

Analyzing Wireless Network Implementation Using Cooja Simulation in Contiki Operating System

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Abstract

This research aims to analyze the performance of different wireless network topologies using the Cooja simulator within the Contiki operating system environment. Four network topologies—chain, ring, tree, and mesh—were simulated to evaluate their energy consumption, hop count, and radio duty cycle (RDC) performance. The results indicate that the mesh topology balances energy efficiency and performance, making it suitable for Internet of Things (IoT) and wireless sensor network (WSN) applications. In contrast, the chain topology exhibited higher energy consumption and increased hop count, highlighting the importance of choosing an appropriate topology to ensure network efficiency and quality of service (QoS).

Keywords: Cooja Simulator, Contiki Os, Energy Consumption, Network Topologies, Wireless Sensor Networks

تحليل تنفيذ الشبكة اللاسلكية باستخدام محاكاة كوجا في نظام التشغيل كونتيكي

جنان محسن¹

المستخلص

يهدف هذا البحث إلى تحليل أداء مختلف طوبولوجيات الشبكات اللاسلكية باستخدام محاكي Cooja ضمن بيئة نظام التشغيل Contiki. وقد تمت محاكاة أربع طوبولوجيات للشبكات - السلسلة، والحلقة، والشجرة، والشبكة الشبكية - لتقييم استهلاكها للطاقة، وعدد قفزاتها، وأدائها في دورة عمل الراديو (RDC). وتشير النتائج إلى أن طوبولوجيا الشبكة توازن بين كفاءة الطاقة والأداء، مما يجعلها مناسبة لتطبيقات إنترنت الأشياء (IoT) وشبكات الاستشعار اللاسلكية (WSN). في المقابل، أظهرت طوبولوجيا السلسلة استهلاكاً أعلى للطاقة وعدد قفزات متزايداً، مما يُبرز أهمية اختيار طوبولوجيا مناسبة لضمان كفاءة الشبكة وجودة الخدمة (QoS).

الكلمات المفتاحية: محاكي كوجا، نظام تشغيل كونتيكي، استهلاك الطاقة، طوبولوجيات الشبكة، شبكات الاستشعار اللاسلكية

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معلومات البحث

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Introduction

Wireless sensor networks (WSNs) play a pivotal role in Internet of Things (IoT) applications and smart monitoring systems [1]. The efficiency of these networks is affected by various factors, including the chosen network topology. This study focuses on analyzing the performance of four distinct topologies—chain, ring, tree, and mesh using the Cooja simulator within the Contiki

operating system environment. The goal is to evaluate the power consumption, hop count, and radio duty cycle of each topology to determine the most energy-efficient topology that also ensures a high quality of service. Based on this, a wireless sensor network can be constructed that simulates multiple systems and may contain multiple mathematical algorithms[2],[3]. For example, one

study analyzed the performance of the Constrained Application Protocol (CoAP) and found it to be more efficient than HTTP in terms of power consumption and runtime for both client and server operators. The study also highlighted CoAP's lower operating costs and its support for machine-to-machine (M2M) communications [4]. Another study analyzed the security risks of the RPL protocol and simulated potential attacks on IoT systems using the Contiki/Cooja simulator to discuss their impact [5]. These studies highlight the importance of using simulation tools like Cooja to evaluate network protocols and configurations, providing valuable insights for improving wireless sensor network (WSN) designs in IoT applications.

Methodology

The Cooja simulator, integrated into the Contiki operating system, was used to simulate four network topologies: chain, ring, tree, and mesh. Each simulation consisted of 16 sensor nodes and

a drain node. The performance metrics evaluated included:

Power Consumption: Includes power consumption in transmit, receive, and low-power mode (LPM). **Hop Count:** Specifies the number of hops between a source and drain node. **Radio Duty Cycle (RDC):** Measures the duration of radioactivity, which impacts power consumption and network lifetime. Simulations were conducted in a controlled environment to minimize interference and ensure measurement accuracy.

Cooja simulator

The Cooja emulator, an integral part of the Contiki operating system, is designed to simulate wireless sensor networks (WSNs) with high fidelity [6-14]. This emulator allows researchers and developers to simulate the behavior of sensor nodes, facilitating the testing and evaluation of network protocols and applications in a controlled environment. The graphical user interface of the Cooja emulator is shown in Figure (1).

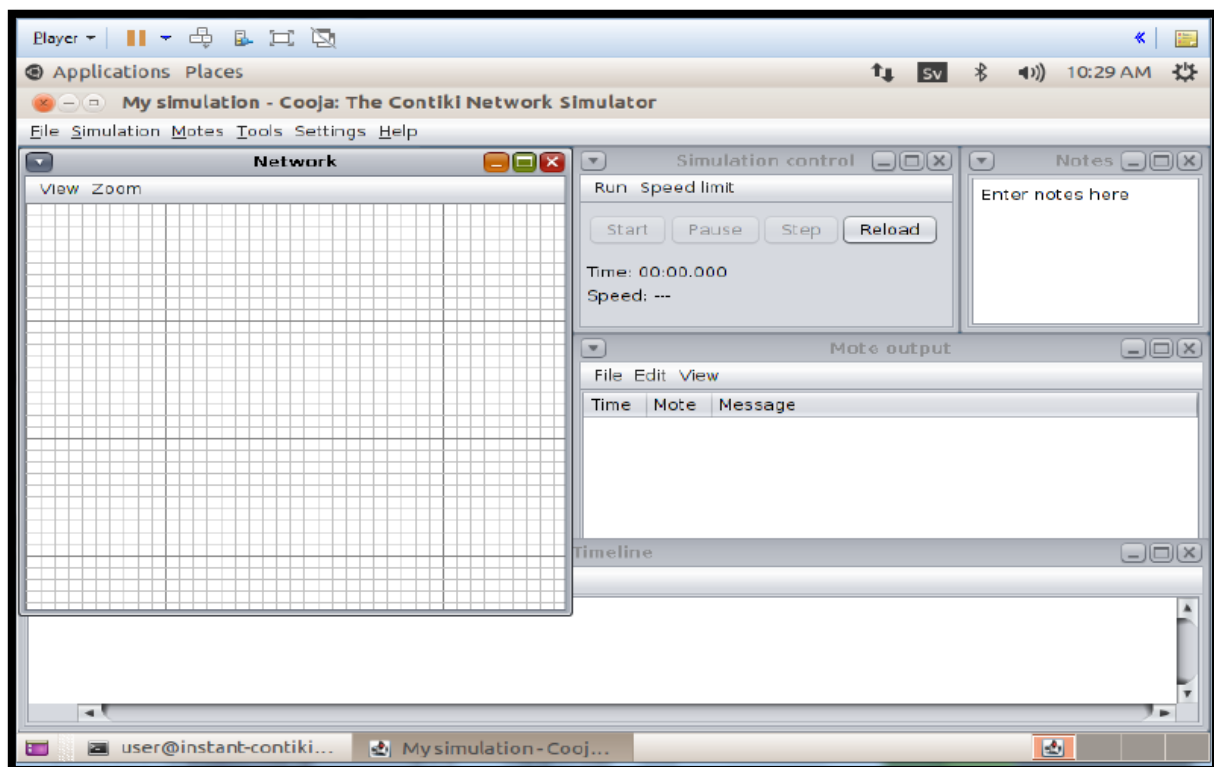


Figure (1): The Cooja UI

Results and Discussion

The simulation results provide valuable insights into the performance of different network topologies in wireless sensor networks (WSNs) using the Cooja simulator on Contiki OS. The evaluation focuses on energy consumption, hop

count, and radio duty cycle (RDC) to determine the most efficient topology for Internet of Things (IoT) applications. We compare and discuss the four topologies. The implementation of the Cooja simulator on Contiki OS is shown in Figure (2).

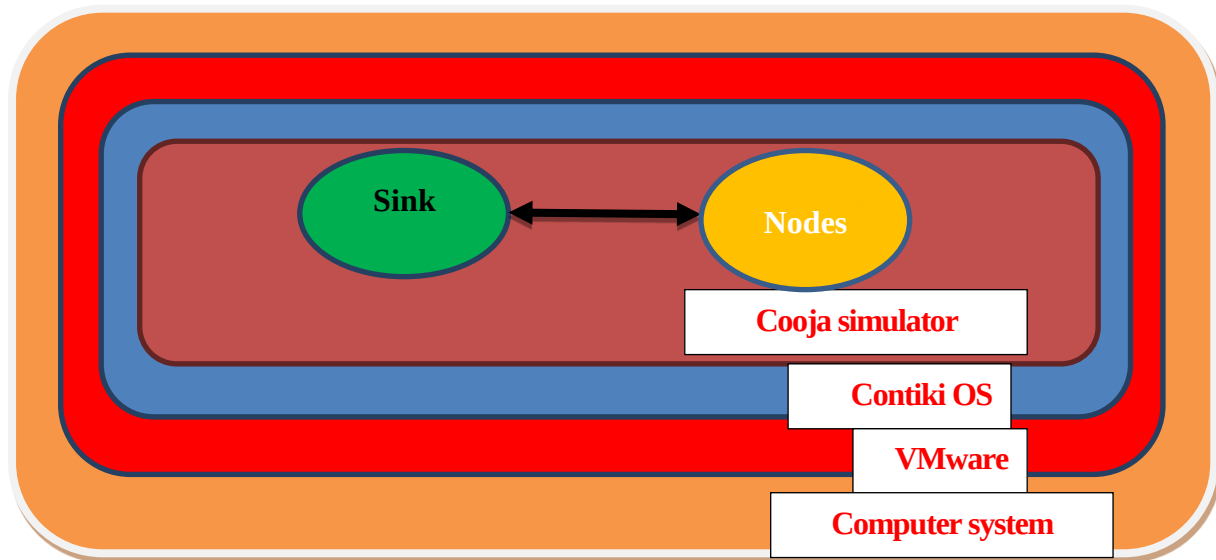


Figure (2) Executing Sink and Nodes by the Cooja Emulator under Contiki

We simulated different topologies (chain, tree, ring, and mesh) using the RPL protocol over UDP. Each network consists of one receiver and 16 nodes as clients. We conducted this experiment to

evaluate performance metrics such as radio duty cycle, energy consumption, and other metrics. The definition of these simulation parameters is presented, as shown in Table (1).

Table (1) The Definition of Simulation Parameters, [15]

Parameter	Definition
CPU	It represents the power that the CPU unit uses.
Low power Mode (LPM)	It represents the power that a node consumes in Low power mode.
Transmit power	It represents The power that a node consumes when transmitting Packets .
Listen power	It represents The power that a node consumes when receiving .packets

Radio duty cycle (RDC)	It is a tool for managing power based on the operation cycle and to guarantee a long network and node lifetime. In order to build up a schedule where the protocol will run the radio at a specific time and the nearby nodes may then send the packets in a timely manner, as illustrated in Figure 4.2, the nodes will not be able to broadcast or receive from the neighbors when the radio cycle is interrupted.
Radio listen	The radio of node is on to receive the message.
Radio transmit	The radio of node is on to transmit the message.
ETX	Represents the expected number of transmissions required to deliver the packet to its intended destination.

Radio duty cycle (RDC) is a tool for managing power based on the operation cycle to guarantee a long network and node lifetime. To build up a schedule where the protocol will run the radio at a specific time, nearby nodes may then send the

packets in a timely manner. The nodes will not be able to broadcast or receive from the neighbors when the radio cycle is interrupted. This concept is illustrated, as shown in Figure (3).

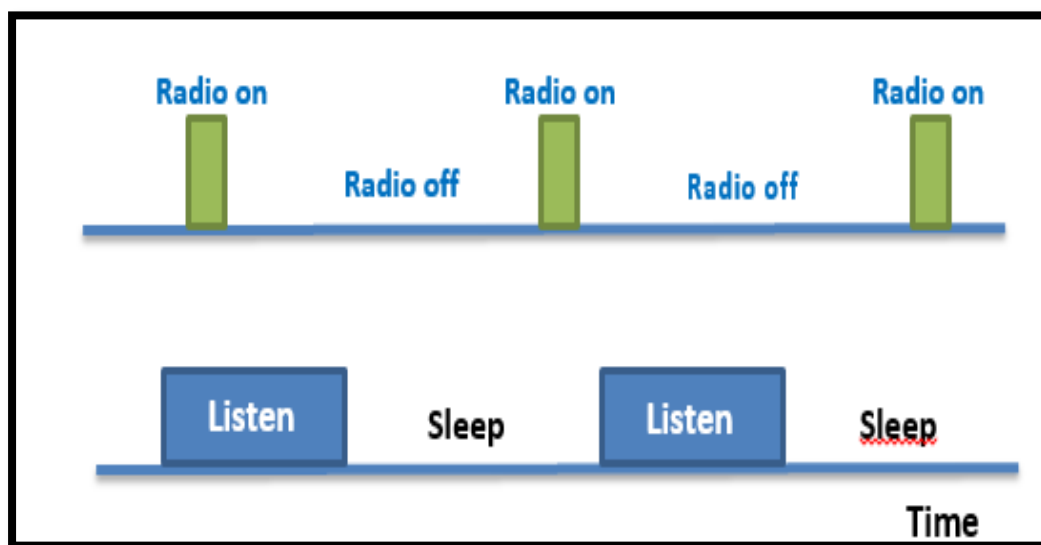


Figure (3) Radio Duty Cycling.

The general simulation parameters used to simulate the topologies are presented, as shown in Table (2).

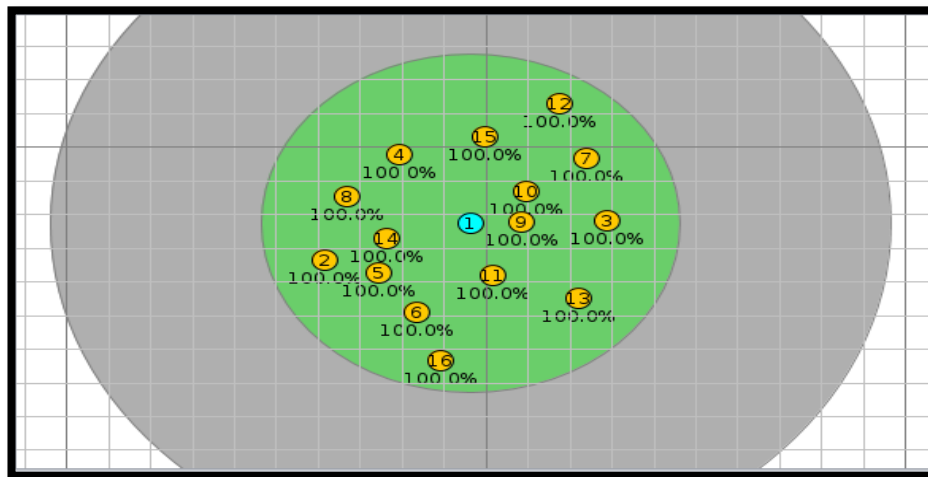
Table (2) General Simulation Parameters (topologies simulation)

Parameter	value
Operating System	Contiki 3.0
Radio Environment	Unit Disk Graph Medium (UDGM)
Number of nodes	50 m
Node transmission range	16
Node carrier sensing range	100 m
TX/Rx ratio	100 %
Time	260s

Grid Topology

In Grid topology simulation, the network consists of 1 sink and 16 clients distributed in a grid form.

Their distribution is presented, as shown in Figure (4).

**Figure (4) Distribution of Grid Topology**

The power consumption is displayed, as shown in Figure (5).

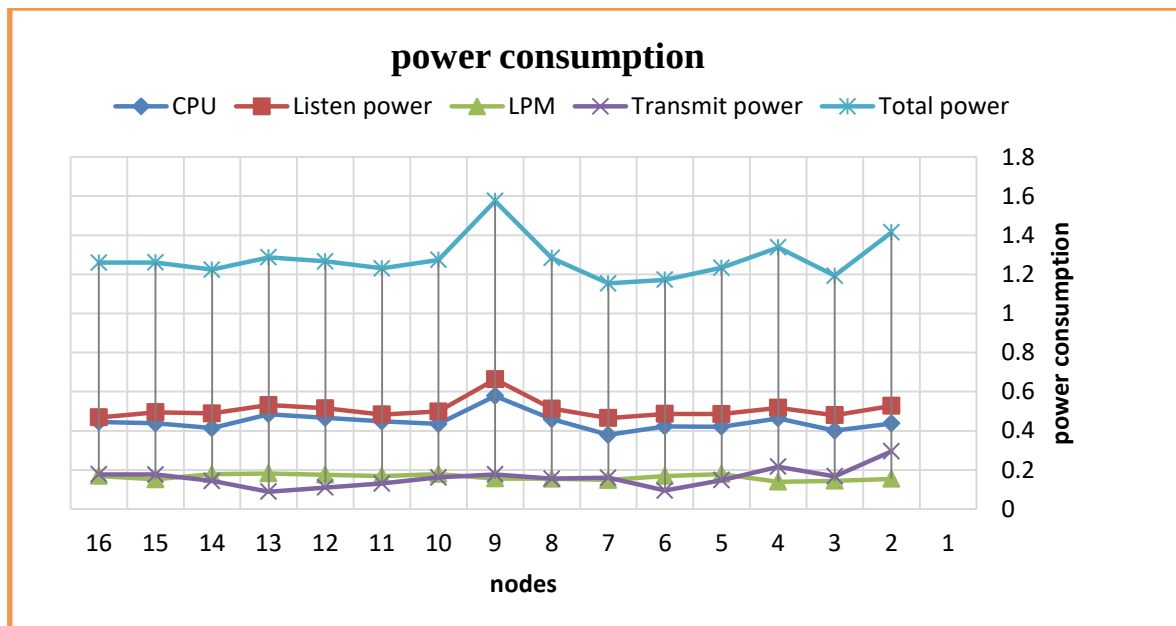


Figure (5) Power Consumption (Grid Topology)

The average radio duty cycle is shown, as shown in Figure (6).

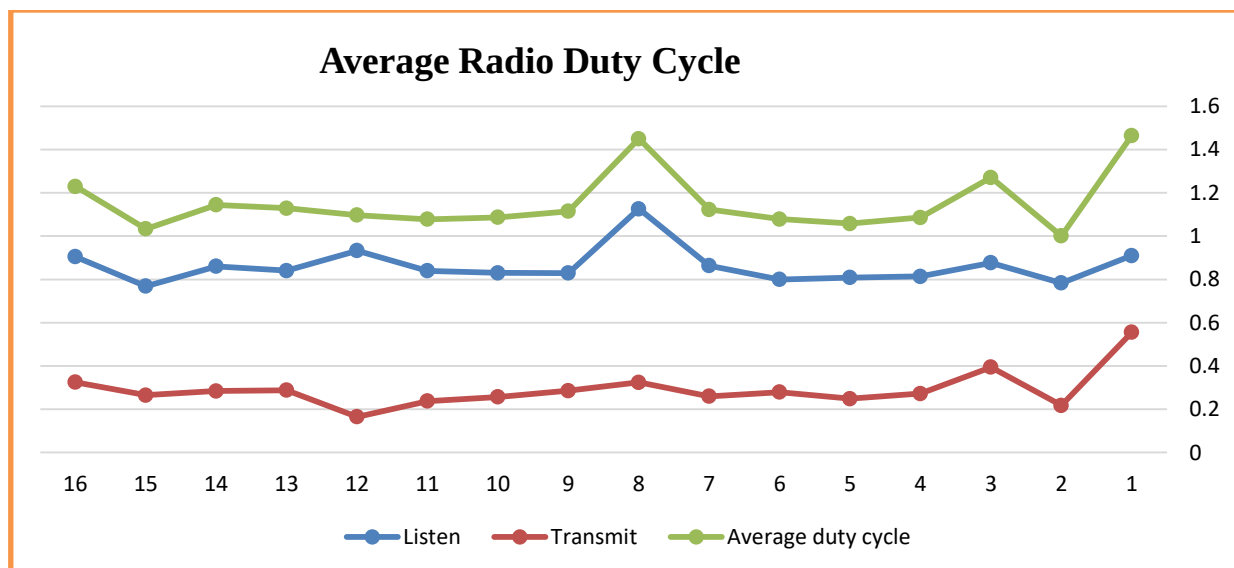


Figure (6) Average Radio Duty Cycle (Grid Topology)

Ring Topology

In Ring topology simulation, the network consists of 1 sink and 16 clients. The sink is located in the

center, with all nodes forming a ring around it, as shown in Figure (7).

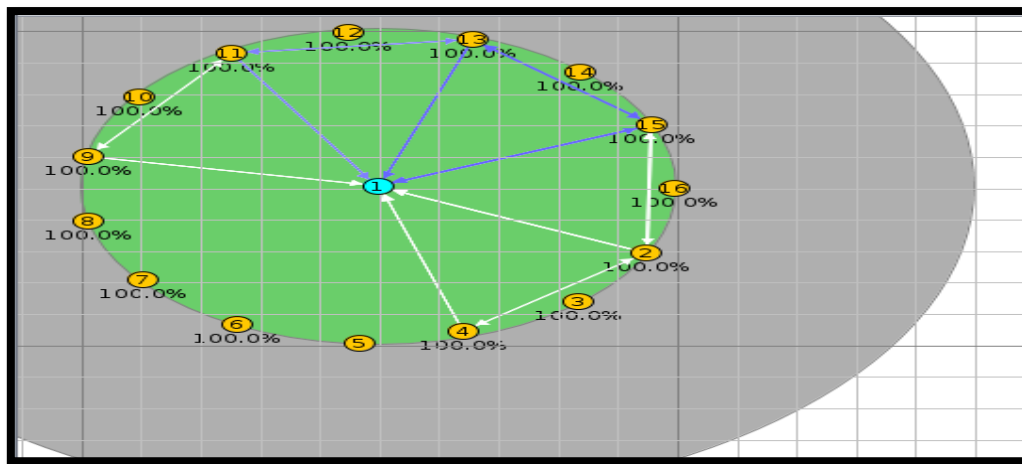


Figure (7) Distribution of Ring Topology

The power consumption is displayed, as shown in Figure (8).

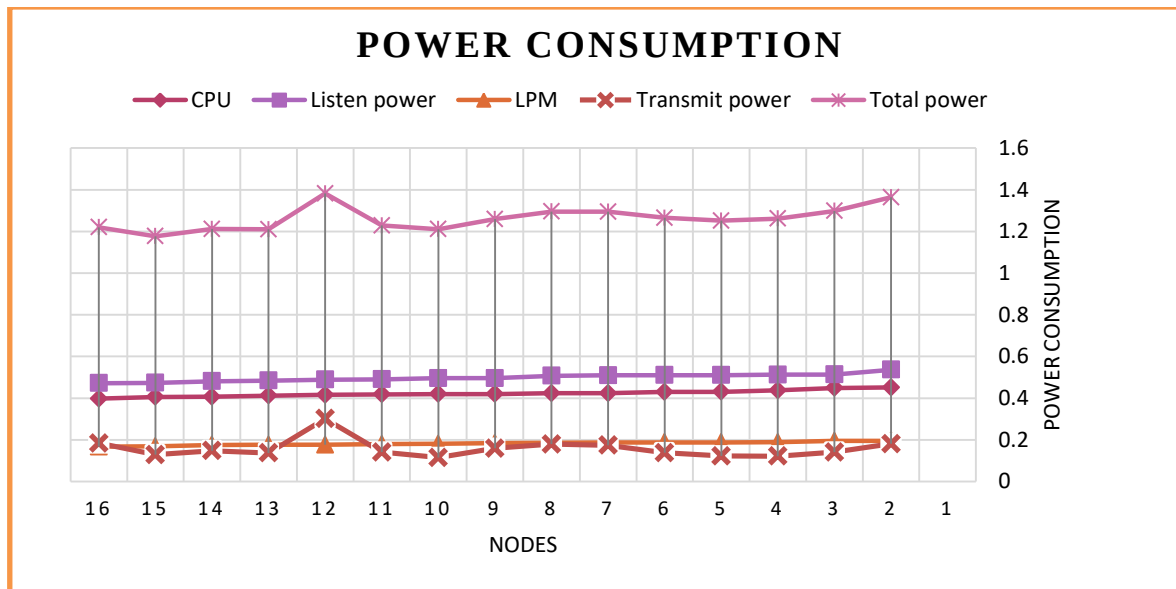


Figure (8) Power Consumption (Ring Topology)

The average radio duty cycle is displayed, as shown in Figure (9).

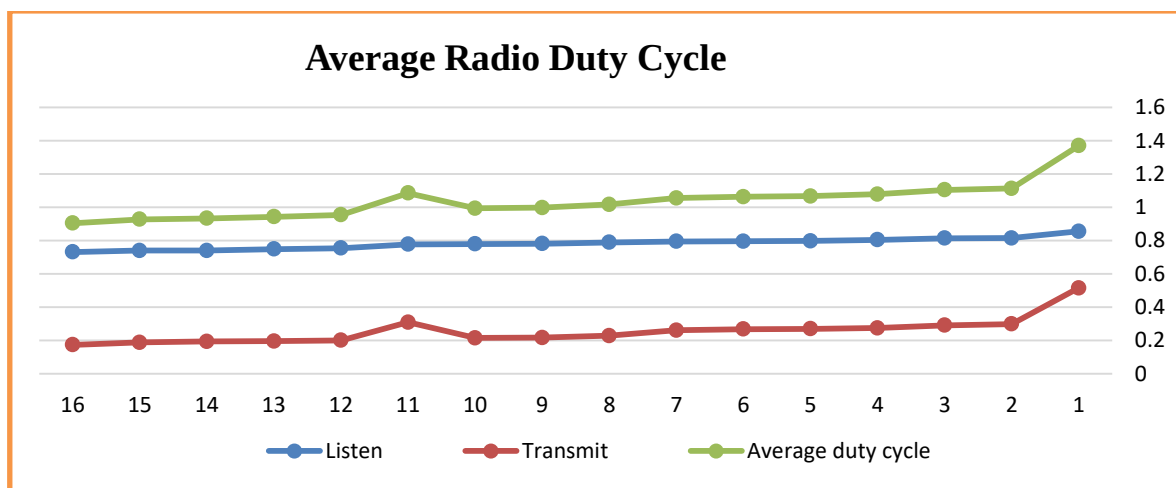


Figure (9) Average Radio Duty Cycle (Ring Topology)

Chain Topology

In Chain topology simulation, the network consists of 1 sink and 16 clients. The sink is located in the

center, with all nodes forming a chain from left and right, as shown in Figure (10).

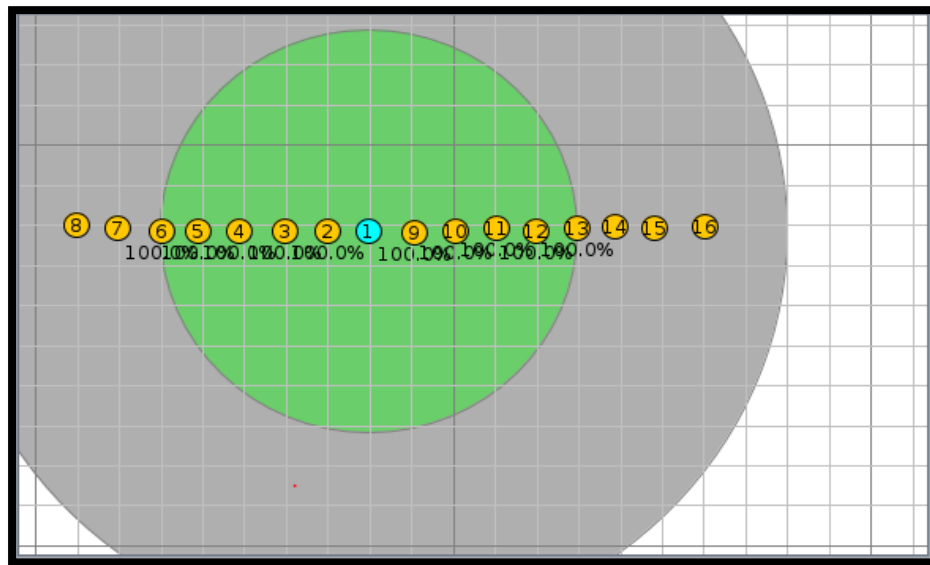


Figure (10) Chain Topology Distribution

The power consumption is displayed, as shown in Figure (11).

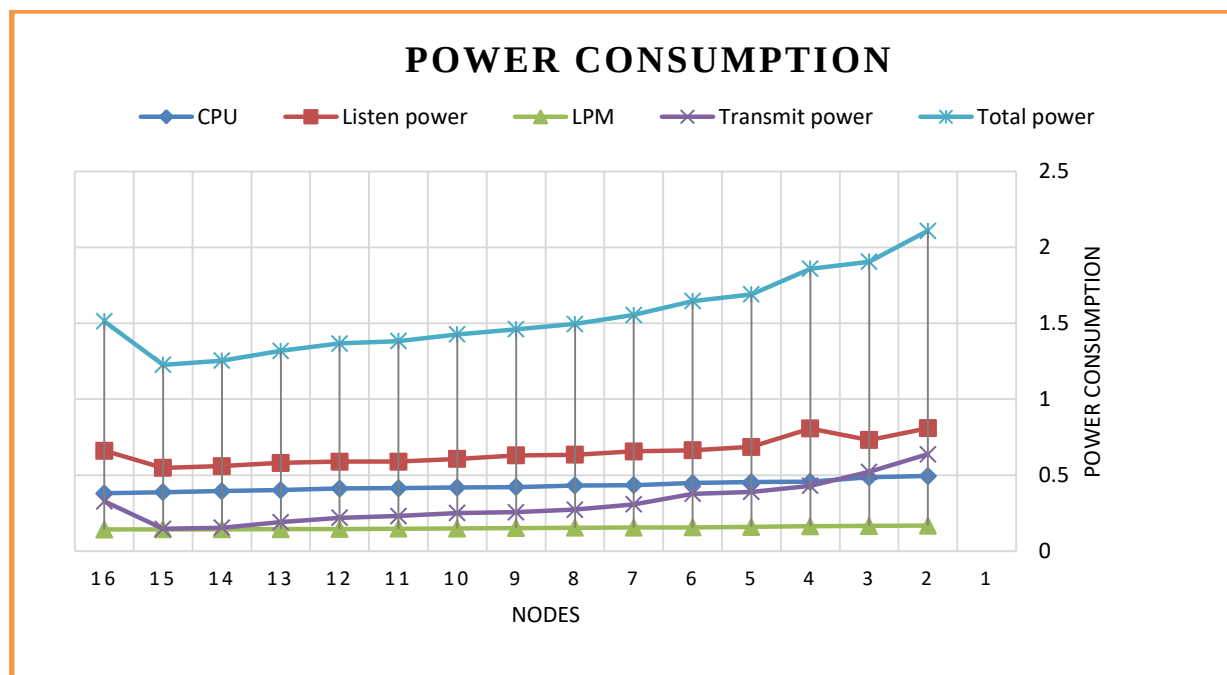


Figure (11) Power Consumption (Chain Topology)

The average radio duty cycle is displayed, as shown in Figure (12).

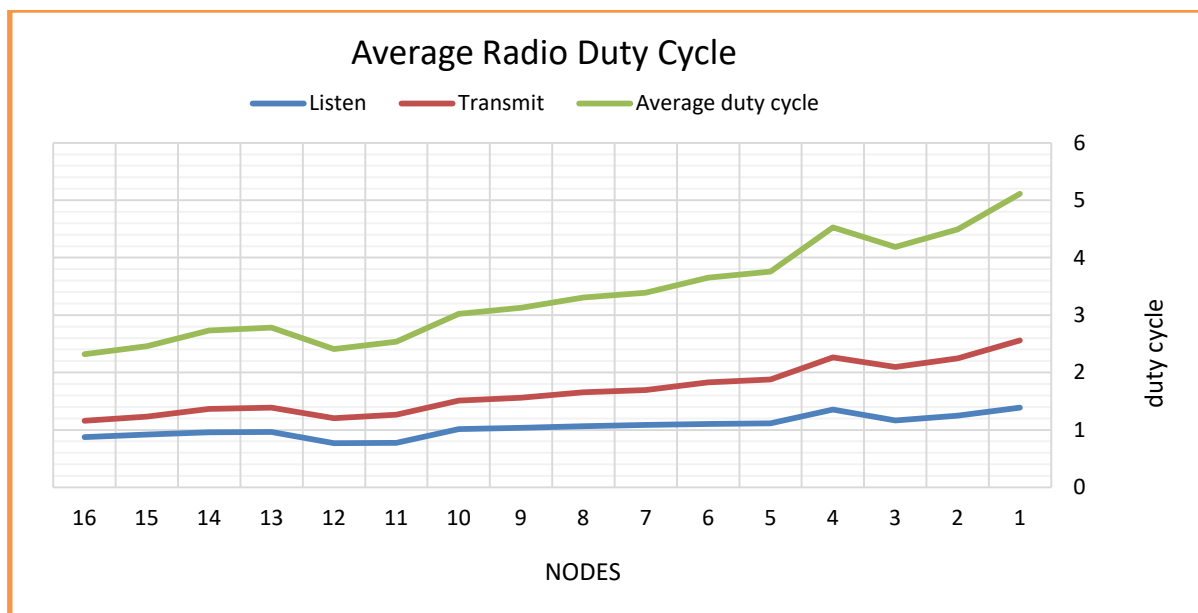


Figure (12) Average Radio Duty Cycle (Chain Topology)

Tree Topology

In Tree topology simulation, the network consists of 1 sink and 20 clients. The sink is located at the

top, with all nodes arranged as a tree leaf from top to bottom, as shown in Figure (13).

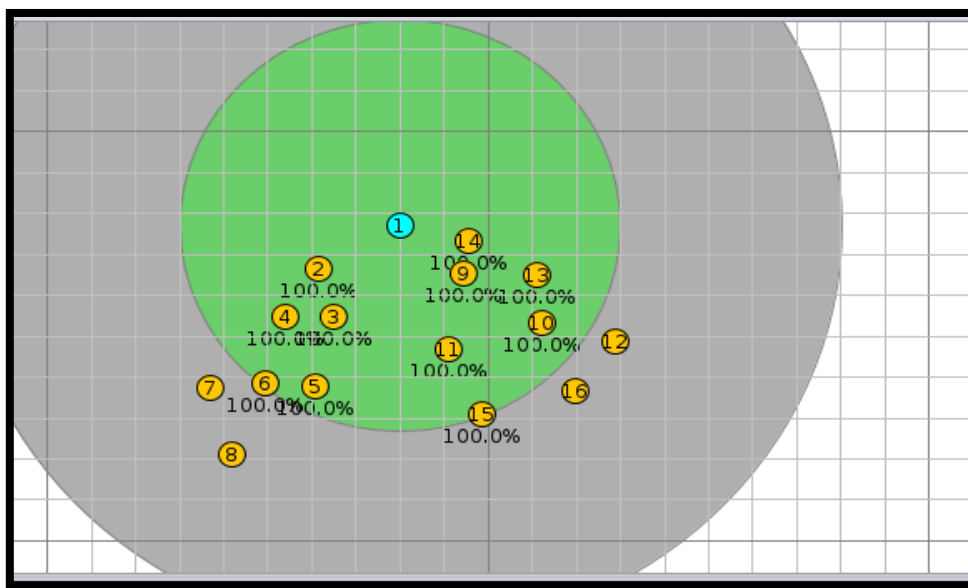


Figure (13) Tree Topology Distribution

The power consumption is displayed, as shown in Figure (14).

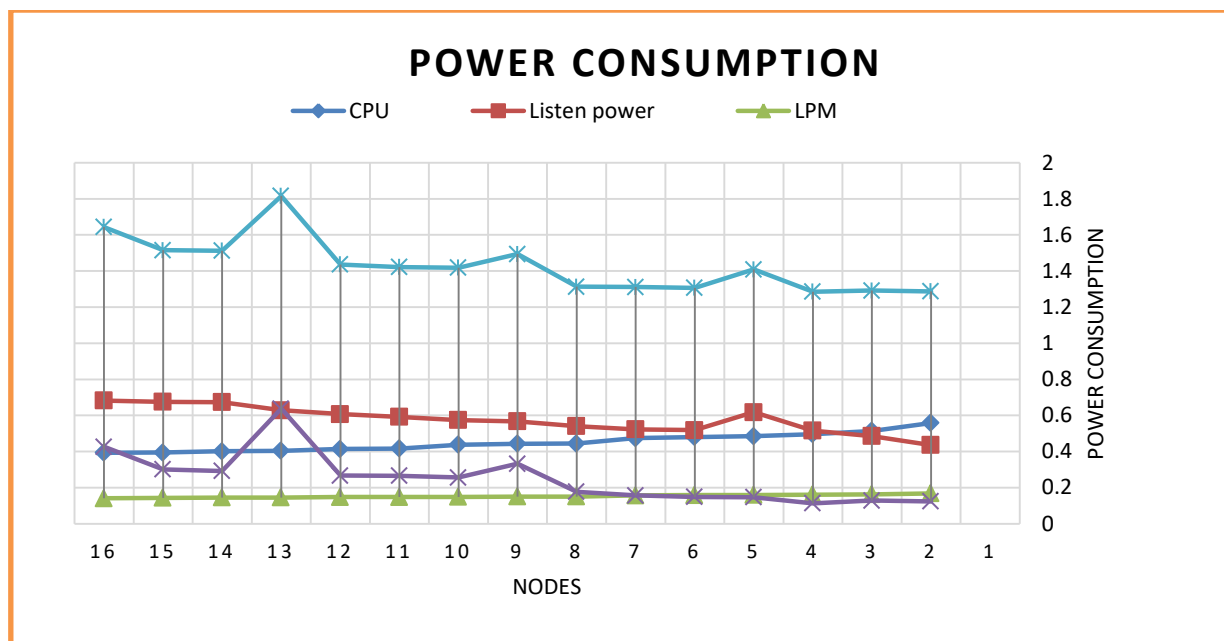


Figure (14) Power Consumption (Tree Topology)

The average radio duty cycle is displayed, as shown in Figure (15).

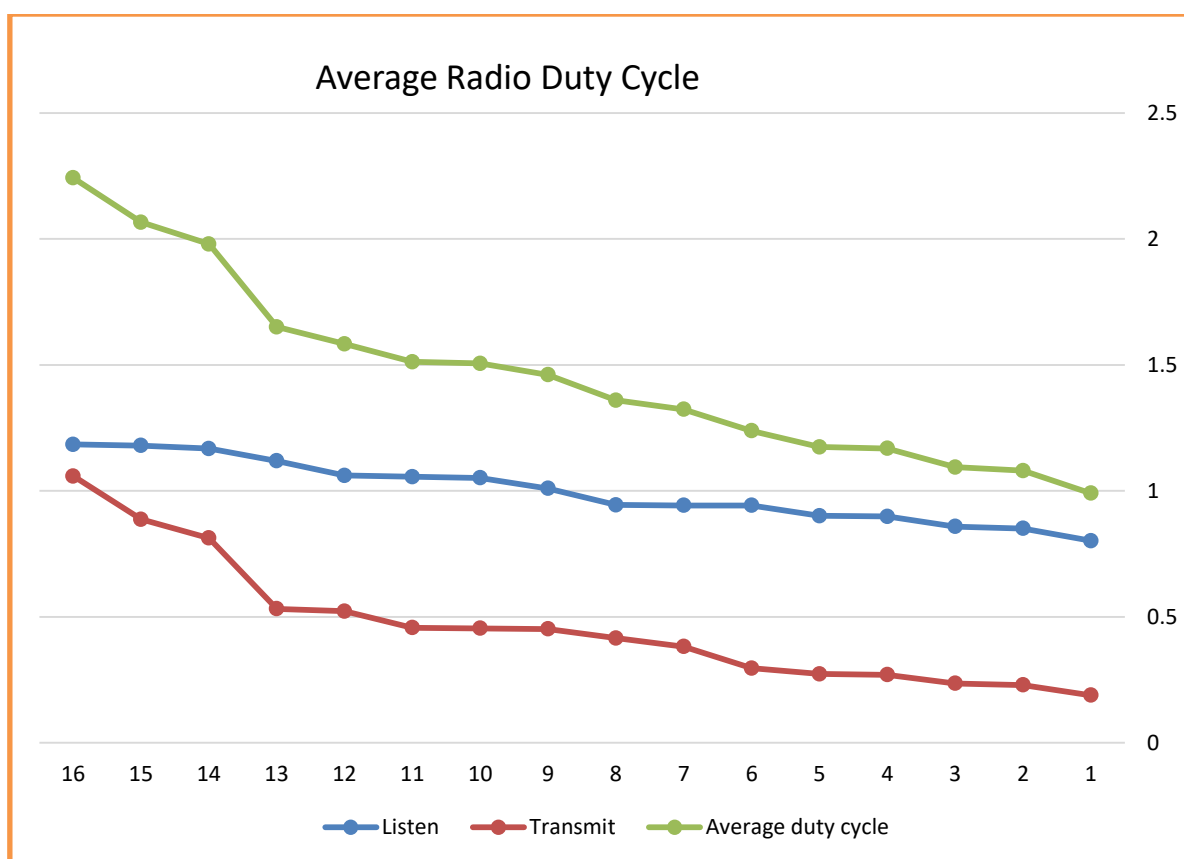


Figure (15) Average Radio Duty Cycle (Tree Topology)

Conclusions and recommendations

By simulating different topologies using the Cooja simulator within the Contiki operating system

environment, the study demonstrates the impact of power consumption, hop count, and radio duty cycle (RDC) on network efficiency. After

simulating the four topologies mentioned above, (as shown in Figure (16)).
we compared them in terms of power consumption

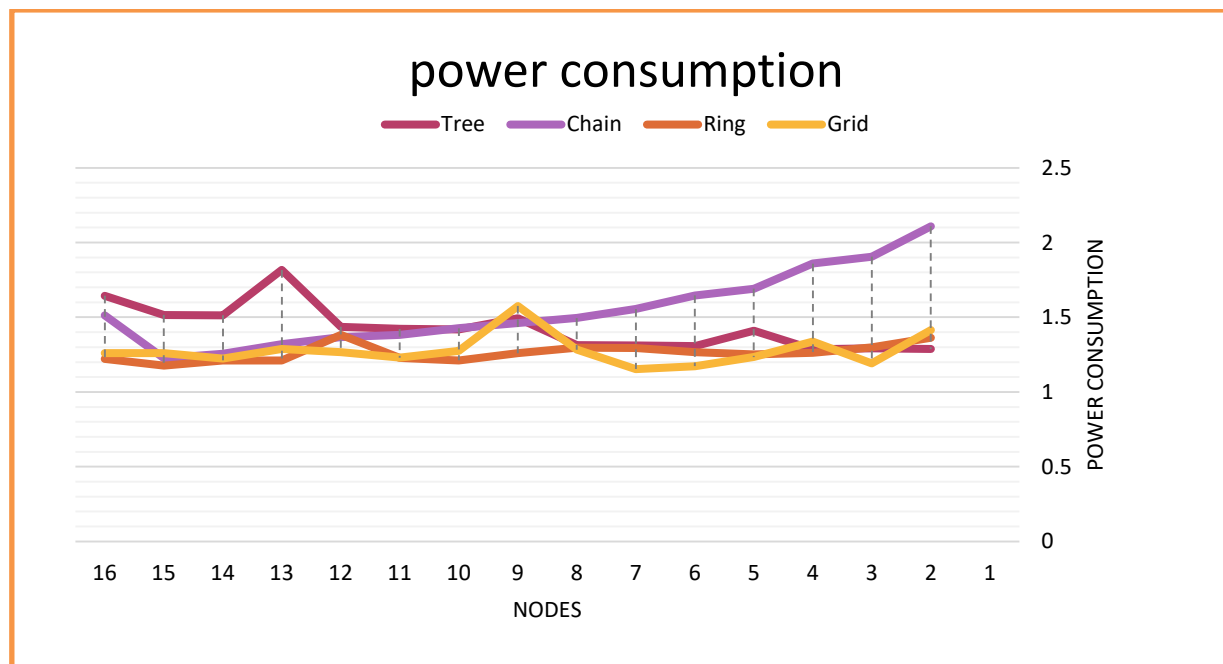


Figure (16) Power Consumption (Four Topologies)

duty cycle (as shown in Figure (17)).

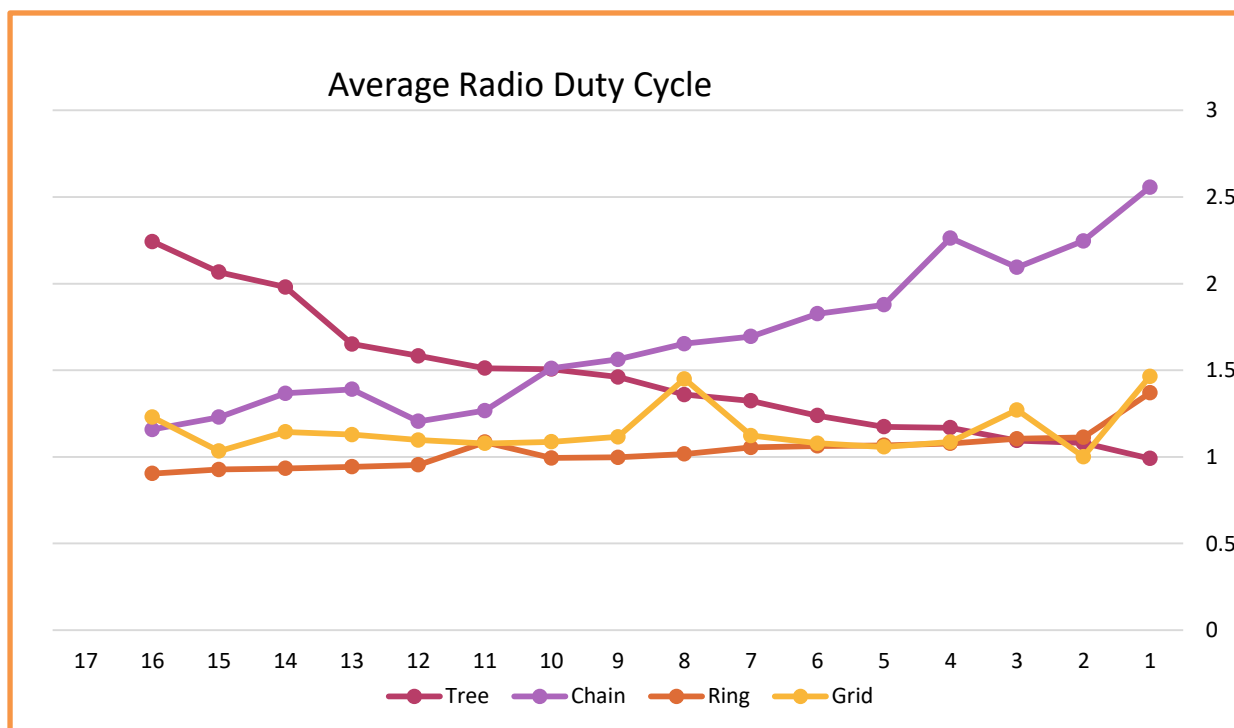


Figure (17) Average Radio Duty Cycle (Four Topologies)

hop count (as shown in Figure (18)).

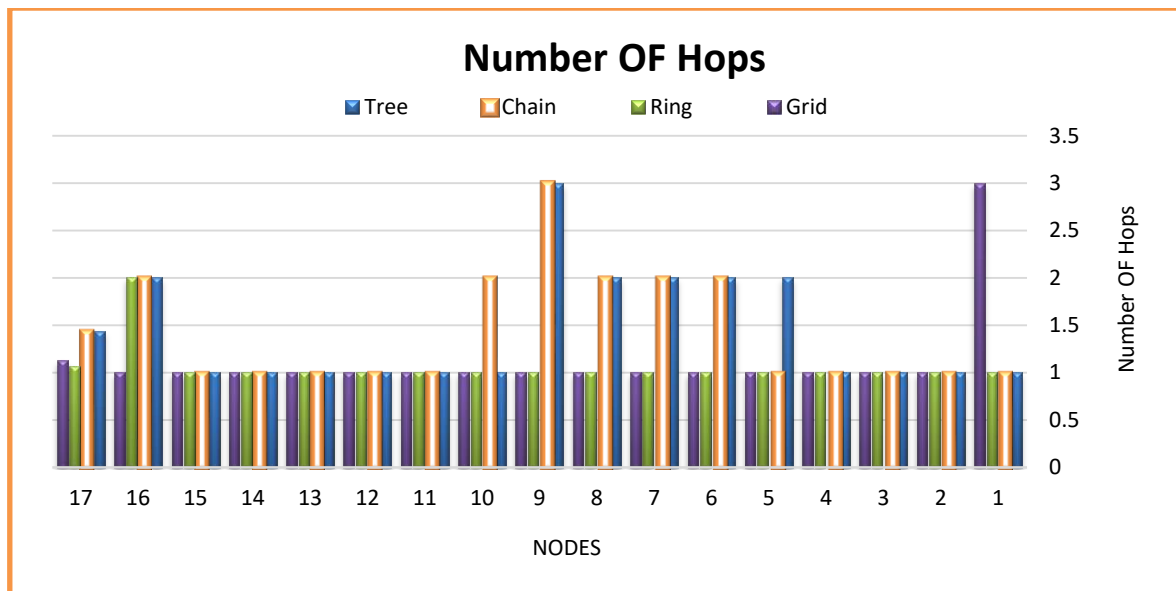


Figure (18) Number of hops (Four Topologies)

and ETX (as shown in Figure (19)).

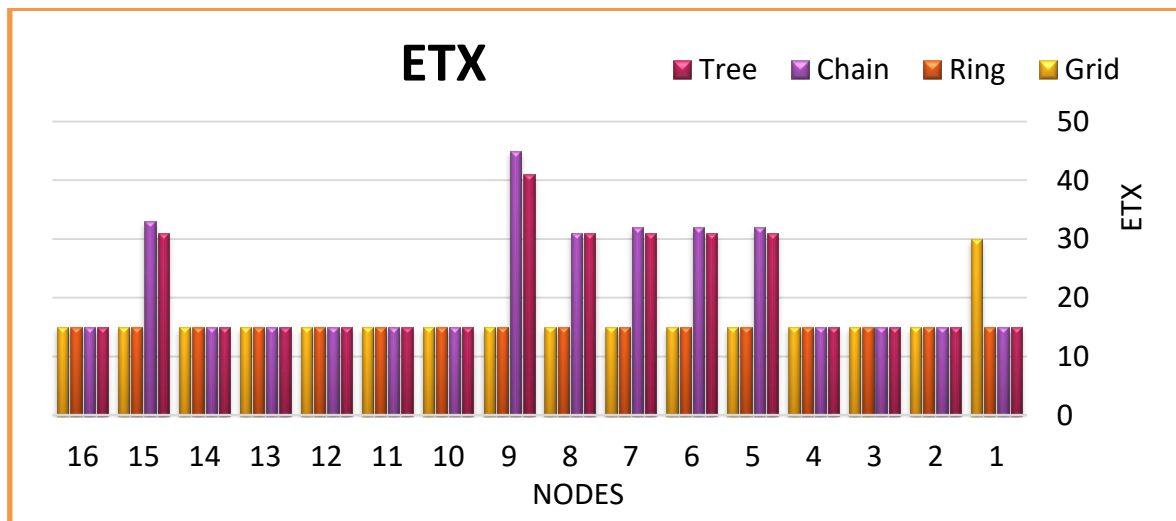


Figure (19) Expected Transmission Count (Four Topologies)

A more precise comparison of the metrics for the four topologies is provided, as shown in Table (3).

Table (3) Comparison between the Four Topologies

Measurements	Grid	Tree	Ring	Chain
Average Power consumption (mw)	1.277	1,430	1.262	1.547
Average radio duty cycle (%)	1.152	1.464	1.037	1.681
Average hops	1.125	1.437	1.062	1.437
Average ETX	15.937	21.625	15.000	22.187

In Figure 16, we see in the topology of the chain more power consumption compared to the other topology, and it also contains the largest number of hops that consume more power. We also observe that the Tree topology uses a lot of power, but not as much as the Chain topology or Ring topology. This indicates that the average power consumption is balanced and superior to that of the other topologies because the average number of hops is roughly one. After ring topology, grid topology uses less power and has an approximate hop average of one. Energy-intensive nodes are either located distant from the sink or obstruct other nodes that serve as a bridge to transport data to the sink. The average radio duty cycle across the four topologies is displayed in Figure 4.18. In a chain topology, the nodes have a longer working duration than in other topologies. The nodes will not sleep for a short while. Regarding the Ring architecture, more energy is produced by the nodes' ability to sleep and wake up as needed. It is also known that if the number of hops increases to any network that means increased latency, and this latter leads to reduce the throughput.

References

- [1] Palattella MR, Accettura N, Vilajosana X, Watteyne T, Grieco LA, Boggia G, et al. Standardized protocol stack for the internet of (important) things. *IEEE Commun Surveys & Tutorials*. 2012;15(3):1389-406.
- [2] Mohsin J, Saleh FH, Al-Muqarm AMA. Real-time surveillance system to detect and analyze the suspects of COVID-19 patients by using IoT under edge computing techniques (RS-SYS). In: *Proceedings of the 2020 2nd Al-Noor International Conference for Science and Technology (NICST)*; 2020 Aug; p. 68-73. IEE.
- [3] Mohsin J, Al-Shably ZH. Implementations of the Lenstra–Lenstra–Lovász algorithm in MATLAB. In: *AIP Conference Proceedings*; 2024 Nov; Vol. 3219, No. 1. AIP Publishing.
- [4] Krari A, Hajami A, Jarmouni E. Study and analysis of RPL performance routing protocol under various attacks. *Int J Tech Phys Probl Eng (IJTPE)*. 2021;(49):152-61.
- [5] Naik KP, Joshi UR. Performance analysis of constrained application protocol using Cooja simulator in Contiki OS. In: *Proceedings of the 2017 International Conference on Intelligent Computing, Instrumentation & Control Technologies (ICICICT)*; 2017 Jul; pp. 547-50.
- [6] Mohsin J, Albermany S. Proposing an IoT secure framework for monitoring COVID-19 patients. In: *Proceedings of the 2023 Al-Sadiq International Conference on Communications and Information Technology (AICCIT)*; 2023 Jul; pp. 263-6.
- [7] Khoury D, Haddad S, Sondi P, Haidar GA, Semaan D, Sayah J. Performance evaluation and analysis of LightCert4IoT using Cooja-Contiki simulator. *IEEE Access*. 2024;12.
- [8] Khan MA, Ahmadon MA, Rauf NAA, Zaid AM, Mahamad AK, Saon S, et al. Implementation and simulation of UDP client-server environment using Contiki Cooja simulator. Presented at: *2023 IEEE International Conference on Communications and Information Technology*; 2023.

- [9] Rana AK, Sharma S. Contiki Cooja security solution (CCSS) with IPv6 routing protocol for low-power and lossy networks (RPL) in Internet of Things applications. In: *Mobile Radio Communications and 5G Networks: Proceedings of MRCN 2020*. Singapore: Springer; 2021. p. 251-9.
- [10] GOI I. Network packet capturing and analysis using Wireshark in IoT network using Cooja simulator. *Unpublished*.
- [11] Elappila M, Chinara S. Implementation of survivability-aware protocols in WSN for IoT applications using Contiki-OS and hardware testbed evaluation. *Microprocessors and Microsystems*. 2024;104:104988.
- [12] Joshi H, Rathod D. Internet of Things (IoT)-based distributed denial of service (DDoS) attack using COOJA network simulator. In: *IoT with Smart Systems: Proceedings of ICTIS 2021, Vol. 2*. Singapore: Springer Nature Singapore; 2022. p. 671-7.
- [13] Periwat MG, Deere J. Analysis of simulators for designing network architecture in Wireless Sensor Network applications. *Unpublished*.
- [14] Tati A, BenSaci C. Simulation and evaluation of an IoT communication protocol [Ph.D. dissertation]. Algeria: Univ. of Kasdi Merbah Ouargla; 2023.
- [15] Jassim JHZ. Improvement of A5/1 encryption algorithm based on filtration technique for IoT application [M.S. thesis]. Iraq: Univ. of Babylon; 201