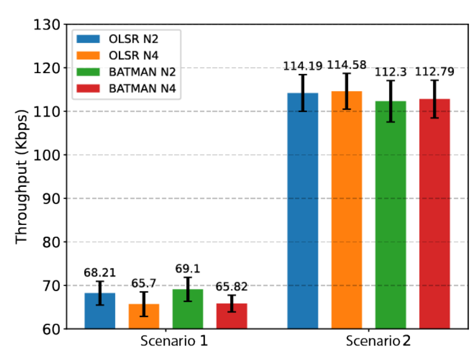

Figure 11. Average throughput

For scenario 2, the OLSR protocol achieves a throughput of 114.19 Kbps at node 2 and 114.58 Kbps at node 4. Similarly, for the BATMAN protocol, the observed throughput values are 112.3 Kbps at node 2 and 112.79 Kbps at node 4.

It is important to note that in the first scenario, only node 2 functioned as the transmitter and node 4 as the receiver, whereas in the second scenario, nodes 2 and 4 were configured for bidirectional communication. Consequently, higher throughput values are observed in the second scenario. Furthermore, these values remain within the multi-hop bandwidth capacity for both routing protocols.

3.5. Energy Consumption

Table 4 provides the energy measurements for each node in both scenarios. These measurements consider the maximum current consumed by the wireless interface and the 5 V operating voltage supplied by the USB (Universal Serial Bus) Type A port.

Table 4. Energy consumption at each node

Scenario	Protocol	Energy mAh			
		Node 1	Node 2	Node 3	Node 4
1	OLSR	206.75	201.5	176.6	205.53
	BATMAN	207.05	199.95	176.6	205.94
2	OLSR	79.22	72.57	79.42	76175
	BATMAN	87.57	72.93	88.3	72410

An analysis was performed to estimate the autonomy of the nodes based on their energy consumption during the experiments conducted in the two scenarios. The calculation utilized the 10 Ah capacity of the Eco move Electric Bikes battery [32] and the maximum current measurements for each node obtained using the INA219 current sensor [33]. Table 5 presents the estimated autonomy in hours.

Table 5. Estimation of autonomy time (h) for each node

Scenario	Protocol	Estimated autonomy time h			
		Node 1	Node 2	Node 3	Node 4
1	OLSR	24.18	24.18	28.31	24.32
	BATMAN	24.12	25.00	28.31	24.27
2	OLSR	31.55	34.44	31.47	32.81
	BATMAN	28.54	34.27	28.31	34.52

It is important to highlight that in some cases, the nodes' autonomy exceeds 24 hours. This can be attributed to the selection of test scenarios involving minimal motor usage, resulting in reduced battery consumption for the bicycle. Furthermore, during the experiments, only short-distance trips were conducted at speeds below 15 km/h.

4. Conclusions

This research proposes a MANET-based solution as an emergency communication system within the framework of sustainable mobility, specifically utilizing electric bicycles. A network comprising four mobile nodes and one primary fixed node was configured to conduct experiments, enabling the evaluation of proactive routing protocols, OLSR and BATMAN, in multi-hop topologies under mobility conditions.

Based on the experimental results, the OLSR protocol demonstrated superior performance in terms of bandwidth in multi-hop network topologies. The maximum throughput achieved at one hop was 6 Mbps, decreasing progressively with the number of hops to 3.08 Mbps for two hops and 2.54 Mbps for three hops. Conversely, the BATMAN protocol exhibited a similar trend but achieved lower threshold values, with maximum throughputs of 4.63 Mbps for one hop, 2.91 Mbps for two hops, and 2.038 Mbps for three hops.

Additionally, the average delay values for scenario 1 remained below 50 ms, while for scenario 2, they were approximately 20 ms. These results indicate favorable communication performance for both protocols, aligning with the ITU-T G114 recommendations, which consider delays of up to 150 ms acceptable for real-time communication. Similarly, the PRR percentages demonstrated strong performance, with packet reception rates exceeding 96% in both scenarios. Lastly, the throughput results confirmed that this metric aligns with the channel's evaluated bandwidth capacity, ensuring reliable and seamless communication.

The analysis of the results for audio transmission, identified as the most critical case due to its stringent delay and PRR requirements, indicates that the OLSR protocol exhibited superior adaptability in the experiments conducted in this study. Moreover, the findings underscore the feasibility of leveraging emerging technologies such as MANET for the development of communication systems within the context of sustainable mobility.

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References

[1] E. Salmeron-Manzano and F. Manzano-Agugliaro, "The electric bicycle: Worldwide research trends," *Energies*, vol. 11, no. 7, 2018. [Online]. Available: https://doi.org/10.3390/en11071894

[2] K. Pangbourne, D. Stead, M. Mladenovic, and D. Milakis, *The Case of Mobility as a Service: A Critical Reflection on Challenges for Urban Transport and Mobility Governance.* United Kingdom: Emerald, 2018, pp. 33–48. [Online]. Available: https://upsalesiana.ec/ing33ar3r2

[3] X. Xia, H. Jiang, and J. Wang, "Analysis of user satisfaction of shared bicycles based on sem," *Journal of Ambient Intelligence and Humanized Computing*, vol. 13, no. 3, pp. 1587–1601, Mar 2022. [Online]. Available: https://doi.org/10.1007/s12652-019-01422-y

[4] Z. Yang, J. Chen, J. Hu, Y. Shu, and P. Cheng, "Mobility modeling and data-driven closed-loop prediction in bike-sharing systems," *IEEE Transactions on Intelligent Transportation Systems*, vol. 20, no. 12, pp. 4488–4499, 2019. [Online]. Available: https://doi.org/10.1109/TITS.2018.2886456

[5] S. Shen, Z.-Q. Wei, L.-J. Sun, Y.-Q. Su, R.-C. Wang, and H.-M. Jiang, "The shared bicycle and its network—internet of shared bicycle (iosb): A review and survey," *Sensors*, vol. 18, no. 8, 2018. [Online]. Available: https://doi.org/10.3390/s18082581

[6] F. Chen, K. Turoń, M. Kłos, W. Pamuła, G. Sierpiński, and P. Czech, "Fifth generation bike-sharing systems: examples from poland and china," *Scientific Journal of Silesian University of Technology. Series Transport*, vol. 99, pp. 05–13, 05 2018. [Online]. Available: http://dx.doi.org/10.20858/sjsutst.2018.99.1

[7] T. Bielinski and A. Wazna, "New generation of bike sharing systems in china: Lessons for european cities," *Journal of Management and Financial Sciences*, no. 33, pp. 25–42, 2019. [Online]. Available: https://doi.org/10.33119/JMFS.2018.33.2

[8] S. Yoo, S. Hong, Y. Park, A. Okuyama, Z. Zhang, Y. Yoshida, and S. Managi, "Danger, Respect, and Indifference: Bike-Sharing Choices in Shanghai and Tokyo using Latent Choice Models," MPRA Paper 108312, 2021. [Online]. Available: https://upsalesiana.ec/ing33ar3r8

[9] M. Frikha, *Ad Hoc Networks: Routing, Qos and Optimization*. Wiley, 2013. [Online]. Available: https://upsalesiana.ec/ing33ar3r9

[10] P. Astudillo Picon, C. Quidne Romero, S. Gonzalez Martinez, and I. Palacios Serrano, "Evaluación y comparación de códecs de video para el despliegue de un sistema de comunicación resiliente," *Revista Tecnologica ESPOL*, vol. 34, no. 3, pp. 12–30, 2022. [Online]. Available: https://doi.org/10.37815/rte.v34n3.935

[11] J. Loo, J. Lloret, and J. Ortiz, *Mobile Ad Hoc Networks*. Taylor & Francis, 2011. [Online]. Available: https://doi.org/10.1201/b11447

[12] K. Polshchykov, S. Lazarev, and E. Kiseleva, "Decision-making supporting algorithm for choosing the duration of the audio communication session in a mobile ad-hoc network," *Revista de la Universidad del Zulia*, vol. 10, no. 27, pp. 101–107, dic. 2019. [Online]. Available: https://upsalesiana.ec/ing33ar3r12

[13] M. A. Al-Absi, A. A. Al-Absi, M. Sain, and H. Lee, "Moving ad hoc networks—a comparative study," *Sustainability*, vol. 13, no. 11, 2021. [Online]. Available: https://doi.org/10.3390/su13116187

[14] A. Rosa, P. Á. Costa, and J. Leitão, "Generalizing wireless ad hoc routing for future edge applications," in *Mobile and Ubiquitous Systems: Computing, Networking and Services*, T. Hara and H. Yamaguchi, Eds. Cham: Springer International Publishing, 2022, pp. 264–279. [Online]. Available: https://doi.org/10.1007/978-3-030-94822-1_15

[15] L. Reis, D. Macedo, and J. Nogueira, "Autoconfiguraçao de rotas em redes ad-hoc de vants," in *Anais do XXVII Workshop de Gerência e Operação de Redes e Serviços*. Porto Alegre, RS, Brasil: SBC, 2022, pp. 99–112. [Online]. Available: https://doi.org/10.5753/wgrs.2022.223504

[16] D. G.C., A. Ladas, Y. A. Sambo, H. Pervaiz, C. Politis, and M. A. Imran, "An overview of post-disaster emergency communication systems in the future networks," *IEEE Wireless Communications*, vol. 26, no. 6, pp. 132–139, 2019. [Online]. Available: https://doi.org/10.1109/MWC.2019.1800467

[17] F. A. León Mateo, M. d. R. Cruz Felipe, and E. T. Zambrano Solorzano, "Revisión de estudios sobre sistemas fanet y drones para emergencias o desastres naturales," *Serie Científica de la Universidad de las Ciencias Informáticas*, vol. 15, no. 4, pp. 41–56, 2022. [Online]. Available: https://upsalesiana.ec/ing33ar3r17

[18] A. M. Soomro, M. F. Bin Fudzee, M. Hussain, H. M. Saim, G. Zaman, A. Rahman, H. AlUbaidan, and M. Nabil, "Comparative review of routing protocols in manet for future research in disaster management," *Journal of Communications*, 2022. [Online]. Available: https://doi.org/10.12720/jcm

[19] M. O. Olusanya and O. R. Vincent, "A manet-based emergency communication system for environmental hazards using opportunistic routing," in *2020 International Conference in Mathematics, Computer Engineering and Computer Science (ICMCECS)*, 2020, pp. 1–6. [Online]. Available: https://doi.org/10.1109/ICMCECS47690.2020.240894

[20] A. Guillen-Perez, A.-M. Montoya, J.-C. Sanchez-Aarnoutse, and M.-D. Cano, "A comparative performance evaluation of routing protocols for flying ad-hoc networks in real conditions," *Applied Sciences*, vol. 11, no. 10, 2021. [Online]. Available: https://doi.org/10.3390/app11104363

[21] Wardi, Dewiani, M. Baharuddin, S. Panggalo, and M. F. B. Gufran, "Performance of routing protocol olsr and batman in multi-hop and mesh ad hoc network on raspberry pi," *IOP Conference Series: Materials Science and Engineering*, vol. 875, no. 1, p. 012046, jun 2020. [Online]. Available: https://dx.doi.org/10.1088/1757-899X/875/1/012046

[22] J. Yi and C. Poellabauer, "Real-time multicast for wireless multihop networks," *Computers & Electrical Engineering*, vol. 36, no. 2, pp. 313–327, 2010, wireless ad hoc, Sensor and Mesh Networks. [Online]. Available: https://doi.org/10.1016/j.compeleceng.2009.03.009

[23] Z. haitao, Z. yuting, Z. hongbo, and L. dapeng, "Resource management in vehicular ad hoc networks: Multi-parameter fuzzy optimization scheme," *Procedia Computer Science*, vol. 129, pp. 443–448, 2018, 2017 INTERNATIONAL CONFERENCE ON IDENTIFICATION,INFORMATION AND KNOWLEDGEIN THE INTERNET OF THINGS. [Online]. Available: https://doi.org/10.1016/j.procs.2018.03.022

[24] M. Elaryh Makki Dafalla, R. A. Mokhtar, R. A. Saeed, H. Alhumyani, S. Abdel-Khalek, and M. Khayyat, "An optimized link state routing protocol for real time application over vehicular ad hoc network," *Alexandria Engineering Journal*, vol. 61, no. 6, pp. 4541–4556, 2022. [Online]. Available: https://doi.org/10.1016/j.aej.2021.10.013

[25] K. A. Polshchykov, S. A. Lazarev, E. D. Kiseleva, E. M. Mamatov, and E. V. Ilinskaya, "Audio communication quality provisionin a self-organizing network," *Procedia EnvironmentalScience, Engineering and Management*, vol. 9, pp. 509–515, 2022. [Online]. Available: https://upsalesiana.ec/ing33ar3r25

[26] M. Hosseinzadeh, S. Ali, A. H. Mohammed, J. Lansky, S. Mildeova, M. S. Yousefpoor, E. Yousefpoor, O. Hassan Ahmed, A. M. Rahmani, and A. Mehmood, "An energy-aware routing scheme based on a virtual relay tunnel in flying ad hoc networks," *Alexandria Engineering Journal*, vol. 91, pp. 249–260, 2024. [Online]. Available: https://doi.org/10.1016/j.aej.2024.02.006

[27] R. Prasad P and Shivashankar, "Enhanced energy efficient secure routing protocol for mobile ad-hoc network," *Global Transitions Proceedings*, vol. 3, no. 2, pp. 412–423, 2022, global Transitions 2019. [Online]. Available: https://doi.org/10.1016/j.gltp.2021.10.001

[28] M. Arun and R. Jayanthi, "An adaptive congestion and energy aware multipath routing scheme for mobile ad-hoc networks through stable link prediction," *Measurement: Sensors*, vol. 30, p. 100926, 2023. [Online]. Available: https://doi.org/10.1016/j.measen.2023.100926

[29] Iper.fr. (2023) iperf - the tcp, udp and sctp networkbandwidth measurement tool. [Online]. Available: https://upsalesiana.ec/ing33ar3r29

[30] FFmpeg. (2023) A complete, cross-platform solution to record, convert and stream audio and video. [Online]. Available: https://upsalesiana.ec/ing33ar3r30

[31] W. E. Castellanos Hernández, "Quality of service routing and mechanisms for improving video streaming over mobile wireless ad hoc networks," Ph.D. dissertation, Universitat Politecnica de Valencia, 2015. [Online]. Available: http://dx.doi.org/10.4995/Thesis/10251/53238

[32] Ecomove. (2023) Tiv - ecomove. [Online]. Available: https://upsalesiana.ec/ing33ar3r32

[33] Adafruit. (2023) Adafruit ina219 current sensor breakout. [Online]. Available: https://upsalesiana.ec/ing33ar3r33