energies

Editorial

Energy Efficiency in Wireless Networks

Rajagopal Maheswar [1,*], Murugan Kathirvelu [2] and Kuppusamy Mohanasundaram [3]

1 Department of Electronics and Communication Engineering, Centre for IoT and AI (CITI), KPR Institute of Engineering and Technology, Coimbatore 641407, Tamil Nadu, India
2 Department of Electronics and Communication Engineering, KPR Institute of Engineering and Technology, Coimbatore 641407, Tamil Nadu, India; kathirvelu.m@kpriet.ac.in
3 Department of Electrical and Electronics Engineering, KPR Institute of Engineering and Technology, Coimbatore 641407, Tamil Nadu, India; mohanasundaram.k@kpriet.ac.in
* Correspondence: maheshh3@rediffmail.com

The pervasive integration of wireless devices across diverse sectors has experienced an unprecedented surge in recent years. Particularly noteworthy is the profound impact of the post-COVID-19 era, catalyzing a global revolution in the utilization of wireless technology. This epoch has witnessed remarkable advancements not only in the proliferation of devices within networks but also in the diverse applications they serve, spanning sensors, Internet of Things (IoT) devices, mobile phones, and an array of wireless electronic gadgets. These technological advancements have played a pivotal role in sustaining seamless global communication, even amidst the unprecedented challenges posed by the pandemic.

The monumental reliance on wireless devices during the pandemic underscored a significant concern—the monumental energy consumption attributed to their extensive usage across industries, educational institutions, and everyday life. As wireless devices predominantly rely on battery power, addressing energy efficiency becomes an indispensable imperative. The need for effective energy management and control techniques and infrastructures is paramount to prolonging the lifespan of both individual devices and the overarching networks they comprise.

In response to these pressing challenges, the present wireless landscape has spurred the research community to delve deeper into the realm of energy efficiency issues. This Special Issue endeavors to delve into the multifaceted dimensions of energy efficiency in wireless devices, particularly focusing on communication protocols, energy harvesting, management strategies, device scheduling, edge computing, and their implications across various wireless sensor, underwater, and IoT applications.

Liu et al. explores computation offloading within blockchain-integrated Internet of Things (IoT), focusing on securing the data uploading link from sensors to a base station using intelligent reflecting surface (IRS)-assisted physical-layer security (PLS). The study aims to enhance energy efficiency while considering Gas fees in computation offloading, as existing schemes often neglect Gas fees, leading to dissatisfaction among high Gas providers. It introduces a Gas-oriented computation offloading scheme ensuring low dissatisfaction among sensors, reducing energy consumption, and improving computational resource allocation based on Ethereum's decentralized platform. The system employs an IRS-assisted uplink communication model and utilizes Ethereum's core layers for task data transmission, contract creation, result computing, and blockchain-based transaction synchronization. The research addresses the integration of computational resources from mobile-edge computing (MEC) servers with sensors' limited computational abilities. This study presents a comprehensive framework considering wireless channels' time-varying characteristics and aims to optimize energy efficiency while ensuring fair computational resource allocation within the IoT blockchain network [1]. Singh and Das explores CoAP protocols for IoT devices, addressing concerns of duplicate updates to Resource Directories (RD), impacting battery life. Their proposed dynamic update interval tuning method,

check for updates

Citation: Maheswar, R.; Kathirvelu, M.; Mohanasundaram, K. Energy Efficiency in Wireless Networks. *Energies* **2024**, *17*, 417. https://doi.org/10.3390/en17020417

Received: 1 September 2023
Accepted: 3 January 2024
Published: 15 January 2024

alternating odd and even updates, reduces duplicates, extends battery life by 70%, outperforming other power-saving approaches [2].

Lu et al. introduces EA-DFPSO, an innovative task scheduling algorithm for mobile edge networks. EA-DFPSO optimizes energy efficiency and task execution time using a dual fitness function, outperforming traditional algorithms, reducing task time, and conserving energy in edge computing [3]. Sarwesh and Mathew introduces a cross-layer design for enhancing device sustainability in smart cities, crucial for IoT applications like e-health and smart grids. A network architecture integrating physical, data link, and network layers is proposed, aiming to optimize communication efficiency, using a weighted sum approach for routing metrics. The model focuses on managing energy-efficient communication, utilizing 45 routing metric combinations and computing Weight Factor (WF) values for routing metric pairs and triplets. The proposed approach, MTPM + ETP + ND, outperforms others, regulating node transmission power for enhanced device lifetime. Utilizing AODV routing, IEEE 802.15.4 radio models, and weighted sum approaches, the study aims to balance energy efficiency and performance in smart city IoT networks [4].

Gismalla et al. explores Device-to-Device (D2D) communication in 5G and beyond networks, investigating its basics, applications, and challenges. It categorizes D2D as in-band (IBD) and out-band (OBD) modes. IBD shares resources with cellular networks, enhancing spectral efficiency either through underlay or overlay modes. OBD operates in unlicensed spectrum bands, offering controlled or autonomous modes. The study emphasizes D2D integration in video streaming, Machine-to-Machine (M2M) communication, and local voice/data services, showing how D2D enhances network performance. Challenges and future research directions in D2D for 5G and upcoming 6G networks are discussed, emphasizing its pivotal role in future wireless communications. The paper's thorough analysis outlines D2D's significance, classification, and potential applications in next-generation networks [5]. Alsamhi et al. addresses the challenges in multi-drone collaboration within the Internet of Drones (IoD), focusing on consensus achievement security, energy efficiency, and real-time connectivity. It highlights the threat of Byzantine drones disrupting swarm coordination and proposes a blockchain-based approach to enhance consensus security while managing multi-drone collaboration. This method employs blockchain as a communication tool to broadcast instructions, ensuring consensus among anonymous drones in a P2P network. It emphasizes using blockchain to evaluate data quality and trustability, enabling efficient collaboration without raw data exchange. The approach involves drones joining the network via PoW solutions to maintain the blockchain and assess peer computing resources, allowing drones to share processed data for consensus. This novel framework enhances collaboration, enabling drones to enhance situational awareness without directly exchanging raw data while leveraging blockchain's security in decision-making systems amidst trust issues among participants [6].

Usha et al. proposed SWEEPER protocol enhances FANETs by conserving node energy during transmission. Using a waterfall model approach and asymmetric key cryptography, it establishes efficient routing and security management. It selects trusted nodes for packet forwarding, outperforming existing protocols in delay, energy conservation, and packet delivery rate (PDR), thereby maximizing throughput [7]. Fan et al. focuses on enhancing energy efficiency in underwater acoustic communication (UWA) by adapting transmission power to the channel condition. It introduces the Dyna-Q algorithm, employing an adaptive action space to manage power control based on real and simulated experiences. The method aims to maximize long-term energy efficiency by switching power levels during transmission. Using Orthogonal Frequency-Division Multiplexing (OFDM), simulations and field trials exhibit the proposed method's superiority over existing methods like original Dyna-Q with fixed action spaces. Adaptive actions enhance performance, allowing drones to explore optimal actions, improving the system's energy efficiency performance. The research outlines the algorithm and its implementation for efficient underwater communication [8].

Kong et al. introduces a solution using the deep deterministic policy gradient (DDPG) algorithm to address energy efficiency in edge computing for the Internet of Vehicles. It minimizes mobile network operator (MNO) energy costs by integrating computing and caching, turning the problem into a reinforcement learning scenario. The method reduces energy consumption by over 15% while ensuring timely task completion [9]. Li and Lee focuses on piezoelectric energy harvesting, analyzing parameters influencing performance and offering future development guidance. It details six key parameter groups: materials, structure, excitation sources, frequency, electrical load, and energy accumulation. Examples like off-resonance cymbal transducers, resonant cantilever designs, and impact generators demonstrate optimization approaches. Various structural designs amplify force on piezoelectric materials, increasing power output. For instance, optimizing cymbal dimensions substantially enhanced power from 1.2 mW to 52 mW. Resonant cantilevers achieved higher frequencies, producing significant voltage outputs. Impact designs, like steel ball-piezoelectric vibrator systems, indicate up to 10% efficiency for high-voltage generation [10].

This volume extends an invitation to researchers and experts to contribute original insights and contributions encompassing topics like energy-efficient physical layer design, communication protocols, scheduling algorithms, cross-layer design issues, device-to-device communication, advancements in drone technologies, VANET/FANET management, underwater communication strategies, edge computing techniques, and energy harvesting methodologies tailored specifically for wireless devices.

This preface sets the stage for a comprehensive exploration of energy efficiency concerns in wireless technology, advocating for innovative solutions and scholarly contributions to enhance the efficacy and sustainability of wireless device ecosystems.

Forty-two manuscripts were submitted for consideration for the Special Issue, and all of them were subject to the rigorous review process. In total, eighteen papers were finally accepted for publication and inclusion in this Special Issue (sixteen research articles and two reviews). The contributions are listed below:

Analysis of the Published Contributions in the Special Issue

#	Research Area	Focus	Type of Research
C1	Wireless Communications, 5G and Beyond, Multiple-Input Multiple-Output (MIMO), Non-Orthogonal Multiple Access (NOMA), Communication Technologies	Integration and assessment of MIMO and NOMA technologies in 5G networks to enhance various performance metrics such as bit error rate (BER), spectrum efficiency (SE), average capacity rate, and outage probability (OP) in both the downlink (DL) and uplink (UL) scenarios.	Simulation-based performance evaluation and analysis using MATLAB software program to investigate the impact of MIMO-NOMA integration on the aforementioned performance metrics. The research aims to evaluate the performance enhancements achieved by employing MIMO-NOMA technology compared to traditional methods in a 5G network setup.
C2	Wireless Sensor Networks (WSN), Industrial Internet of Things (IIoT), Routing Protocols, Network Security, Energy Efficiency	Development of a Meta-heuristic Secure and Energy-Efficient Routing Protocol (MHSEER) for WSN-based IIoT systems to address challenges related to energy constraints, resource management, security (intrusion detection and avoidance), and system performance optimization.	Applied research focusing on the development and evaluation of a novel routing protocol (MHSEER) for WSN-IIoT systems, utilizing meta-heuristic techniques for secure, energy-efficient, and reliable data routing while addressing security concerns through counter-encryption mode (CEM).

Analysis of the Published Contributions in the Special Issue			
#	**Research Area**	**Focus**	**Type of Research**
C3	Wireless Sensor Networks (WSNs), Energy-Efficient Routing, Optimization Algorithms, Network Lifetime Enhancement	Development of a dynamic cluster head-based energy-efficient routing system for Wireless Sensor Networks (WSNs) to address energy consumption and network lifespan challenges. The research emphasizes improving network performance by optimizing cluster head selection, transmission paths, and energy-efficient routing protocols.	Applied research focusing on the implementation and evaluation of an enhanced routing system utilizing Improved Coyote Optimization Algorithm (ICOA) and Improved Jaya Optimization Algorithm with Levy Flight (IJO-LF). The research involves the comparison of the proposed approach with traditional methods and established routing protocols like Power-Efficient Gathering in Sensor Information Systems (PEGASIS) and Threshold sensitive Energy Efficient Sensor Network protocol (TEEN). The evaluation is conducted using MATLAB simulations and performance metrics such as data packets collected by the Base Station (BS), energy consumption, node longevity (alive nodes), and node depletion (dead nodes).
C4	Wireless Sensor Networks (WSNs), Energy-Efficient Protocols, Medium Access Control (MAC) Protocols, Routing Protocols, Channel Allocation, Load Balancing Strategies	Investigation and evaluation of energy optimization strategies and protocols in Wireless Sensor Networks (WSNs). The research focuses on improving network performance and extending the network lifetime by reducing energy consumption in various WSN operations, such as medium control, routing, and channel management. It explores the impact of different protocols and strategies on energy efficiency in WSNs to identify optimal communication strategies.	Literature review and experimental comparison of energy-efficient MAC protocols, channel scheduling policies, and routing protocols in WSNs. The study conducts a detailed analysis of existing techniques and evaluates eight different energy optimization strategies, including WMAC, channel allocation, sleep/wake protocols, integrated routing and WMAC policies, balanced routing, and cooperative routing. The research involves simulation-based experiments to assess the performance of these strategies and protocols, aiming to identify effective approaches for energy optimization in WSNs.
C5	Internet of Things (IoT), Wireless Sensor Networks (WSNs), Network Security, Encryption Algorithms, Energy-Efficiency	Development and evaluation of a secure encryption algorithm, termed Secure Encryption Random Permutation Pseudo Algorithm (SERPPA), specifically designed for enhancing security and reducing energy consumption in IoT-based Wireless Sensor Networks (WSNs). The research aims to address security vulnerabilities in IoT systems and WSNs by proposing a novel encryption approach that focuses on network security while considering energy efficiency.	Applied research involving the design, implementation, and evaluation of the SERPPA algorithm for securing IoT-based WSNs. The study conducts performance comparisons between SERPPA and other existing secure IoT device solutions, such as Group Key Agreement (GKA) and Multipath Key Establishment (MPKE). The research assesses various metrics including energy consumption, overheads, computation cost, time consumption, data transfer rate, and throughput to determine the effectiveness of SERPPA in comparison to the existing solutions.

Analysis of the Published Contributions in the Special Issue			
#	Research Area	Focus	Type of Research
C6	Wireless Sensor Networks (WSNs), Internet of Things (IoT), Energy-Efficient Routing, Security, Heterogeneous WSNs	Development and evaluation of an energy-optimizing secure routing scheme tailored for IoT applications within Heterogeneous Wireless Sensor Networks (HWSNs). The research primarily addresses the challenges of limited energy resources and security concerns in IoT-integrated WSNs. It proposes a routing scheme that focuses on securing confidential IoT data while optimizing energy usage, improving network lifetime, implementing load balancing, and enhancing data storage capacity in heterogeneous sensor nodes.	Applied research involving the design, implementation, and evaluation of an energy-efficient and secure routing protocol for IoT applications in heterogeneous WSNs. The study presents a multipath link routing protocol (MLRP) for secure routing of confidential IoT data through nodes with varying energy levels in HWSNs. It incorporates the hybrid-based TEEN (H-TEEN) protocol for energy and network lifetime improvement along with load balancing capabilities. Additionally, the research employs the ubiquitous data storage protocol (U-DSP) to enhance data storage capacity. The evaluation includes comparisons with existing routing protocols to assess improvements in performance metrics such as throughput, energy efficiency, end-to-end delay, network lifetime, and data storage capacity.
C7	Edge Computing, Cloud Computing, Container-Based Virtualization, Security in Docker Containers, Homomorphic Encryption, Blockchain	Development and evaluation of a distributed system framework called Safe Docker Image Sharing with Homomorphic Encryption and Blockchain (SeDIS-HEB) to address security issues in Docker container images for edge and cloud-based applications. The study specifically aims to provide secure Docker image sharing, upload, and download functionalities while mitigating vulnerabilities and malware risks associated with Docker containers.	Applied research involving the design, implementation, and evaluation of the SeDIS-HEB framework, focusing on security aspects in Docker container-based virtualization. The study utilizes homomorphic encryption, authentication mechanisms, and blockchain technology to ensure secure Docker image sharing. The evaluation includes testing the framework using the InterPlanetary File System (IPFS) for secure Docker image upload and assessing its effectiveness in preventing unauthorized access, ensuring data confidentiality, access control authentication, denial-of-service protection for image metadata, and ensuring Docker image availability.

Analysis of the Published Contributions in the Special Issue			
#	Research Area	Focus	Type of Research
C8	Wireless Communication, Non-Orthogonal Multiple Access (NOMA), Cooperative Communication, Multiple-Input Multiple-Output (MIMO), Massive MIMO, 6G Networks	The focus of this research is to investigate and design various parameters such as varied distances and power location coefficients for distant users in a Cooperative Non-Orthogonal Multiple Access (NOMA) setup. Specifically, the study aims to evaluate the outage probability (OP) performance concerning the signal-to-noise ratio (SNR) for 6G downlink (DL) NOMA power domain (PD) networks and DL cooperative NOMA PD networks. The research innovatively combines DL cooperative NOMA with different MIMO configurations (16 × 16, 32 × 32, 64 × 64) and massive MIMO configurations (128 × 128, 256 × 256, 512 × 512) to enhance OP performance and mitigate the effects of power location coefficients for distant users.	This study involves simulation-based analysis and performance evaluation using MATLAB software. It focuses on assessing the impact of various parameters and configurations on the outage probability performance in cooperative NOMA systems with different MIMO and massive MIMO setups. The research aims to understand the effects of power location coefficients, distance variations, and MIMO configurations on the system's outage probability in 6G wireless networks.
C9	Wireless Underground Sensor Networks (WUGSN), Data Transmission, Channel Assessment Techniques, Security Approaches, Deep Learning, Multi-Channel Attribute Qualities, Intrusion Detection Systems	Development of Multi-Channel Assessment Policies for Energy-Efficient Data Transmission in Wireless Underground Sensor Networks (WUGSNs). The research aims to address the challenges related to uncertain communication barriers, real-time channel attribute learning, and reactive data transmission models in WUGSNs by proposing the Deep Learning-based Multi-Channel Learning and Protection Model (DMCAP). This model focuses on evaluating and classifying underground acoustic channels, underground to surface channels, and surface to ground station channels using various machine learning techniques to optimize data transmission in uncertain WUGSN environments.	Applied research involving the development and evaluation of a comprehensive model (DMCAP) utilizing Deep Learning techniques, including Multi-Channel Ensemble Models, Ensemble Multi-Layer Perceptron (EMLP) Classifiers, Nonlinear Channel Regression models, Nonlinear Entropy Analysis Model, Ensemble Nonlinear Support Vector Machine (ENLSVM), and Variable Generative Adversarial Network (VGAN) engine for intrusion detection. The research involves experimentation with a testbed to analyze channel parameters, uncertainties, and the performance of the proposed model in comparison to existing techniques.

Analysis of the Published Contributions in the Special Issue			
#	**Research Area**	**Focus**	**Type of Research**
C10	Next-Generation Communication Networks, 6G Networks, Cybertwin Communication Models, Blockchain Applications in Communication Networks, Cloud Computing Architectures, UAV (Unmanned Aerial Vehicle) Networks, Internet of Everything (IoE), Data Security, Edge Computing	The focus of this research is on proposing and developing a novel communication architecture for Unmanned Aerial Vehicle (UAV) networks within the context of 6G technology. The proposed architecture utilizes innovative concepts such as cybertwin-based communication models, blockchain (BC) technology, and a Compute First Networking (CFN) framework tailored for UAV networks. It emphasizes the integration of cloud computing resources, edge computing capabilities, and IoE applications while prioritizing energy efficiency, scalability, low latency, and data security.	This research involves the design and conceptual development of a novel UAV 6G network architecture that leverages cybertwin communication models, blockchain-based secure communication (BC-UAV), and a Compute First Networking (CFN) framework. The study likely involves a combination of theoretical modeling, system architecture design, and possibly simulation-based analysis to illustrate the proposed concepts' feasibility and effectiveness. The research aims to address challenges such as data security, network latency, scalability, and energy efficiency in UAV communication networks using innovative approaches like blockchain-based security measures and compute-centric networking.
C11	Internet of Things (IoT), 6G Wireless Communication, Smart Cities, Energy Efficiency	The focus of this research is to explore and highlight the key technologies, applications, and trends associated with the implementation of Internet of Things (IoT) for energy-efficient 6G wireless communication in smart cities. The study aims to understand and present the current state, key technologies, potential applications, and emerging trends related to the integration of IoT devices and energy-efficient 6G communication standards in the context of smart city development.	This article provides to be a systematic review or literature survey that synthesizes information from 20 articles obtained from databases and Google searches, spanning the years between 2015 and 2021, written in English. The research methodology involves a systematic review approach to gather relevant information and insights from existing literature and scholarly sources. The study aims to identify key technologies such as quantum communication, blockchain, visible light communication (VLC), 6G brain–computer interface (BCI), and symbiotic radio, along with their applications in smart city domains like the 15 Minute City, Industrial Town, Intelligent Transport systems, among others. The article intends to analyze and present trends showcasing the potential of using 6G via IoT devices for smart city advancements.

Analysis of the Published Contributions in the Special Issue			
#	**Research Area**	**Focus**	**Type of Research**
C12	Unmanned Aerial Vehicles (UAVs), Cooperative Navigation, Multiagent Systems, Deep Reinforcement Learning, Energy Efficiency	The focus of this research is on developing and evaluating a novel multiagent deep reinforcement learning (MADRL)-based fusion-multiactor-attention-critic (F-MAAC) model for achieving energy-efficient cooperative navigation control among multiple UAVs. The study aims to address the challenge of efficiently coordinating multiple UAVs in unknown dynamic environments with limited operational time and range. It specifically focuses on improving energy efficiency in cooperative navigation tasks by enhancing the capabilities of the multiactor-attention-critic (MAAC) model.	This research presents a model-based study that involves the development and evaluation of a novel reinforcement learning approach, the F-MAAC model, for energy-efficient cooperative navigation among multiple UAVs. The study utilizes the Unity engine to create a UAV Logistic Delivery Service (LDS) environment for training and validating the proposed model. It incorporates a sensor fusion layer and dissimilarity weights computation layer into the MAAC model to enhance information utilization and compensate for lost information through the attention layer. The research employs simulation-based evaluations to compare the performance of the F-MAAC model with conventional reinforcement learning models (DDPG, MADDPG, and MAAC) in terms of episode rewards, total deliveries achieved, and deliveries per distance traveled.
C13	Edge Computing, Energy Efficiency in Edge Devices, Cognitive Management, Offloading Strategies, Resource Allocation	The focus of this research is on developing and evaluating a Cognitive Energy Management Scheme (CEMS) for edge devices to enhance energy efficiency while considering computational states, offloading strategies, and device scheduling. The study aims to address the challenge of optimizing energy usage in edge devices by introducing a cognitive management scheme that swaps between different states (computational and offloading) based on learned states, device loads, and energy availability.	This article presents an applied research study focusing on the development and implementation of the Cognitive Energy Management Scheme (CEMS) for edge devices. The research involves the design and implementation of a scheme that employs state learning techniques to determine optimal computational intervals for scheduling or offloading tasks based on device load. The proposed scheme uses rewards and state transitions to manage device allocation effectively, prevent energy convergence, and address issues related to non-linear swapping and missing features in cognitive management systems.

Analysis of the Published Contributions in the Special Issue			
#	Research Area	Focus	Type of Research
C14	Underwater Wireless Sensor Networks (UWSN), Energy Optimization, Data Aggregation, Clustering Techniques, Underwater Communication Protocols.	The focus of this research is to address the challenges in maintaining battery life in Underwater Wireless Sensor Networks (UWSNs) by proposing an Improved Efficient Data Aggregation in a Hexagonal Grid with Energy Optimization (IEDA-HGEO) protocol. The aim is to enhance data transmission efficiency while optimizing energy consumption through an optimal clustering process specifically designed for UWSNs. The paper aims to improve upon existing routing protocols like ERP2R and EGRC by introducing a protocol tailored for underwater communication, considering the sparse deployment of nodes and the dynamic nature of the underwater channel.	This article presents a protocol design and performance evaluation study within the realm of underwater wireless sensor networks. It involves the proposal of a new protocol (IEDA-HGEO) and subsequent comparative analysis with existing protocols (ERP2R and EGRC) specifically tailored for underwater communication scenarios. The research involves protocol design, simulation, and performance evaluation in terms of various metrics such as energy consumption, efficiency, throughput, packet delivery ratio (PDR), and delay to validate the effectiveness of the proposed IEDA-HGEO protocol.
C15	Energy Harvesting, Wireless Communication, Self-Powered Devices, Ambient Energy Conversion, Sustainability	The focus of this research is on examining and analyzing techniques used in the design of efficient energy-harvesting wireless devices. The study explores self-energy-harvesting methodologies that convert ambient energy from the surroundings into usable power for electronic devices, enabling the development of next-generation wireless devices capable of operating without relying on external power sources. It specifically delves into the recent trends, techniques, and preferred energy sources and generator systems utilized in creating self-powered wireless devices.	This article presents a review paper that consolidates and analyzes recent techniques and trends in the design of self-energy-harvesting wireless devices. The research involves an in-depth analysis of methodologies, energy sources, and generator systems employed to enable wireless devices to harvest ambient energy for sustained and self-powered operation. The study aims to provide insights into current practices and common research directions in the field of energy harvesting for wireless communication devices.
C16	Internet of Things (IoT), Low-Power and Lossy Networks (LLNs), Routing Protocols, Energy Optimization, Wireless Sensor Networks, Optimization Algorithms	This research focuses on improving the energy efficiency and performance of Wireless Sensor Networks (WSNs) within the context of Low-Power and Lossy Networks (LLNs) used in the Internet of Things (IoT). The study particularly addresses issues within the Routing Protocol for Low Power and Lossy Networks (RPL) and proposes enhancements to address problems like energy holes through the initiation of grid formation and cluster head selection using fish swarm optimization (FSO) techniques. The primary goal is to optimize energy consumption and improve packet delivery performance in LLNs.	The article describes an applied research study involving the design and implementation of an enhanced routing and clustering protocol, namely the Graph-Grid-based Convolution clustered neural network with fish swarm optimization (GG-Conv_Clus-FSO), tailored for LLNs within IoT. The research evaluates the proposed protocol's performance in terms of energy optimization and packet delivery ratio (PDR) through comparative analysis with existing state-of-the-art protocols.

Analysis of the Published Contributions in the Special Issue			
#	Research Area	Focus	Type of Research
C17	Wireless Body Sensor Networks (WBSNs), Energy-Efficient Routing, Node Failure Management, Health Monitoring Systems.	This research focuses on addressing critical issues within Wireless Body Sensor Networks (WBSNs), particularly related to limited node energy, node isolation upon failure, increased energy utilization, and heat dissipation within the network. The study proposes a threshold-based fail-proof lifetime enhancement algorithm aimed at optimizing node scheduling based on available energy levels. The primary goal is to enhance the network's reliability and longevity while mitigating issues related to energy depletion, node failures, and network damage, which can impact both the network and the human body being monitored.	The article suggests an experimental research study that involves the development and implementation of a novel threshold-based fail-proof lifetime enhancement algorithm for WBSNs. The research likely includes a real-time system setup and experimentation to validate the proposed algorithm's effectiveness. Comparative analysis is conducted with different existing routing mechanisms to evaluate the proposed algorithm's performance in terms of various network parameters, such as energy efficiency, network lifetime, reliability, and node failure management.
C18	Heterogeneous Networks, Mobile Ad-hoc Networks (MANET), Internet of Things (IoT), Wireless Sensor Networks (WSN), Energy-Efficient Routing, Network Security.	This research focuses on integrating Mobile Ad-hoc Networks (MANET) into the Internet of Things (IoT)-based Wireless Sensor Networks (WSN) to create a heterogeneous network environment. The primary aim is to address security vulnerabilities and energy consumption challenges in IoT-based WSNs by leveraging the trusted routes established by MANET. The research emphasizes Energy Saving Optimization Techniques (MANET-ESO) in IoT to optimize energy consumption and improve security by using MANET as a trusted route between sensor nodes and gateway nodes in the IoT environment.	The paper suggests an applied research study that implements a novel approach (MANET-ESO) for enhancing energy efficiency and security in a heterogeneous network comprising MANET, IoT-based WSN, and smart environments. The study likely involves simulation-based experiments using ns-3 simulation software to evaluate the proposed method's performance. Metrics such as alive node counts, residual energy, throughput, packet delivery ratio, and routing overhead are used to assess the effectiveness of the MANET-ESO technique in improving network performance.

We are delighted to present this special issue of our journal "Energies", featuring a collection of 18 articles spanning diverse domains in the field of energy-efficient wireless communication and networking. The contributions in this issue collectively underscore the significance of energy optimization in wireless systems, illuminating innovative approaches, algorithms, and technologies that pave the way for sustainable and efficient wireless communication in various application scenarios.

In the domain "Energy-efficient physical layer design", authors Hassan et al. propose a novel power domain for 5G networks that integrates MIMO and NOMA technologies. Their work highlights the benefits of this integration in enhancing bit error rate, spectrum efficiency, and capacity rate, even under challenging fading scenarios [C1]. In "Energy-efficient communication protocols" domain, Sharma et al. introduce MHSEER, a meta-heuristic secure and energy-efficient routing protocol for wireless sensor networks in industrial IoT applications [C2]. Adumbabu and Selvakumar present an energy-efficient routing solution employing enhanced optimization algorithms to extend the lifespan of wireless sensor networks [C3]. Dhabliya et al. review energy-efficient network protocols and data transmission schemes for wireless sensor networks, highlighting the significance of cross-layer optimization for optimal channel and routing management [C4]. Nagaraj et al. propose SERPPA, a secure encryption algorithm with energy optimization, addressing the security and efficiency challenges posed by IoT-based wireless sensor networks [C5]. Nagaraju et al. introduce a secure routing scheme for IoT applications in heterogeneous wireless sensor networks, demonstrating notable improvements in terms of throughput, energy efficiency, delay, network lifetime, and data storage capacity [C6].

Kaliappan et al. present SeDIS-HEB, a framework leveraging homomorphic encryption and blockchain for secure Docker image sharing, enhancing security and access control in cloud-enabled environments [C7]. Hassan et al. explores Cooperative Non-Orthogonal Multiple Access (NOMA) for enhanced wireless networks which focuses on optimizing power coefficients for distant users and evaluates outage probability performance using MATLAB simulations. Cooperative NOMA outperforms traditional NOMA, and MIMO and massive MIMO configurations further improve outage probability rates for distant users [C8].

In the domain, "Energy-efficient scheduling algorithms", Soundararajan et al. propose DMCAP, a deep learning-based multi-channel assessment policy for energy-efficient data transmission in wireless underground sensor networks [C9]. Kathole et al. introduce CFN framework BC-UAV, a UAV-based solution for energy-efficient IoE applications in 6G networks [C10]. In "Energy-efficient cross-layer design issues" domain, Kamruzzaman reviews key technologies, applications, and trends in IoT for energy-efficient 6G wireless communication in smart cities, shedding light on the potential of combining IoT devices and 6G technology to create super-smart urban environments [C11]. In the domain, "Energy issues in device-to-device wireless communication", Jeon et al. propose a multi-agent reinforcement learning-based model for energy-efficient cooperative navigation of unmanned aerial vehicles, addressing the challenge of coordinating UAVs for intelligent services in dynamic environments [C12].

Kaliappan et al. introduces a Cognitive Energy Management Scheme (CEMS) for energy-efficient operation of edge devices. It uses state learning to switch between computing and offloading states based on load, preventing device exhaustion. It overcomes non-linear swapping and convergence issues, enhancing computing rate, energy efficiency, and offloading [C13]. In "Energy-efficient underwater communication" domain, Joshi et al. present the IEDA-HGEO protocol, a clustering-based data aggregation and transmission solution for energy-efficient underwater wireless sensor networks, effectively addressing the unique energy challenges posed by underwater environments [C14]. In the domain, "Energy harvesting techniques for wireless devices", Hezekiah et al. review self-energy harvesting techniques for next-gen wireless devices, showcasing the potential of converting ambient energy into sustainable power for a variety of applications [C15]. In "Energy-efficient scheduling algorithms" domain Khan et al. propose GG-Conv_Clus-FSO, a neural network combined with fish swarm optimization for cluster head selection in energy optimization of 6LowPAN networks [C16]. Arumugam et al. resent a threshold-based algorithm for optimizing energy usage in wireless body sensor networks, effectively extending network lifetime [C17]. Krishnamoorthy et al. propose a novel energy-saving optimization technique-based routing protocol for mobile ad-hoc networks in IoT environments, addressing energy and security concerns associated with device-to-device communication [C18].

Thus, this special issue brings together a rich tapestry of research that illuminates the ongoing efforts to design, optimize, and implement energy-efficient wireless communication and networking solutions. We extend our appreciation to the authors for their valuable contributions to this field, and we hope these insights will inspire further advancements in sustainable wireless communication technologies.

Author Contributions: All authors contributed equally in Conceptualization, methodology, software, validation, analysis, investigation, resources, data curation, writing—original draft preparation, writing—review and editing, visualization, supervision, project administration. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: Our sincere and heartfelt thanks to the MDPI publishers and the Editors, MDPI Energies for their continuous support and guidance during the entire process of handling this special issue. We extend our sincere thanks and grateful to all the reviewers for their efforts in reviewing the manuscripts. We also extend our appreciation to the researchers for submitting their research findings to MDPI Energies and for their valuable contributions to this field and we hope these insights will inspire further advancements in sustainable wireless communication technologies.

Conflicts of Interest: The authors declare no conflict of interest.

List of Contributions

1. Hassan, M.; Singh, M.; Hamid, K.; Saeed, R.; Abdelhaq, M.; Alsaqour, R. Modeling of NOMA-MIMO-Based Power Domain for 5G Network under Selective Rayleigh Fading Channels. *Energies* **2022**, *15*, 5668. https://doi.org/10.3390/en15155668
2. Sharma, A.; Babbar, H.; Rani, S.; Sah, D.K.; Sehar, S.; Gianini, G. MHSEER: A Me-ta-Heuristic Secure and Energy-Efficient Routing Protocol for Wireless Sensor Net-work-Based Industrial IoT. *Energies* **2023**, *16*, 4198. https://doi.org/10.3390/en16104198
3. Adumbabu, I.; Selvakumar, K. Energy Efficient Routing and Dynamic Cluster Head Selection Using Enhanced Optimization Algorithms for Wireless Sensor Networks. *Energies* **2022**, *15*, 8016. https://doi.org/10.3390/en15218016
4. Dhabliya, D.; Soundararajan, R.; Selvarasu, P.; Balasubramaniam, M.S.; Rajawat, A.S.; Goyal, S.B.; Raboaca, M.S.; Mihaltan, T.C.; Verma, C.; Suciu, G. Energy-Efficient Network Protocols and Resilient Data Transmission Schemes for Wireless Sensor Networks—An Experimental Survey. *Energies* **2022**, *15*, 8883. https://doi.org/10.3390/en15238883
5. Nagaraj, S.; Kathole, A.B.; Arya, L.; Tyagi, N.; Goyal, S.B.; Rajawat, A.S.; Raboaca, M.S.; Mihaltan, T.C.; Verma, C.; Suciu, G. Improved Secure Encryption with Energy Optimization Using Random Permutation Pseudo Algorithm Based on Internet of Thing in Wireless Sensor Networks. *Energies* **2023**, *16*, 8. https://doi.org/10.3390/en16010008
6. Nagaraju, R.; C, V.; J, K.; G, M.; Goyal, S.B.; Verma, C.; Safirescu, C.O.; Mihaltan, T.C. Secure Routing-Based Energy Optimization for IoT Application with Heterogeneous Wireless Sensor Networks. *Energies* **2022**, *15*, 4777. https://doi.org/10.3390/en15134777
7. Kaliappan, V.K.; Yu, S.; Soundararajan, R.; Jeon, S.; Min, D.; Choi, E. High-Secured Data Communication for Cloud Enabled Secure Docker Image Sharing Technique Using Blockchain-Based Homomorphic Encryption. *Energies* **2022**, *15*, 5544. https://doi.org/10.3390/en15155544
8. Hassan, M.; Singh, M.; Hamid, K.; Saeed, R.; Abdelhaq, M.; Alsaqour, R. Design of Power Location Coefficient System for 6G Downlink Cooperative NOMA Network. *Energies* **2022**, *15*, 6996. https://doi.org/10.3390/en15196996
9. Soundararajan, R.; Stanislaus, P.M.; Ramasamy, S.G.; Dhabliya, D.; Deshpande, V.; Sehar, S.; Bavirisetti, D.P. Multi-Channel Assessment Policies for Energy-Efficient Data Transmission in Wireless Underground Sensor Networks. *Energies* **2023**, *16*, 2285. https://doi.org/10.3390/en16052285
10. Kathole, A.B.; Katti, J.; Dhabliya, D.; Deshpande, V.; Rajawat, A.S.; Goyal, S.B.; Raboaca, M.S.; Mihaltan, T.C.; Verma, C.; Suciu, G. Energy-Aware UAV Based on Blockchain Model Using IoE Application in 6G Network-Driven Cybertwin. *Energies* **2022**, *15*, 8304. https://doi.org/10.3390/en15218304
11. Kamruzzaman, M.M. Key Technologies, Applications and Trends of Internet of Things for Energy-Efficient 6G Wireless Communication in Smart Cities. *Energies* **2022**, *15*, 5608. https://doi.org/10.3390/en15155608

12. Jeon, S.; Lee, H.; Kaliappan, V.K.; Nguyen, T.A.; Jo, H.; Cho, H.; Min, D. Multiagent Reinforcement Learning Based on Fusion-Multiactor-Attention-Critic for Multiple-Unmanned-Aerial-Vehicle Navigation Control. *Energies* **2022**, *15*, 7426. https://doi.org/10.3390/en15197426
13. Kaliappan, V.K.; Lalpet Ranganathan, A.B.; Periasamy, S.; Thirumalai, P.; Nguyen, T.A.; Jeon, S.; Min, D.; Choi, E. Energy-Efficient Offloading Based on Efficient Cognitive Energy Management Scheme in Edge Computing Device with Energy Optimization. *Energies* **2022**; *15*, 8273. https://doi.org/10.3390/en15218273
14. Joshi, S.; Anithaashri, T.P.; Rastogi, R.; Choudhary, G.; Dragoni, N. IEDA-HGEO: Improved Energy Efficient with Clustering-Based Data Aggregation and Transmission Protocol for Underwater Wireless Sensor Networks. *Energies* **2023**, *16*, 353. https://doi.org/10.3390/en16010353
15. Hezekiah, J.D.K.; Ramya, K.C.; Radhakrishnan, S.B.K.; Kumarasamy, V.M.; Devendran, M.; Ramalingam, A.; Maheswar, R. Review of Next-Generation Wireless De-vices with Self-Energy Harvesting for Sustainability Improvement. *Energies* **2023**, *16*, 5174. https://doi.org/10.3390/en16135174
16. Khan, M.; Ilavendhan, A.; Babu, C.N.K.; Jain, V.; Goyal, S.B.; Verma, C.; Safirescu, C.O.; Mihaltan, T.C. Clustering Based Optimal Cluster Head Selection Using Bio-Inspired Neural Network in Energy Optimization of 6LowPAN. *Energies* **2022**, *15*, 4528. https://doi.org/10.3390/en15134528
17. Arumugam, S.K.; Mohammed, A.S.; Nagarajan, K.; Ramasubramanian, K.; Goyal, S.B.; Verma, C.; Mihaltan, T.C.; Safirescu, C.O. A Novel Energy Efficient Threshold Based Algorithm for Wireless Body Sensor Network. *Energies* **2022**, *15*, 6095. https://doi.org/10.3390/en15166095
18. Krishnamoorthy, V.K.; Izonin, I.; Subramanian, S.; Shandilya, S.K.; Velayutham, S.; Munichamy, T.R.; Havryliuk, M. Energy Saving Optimization Technique-Based Routing Protocol in Mobile Ad-Hoc Network with IoT Environment. *Energies* **2023**, *16*, 1385. https://doi.org/10.3390/en16031385

References

1. Liu, Y.; Su, Z.; Wang, Y. Energy-Efficient and Physical-Layer Secure Computation Offloading in Blockchain-Empowered Internet of Things. *IEEE Internet Things J.* **2023**, *10*, 6598–6610. [CrossRef]
2. Singh, N.; Das, A.K. Energy Efficient Communication Using Constrained Application Protocol for IoT Devices. In *Information, Communication and Computing Technology. ICICCT 2022. Communications in Computer and Information Science*; Badica, C., Paprzycki, M., Kharb, L., Chahal, D., Eds.; Springer: Cham, Switzerland, 2022; Volume 1670. [CrossRef]
3. Lu, Y.; Liu, L.; Gu, J.; Panneerselvam, J.; Yuan, B. EA-DFPSO: An intelligent energy-efficient scheduling algorithm for mobile edge networks. *Digit. Commun. Networks* **2022**, *8*, 237–246. [CrossRef]
4. Sarwesh, P.; Mathew, A. Cross layer design with weighted sum approach for extending device sustainability in smart cities. *Sustain. Cities Soc.* **2022**, *77*, 103478. [CrossRef]
5. Gismalla, M.S.M.; Azmi, A.I.; Bin Salim, M.R.; Abdullah, M.F.L.; Iqbal, F.; Mabrouk, W.A.; Othman, M.B.; Ashyap, A.Y.I.; Supa'At, A.S.M. Survey on Device to Device (D2D) Communication for 5GB/6G Networks: Concept, Applications, Challenges, and Future Directions. *IEEE Access* **2022**, *10*, 30792–30821. [CrossRef]
6. Alsamhi, S.H.; Shvetsov, A.V.; Shvetsova, S.V.; Hawbani, A.; Guizani, M.; Alhartomi, M.A.; Ma, O. Blockchain-Empowered Security and Energy Efficiency of Drone Swarm Consensus for Environment Exploration. *IEEE Trans. Green Commun. Netw.* **2023**, *7*, 328–338. [CrossRef]
7. Usha, M.; Sathiamoorthy, J.; Ahilan, A.; Mahalingam, T. SWEEPER: Secure Waterfall Energy-Efficient Protocol-Enabled Routing in FANET. *IETE J. Res.* **2023**, 1–15. [CrossRef]
8. Fan, C.; Wang, Z.; Yang, K. Energy-efficient underwater acoustic communication based on Dyna-Q with an adaptive action space. *Phys. Commun.* **2023**, *61*, 102218. [CrossRef]
9. Kong, X.; Duan, G.; Hou, M.; Shen, G.; Wang, H.; Yan, X.; Collotta, M. Deep Reinforcement Learning-Based Energy-Efficient Edge Computing for Internet of Vehicles. *IEEE Trans. Ind. Informatics* **2022**, *18*, 6308–6316. [CrossRef]
10. Li, T.; Lee, P.S. Piezoelectric Energy Harvesting Technology: From Materials, Structures, to Applications. *Small Struct.* **2022**, *3*, 2100128. [CrossRef]

Short Biography of Authors

Rajagopal Maheswar completed his B.E (ECE) from Madras University in the year 1999, M.E (Applied Electronics) from Bharathiyar University in the year 2002, and Ph.D in the field of Wireless Sensor Network from Anna University in the year 2012. He is having 21 years of teaching experience at various levels and his research interest includes Wireless Sensor Network, IoT, Queueing theory, and Performance Evaluation.

Murugan Kathirvelu received B.E degree in Electrical and Electronics Engineering from Madras University in the year 1998 and M.E degree in Applied Electronics from Anna University in the Year 2004. He received his Ph.D. degree from Anna University, Chennai in the year 2013. He is having 23 years of teaching experience in engineering colleges and his research area includes low-power VLSI Design, Embedded System Design, and Soft Computing Techniques.

Kuppusamy Mohanasundaram received B.E. degree in Electrical and Electronics Engineering from the University of Madras in 2000, M. Tech degree in High Voltage Engineering from SASTRA University in 2002, and Ph.D. degree from Anna University, India in 2014. He is having 21 years of teaching experience and his research interests include intelligent controllers, Power systems, embedded systems, and Power electronics.