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Enhancing and Securing Telemedicine Services in Disaster Recovery Operations with Sustainable Communication Infrastructure and Blockchain Technology

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Abstract: This paper investigates a multifaceted approach to fortifying telemedicine services within a self-powered Disaster Recovery Network (DRN) infrastructure. It introduces an array of innovative methodologies and algorithms tailored to address the logistical complexities of constructing an environmentally friendly DRN infrastructure. Additionally, it delves into the fundamental factors influencing the system's behavior, defines key performance indicators, and outlines performance measurement techniques. The study emphasizes the critical need for seamless integration of diverse reliability methods by introducing a novel blockchain-based DRN clustering algorithm, coupled with an intelligently managed solar energy system. Specifically, it presents the "Duty Cycle Estimation (DCE) – Event Driven Duty Cycling (EDDC)" technique using the Ubicom IP 2022 platform. Moreover, it proposes an experimental platform for comprehensive evaluation, assessing network performance, practicality, power efficiency, and resilience under various failure scenarios. This comprehensive assessment serves to advance the field and pave the way for robust and reliable telemedicine services in the face of disaster.

Keywords: Telemedicine services, DRN infrastructure, Network reliability, Wireless solar router, Solar energy harvesting, Power management, Fault tolerance techniques, Blockchain technology.

1. Introduction

Disasters, whether natural or man-made, wreak havoc on societies, disrupting physical infrastructure and social order [1]. In these critical moments, immediate access to essential resources like food, water, shelter, security, and medical aid is paramount. Effective coordination of these services hinges on a reliable communication network.

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The resilience of a community depends heavily on the physical and mental well-being of its citizens. While resources are available for emergency response, the planning for recovery remains under-resourced [2]. Disaster relief efforts involve a sequence of steps, encompassing communication infrastructure establishment, search and rescue operations, and vital first aid provision. Disaster networks fall into two main categories: disaster mitigation networks, employed during the pre-disaster phase for effective post-disaster relief planning, and Disaster Recovery Networks (DRNs), essential for disaster relief operations. DRNs offer crucial support to victims and personnel, facilitating communication within the affected area. Timely access to critical information by both individuals and rescue organizations is vital for successful emergency management [4]. Previous DRN research has explored various aspects, spanning communication networks [1], information systems [2], emergency procedures [3], and logistical requirements [4]. Meanwhile, contemporary m-health telemedicine research delves into diverse topics, including Medical Video Modality-Aware (m-aware) systems, which adapt encoding, transmission, and evaluation based on individual video modality properties [5–9]. Multilayer and cross-layer optimization systems aim for optimal performance [10–13], alongside studies focusing on clinical quality assessment protocols and recommendations [14-23].

Despite significant progress, research opportunities remain within this field. This paper addresses key questions regarding the implementation of a self-powered DRN infrastructure, crucial for scenarios where electrical power sources are unreliable or unavailable. These questions include:

- What logistical prerequisites are essential for constructing a self-powered DRN infrastructure?
- What factors influence system behavior, and how can they be evaluated and measured for performance assessment?
- How can diverse telemedicine services be effectively integrated with a solar energy-powered system?
- What criteria should be applied when assessing the entire system in terms of network performance, practicality, and power consumption?

This work contributes significantly to the field of DRNs by:

- Proposing a novel self-powered DRN infrastructure: This infrastructure utilizes solar energy harvesting and efficient power management techniques to overcome power supply challenges in disaster scenarios.
- Developing a robust DRN clustering algorithm: This algorithm ensures network resilience against server failures, minimizing service disruptions.
- Conducting comprehensive experimental evaluations: The proposed system is evaluated through simulations and real-world deployments, providing valuable insights into its performance and effectiveness.

The rest of the paper is organized as follows: Section-2 presents the materials and methods of this paper. Section-3 describes the obtained results which is discussed in section-4. The most important conclusions of this work is summarized in section-5.

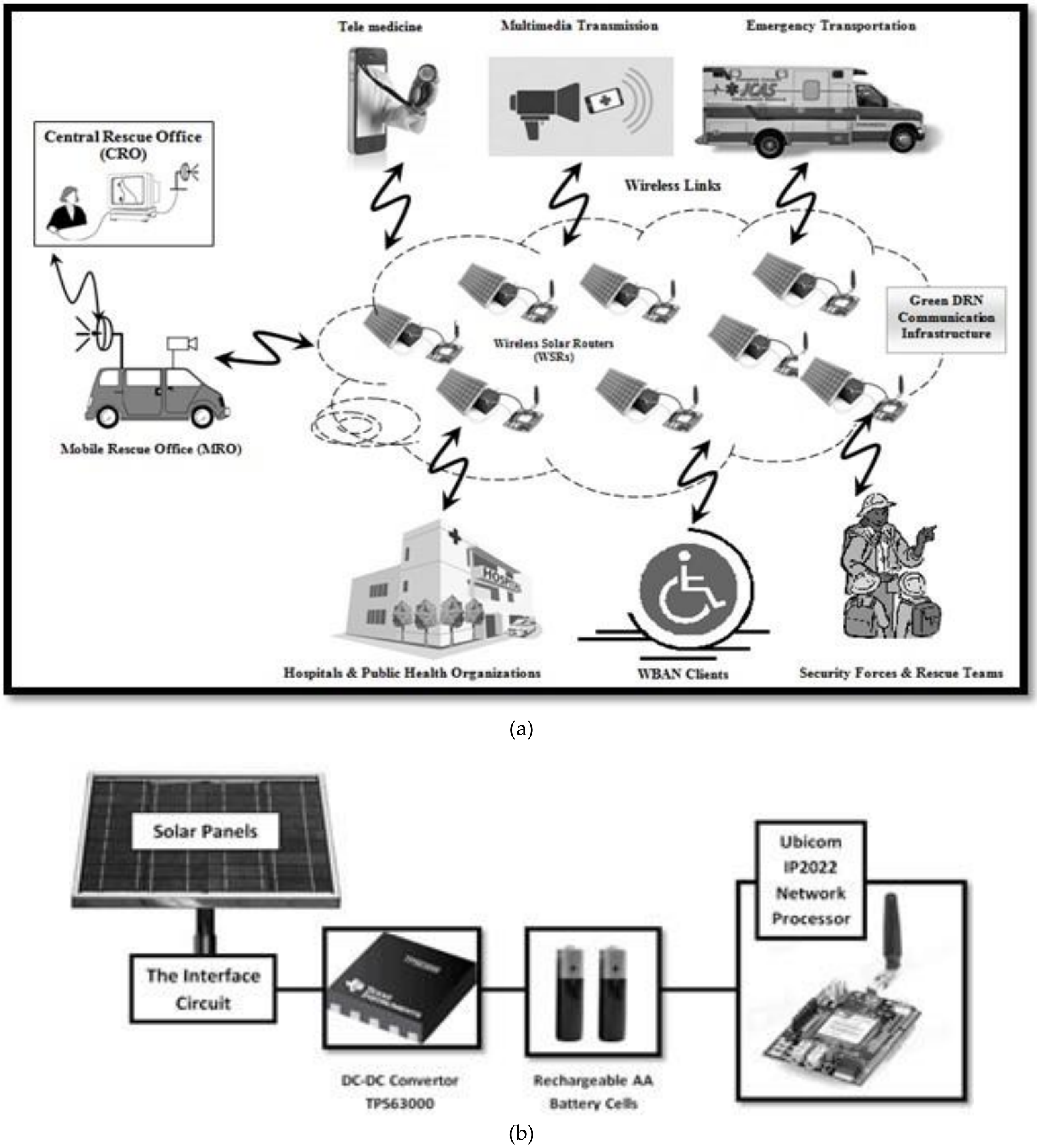
2. Materials and Methods

2.1 Disaster Recovery Network Infrastructure

In this section, we explore the prerequisites and operational details involved in constructing a resilient and environmentally friendly DRN infrastructure. We delve into the hurdles related to self-sufficiency, power management, and connectivity that such a network must surmount. Additionally, we introduce the concept of a "Green DRN Infrastructure." Our paper proposes an approach to enhance the reliability of DRN communication systems by utilizing wireless Ad hoc Network technology. Our strategy entails deploying a wireless network that activates when traditional network services fail or in response to a disaster event. The envisioned DRN infrastructure comprises a range of wireless nodes, both fixed and mobile, each designed to fulfill specific tasks dictated by the requirements of different applications.

A crucial element of this network is the Wireless Solar Router (WSR), a versatile node responsible for providing various essential DRN services to different clients within a designated network area. These services include transmitting data and control signals between critical and industrial facilities, facilitating text messaging, and supporting multimedia services. WSRs, integral components of the DRN infrastructure, receive data packets from diverse sources and relay them to a local server situated within a Mobile Rescue Office (MRO). These WSRs collaborate to create an ad hoc network, enabling them to collectively transport data packets to their intended destinations. Consequently, an efficient ad hoc routing protocol is required to manage this intricate network, as depicted in Fig. 1 (a).

Within the ad hoc network, each WSR functions as a router, enabling the forwarding of traffic originating from other WSRs towards their respective destinations.



(a)

(b)

Fig. 1: Self Powered DRN Infrastructure (a) DRN Topology (b) WSR Architecture

The adoption of ad hoc networking to enhance the reliability of DRN systems offers substantial advantages over conventional wireless and wired methods. Ad hoc networks establish connections among nodes without relying on centralized infrastructure or administrative oversight, resulting in significantly reduced ownership, installation, and maintenance costs compared to other networking approaches. To meet power supply requirements, WSRs are typically located in proximity to wired electricity sources. However, this localized placement limits the coverage area of the proposed DRN infrastructure and, consequently, the reach of its services. To overcome this constraint, we propose the implementation of self-powered WSRs. In this context, we suggest that WSRs harness and store the energy they need from the surrounding environment, with a particular emphasis on solar energy, as illustrated in Fig. 1 (b). This innovative approach enables the deployment of WSRs in virtually any location, independent of power supply availability, thereby extending the coverage area of the DRN infrastructure considerably.

2.2 *Reliability enhancement using blockchain based clustering algorithm*

To ensure the seamless operation of Environmental Monitoring services in disaster recovery scenarios, we propose a Blockchain based DRN clustering algorithm that enhances network reliability. This section details the design and workings of this algorithm, shedding light on how it optimizes the network's performance. The continuity of rescue services relies on the DRN server's interaction with the WSRs. However, the DRN server can become unavailable due to technical issues or Denial of Service (DoS) attacks. In such cases, rescue operations face downtime. To address this, we propose a specialized DRN clustering algorithm for a fault-tolerant infrastructure. We divide the DRN infrastructure into logical clusters, each with a DRN server and associated WSRs. Inter-cluster communication is established through secure wireless connections, including a central DRN server, see Fig.2. This setup allows for data exchange, node updates, and security reports, enhancing overall infrastructure awareness and threat detection. It also limits network size and isolates issues, ensuring efficiency and security. The primary actors within the system include:

Neighboring WSRs (N-WSRs): They monitor the local DRN server's availability. If no response is received, they broadcast a "DCS Not Available" alarm, suspending security reporting and DRN services.

DRN Cluster Server (DCS): Conducts reporting and archiving with the Central Server (CS). In case of failure, it can be replaced, following secure procedures.

Central Server (CS): Oversees cluster activities, monitors DCS availability, and reallocates WSRs when necessary.

Other WSRs: Suspend "DCS-based" services upon "DCS Not Available" alarm and await invitations from operational DCSs.

Gateway-WSR (G-WSR): Connects adjacent DRN clusters and negotiates bridge connections. Transactions for DRN clustering are secured [15].

The blockchain-based DRN clustering algorithm significantly enhances network reliability by providing fault tolerance and rapid recovery mechanisms. If a DCS fails, its associated WSRs can seamlessly switch to another operational DCS without disrupting ongoing communication. This is achieved through the decentralized nature of the blockchain, which ensures that cluster configuration information and WSR registration data are always available and accessible.
Moreover, the system's ability to securely share intrusion detection rules and threat intelligence information among WSRs and the CS enables proactive threat detection and mitigation. This helps to prevent widespread network disruptions caused by cyber attacks and reduces the overall risk of network downtime. The proposed algorithm optimizes resource utilization through transparent and efficient allocation mechanisms. Blockchain-based smart contracts automate resource allocation processes, ensuring fair and transparent distribution of resources among clusters and WSRs. This approach eliminates the need for manual resource allocation and reduces the risk of resource bottlenecks or underutilization. The system's ability to track resource usage and generate billing transactions further enhances resource utilization by promoting accountability and encouraging efficient resource consumption. WSRs can clearly see how their resource usage is being billed, which incentivizes them to optimize their resource utilization patterns.

The integration of blockchain technology into the DRN clustering algorithm ensures secure communication among network participants. Data sharing between WSRs and the CS is encrypted and signed using blockchain-based cryptography, preventing unauthorized access and ensuring data integrity. Additionally, the use of blockchain-based digital certificates for identity management and authentication provides a secure and reliable mechanism for verifying the identities of WSRs and the CS.

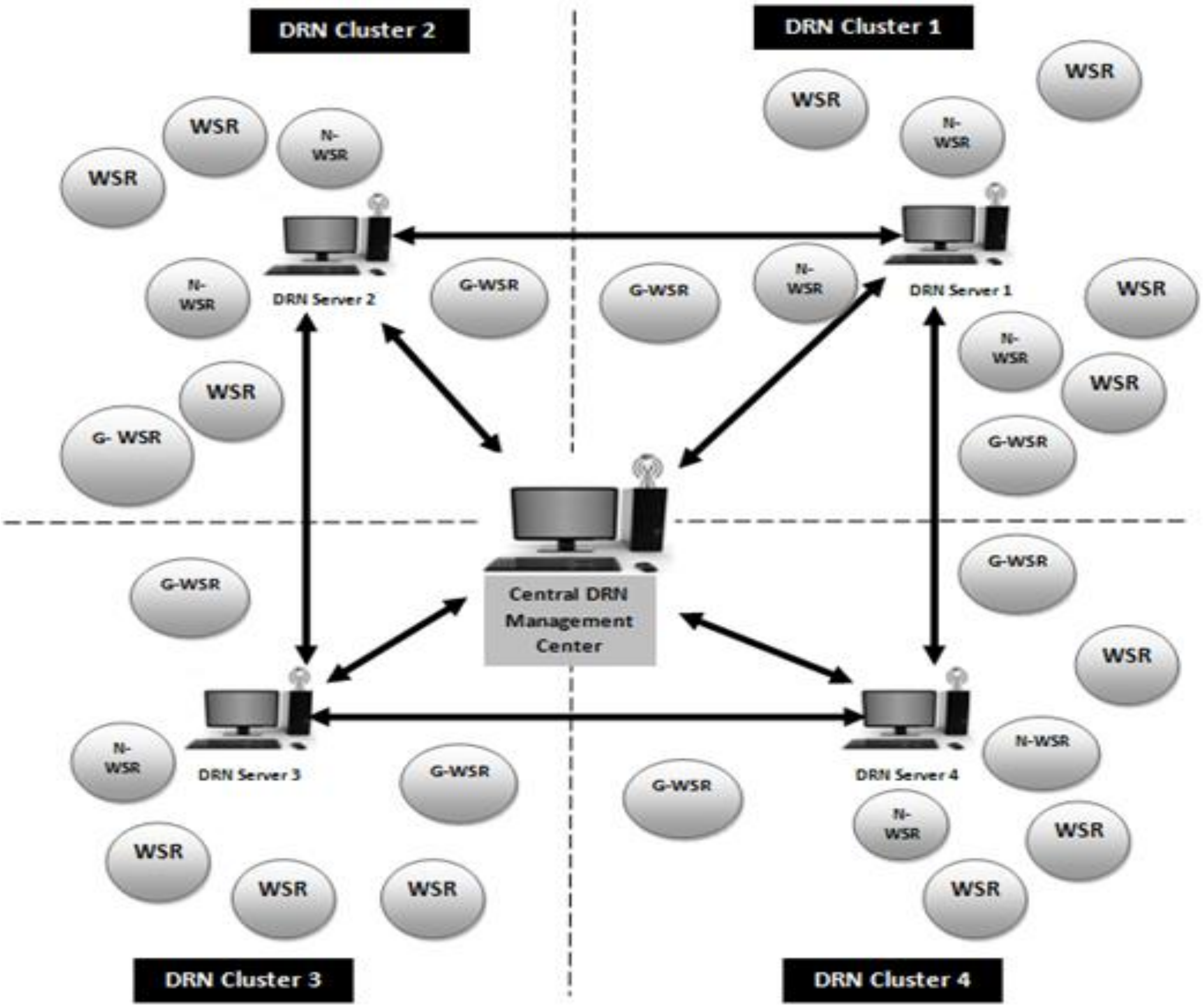


Fig. 2: DRN Clustering

This helps to prevent impersonation attacks and ensures that only authorized entities can access network resources and services. The blockchain-based DRN clustering algorithm operates in a decentralized and autonomous manner, with minimal intervention from network administrators. Clusters operate independently, managing their own resources and communication within their respective geographical areas. The CS plays a coordinating role, providing overall network oversight and facilitating communication between clusters.

Following, is a simplified and easy-to-follow breakdown of the blockchain-based DRN clustering algorithm:

Step 1. Initialize Clusters and Elect DCSs: Create a separate blockchain ledger for each cluster. Within each cluster, conduct a blockchain-based voting mechanism to elect a DCS.

Step 2. Register WSRs: Each WSR registers its public key with the DCS of its respective cluster.

Step 3. Share Data Securely: To share data, encrypt it using the recipient's public key. Sign the encrypted data with the sender's private key to ensure integrity. Broadcast the encrypted and signed data to the cluster's blockchain network.

Step 4. Exchange Intrusion Detection Rules and Threat Intelligence: Broadcast intrusion detection rules to the cluster's blockchain network. Broadcast threat intelligence information to the cluster's blockchain network.

Step 5. Allocate Resources Efficiently: The CS allocates resources to WSRs based on their needs and availability. Broadcast resource allocation transactions to the cluster's blockchain network.

Step 6. Track Resource Usage and Generate Billing: Track the resource usage of each WSR. Generate billing transactions based on resource usage. Broadcast billing transactions to the cluster's blockchain network.

Step 7. Verify Identities and Authorization: Obtain blockchain-based digital certificates for WSRs and the CS. Verify the validity of digital certificates for authentication. Grant or deny access based on authorization levels.

Step 8. Monitor Network Health and Respond to Issues: Continuously monitor network traffic, intrusion detection alerts, and resource usage. Identify and address network issues promptly. Review and update system configuration as needed.

2.3 Sustainable power management

Our research introduces an innovative power management system, the "Duty Cycle Estimation (DCE) – Event Driven Duty Cycling (EDDC)" technique, to effectively harness solar energy and sustain network operations. This section offers a thorough explanation of this technique, emphasizing its significance in creating environmentally friendly communication infrastructure. In our study, we have chosen the versatile UBICOM IP2022 platform [16] to implement our envisioned WSR due to its multifunctional capabilities. As integral components of the DRN infrastructure, WSRs experience varying network traffic conditions, significantly impacting their power consumption and operational lifespan. Our primary objective in this research is to provide an alternative power source for WSRs and implement an energy management strategy that optimally governs the utilization of energy stored in the WSRs' battery cells.

To achieve the first goal, we introduce a solar energy harvesting module, as illustrated in Figure (1b). At the core of this module lies the harvesting circuit, responsible for collecting energy from the solar panels, managing energy storage, and directing power to the intended system. In our setup, we utilize a DC-DC converter, specifically the Texas Instruments TPS63000 low-power boost-buck DC-DC converter [16], to ensure a consistent supply voltage to the embedded system.

Simultaneously, we present a novel duty cycling methodology aimed at efficiently controlling power consumption within the WSR circuitry. Duty cycling involves the periodic transition of embedded nodes between energy-intensive states (active) and low-energy states (sleep) to conserve energy [17]. During active states, nodes can perform their regular functions, whereas in low-energy states, nodes limit their operations to specific tasks to save energy [17]. We term this methodology "DCE – EDDC", which comprises two key components: dynamic duty cycle estimation and the management of WSR behavior during active periods.

DCE Algorithm: Within the scope of this paper, we propose that WSRs should adjust their operations based on the available energy, specifically linking the service rate of the WSR to its power budget. In this algorithm, sleep periods are dynamically determined each day, considering factors such as WSR power consumption, weather conditions, and the amount of stored energy. To achieve this, we establish a relationship among Duty Cycling periods, Average Service Rate (ASR), and Available Energy (AE). The key terms include:

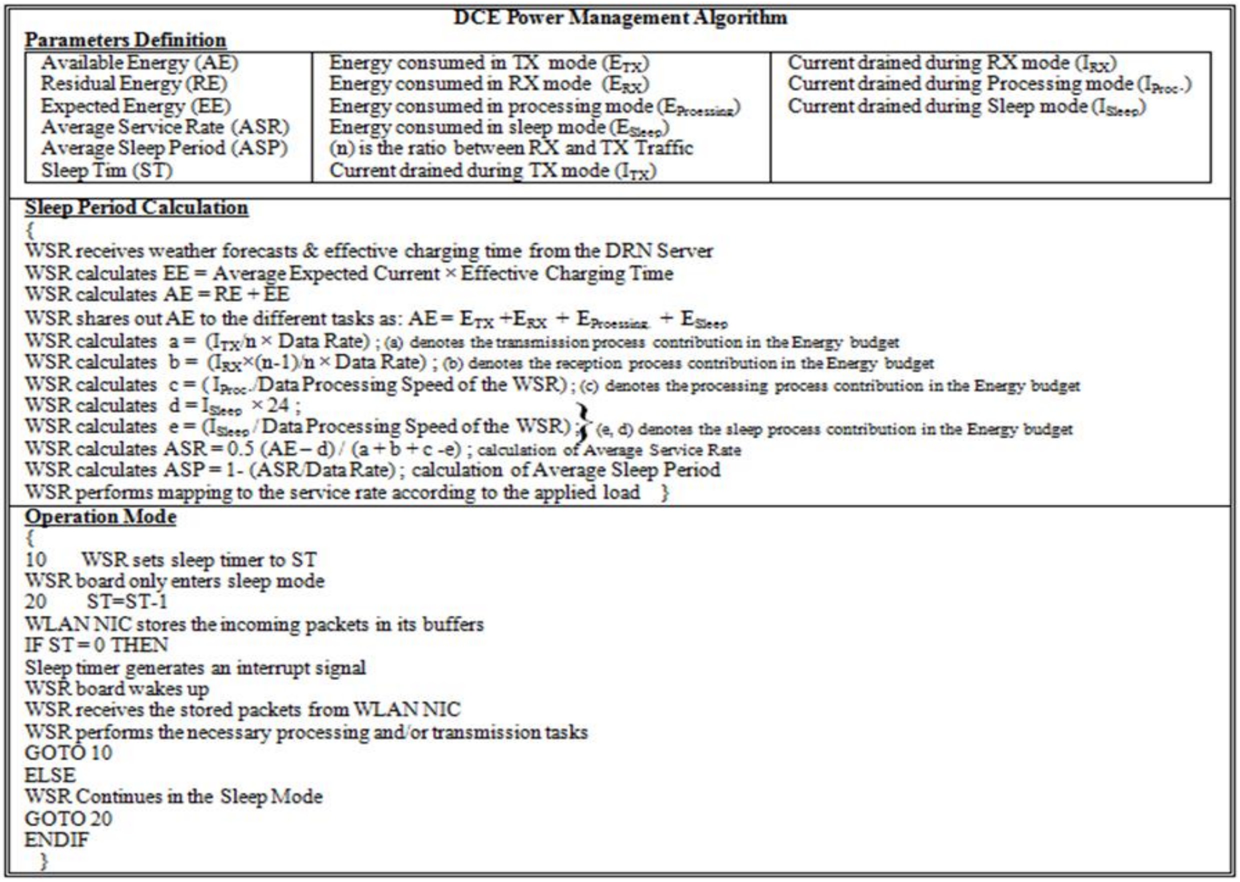
Average Service Rate (ASR): The average of the total traffic (in bps) transmitted and received by the WSR.

Duty Cycling Periods: Time is divided into slots, making Duty Cycle the ratio of sleep periods to the total slot time.

Available Energy (AE): The sum of residual energy in the batteries from the previous day plus the anticipated energy for the next day.

Our approach follows the steps illustrated in Fig. 3 (a). Each time slot is divided into active and sleep periods, with a WSR initially entering the sleep period for a predetermined duration calculated in accordance with AE. When the active period commences, the WSR awakens and processes the stored packets in the WLAN NIC, as depicted in Fig. 3 (a).

EDDC Algorithm: In our paper, we propose that WSR behavior during active periods is governed by two factors: scheduled tasks and responses to packet reception events targeting specific WSRs. The suggested EDDC technique leverages a critical feature known as "Clock Stop Mode."



DCE Power Management Algorithm

Parameters Definition

Available Energy (AE)
Residual Energy (RE)
Expected Energy (EE)
Average Service Rate (ASR)
Average Sleep Period (ASP)
Sleep Tim (ST)

Energy consumed in TX mode (E_{TX})
Energy consumed in RX mode (E_{RX})
Energy consumed in processing mode ($E_{Processing}$)
Energy consumed in sleep mode (E_{Sleep})
(n) is the ratio between RX and TX Traffic
Current drained during TX mode (I_{TX})

Current drained during RX mode (I_{RX})
Current drained during Processing mode ($I_{Proc.}$)
Current drained during Sleep mode (I_{Sleep})

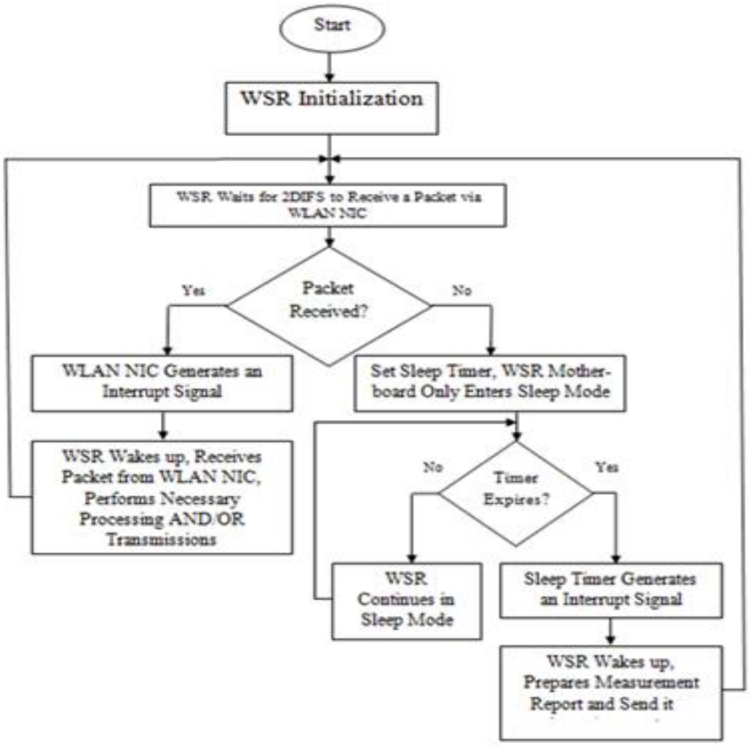
Sleep Period Calculation

```
{
WSR receives weather forecasts & effective charging time from the DRN Server
WSR calculates $EE = \text{Average Expected Current} \times \text{Effective Charging Time}$
WSR calculates $AE = RE + EE$
WSR shares out AE to the different tasks as: $AE = E_{TX} + E_{RX} + E_{Proessing} + E_{Sleep}$
WSR calculates $a = (I_{TX}/n \times \text{Data Rate})$ ; (a) denotes the transmission process contribution in the Energy budget
WSR calculates $b = (I_{RX} \times (n-1)/n \times \text{Data Rate})$ ; (b) denotes the reception process contribution in the Energy budget
WSR calculates $c = (I_{Proc.}/\text{Data Processing Speed of the WSR})$ ; (c) denotes the processing process contribution in the Energy budget
WSR calculates $d = I_{Sleep} \times 24$ ;
WSR calculates $e = (I_{Sleep}/\text{Data Processing Speed of the WSR})$ ; } (e, d) denotes the sleep process contribution in the Energy budget
WSR calculates $ASR = 0.5\,(AE - d)/(a + b + c - e)$ ; calculation of Average Service Rate
WSR calculates $ASP = 1 - (ASR/\text{Data Rate})$ ; calculation of Average Sleep Period
WSR performs mapping to the service rate according to the applied load }
```

Operation Mode

```
{
10      WSR sets sleep timer to ST
WSR board only enters sleep mode
20      ST=ST-1
WLAN NIC stores the incoming packets in its buffers
IF ST = 0 THEN
Sleep timer generates an interrupt signal
WSR board wakes up
WSR receives the stored packets from WLAN NIC
WSR performs the necessary processing and/or transmission tasks
GOTO 10
ELSE
WSR Continues in the Sleep Mode
GOTO 20
ENDIF
  }
```

(a)



(b)

Fig. 3: DCE-EDDC Algorithm (a) DCE Algorithm (b) Flowchart of EDDC Algorithm

In this mode, the system clock may be disabled, deactivating the CPU core clock and consequently, the WSR's mother board. While the system clock is disabled, the interrupt logic continues to function, and a sleep timer remains active. Transitioning from the clock stop mode (sleep mode) to normal execution is feasible through sleep timer interrupts or in response to an external interrupt from the WLAN NIC. Importantly, this method doesn't reset the chip, allowing program execution to resume from where it was paused. This mode shifts only the WSR motherboard to a power-saving mode, turning off its circuitry (except the external interrupt circuits, sleep timer, and the program memory). Whenever an interrupt is triggered, such as packet reception by the WLAN NIC or the expiration of the sleep timer, the board promptly awakens within a few clock cycles to execute the necessary actions, as depicted in Fig. 3 (b).

2.4 *Evaluation and experimentation*

To validate the proposed infrastructure, we suggest an experimental platform for thorough evaluation. This section outlines the metrics used to assess network performance, practicality, power consumption, and its resilience in the face of various failure events. To assess the power consumption of the proposed WSR under real-world DRN traffic scenarios, we propose an experimental framework, as illustrated in Fig. 4. This framework entails the generation of diverse DRN traffic profiles, which are then input into a simulation model. This model serves as a representative depiction of a DRN infrastructure and aids in creating the necessary network traffic. Subsequently, a traffic generator PC utilizes this network traffic to simulate the behavior of the DRN in interaction with a WSR.

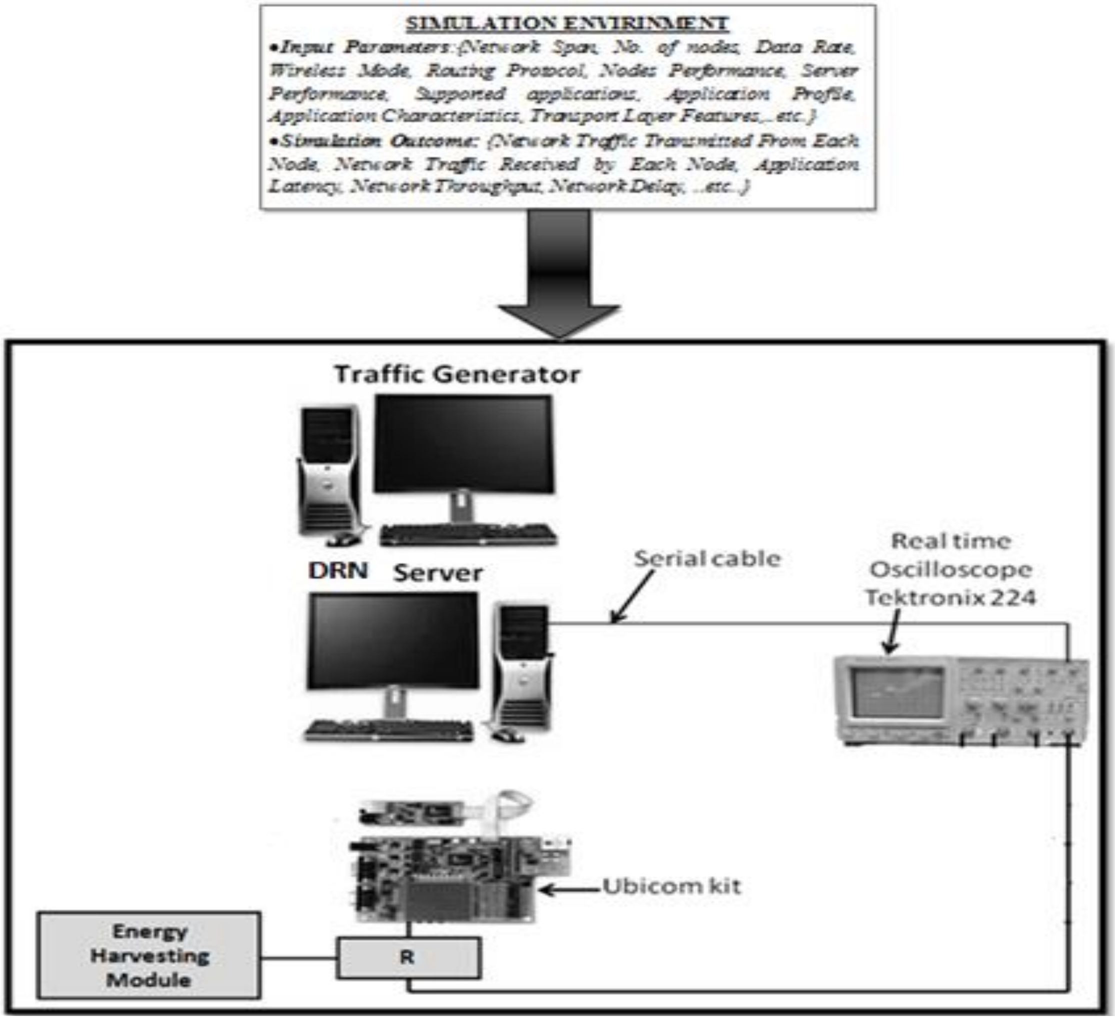


Fig. 4: The Experimental Framework

Table. 1: Simulation model parameters

Name of the parameter		**Specification**
Simulation Time (Minute)		60
No. of WSR nodes		40
Network Span Area (Km^2)		25
WSR Modeling Parameters		Packets Processing Rate (Packet/sec.) = 2000 Memory = 2 M Byte
WLAN settings		Data Rate (Mbps) : 18 for IEEE802.11a
OLSR settings		Hello Interval (sec.) = 2 TC Interval(sec.) = 5 Neighbor Hold Time (sec.) = 6 Topology Hold Time (sec.) = 15 Duplicate Message Hold Time (sec.) = 30
m-Health Applications	Medical Wireless Body Area Network (WBAN) Signaling	5 Sensors/Body Sensors to WSR packet length = (128-512) Bit Sensors to WSR packets rate = (20-1000) Packet/s
	Text Messaging	Message Inter-arrival Time = 10 s Message Size = (200 to 1000) Byte [Uniformly Distributed]
	Medical Image File Transfer	1024×768 Pixels (JPEG Compression) File Size = (0.5-1) MByte Inter-request Interval = 180 s [Poisson Distribution]
	Multimedia Streaming	352 × 288 @ 15 fps 197–421 Kb/s H.264/AVC

The initial step involves the selection of a real-world map for the installation of WSRs. This map serves as a representation of a DRN infrastructure, covering an area of 5x5 square kilometers and accommodating 40 WSRs [15]. Based on a prior analysis [15], it was determined that Optimized Link State Routing (OLSR) outperforms other ad hoc routing protocols in a dynamic ad hoc topology, making it the protocol of choice for our simulation model. The OLSR protocol's functionalities are governed by a predefined set of parameters specified in OLSR RFC 3626 [18], which we incorporated into our simulation model, as outlined in Table (1). To evaluate the performance of our simulated network, various Telemedicine services were introduced [2], as detailed in Table. 1.

In our upcoming experiments, we aim to measure two crucial parameters:

Current Consumption in Normal Mode: In this mode, the Ubicom board, along with its associated accessories, operates without any power management strategies.

Current Consumption in Sleep Mode: In this mode, the power consumption of the Ubicom board and its accessories adheres to the DCE-EDDC power management scheme.

To show case the benefits of implementing the suggested duty cycling methods, we plan to conduct a series of tests using the proposed experimental test bed, as illustrated in Fig. 4.

3. Results

Our investigation will focus on understanding the impact of varying the number of DRN clients served by each WSR on network traffic, as shown in Fig. 5. We will analyze different protocols within the TCP/IP stack, with particular emphasis on application layer traffic in both outbound and inbound directions as the primary contributor to network traffic. Other traffic sources, such as layer 2 and OLSR-related traffic, will have a comparatively lower impact. It's noteworthy that the location of the WSR within the network topology significantly influences its network traffic, with higher traffic (and consequently higher power consumption) observed in WSRs closer to the DRN server. These WSRs were intentionally selected in the experimental model to represent the most power-intensive scenario.

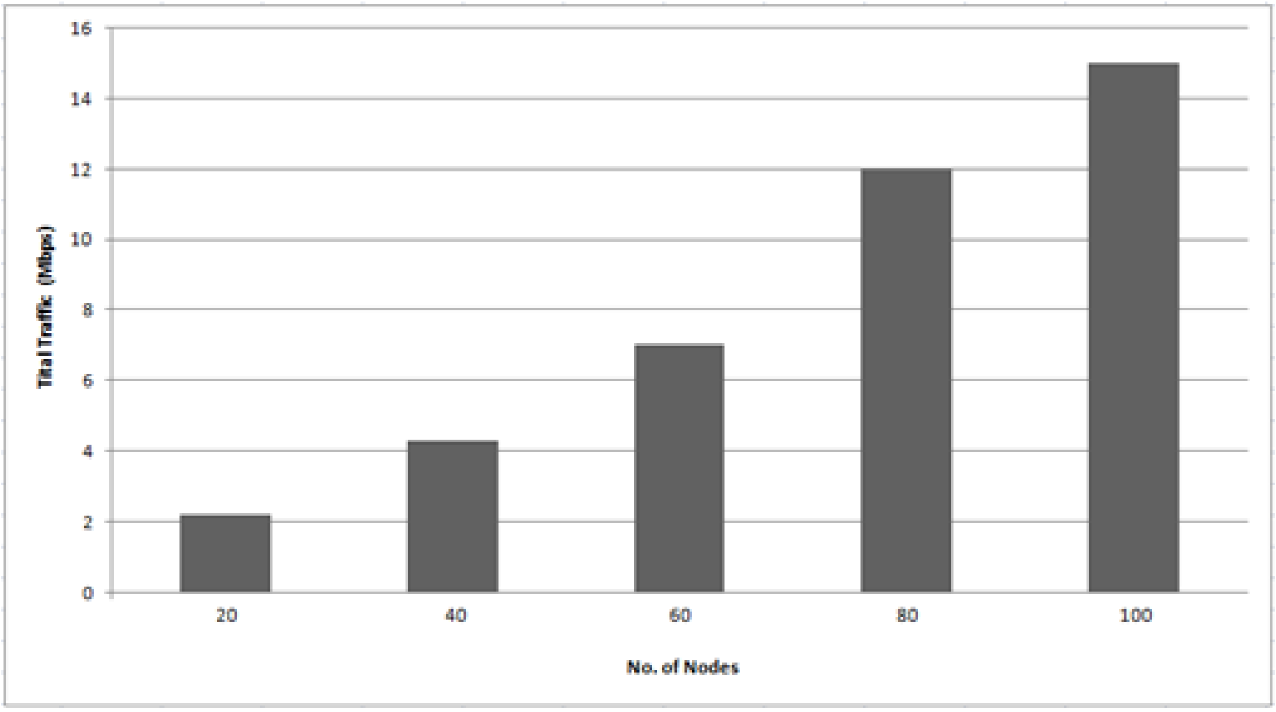


Fig. 5: WSR Traffic Statistics

Our assessment will include the impact of the DCE algorithm in various scenarios, with initial settings outlined in Table. 2. These experiments aim to evaluate the adaptability of the DCE algorithm under diverse operational conditions, taking into account variations in AE levels. Table. 3 provides corresponding values of ASR and ASP from these scenarios, with RE representing battery charging levels and (N) indicating the number of paralleled solar panels. The proposed DCE algorithm demonstrates the ability to dynamically adjust duty cycling based on available energy levels, ensuring that the WSR continues to operate in a pre-planned and managed manner.

Furthermore, we seek to evaluate the effectiveness of the suggested DCE-EDDC power management method in defending against unmanaged network traffic conditions, such as those resulting from an Energy Exhaustive DoS Attack [15]. Various network traffic rates will be directed at the WSR, both with and without the implementation of the proposed power management method. Fig. 6 will provide insights into how well the properly managed WSR sustains its battery life, irrespective of fluctuations in incoming traffic rates, while the unmanaged power consumption resulting from varying traffic rates significantly diminishes the battery life of the WSR.

Table. 2: Initial settings of DCE experiments

Parameter	Value
Data Rate	18 Mbps (IEEE802.11a)
Traffic Characteristics	n = $(\frac{RX\ Traffic}{TX\ Traffic})$ =4
Data Processing Speed of the WSR	24 Mbps
I_{TX}	150 mA
I_{RX}	120 mA
$I_{Proc.}$	150 mA
I_{Sleep}	1 mA
Battery Characteristics	3 v, 2800 mAh
Solar Panel	SP1
Average Current Produced in a Sunny Day	34 mA
Effective Charging Time	15 Hours
Average Current Produced in a Cloudy Day	20.5 mA
Effective Charging Time	13 Hours
Average Current Produced in a Rainy Day	14.4 mA
Effective Charging Time	11 Hours

In this sub section of the paper, we suggest to employ the simulation model to assess the effectiveness of the proposed clustering algorithm. The simulation model was constructed based on the following assumptions:

Table. 3: ASR & ASP values under different conditions

RE (% of battery capacity)	N	Weather Condition	AE (mAh)	ASR (Mbps)	ASP (s)
100%	1	Sunny	4960	7.75	0.57
100%	1	Cloudy	3801	5.94	0.67
100%	1	Rainy	3482	5.44	0.7
75%	1	Sunny	4260	6.66	0.63
75%	1	Cloudy	3101	4.85	0.73
75%	1	Rainy	2782	4.35	0.76
50%	1	Sunny	3560	5.56	0.69
50%	1	Cloudy	2401	3.75	0.79
50%	1	Rainy	2082	3.25	0.82
25%	1	Sunny	2860	4.47	0.75
25%	1	Cloudy	1701	2.66	0.85
25%	1	Rainy	1382	2.16	0.88
100%	2	Sunny	7120	11.13	0.38
100%	2	Cloudy	4802	7.5	0.58
100%	2	Rainy	4164	6.51	0.64
75%	2	Sunny	6420	10.03	0.44
75%	2	Cloudy	4102	6.41	0.64
75%	2	Rainy	3464	5.41	0.7
50%	2	Sunny	5720	8.94	0.5
50%	2	Cloudy	3402	5.32	0.7
50%	2	Rainy	2764	4.32	0.76
25%	2	Sunny	5020	7.84	0.56
25%	2	Cloudy	2702	4.22	0.77
25%	2	Rainy	2064	3.23	0.82

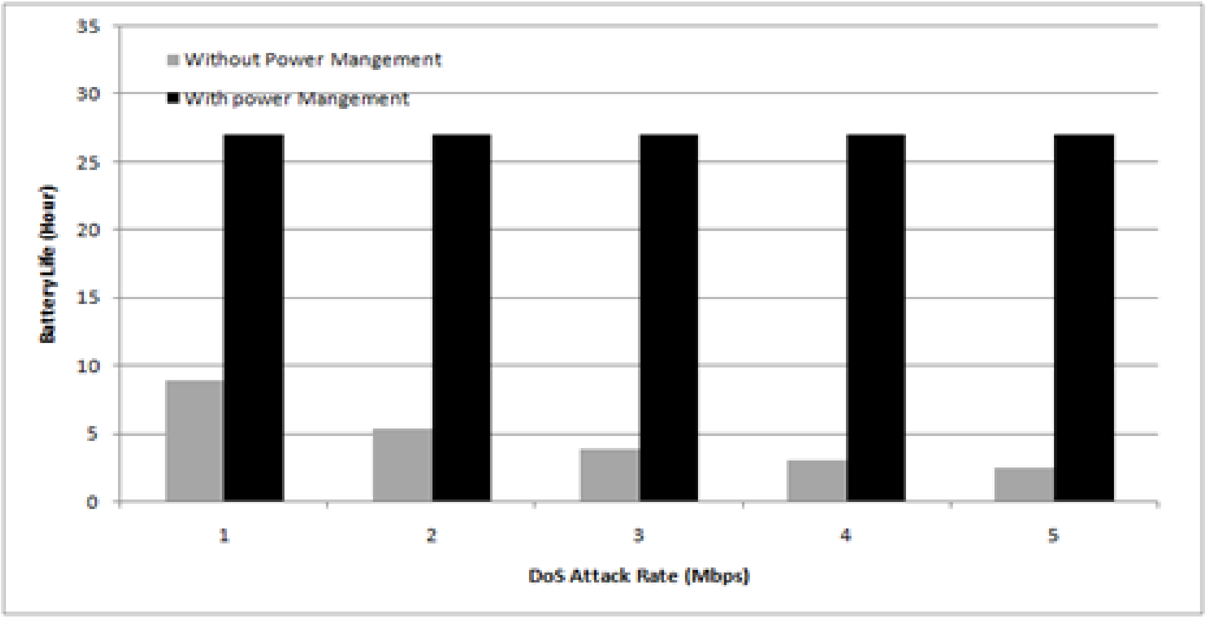


Fig. 6: WSR Battery life according to different DoS attack rates

Table. 4: Effect of cluster size on the DRN performance

No. of WSRs	Network Load (Mbps)	Average Response Time (s)	Total Routing Traffic (kbps)	%Packet Loss	Average Server CPU%	Average WSR CPU%	Network Status
10	1.23	0.033	7	0	5	15	Not Congested
25	3.12	0.062	15	0.53	12	19	Not Congested
50	5.3	0.156	31	3.5	21	25	Not Congested
75	8.5	0.357	50	8.6	34	32	Congested
100	11	0.712	70	12.2	44	39	Congested
125	13.5	3.11	92	25.3	54	46	Congested
150	14.05	12.78	112	34.5	58	54	Congested

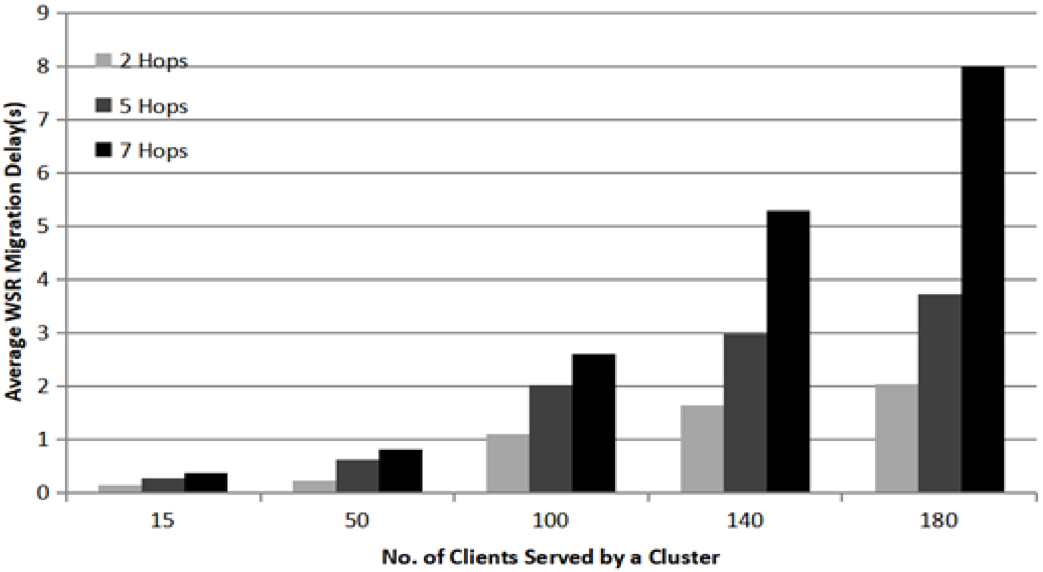


Fig. 7: Average WSR migration delay

- The WSRs are uniformly distributed around a centrally positioned DRN server.
- All WSRs share the same modeling parameters outlined in Table (1). The coverage area of each WSR is 500 meters.
- The number of users served by each WSR is assumed to be identical.
- The applications supported by the DRN infrastructure are detailed in Table (1).
- The ad hoc network utilizes the OLSR protocol to forward packets, with OLSR parameters set according to Table (1).
- A packet loss ratio exceeding 5% is considered indicative of network congestion [5].

We will examine the advantages associated with selecting an optimal cluster size. As outlined in Table.4, the quantity of WSRs in the DRN infrastructure significantly influences the overall system performance. With an increase in cluster size, a greater volume of network traffic necessitates processing by various components (WSRs, DRN server, and communication network), resulting in performance degradation due to the additional load. Beyond specific thresholds in cluster size, heightened network traffic congestion leads to increased packet losses, and the surviving packets encounter additional delays en route to their destinations. Based on these observations, we propose restricting the number of WSRs in each cluster to 50. This recommendation, based on the current simulated network settings, remains subject to adjustment under different circumstances. The aim of the forthcoming tests is to evaluate the proposed Disaster Recovery Network (DRN) clustering and Wireless Solar Router (WSR) migration procedure in response to a DCS failure event. The metric employed to gauge the resilience of the DRN clustering algorithm in the face of diverse failure events, such as DCS collapse, is the average WSR Migration Delay (WSRMD). WSRMD is defined as the time needed by the clustering algorithm to re-establish connectivity between specific areas of the network (i.e., WSRs) and the DRN infrastructure following a failure event. The WSRMD value is shaped by the cumulative delays of various procedures illustrated in Fig. 2. The tests consider typical Telemedicine applications as network load conditions. Furthermore, a uniform network topology is assumed, with the DCS positioned at the center and 10 WSRs evenly distributed around it. The number of hops between the foreign DCS and the G-WSR is assumed to be either 2, 5, or 7 based on the cluster geometry, with the same assumptions applied to the other cluster where the migrated WSR already exists. Fig. 7 provides a visual representation of the variation in WSRMD values under different network conditions.

The performance of the proposed fault-tolerant algorithm is evidently affected by network load conditions and the number of hops from source to destination. Nevertheless, the clustering algorithm demonstrates its ability to recover a specific segment of the DRN infrastructure with varying delay values in response to the load settings. These delay values, however, may be considered acceptable given the requirements of the envisioned DRN services [5, 8].

4. Discussion on results

Table. 5 compiles the statistical findings derived from a range of experiments, taking into consideration the influence of the proposed power management techniques and the DRN clustering algorithm. The data presented in Table. 5 underscores the substantial reduction in the number of paralleled solar panels and a decreased battery capacity required for WSRs when operating in Sleep mode to support multiple Telemedicine applications. These results underscore the remarkable effectiveness of the suggested power management scheme in extending the lifespan of solar energy-harvested battery-based WSRs and enhancing their reliability, ultimately contributing positively to the establishment of a dependable and available DRN infrastructure.

Furthermore, it is evident that the suggested fault-tolerant algorithm has demonstrated its capability to restore the DRN infrastructure with a satisfactory level of performance in alignment with the demands of Telemedicine services [10-12]. Additionally, the network's performance, installation time, and cost have all met the stipulated requirements within the acceptable range for DRN operations [10-12].

On the other hand, Table. 6 compares the main features of current work with other DRN solutions. The proposed system enjoys a wider range of solutions and covers all the essential requirements to build a reliable and secured DRN infrastructure.

Table. 5: Evaluation metrics of green tele-medicine DRN infrastructure

Network Type		**Wireless Mesh Network (WMN)**
Ad Hoc Routing Protocol		Optimized Link State Routing (OLSR)
WSR Node		Ubicom IP2022 Network Processor Platform, 120 MHZ CPU, 2 Mbyte memory
Wi Fi Standard		IEEE802.11a, 18 MHZ
WSR Transmit Power (W)		25 dBm
Antenna Type		Omni Antenna 2.4GHz/5GHz Dual Band Gain: 1.5 dBi (2.4GHZ) / 4.5 dBi (5GHZ)
WSR Radial Transmit Range (m)		300
Average Installation Time/WSR		30 Minute
Estimated Cost/WSR		150 $
Quality of Service (QoS) Support		Yes
Remote WSR Management		Yes, via Simple Network Management Protocol (SNMP)
Network Performance	Average Network Access Delay (s)	0.00169
	Average File Transfer Latency (s)	6
	Average Video Streaming Latency (s)	0.5

DRN Clustering Algorithm	Average Network Convergence Time (s)	0.45
	Average Service Interruption Time (s)	0.8
	%Packets Loss	4%
Requirements of Solar System	Solar Panel Dimensions (High (cm) × Width (cm))	36 × 29
	Mean Voltage (v)	4
	Mean Current (mA)	360
	Rated Power (w)	1.5
	No. of Paralleled Solar Panels Required [Normal Mode]	6
	No. of Paralleled Solar Panels Required [Sleep Mode]	2
	Battery Capacity (mAh) [Normal Mode]	2300
	Battery Capacity (mAh) [Sleep Mode]	750
Power Consumption Analysis	Average Drained Current (mA) [Normal Mode]	150
	Average Drained Current (mA) [Sleep Mode]	70
	Battery Life (Hour)/Normal Mode [2800 mAh Battery Cells]	15
	Battery Life (Hour)/Sleep Mode [2800 mAh Battery Cells]	29

Table. 6: Comparison with other DRN solutions

Network Type	Current Work	OEMAN [23]	Team Phone [24]
Network Type	Wireless Mesh Network (WMN)	Multihop access networks	Cellular Networks, Ad Hoc Networks and Opportunistic Networks
DRN Node	Wireless Solar Router (WSR)	Smart phone, Laptop PCs	Smart phone
Power Source	Solar Energy, Battery Cells	Battery Cells	Battery Cells
Routing Protocol	OLSR	Simple routing in tree-based topology	AODV, DTN2
Security Features	Blockchain Technology	None	None
Reliability Solutions	DRN Clustering Algorithm	None	None
Power Management	DCE-EDDC	None	Wake-up Scheduling
Research Methodology	Simulation, Experimental Work	Experimental Work	Experimental Work
Supported Applications	Text Messaging, Field Measurements, File Transfer, Multimedia Streaming	Internet Access	Text Messaging

5. Conclusions

This paper presents a robust strategy for implementing a self-powered and reliable DRN infrastructure tailored to support various Telemedicine applications. The study delves into a variety of methodologies and algorithms essential for realizing such an infrastructure, providing valuable insights. A key determinant for the successful implementation of an "energy harvesting-battery based" embedded system lies in the adaptive capacity of the intelligent power management algorithm to diverse DRN operational scenarios. The proposed "DCE – EDDC" method offers several advantages, including simplified implementation, optimized energy resource utilization, and heightened network performance. Notably, this approach brings substantial economic benefits by requiring fewer solar panels and a suitable battery capacity. Additionally, it is crucial for management strategies to strike a balance between a highly reliable and well-performing system, considering the embedded nature of a WSR. Integrating disaster recovery algorithms and techniques with a solar energy-powered system is an innovative and unexplored frontier in prior research endeavors. This combination holds promise for advancing the fields of disaster recovery and telemedicine, providing enhanced reliability and performance. Moreover, incorporating blockchain technology into the DRN infrastructure brings additional benefits, such as increased security, transparency, and traceability. The decentralized and tamper-resistant nature of blockchain ensures the integrity of data transactions within the network, further enhancing the overall robustness of the system. This integration not only addresses sustainability and economic considerations but also contributes to the security and trustworthiness of the disaster recovery and telemedicine applications.

Conflict of Interest

The authors should declare "No conflict of interest".

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