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Resource Allocation Challenges and Strategies for RF-Energy Harvesting Networks Supporting QoS

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Abstract— This paper specifically addresses the resource allocation challenges encountered in wireless sensor networks that incorporate RF energy harvesting capabilities, commonly referred to as RF-energy harvesting networks (RF-EHNs). RF energy harvesting and transmission techniques bring substantial advantages for applications requiring Quality of Service (QoS) support, as they enable proactive replenishment of wireless devices. We commence by providing an overview of RF-EHNs, followed by an in-depth examination of the resource allocation challenges associated with this technology. In addition, we present a case study that focuses on the design of an efficient operating strategy for RF-EHN receivers. Our investigation highlights the critical aspects of service differentiation and QoS support, which have received limited attention in previous research. Besides, we explore previously unexplored areas within these domains.

Keywords-WSN, QoS Parameters, Resource Allocation, Energy Distribution and Energy Harvesting.

I. INTRODUCTION

The energy to convert received RF signals into electricity has recently gained scientific attention [1], [2]. This method has emerged as an effective substitute for powering wireless networks with limited energy resources. Energy constraints impose limitations on wireless sensor networks, thereby restricting their lifespan and hindering overall network performance. RF energy harvesting networks (RF-EHNs) have rapidly gained popularity in various domains such as wireless sensor networks [3], wireless body networks [4], and wireless charging systems. This is primarily due to their ability to harness radio waves as a power source. An illustrative example of this is the prototype sensor node developed by [5], which successfully utilizes ambient RF energies for energy replenishment. The writers of [6] have developed an integrated circuit that operates on RF power and incorporates work-on-demand regulations for wireless systems deployed in medical applications. In parallel, the Consortium of Wireless Power is actively engaged in establishing an international standard for RF energy harvesting, encompassing transmission technologies. It is worth noting that the term "RF energy harvesting" typically refers to the capability of cable-free devices to capture and utilize RF energies. The process and method through which an RF source transmits RF energies to wire-free devices is commonly known as RF energy transfer. RF energy harvesting utilizes electromagnetic radiation in the form of radio waves, ranging from 300 GHz to 3 KHz, to transmit energy. Through modulation of the phase and amplitude of RF signals, wireless data is encoded. Simultaneously, cable-free energy transfer is achieved by radiating far-field RF energy. It can power a huge number of low-power devices distributed across a big region. Wireless sensor networks must be redesigned in order to maximize RF energy harvesting and transmission efficiency. In particular, the resource allocation of a wireless sensor network must balance RF energy supply, network performance, and energy efficiency. Concerned article examines recent RF-EHN developments. We begin with presenting a primer of the RF-EHNs.

Consequently, we explored and presented the issues of distributing resources, emphasizing the necessity for policy for receiver operation by demonstrating a case study in general RF-EHN. The issue of receiver operation with service differentiation has not been addressed before in the literature. We design an optimum operating strategy that offers service difference between high priority (HP) and low priority (LP) information, while also meeting QoS criteria. An HP and LP weighted sum data throughput is maximized while energy availability and maximum packet loss probability are constrained. Ongoing research on RF-EHNs is summarized in a final section. Concerned part describes overall structure and design circuit of energy harvester for RF. In addition, we discuss potential future research objectives in the RF-EHNs.

II. RF ENERGY HARVESTING NETWORK:AN OVERVIEW

This section will begin with an overview of the fundamental architecture of an RF-EHN (RF Energy Harvesting Network) before delving into the circuit design features of an RF energy harvester. Following that, we will concentrate on introducing the technique of RF energy collecting.

A. RF Energy Harvesting NetworkArchitecture

Fig. 1 depicts the usual design of a centralized RF-EHN (RF Energy Harvesting Network): Information gateways, RF energy sources and Network nodes/devices. Base stations, wireless routers, and relays are all examples of information gateways.

User devices were considered as network nodes which are capable to communicate through gateways of data and RF energy sources. These two components may be combined in certain instances.

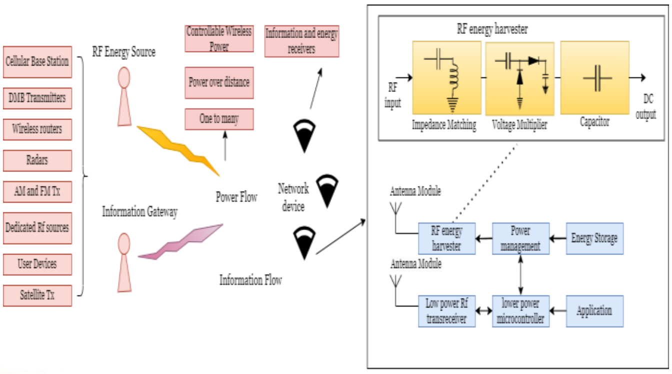

Figure 1. General architecture of an RF energy harvesting network.

However, unlike Fig.1, decentralized RF-EHN contains network nodes that can interact. As such, Fig. 1 depicts a network node having RF energy harvesting capabilities. The primary components of an RF energy harvesting node are as follows.

- The app to do few networks' tasks.
- Microcontroller with low power for application information computing.
- A low-power RF transceiver for transmitting or receiving information.
- An energy harvester that collects RF signals and converts them to electricity.
- In this case, the power management module determines whether to store or utilize the RF energy harvester's electricity.
- A storage battery is integrated into the RF-EHN architecture to store the captured RF energy for future use.

Each of these components adds up to overall performance pertaining to Radio frequency energy harvester. Fig. 1 shows the RF energy harvester's block diagram too.

- The antenna module within the RF-EHN architecture can be built to operate with a single band or many bands of frequencies to allow for concurrent collection from numerous sources. Because the energy density of RF signals varies with frequency, this flexibility enables RF energy harvesters to effectively capture energy from a wide variety of frequencies.
- Impedance matching is performed by a resonator circuit operating at the specified frequency to optimize power transfer between the antenna module and the multiplier. This resonator system enables excellent impedance matching, particularly at the specified frequency, which leads to great efficiency.

- Within the RF-EHN, an RF rectifying diode is in charge of converting RF signals into DC voltage. Lower built-in voltage diodes often have higher conversion efficiency. Capacitors are used to guarantee that electricity is delivered smoothly to applications. Capacitors can act as temporary reservoirs, storing energy for later use, in situations where quick access to RF energies is not accessible.

The RF transceiver and energy harvesters are separate entities in the aforementioned network node design. This architecture allows the node to gather energy while still transmitting data. As a result, it is possible to harvest both out-of-band and in-band radio frequency energy. This design method allows for more efficient use of available RF energy, boosting the network's total energy harvesting capabilities. Network nodes may collect in-band RF energies out of identical frequency range as data communication. Out-of-hand RF energy harvesting gathers R-F energy out of various frequencies range than utilized in data transmission. Because R-F frequencies may convey both energy and information, they can potentially be used for both energy harvesting and information receiving. So called SWIPT [7] is notion of simultaneous power transmission and wireless information. R-F energy harvester and messages receiver may use identical module of antenna. To solve the constraint of existing circuits, which are unable to directly extract energy from the same RF messages used for decoding, the concept of placing the data receiver and energy harvester in the same position is developed. The network intends to optimize the energy extraction process by collocating the data receiver and energy harvester. This configuration enables efficient energy harvesting without jeopardizing the circuit's decoding functionality, guaranteeing that both data reception and energy harvesting can be handled effectively at the same site [8]. these include time shifting and power splitting receiver designs. To switch between receiving information or RF energy, a network node uses a time switching architecture. Dividing power architecture splits incoming R-F in 2 flows for R-F energy harvester and information receiver. A theoretically greater data rate and R-F energy harvesting compared to split in time is known [9]. In reality, however, power splitting is more difficult than time splitting on the hardware level. There are two ways to collect RF energy: power splitting and time switching.

B. *Technique for Energy Harvesting in R-F*

Quantity of harvesting R-F energies depends on the transmit power, the RF signal wavelength, and the distance between the source and the harvesting node. Friis equation [10] may be used to determine the captured RF energy. RF energy harvesting provides the following advantages over other energy harvesting methods:

- It is possible to manage and maintain energy transfer across long distances utilizing RF sources, particularly in stationary RF-EHN configurations.
- RF energy harvesting is well-suited for portable devices, providing a dependable and convenient source of energy.
- However, that the amount of acquired RF energy might change dramatically between network nodes positioned at different distances from the RF source.

On the other hand, passive adoption to environmental resources is not possible with RF energy harvesting and transmission. There are two sorts of RF sources: dedicated and ambient. When a more reliable energy supply is required, dedicated RF sources may be used. It is important to highlight in the context of RF energy transmission that ambient RF sources, such as radio towers and TV transmissions, are not normally intended as main sources of energy. These RF signals are plentiful in the environment and entail no additional costs. The focus of RF energy harvesting, on the other hand, is on gathering energy from static or moving RF sources, which can then be used to power wireless devices and systems. Spatially stochastic geometry is used to analyze sensor performance in [11]. Also, in a cognitive radio network, the research in [12] shows energy harvesting out of dynamic ambient R-F. Secondary client may collect R-F energy out of neighboring main clients and transfer information if they are idle or sufficiently far away. Density of power obtained out of a downlink of GSM1800 are claimed to be with similar degree of power compared to obtain out of GSM900 downlink [13]. This is achieved via 2cable less equipment’s driven through ambient R-F messages, proximity of maximum 2.5 outside, 1.5 feet inside, according to state-of-art prototype implementation presented in [14]. The end-to-end system can work battery-free up to 6.5 kilometers from the TV tower, according to several tests.

C. *RF Energy Harvesting: Existing Applications*

Uses pertaining to RF-EHNs include wireless sensor network. An RF energy harvester may provide energy to a sensor node. Examples include [15]'s prototype sensor node powered by ambient RF energy. Wireless body networks are one of the RF-most EHN's appealing healthcare and medical applications a battery-free circuit may be achieved by using RF energy harvesting. An application-specific integrated circuit (ASIC) driven by RF and using conventional 0.18-m CMOS technology is designed in [16] the chip is for medical wireless body networks. A wireless keyboard and mouse, for example, may be charged via RF energy harvesting.

III. ALLOCATION OF RESOURCES FOR RADIO FREQUENCY ENERGY HARVESTING NWTWORK: DESIGN ISSUES

RF energy harvesting added RF-EHNs to wireless devices. Thus, allocation of resource within RF-EHNs should consider both information transmission and reception RF energy harvesting too. Receiver operating policy, beam forming, MAC, routing protocol and cooperative relaying are all design concerns. We also examine cutting-edge design solutions to these concerns.

A. Policy for Receiver Operations.

In the context of wireless nodes with identical arrays of antennas, simultaneous message reception and RF energy harvesting necessitates the use of a receiver operating strategy. This method is required to efficiently regulate message reception while harvesting RF energy. The wireless nodes may enable flawless coordination between message reception and energy harvesting operations by applying suitable methods and protocols, hence optimizing the overall performance of the system. To achieve specified performance objectives, the policy might be built to cope with different physical and MAC layer trade-offs. A significant number of existing policies for managing concurrent message receipt and RF energy harvesting are time switching or power splitting in nature. These techniques provide frameworks for coordinating the allocation of time and power resources between the two activities and serve as the foundation for current solutions. Switching of time design focuses on synchronizing RF energy harvesting time and information reception. The operational philosophy of power splitting architecture tries to optimize the ratio for dividing incoming RF signals. This allows for efficient RF energy allocation between message receiving and energy harvesting. A basic greedy switching strategy is studied in [17]. The policy allows the relay node to communicate when it has enough energy left. With a large range of SNR, greedy switching achieves near ideal performance (SNR). The authors of [18] explore a 3-node amplify-and-forward network having R-F energy harvestings. Time switching and power splitting architectures are offered as relaying techniques for the relay node. In their calculations, the authors calculate the ideal RF energy harvesting duration for time switching relaying and the minimal power division ratio for power splitting relaying. The evaluation findings show that the time switching-based relaying protocol outperforms in terms of throughput when the SNR is low and the transmission rate is high. This protocol, however, incurs substantial hardware complexity due to the consideration of fluctuating transmit power. According to [19], in multi-channel cognitive radio networks, a secondary user is in charge of channel selection for both information transmission and energy harvesting. An ideal strategy for the secondary user is generated using a Markov decision procedure (MDP) based on the levels of residual energies and the number of waiting data chunks in the information queues.

B. Beam forming

One of the major issues in energy transfer and RF information is the decline in energy transfer efficiency as transmission distance rises. Spatial multiplexing methods with several antennas can be used to address this difficulty. Furthermore, beam forming systems employing multiple antennas have the potential to improve the efficiency of RF energy transmission [20] and Simultaneous Wireless Information and Power transmission (SWIPT) [7] without the requirement for increased transmit power or bandwidth. The beam forming idea is first examined in a three-node multiple-input multiple-output (MIMO) network [7]. This network is made up of a single transmitter, an energy harvester, and a data receiver. Writers in [7] examine optimum ways of communication in balancing information rate and RF energy transfer at a multi-antenna transmitter using beam forming. Energy beam formation with large-scale systems of MIMO may be used for improving effectiveness of energy with high range of distance transfer of power, according to authors of [20]. To maximize energy efficiency, a resource allocation strategy is suggested that optimizes power transfer and time span of RF energy transmission. With eavesdroppers, beam forming has been promoted for secure communication. The authors of [21] propose using beam forming techniques to improve the security of sent information to the intended receiver. This entails making artificial noise and directing it at possible eavesdroppers. A non-convex optimization problem is constructed to optimize the beam forming design. The goal is to reduce overall transmit power while meeting the criteria for information transmission and artificial noise creation. By properly regulating the beam forming method, the suggested approach intends to assure safe and dependable communication.

C. MAC Protocol

Coordination of network node broadcasts is required to ensure QoS support and fairness. Network’s Nodes must not merely access medium for transfer of data but capture RF energies too. But the time it takes to collect enough energy varies amongst nodes depending on parameters like RF energy source type and distance from node. Network nodes are coordinated via MAC rules such as polling or CSMA/CA, which use either a contention-free or contention-based method. To ensure fairness and high throughput, contentions-free MAC must account for every node's RF energy harvesting procedure. To send data, each node in the contended MAC protocol competes for radio resources. Due to communication failures, prolonged RF energy harvesting duration may cause resource contention. On RF-

EHNs, [22] the authors describe an energy adaptive MAC protocol. In order to adjust back off time node's duty cycle, two energy adaptive techniques are proposed: energy adaptive contention algorithms and energy adaptive duty cycle. But energy adaptive MAC needs centralized out-of-band and control energy. [23] Investigates the use of in-band RF energy sources as an alternate option. The RF-MAC protocol, which is based on the CSMA/CA-dependent MAC protocol, intends to optimize the rate of RF energy delivery to meet the energy needs of sensor nodes while minimizing data transmission disturbances. This is accomplished by carefully selecting RF energy sources and carefully evaluating the frequency of data and energy intercommunication.

D. *Cooperative Relaying*

By leveraging intermediate relay nodes, cooperative relaying may increase network efficiency and dependability. As a result, it is particularly well suited for use in energy-constrained networks such as RF-EHNs. In cooperative relaying, the choice of relay is an important decision consideration. However, the preferred relay for information transfer does not always have the strongest energy harvesting channel. Thus, relay selection must balance information and energy transmission efficiency. Determining which relay to use requires knowhow regarding energy status and channel state (prospective external RF energy arrival and internal energy reserve). Cutoff-checking selection and time-sharing system are studied in [24]. The source node uses a time-sharing selection approach, rotating between relays that have the highest signal-to-noise ratio (SNR). Furthermore, the source node uses threshold-checking to pick the relay with the highest RF energy collecting rate. In terms of achieving the given RF energy harvesting requirement, the threshold-checking selection approach surpasses other examined methods. However, if the normalized average SNR for each connection rises sufficiently, to roughly 5 dB, the time-sharing selection technique outperforms in terms of minimizing the risk of outages. The authors of [25] use a system-level approach and investigate an arbitrarily selected relay mechanism in a sectorized region with central angles pointed towards each receiver. They examine a large-scale network in the context of Simultaneous Wireless Information and Power Transfer (SWIPT) utilizing a geometry method.

E. *Routing Protocol*

Routing is crucial in an RF-EHN since multihop transmission is frequently used. Unlike energy-aware routing in typical wireless networks, routing methods in RF-EHN must include RF energy propagation and network node circuit design, such as the sensitivity of RF energy harvesters. This is important because the amount of captured RF energy varies from node to node. Furthermore, the routing metric must be simultaneously determined based on RF energy harvesting factors (such as RF signal density, energy conversion rate, and distance from RF sources) and network parameters (such as connection quality and hop count). By taking these factors into account, routing protocols may efficiently optimize energy utilization and overall network performance in RF-EHNs. An in-band RF energy sensor is used in [26] to charge wireless sensor nodes. It is shown that utilizing hop count as a routing statistic is inappropriate for such networks. To solve this, a new routing metric based on sensor node charging time is developed. The AODV routing protocol is then given a new routing metric in which sensors priorities routes with the quickest charging time by default. By taking into account the time necessary for nodes to replenish their energy stores, this technique strives to optimize energy use and increase overall network performance.

IV. A Case Study: Design Optimization for a Mobile Energy Harvesting Node with Communication Delay Constraints.

Concerned portion presents receiver operating problem's case study containing combined service differentiation and QoS support within RF-EHN.

A. *System prototype*

We define a node as one that has both LP (Low-Priority) and HP (High-Priority) information. These kinds are kept in distinct queues, each one allocated to a different application layer. Both queues are limited in size. The node has the option of requesting RF energy transfer or transmitting data chunks comprising HP or LP information inside the coverage the area of a unified access point (AP). A time switching receiver design, as described in [7], is implemented in the node to accomplish this. In other words, the node may either collect RF energy or transmit data. The node also has a limited-capacity battery for storing AP energy. Every data type has different packet loss requirements. This happens when a packet arrives and finds the Queue or battery full. Maximum packet loss probability requirements for LP and HP data may differ.

B. *Problem of Optimization*

Within the AP's coverage region, the node must decide how to operate its receiver. Following the time switching design, this entails choosing between harvesting RF energy and transferring a packet from the LP or HP data queue to the AP. The primary goal is to maximize the weighted total of LP and HP data throughput while complying with the QoS specifications. Several aspects must be considered in order to solve this decision-making challenge. These comprise the independent arrival probabilities of LP and HP data packets (αa and λa respectively), the probability of successful packet transmission (μ), and the RF energy harvesting and transfer mechanism. In the latter case, the node can request RF energy from the AP, which results in the successful harvesting of w units of energy (raising the battery's energy level) with a chance of σw. It should be noted that the precise value of σw can be obtained by experimental investigation. Effective judgments may be taken to optimize throughput and fulfill QoS requirements for LP and HP data transmission in the presence of an AP by carefully evaluating these parameters.

C. *Optimization Formulation*

An optimization model based on a restricted Markov decision process is developed to optimize throughput while meeting the QoS criterion for packet loss probability. This model seeks to establish the best operating strategy for the node based on its present condition. The available energy level in the battery and the number of packets in the LP and HP data queues form the state space. The action space consists of either sending a packet to the AP from the LP or HP data queues, or requesting RF energy from the AP. State transitions occur in two scenarios: during data transmission, when the energy level drops by K units and the corresponding data queue drops by one packet with a probability of μ, and during an RF energy transfer request, when the energy level rises by w units with a probability of σw. The optimization model seeks to determine the best actions to maximize throughput and minimize packet loss probability while taking system restrictions into account by analyzing these state transitions. The number of packets in the HP and LP data queues in the node's system might rise by a given amount, indicated as "a," with probability αa and λa, respectively. These probabilities reflect the possibility of HP and LP data packet arrivals.

The optimum operation policy, indicated by π, is a mapping that decides the node's behavior depending on its current state. The goal of the optimum operating strategy in this scenario is to maximize the long-term average weighted total of throughput for the LP and HP data. Simultaneously, it guarantees that packet loss requirements for both LP and HP data stay within defined criteria. The optimum operating strategy enables the node to make educated decisions that balance the trade-off between maximizing throughput and minimizing packet loss for LP and HP data. The optimization model's goal function is:

$$\underset{\pi}{max}: \mathcal{J}_T(\pi) = \underset{t\to\infty}{lim} inf \frac{1}{t} \sum{}^{t}{}_{t'=1} \ \mathbb{E}\left(\omega_{\mathrm{LP}} \tilde{\mu}_{l,t'} + \omega_{HP} \tilde{\mu}_{h,t'}\right) \quad (1)$$

In which $\mathcal{J}_T(\pi)$ was weighted sum function of throughput, w_{HP} & w_{LP} is weight of HP and LP messages, correspondingly. If the node is transmitting a packet from the LP data queue and the battery has adequate energy (more than or equal to K), then µLP, t′ equals. µLP, t′ is set to 0 if the LP data queue is empty or there is insufficient energy. Similarly, when the node sends a packet from the HP data queue and has adequate energy, µHP, t′ is set toµ. Otherwise, µHP, t′ is set to 0 if the HP data queue is empty or there is insufficient energy. Consider the LP data. Possibilities of packet loss limitation were stated as following.

$$\mathcal{J}_{\mathrm{LP}}(\pi) = \underset{t\to\infty}{lim} sup \frac{1}{t} \sum_{t'=1}^{t} \ \mathbb{E}(\mathcal{J}_{\mathrm{LP}}) \leq L_{\mathrm{LP}} \qquad (2)$$

Shows packet losses needs pertaining to LP messages. Instant packet loss probability is

$$\mathcal{L}_{\mathrm{LP}}(\pi) = \frac{\sum_{a=Q_{\mathrm{LP}}-q_{\mathrm{LP}}+1}^{A} \alpha_a}{\bar{\alpha}} \qquad (3)$$

if the queue for LP data is full (QLP). Quantity (qLP), Arrival Rate (a), and Average Packet Arrival Rate (qLP) are all used to calculate the average packet arrival rate for LP data. Similar methods may be used to calculate the HP data's immediate packet loss probability, omitted due to space constraints. [19] Presents a comprehensive formulation of the Markov decision process-based optimization issue. We may use a conventional approach to solve the restricted Markov decision process [27] to get the best node operating policy.

D. *Performance Assessment*

1) Configuring Parameters-The node features a 50-unit energy battery. Maximum HP and LP queue sizes are four packets. Unless otherwise noted, LP and HP have 0.15 packets arrival possibilities. Node's chance of successfully transmitting a packet is 0.99. Success in R-F energy harvesting was 0.98. Node would get four energy units if RF energy harvesting is effective. For LP data, the threshold is 0.1, but not for HP data. Suppose a node takes three actions with equal probability. Table1 shows the parameters configuration with description used for simulation.

TABLE I. PARAMETER CONFIGURATION FOR NODE'S ENERGY AND DATA MANAGEMENT

Parameter	Value	Description
Battery Size	50 units of energy	The size of the node's battery in units of energy.
Maximum LP Queue Size	4 packets	The maximum number of packets that can be stored in the LP data queue.
Maximum HP Queue Size	4 packets	The maximum number of packets that can be stored in the HP data queue.
LP Packet Arrival Probability	0.15	The probability of packet arrival for LP data.
HP Packet Arrival Probability	0.15	The probability of packet arrival for HP data.
Successful Packet Transmission Probability	0.99	The probability of successful packet transmission from the node to the AP.
Successful RF Energy Transfer and Harvesting	0.98	The probability of successful RF energy transfer and harvesting.

RF Energy Harvested	4 units	The amount of energy (in units) harvested by the node if RF energy transfer is successful.
LP Packet Loss Probability	No requirement	The packet loss probability requirement for LP data (no specific requirement stated).
HP Packet Loss Probability	0.1	The maximum allowable packet loss probability for HP data.

2) Discussion-First of all, based on above parameters impact of Success Probability of Transmission on Successful Transmissions is studied as per observations in Table 2, we can comment that, the transmission success probability measures the possibility of a packet being successfully transferred from the node to the access point. We see a continuous decline in the number of successful transmissions as the success probability of transmission reduces from 0.90 to 0.60. This means that as the probability of successful transmission falls, the node confronts greater difficulties in successfully transferring packets to the access point. When the transmission success probability is set to 0.90, we get the largest number of successful transmissions, with 127 packets successfully transferred. As the success probability is reduced to 0.80, 0.70, and 0.60, the number of successful transmissions falls to 109, 111, and 105, respectively.

TABLE II. IMPACT OF SUCCESS PROBABILITY OF TRANSMISSION ON SUCCESSFUL TRANSMISSIONS

Success Probability	**Successful Transmissions**
0.90	127
0.80	109
0.70	111
0.60	105

For the next observation initial conditions for Energy levels, LP (low priority) queue sizes, and HP (high priority) queue sizes are studies for 1000 number of iterations. The results obtained are shown in Fig.2

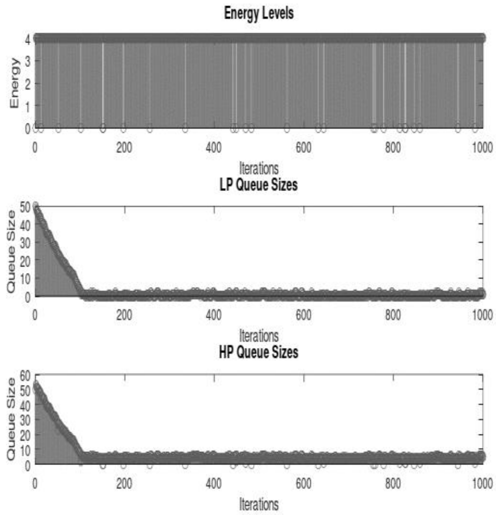

Figure 2. Energy levels, LP (low priority) queue sizes, and HP (high priority) queue sizes for 1000 no.of iterations

Energy levels, LP (low priority) queue sizes, and HP (high priority) queue sizes are depicted in graphs over time. The energy levels graph depicts energy fluctuates as the node harvests and uses energy. The sizes of the LP and HP queues graphs show how queue sizes fluctuate as a result of packet arrivals, successful transmissions, and energy levels. These queue sizes are displayed in the stem graphs at each iteration.

Subsequently the best wireless sensor node operating strategy based on the LP and HP packet counts is studied and following observations are made with respect to graph in Fig.3

- The action of seeking RF energy relates to the region where both LP and HP packet counts are low (near the origin). This implies that when the quantity of packets in both queues is minimal, it is better to priorities energy replenishment over packet transmission.
- As the number of LP and HP packets grows the best strategy changes towards packet transmission. When both the LP and HP packet counts are high, the best course of action is to send an LP packet. When there is a significant demand for data transmission, the node prioritizes sending low priority packets.
- When the LP packet count is large but the HP packet count is low, the best course of action is to send an HP packet. This means that when there are a large number of high priority packets waiting, the node prioritizes sending HP packets to fulfill the priority criteria.

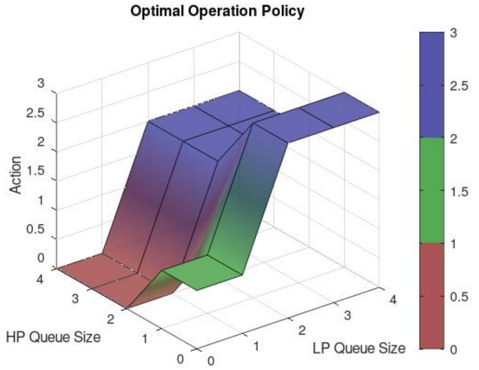

Figure 3. Optimal operational policy

The color map and color bar have been customized to symbolize three distinct actions: seeking RF energy, sending an LP packet, and sending an HP packet. The red color symbolizes seeking RF energy, the green color represents sending an LP packet, and the blue color represents sending an HP packet.

Furthermore, the initial condition for 3 different actions studied and shown in Fig.4-

a) Request RF Energy (Action 1):

The graph depicts the probability of a node seeking RF energy while it is in a low energy state (battery level less than 5 units). The probability of requesting RF energy reduces as the LP and HP queue sizes grow. This means that when a node has a large number of packets in its queues, it uses less RF energy and chooses to send packets instead.

b) Send LP Packet (Action 2):

The graph depicts the probability of a node delivering a low priority (LP) packet when in a low energy condition. As the LP and HP queue sizes grow, so does the probability of receiving an LP packet. This means that if a node has a large amount of packets in its queues, it is more likely to priorities LP packet delivery above other activities.

c) Send an HP packet (Action 3):

The graph depicts the probability of a node delivering a high priority (HP) packet while in a low energy condition. Similar to Action 2, as the LP and HP queue sizes grow, so does the probability of receiving an HP packet. This implies that when the node has a large number of packets in its queues, it prioritizes HP packet transmission in order to fulfill the packet loss criterion.

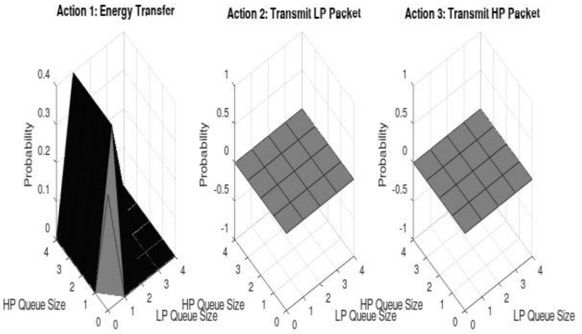

Figure 4. probability of a node seeking RF energy, probability of a node delivering a low priority (LP), probability of a node delivering a low priority (HP)

Let us first examine the most effective operating strategy for the node by analyzing the optimization model's solution while keeping the node's battery energy level as low as possible, precisely at 5 units. Fig.5 depicts the results of solving the optimization issue (1) while sticking to the limitations related to the packet loss probability required for both LP and HP data. Figure 5(a) shows that when the queue is short on packets, the node prefers to seek RF energy. Similarly, when both queues are full, the node tends to seek RF energy because to the higher energy need for data transmission. As the number of packets in the queues grows, the node is more likely to send a packet, particularly for HP data, in order to meet the packet loss requirement. The relevant packet transmission policy is depicted in Fig. 5(b) and (c).

Fig.6 shows the throughput and packet latency as the HP data weight changes. We found if data of HP was heavy, best procedure strategy allows the node to send more packets from the HP data queue than the default operation policy. As a consequence, HP data throughput improves while LP data throughput declines. With increasing HP data weight come increased LP data delay and decreased HP data delay.

The optimization model's weights may be changed to obtain a certain performance. Interesting to see how changing the weight affects the uneven performance of HP and LP statistics. However, whereas HP data throughput and delay increase, LP data throughput and delay deteriorate. As energies may get utilized concerning future packet transfer of HP information, node must conserve energy by not delivering LP data packets too often.

We also investigate the proposed operation policy's packet loss behavior. Fig.7 depicts the impact of altering packet arrival rates for both high-priority (HP) and low-priority (LP) data.

Suppose a node takes three actions with equal probability. On the other hand, if the HP and LP arrival rates are different, the packet loss probability increases. Packet loss probabilities increase with packet arrival probabilities. However, the best operating strategy preserves the HP data packet loss probability at 0.1, but the LP data packet loss probability grows and becomes unbounded. Also shown are the results of the static strategy, which fails to reach acceptable performance, especially with HP data. In coordinating uploading information transfer and download energies transmission, researched model may be expanded to numerous nodes. The scheduling policy must be a critical aspect in node operating policies.

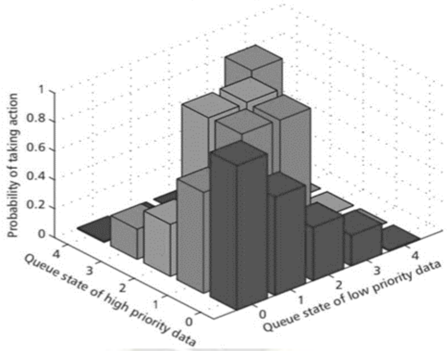

Figure 5. A. Optimal operation policy for requesting for RF Energy

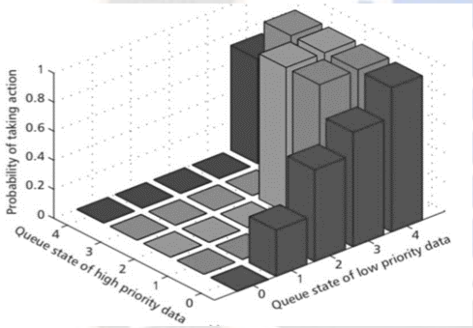

Figure 5. B. Optimal operation policy for transmitting a packet from the queue of LP data

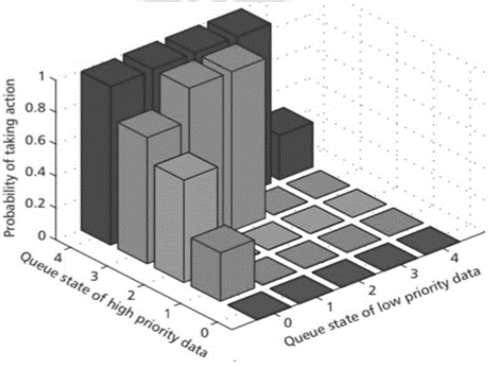

Figure 5. C. Optimal operation policy transmitting a packet from the queue of HP data.

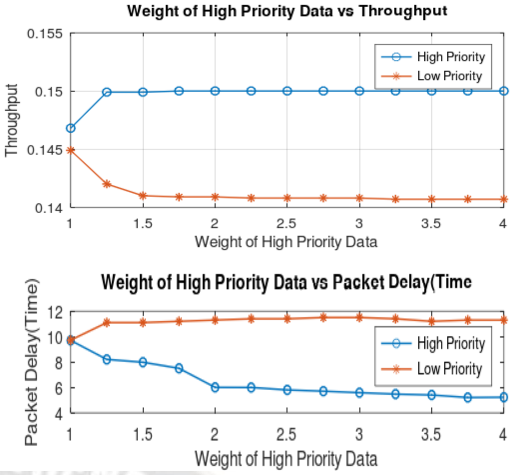

Figure 6. Throughput and delay under different weight of highPriority data.

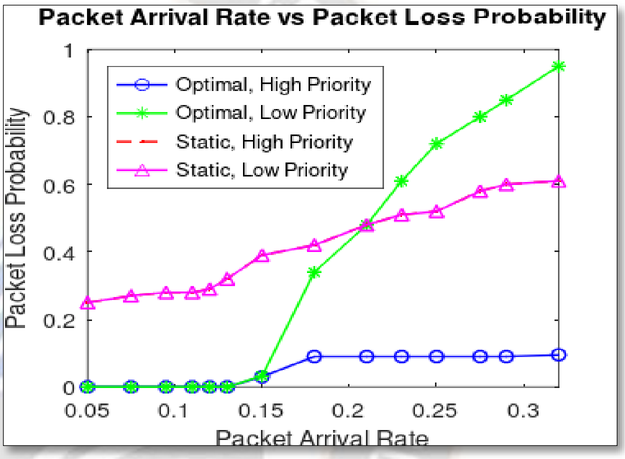

Figure 7. Packet loss probability under different packet arrival Rates.

V. Open Research Problems

Open Research Issues in RF-EHNs: Challenges and Objectives considering Technological Directions are tabulated here in Table3

TABLE III. Open Research Issues in RF-EHNs: Challenges and Objectives considering Technological Directions

Open Research Issues (considering Technological Directions	**Challenges**	**Objectives**
Distributed Energy Beamforming	Time synchronization, coordination of distributed carriers	Achieve diversity gains through simultaneous transmission of RF energy
Cooperative Sensing and Spectrum Sharing	Different spectrum conditions, information exchange and fusion	Identify occupied spectrum bands and optimize RF energy harvesting
Interference Management	Integration with power management schemes	Turn harmful interference into useful energy while

		improving energy efficiency
Energy Trading	Amount of RF energy, pricing, optimization of tradeoff between revenue and cost	Establish an RF energy market, ensure on-demand trading and energy efficiency

Addressing open research questions while considering application directions is critical for understanding the challenges and investigating solutions and opportunities. Researchers can effectively address the highlighted obstacles and capitalize on the prospective possibilities by combining the insights gathered from various application directions. This integrated approach offers a comprehensive understanding of the area, simplifying the creation of novel solutions and realizing the full potential of RF energy harvesting. Table 4 highlights these points.

TABLE IV. APPLICATION DIRECTIONS FOR RF ENERGY HARVESTING: CHALLENGES AND SOLUTIONS/OPPORTUNITIES.

Application Directions	**Challenges**	**Potential Solutions/Opportunities**
Wireless Machine-to-Machine (M2M) Communications	Powering a massive number of unmanned wireless M2M devices	RF energy harvesting using technologies like WiFi, IEEE 802.15, ZigBee, and UWB
Vehicular Communications	Powering wireless devices using vehicular transmitters	Harvesting RF energy from onboard units or roadside units for passenger or pedestrian devices
Smart Automation	Eliminating wired power supply connections in automation systems	RF energy harvesting for powering sensors and actuators, especially on moving components
Device-to-Device (D2D) Communications	Utilizing occupied spectrum for RF energy harvesting	Harvesting RF energy for local direct D2D communications in cellular networks

VI. Conclusion and future work

Radio frequency (RF) energy harvesting and transmission systems will be critical in powering the next generation of wireless networks. This article presents an overview of RF energy harvesting networks (RF-EHNs), including network design and enabling mechanisms. The key design difficulties in resource allocation for RF-EHNs are introduced, coupled with a summary of current research advances. A case study is also described, concentrating on the design of a quality-of-service (QoS)-aware receiver operating policy with service differentiation in a generic RF-EHN. An ideal operating strategy is developed with the goal of maximizing the throughput of a mobile node equipped with RF energy harvesting capabilities while guaranteeing service distinction for two different types of data. During the policy optimization process, the restrictions of packet loss probability are taken into account. Future research prospects for RF-EHNs are also explored, highlighting areas that require greater analysis and exploration. Researchers may progress the area of RF-EHNs by tackling these research directions and discovering new possibilities and solutions.

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