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Incorporation of Energy Efficient Computational Strategies for Clustering and Routing in Heterogeneous Networks of Smart City

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Abstract: For decision-making and governance, smart cities depend on tracking data collected via a substantial percentage of wireless sensing nodes. However, several limitations affect Wireless Sensor Network (WSN)-based Internet of Things (IoT) services, such as low battery life, recurrent connectivity problems due to multi-hop connections, and a limited channel capacity. Furthermore, in many systems, clustering and routing are handled independently, which prevents the adaptation of effective strategies for optimal energy usage and prolonged network lifespan. This research gathers data from heterogeneous IoT nodes linked via WSN and distributed across a smart infrastructure. There are two interrelated problems to be addressed with respect to energy efficiency computations: clustering and routing. We provide a new clustering strategy through which efficient routing of critical and regular data is handled. As a result, both clustering and routing have been significantly strengthened, which balances the communication load across different sectors of the smart infrastructure network. Minkowski distance and ranking strategy are used for routing and selecting cluster heads, respectively. Deterministic distributed–time division multiple access (DD-TDMA) scheduling is employed to balance the communication load across the network. The experimental results show that the proposed work outperforms some of the popular cluster-based routing strategies.

Keywords: smart city; WSN; energy efficiency; clustering; routing; DD-TDMA; data transmission; cluster head; IoT; base station

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1. Introduction

In the last few years, urbanization has skyrocketed due to rapid population growth. UN-Habitat [1] predicted that the world's populace would increase to approximately ten billion by 2050, almost thrice the status of the present global population. As a result, community safety, smart transit, clean energy, sustainable development, and productivity improvements are critical problems modern cities must address. An inadequate supply of clean water and a rapidly growing population has prompted the development of a new way of thinking about cities, called intelligent urbanization or smart city concept. As the density of population in metropolitan areas has grown at an extremely fast rate, the overall infrastructure and amenities are required to meet the needs of residents. As a result, many digitized components, such as smartphones, sensors, controllers, and smart gadgets, have emerged as massive business goals of the IoT because they can be interconnected via the Internet [2]. Additionally, wired networks are more complex and expensive to set up and manage than wireless ones. Therefore, modern networking systems prioritize wireless communication because of these realities.

It is of primary importance for the smart infrastructure to gather and analyze information from the physical environment. Sensory information/records are generated through various sorts of sensors in multiple spots with diverse functionalities. In order to be smart, an environment has to be aware of what is going on both outside and within its service area, and it is enabled via a wireless sensor network (WSN) [3,4]. Figure 1 represents the backbone elements of smart cities.

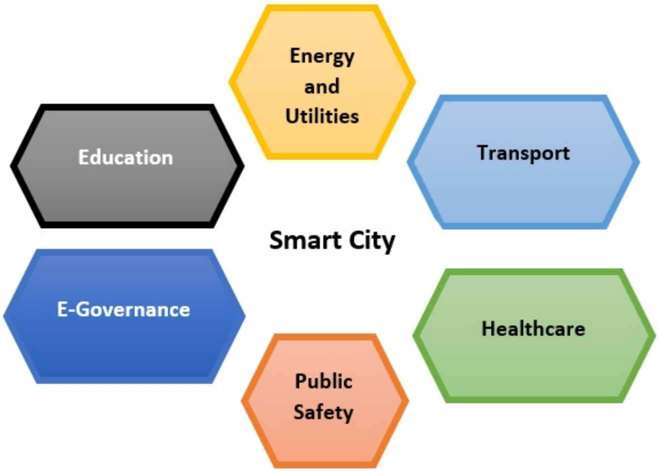

Figure 1. Backbone elements of a smart city

WSN is a network of autonomous, multipurpose, and low-power sensing units embedded with communication units that are linked to access points or base stations (BS) [5,6]. The utilization of generalized/conventional ad-hoc routing methods for data transmission in WSN is restricted by increased node density, limited data rates, and other resource limitations. WSN routing methods often emphasize adaptive routing and resource and service awareness [7,8]. Figure 2 depicts the WSN-based communication architecture of smart cities.

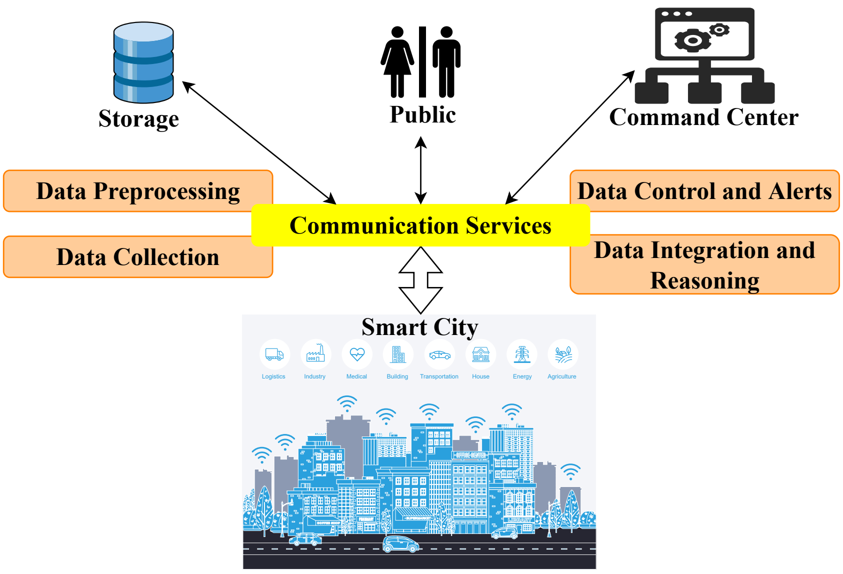

Figure 2. WSN-based communication architecture of smart cities.

Smart cities are designed to process infrastructural systems such as water and sewage disposal management, urban and resource management, and transit, in addition to medical centers, transmission and distribution power grids, and several other operations. The delivery of goods and services from one place to another is a vital element of smart city design [9,10] and an important service for everyday living. Routing mechanisms have to be flexible enough to meet the requirements of a large-scale network. Routing is perhaps more difficult due to the frequent changes in data routing paths. Routing techniques should be developed in such a manner that they can handle unforeseen node failures. The classification of routing strategies depends on the functionality of the evolved protocols. Prominent routing strategies are query-based, multi-path, Quality of Service (QoS)-based, and negotiation (reactive) based routing, which are delineated as follows. In query-based, to fulfill the query and responses better, the transfer of data is performed. Next, the BS disseminates the required data across the network under the user's demand. The primary difficulty with query-based systems is receiving similar queries at the BS/sink side for several instances. It is therefore essential to eliminate unnecessary/excess ones.

In multi-path routing, multiple paths are built between transmitter and receiver to better balance the load. In addition, the backup routes allow the system to continue running despite link failures/errors, which is referred to as fault tolerance. Thus, dependability is achievable. The negotiation-based routing strategy aims to minimize data redundancy by letting both the sender and receiver reach proper negotiation to complete established communication. As a result, mutual understanding happens among sink nodes, and they work together to choose the route for transmission depending on context.

In QoS-based routing, the transmission path is planned to use a predetermined and designated route. QoS-based networking aims to help route discovery by allowing protocols to find suitable routes for traffic to flow. This routing's efficiency is evaluated based on the volume of traffic.

Most research has described numerous methods and techniques for robust WSNs integrated with IoT networks [11]. However, these studies do not address total centralization, and they create additional issues such as increased overhead in exchanging packets with proper energy efficiency strategies. It is, therefore, necessary to develop a new approach incorporating the combination of both distributive and centralized systems. The network may be partitioned into smaller regions by gathering the network devices in a particular location, known as clustering. Every cluster has one administrative device, known as the cluster head (CH). The CH organizes the monitoring of media access, gathers information, analyzes the data in a certain manner, and interacts with the gateway node of the IoT network or other centralized units. To prevent one device from being overloaded and distribute the energy usage more evenly, the CH responsibility is periodically cycled across units in the cluster.

Sensing nodes in WSNs are distributed across vast regions of smart infrastructure to gather the data they are interested in. Because their energy systems are battery-centric and have limited communication range, they need to use a multi-hop routing strategy to transmit the aggregated data to the sink or BS. Thus, clustering is one of the prominent alternate resolutions for this problem. However, it is typically viewed as a single-hop strategy, i.e., each CH sends information directly to its destination.

Clustering is driven by the properties of the CH regarding cluster density, the overall lifespan of the network, and its stability. The most critical CH traits are mobility, type, and function. Here, type denotes the general potentialities of the cluster head wherein network administrators can equip such nodes with powerful capabilities and abundant resources that mainly include sufficient energy and decent storage. With mobility, the movement of the CH may create additional challenges for communicating with the cluster members, other CHs, or the BS. Cyber-physical systems based on WSN and IoT usually use CHs to aggregate the sensor data and integration activities or relay information. With increasing urban density, large-scale networks have a scalability issue.

Consequently, electing a CH becomes difficult in such situations. In allowing any node to be a CH or normal member node, the decision procedures must abide by many primary concerns. Most research has confirmed that the clustering operation is an Non-deterministic polynomial (NP)-hard optimization issue [11]. Searching across vast spaces of potential outcomes is necessary to find solutions to NP optimization issues.

It is therefore essential to know that the fusion of the two techniques, as noted earlier, is also preferred for vast deployment regions. If any CH along the routing path fails, data transfer will be impacted. Hot spots are an issue with this hypothesis. These causes are primarily energy depletion, vital component exhaustion, and other recognized factors. Thus, including Fault-Tolerant (FT) capabilities in network systems is crucial, particularly in smart environments. There are two primary ways of classifying fault tolerance methods in WSNs: they can depend on either the stage when the mechanism activates (during the sensing or routing stage) or the cause of the errors and their propagation (whether they are hardware or software). From these factors, FT techniques in WSN are categorized into two types: one is 'proactive', and the other is 'reactive'.

Energy-based and data-based FT are two subcategories of node-based proactive methods. FT based on energy improves network MTTF and its lifespan. This approach relies on the clustering of deployed sensing nodes, network backbone scheduling, and node hibernation. Data recovery is made easier with the help of proactive data FT methods. One of the effective ways to combat data errors is via duplicate transmissions with the same information and comparing them to detect faults.

Reactive FT strategies are activated by reactive methods when faults occur. This method waits for errors and subsequently starts the restoration/recovery procedures as an appropriate countermeasure. These techniques are further classified into three broad categories: network-based, node-based, and holistic, which are all based on the cause of the fault.

Node-based reactive techniques are used to recover from node failures. They consist of strategies such as switching to the sleeping backup node on the occurrence of node failure. Network-based reactive techniques use multiple paths, backup paths, and path recalculation in case of network/link failure. Moreover, for restoring the connectivity, extra nodes are deployed or the existing nodes are repositioned. These are the techniques that can deal with and recover from both network and node-based faults. They provide complete fault tolerance for various faults. An effective WSN method makes use of existing resources to prolong the network lifespan or avert faults. Furthermore, these preemptive tactics are used to prevent any future failures that happen due to potential faults. Thus, all the associative methods consist of two primary techniques to overcome FT issues during base operations: maintaining network connectivity and multi-path routing. Here, the first technique is used to prolong the life of a WSN through an improved connectivity level. The bridge safeguarding method is a perfect illustration of a connection maintenance technique that extends the lifespan of WSNs that includes sufficient bridged units. In addition, the use of numerous routes inside the network increases data transmission reliability and provides a backup in the event of a network failure. Table 1 offers notations, terms, and abbreviations for the various variables used throughout the research.

Table 1. Notations and its Definition.

Notations	Definitions
ξ	Overall energy consumption of the smart network
e_{sel}	Energy consumption for CH selection
e_{adv}	Energy consumption for advertising the selection
e_B	Energy consumption for the processing beacon signal
e_{SD}	Energy consumption to sense the data
$e^A_{T_x}$	Energy consumption to transmit aggregated data
$e^A_{T_P}$	Energy consumption for aggregating various service data
Ψ	Free space
Φ	Multi-path
T_x/R_x	Transmission/reception
φ	Size of control packet
η	Size of data packets
h	Hop count

Table 1. *Cont.*

Notations	Definitions
R_i	Ranking node
Z	Number of clusters
D	Distance
α	Reception ratio
υ	Data packets
RAD	Radius
T	Throughput
R	Regular smart service
P	Periodic smart service
E	Emergency smart service

1.1. Motivation

Smart devices may be categorized by their service providence and geographic locations, usually evaluated using a specific analytical system. The collection of detailed data is facilitated by sensor services for specific current initiatives that monitor every day-to-day activity of the populace in smart cities, such as bicycling, car parking, and so on. Many services use an IoT structure based on WSNs to assist noise and air emission control, vehicle mobility, monitoring, and surveillance systems.

Due to the obvious way a WSN is organized, routing protocols are split into flat and hierarchical structures. A flat routing structure makes each sensor node execute the same routing function and activities. As a result, all the deployed sensing nodes are configured to immediately transmit any detected information to the BS. A hierarchical routing design organizes the deployed sensing nodes into groups named 'clusters'. Nodes in a cluster are defined by their assigned functions and roles or responsibilities. The common hierarchical structure is divided into two layers: in the lower layer, member nodes perceive data from the external phenomena or deployed environment and eventually send the data to their corresponding CH, whereas in the upper layer, CH compresses and relays the received data to the BS [12].

When developing a smart network, scalability, resilience, and a reduction in network traffic are the primary concerns that should be addressed. In many networking systems, the individual administration of both clustering and routing leads to the prevention of optimal energy utilization and enhancement of network lifespan; thus, this major issue prompted us to develop a distinct clustering process and routing strategy for static regions in smart cities. Moreover, additional FT capabilities are also taken into consideration, especially during data transmission. This study addresses both the categorization of deployed nodes and data routing as a single issue. Static clusters in smart cities are created based on the node's position and communication range. Once the clusters and the controller node have been identified, a routing method is suggested, including FT capability.

1.2. Contribution

1. We complete work focused on the CH-based hot-spot issues that arise in WSNs with optimal clustering [13] and energy-efficient routing. This approach uses sensing node locations and implements a simpler CH determination procedure that elects a potential CH concerning the service applicability in a smart environment, connectivity, and energy capacity.
2. Additionally, we provide a routing method that allows the alternative path to be found for any CH in the event of a failure.
3. The suggested approach is for substantial IoT-enabled network systems that apply to be installed in smart cities to prolong the lifespan of the entire network.

In the rest of the research, readers will find the following details. Section 2 summarizes the recent relevant research work on clustering and routing strategies. Section 3 presents the research statement, including information about proposed clustering and routing strategies for smart cities. Section 4 discusses the specifics of the computational strategy model and examines the research outcome with brief discussions compared to existing models. Finally, Section 5 summarizes the main points of the research.

2. Related Work

When nodes lose power, WSN partitions and their network cease to communicate, which is a common concern and is defined as a hot-spot scenario where the WSN becomes disconnected due to the node's energy depletion [14]. To resolve this kind of issue, experts employ two distinct approaches. One discussion concerns only node segmentation and selection of the controller node in a single-hop network. The residual energy of each node determines the controlling capabilities of that cluster. These techniques use the unrealistic assumption that all the deployed sensor nodes and the sink have predetermined transmission spacing [15]. In the current research, clustering processes and routing strategies are also considered distinct difficulties and lead to problems at the hot spot due to uneven resource distributions between WSN nodes [16]. According to the authors, the clustering process and routing strategies must be addressed together and not as distinct concerns [17].

In a comparative study, the research work from [18] investigated the strengths and weaknesses of several clustering algorithms. The study summarized a few key topics in the cluster-building process, including the structure, kinds, and benefits of clustering. In addition, it extensively addressed some Low-Energy Adaptive Clustering Hierarchy (LEACH)-oriented protocols with concern for reactive and proactive techniques in WSNs. In LEACH, every node seems to have a fair probability of becoming a group lead (cluster head), culminating in a dissipation of energy that is more evenly distributed. The core section of the study, advantages, key features, and applications of these techniques were elaborately described and compared to other prominent protocols.

The authors in [3] reviewed WSN clustering methods and categorized them, relying upon specific clustering processes and their characteristics and cluster head selection parameters. They examined the main design problems and discussed the performance of clustering protocols centered on categorizing identifiable clustering techniques, clustering methods dependent on neighborhood data, clustering algorithms with biological inspiration, and stochastic clustering strategies. The authors in [19] examined clustering methods, particularly the cluster head selection techniques of adaptive, deterministic, and mixed metric approaches. A cost comparison was made to find out how the selection of CH influenced the creation of clusters, the spread of CHs across the network, and the formation of clusters. In addition, a more extensible, resourceful, and robust clustering method for data collection in the network was presented.

Aa significant amount of research concentrates on cluster formation alone to improve the energy consumption of nodes, including low energy adaptive hierarchical clustering (LEACH) and balanced energy-efficient network-integrated super heterogeneous (BEENISH) [20]. It evaluates the remaining energy of nodes solely on selecting CHs. Researchers in [20] discuss their findings concerning the [21] distributed energy-efficient clustering algorithm (DEEC), the developed DEEC (DDEEC) [22], and the enhanced DDEEC (EDDEEC) algorithms [23]. The findings show the optimal data transmission rate in the BEENISH [20] algorithm with the maximum number of nodes at each round. However, this technique does not work if nodes are positioned randomly or change their groupings often.

This work also identified three benefits of the clustering and aggregation technique for WSNs: improved scalability, low maintenance costs, and reduced overhead. After classifying WSN segmentation patterns based on the eight characteristics of clustering, the researchers investigated and evaluated a total of six prominent clustering techniques for WSN, including power-efficient gathering in sensor information systeM (PEGASIS), LEACH, energy-efficient unequal clustering (EEUC), Hybrid Energy-Efficient Distributed clustering (HEED), and others, with many other relevant metrics [24].

Authors in [25] discussed energy infrastructure and its efficiency in WSNs and evaluated routing methods from communication distribution in their study of clustering techniques. The paper proposes a basic categorization of clustering and routing techniques.

There are two types of clustering classes, namely, on-demand clustering routing and pre-established clustering routing. Further, the nine clustering procedures that fall under the two categories are included in this article briefly. Furthermore, many new study directions are included in the assessment.

To address energy efficiency and member rotation, CH is chosen based on the periodic rotation of CH among cluster members and remaining energy. However, the nodes' premature die-out is primarily due to their proximity to the BS. One of the significant causes for this is their inability to choose a CH [26]. The topic of this concern is resolved through LEACH-extended message passing (LEACHXMP) [27], which employs a clustering-based approach and assigns essential parameters for the selection process of CH. The base factors are the node's density, distance, and current residual energy.

Orphan-LEACH (O-LEACH) is a variation of the LEACH methodology [28]. The O-LEACH technique is predicated on the LEACH procedure that is randomly selecting the cluster heads. Therefore, a few member nodes were left orphaned since they were disconnected from their corresponding CH. The idea of intermediary edge devices (gateway nodes) was proposed, which gather data from all member nodes and provide them to their respective CHs. Gateway nodes are chosen on a first-reach, first-service principle. A gateway node may be chosen regardless of its remaining battery life. O-LEACH offers more excellent coverage, connectivity, and energy efficiency compared to conventional LEACH. However, a significant drawback is the difficulty in gathering knowledge about orphan nodes. Additional challenges include delayed data transmission and excessive control overhead. Only a few researchers consider routing and clustering [15] together as a specific subjective and single issue in WSNs. The JCR algorithm shows that one way to create network architecture for data collecting in a massive WSN is via a gradient routing and back-off clock [17].

The report in [29] described the capabilities of a few clustering algorithms, and they also gave a short analysis of their pros and cons. Only seven of the most used clustering techniques in WSNs were chosen by the researchers for the study. They are S-LEACH, EECS, TL-LEACH, APTEEN, TEEN, and others. Moreover, the study contrasted various clustering algorithms in terms of network lifespan and energy use.

The research of [30] presented a study on clustering methods for WSNs in a detailed manner. The study included nine standard clustering algorithms for WSNs, such as LEACH, EECS, TL-LEACH, EEUC, HEED, and so on. The major problems for these protocols during clustering were covered in the investigation. Additionally, the scientists examined various clustering methods based on various criteria, including the amount of remaining energy, cluster density, the uniform distribution of cluster head, hop-count, the time taken, and the techniques by which the clusters were formed.

In [31], the routing protocols for WSNs and their various cluster architectures were discussed. Their categorization consisted of cluster head selection criteria with centralization impact (within the cluster), the number of hops among communicative nodes, and communication (intra-cluster level). The study also emphasized the difficulties in the segmentation of nodes in WSNs and elaborately presented several clustering methods.

The research in [32] briefly discusses the difficulties of network lifespan extension by using clustering and routing methods compared to one another. In reviewing several routing techniques, the review looked at many challenging aspects and simplified the various routing methods. Furthermore, the assessment included information on several traditional WSN routing algorithms that use clustering and a comprehensive evaluation.

Every previous investigation into hot-spot issues has approached the matter differently. Although various techniques, such as O-LEACH [28] and JCR [17], have offered multi-hop forwarding options, the network still produces inefficient outcomes, as the intermediary units among CHs are added dynamically. Because of this, they addressed routing and clustering as a single integrated strategy that is always essential. According to [15], and optimization strategy dependent on LEACH-C is proposed whereby the CHs are chosen as per geometrical distances and residual energy among various deployed nodes in the network.

The study in [33,34] used the residual neural network architecture to dynamically collect information about spatial dependence and temporal features to anticipate crowds' ultimate congestion. Additional efforts use vehicular networks to estimate where vehicles will be in the future. In [35], the authors used routing computation and the multi-attribute automotive independent entity routing decision-making procedures to improve packet arrival rate, decrease end-to-end time, and address the uncertainty associated with multiple characteristics. Compared to its contemporaries, the proposed work increases the proportion of packets delivered and decreases the average end-to-end time in metropolitan areas.

The detailed Inter-clustering slot configuration as shown in Table 2. However, the following aspects of our work are unique and are explained in the upcoming sections.

Table 2. Inter-clustering slot configuration.

Cluster Nodes	FT Nodes	Alloted Slot	@slot_0	1-Hop Route
CH1, CH4, CH6	R1	1	CH1, . . . , CHn	CH1→(CH5CH7) CH4→(CH3) CH5→(CH6)
CH2	R1	3	CH1, . . . , CHn	R5→(R4R6) R7→(R2R8)
		. . .		
CH2	R1	n	CH1, . . . , CHn	. . .

3. Research Statement

While selecting CHs, prior research has overlooked routing strategies, as discussed in Section 2. As a result, the selection of CHs, routing configuration, and communication failures becomes ineffective. The overall cluster count decreases after extending the deployed node transmit power [36]. The standard benchmark protocols [15] also do not make use of any routing strategy. As a result, the multi-path routing method is implemented in the proposed article, where the present CH looks for another nearby CH with half of its transmission distance. The newly chosen intermediate CH node serves as a data forwarder to the sink or BS. Figure 3 shows below as Contributions of previous surveys on clustering and routing protocols in WSNs.

Reference	Contribution
Deosarkar, B.P, 2008	▪ The basics of clustering, including how it works and examples of the process, are covered. ▪ Evaluation of LEACH-centric algorithm. ▪ Review of reactive and proactive protocols and their implementations in WSNs.
Vinoth Kumar, V, 2020	▪ Classification is delineated, which is dependent on the creation of clusters and the adoption of cluster head selection parameters. ▪ The subject of the critical design problems in cluster formation. ▪ Examination of WSN clusters operational constraints.
Kang, J, 2018	▪ A categorization of WSN clustering methods is presented. ▪ Investigation of standard WSN clustering methods under both on-demand and pre-established patterns. ▪ Suggestions for potential research are summarized.
Zhao, L, 2022	▪ The categorization of items focused on three characteristics, each of which may depend on the others. ▪ In addition, WSN clustering discussions are included. ▪ A study of the standard routing methods used in clustering.
Techno-Pods, 2020	▪ Discussions on well-known WSN routing methods. ▪ An examination of well-known cluster-based routing methods concerning energy savings and network longevity.
Zhao, L, 2021	▪ Research on clustering is discussed, and some of the more complex issues are outlined. ▪ Illustration of categorization of routing methods used in wireless sensor networks. ▪ An investigation of traditional routing methods. ▪ Comparison of traditional WSN routing and clustering methods.
Xu, L, 2017	▪ Research on the routing techniques used in WSNs that are popular. ▪ An evaluation of standard WSN routing methods for clustering.

Figure 3. Contributions of previous surveys on clustering and routing protocols in WSNs [17,19,27,35–37].

The literature survey in the previous section shows that only a few studies have addressed clustering, optimal selection of CH, and routing in tandem [16,37]. Thus, this article aims to provide a mechanism that creates a network topology with long-term reliability and interconnectedness.

4. Clustering and Routing Strategy

4.1. Modeling of a Smart City Environment

It is too expensive to design and test newly developed protocols on a real WSN with the desired volume of nodes (probably high); therefore, the bulk of protocol improvement research [29,37–39] used a modeling and simulation approach; sometimes using an emulator for demonstration purposes. Therefore, the proposed WSN protocols were tested and analyzed using simulation-based testing tools, namely Ptolemy-II Visual sense for modeling and Mannasim framework for simulation.

This study, which is part of the CRS design and operational analysis, uses a desired network and power model to regulate the behavior of the WSN for smart environs. Therefore, the preferred simulation tools are made to employ most of the network characteristics and power dissipation estimates from the standard LEACH routing protocol.

4.2. Network Set-Up

To study the scenario in this research, we are assuming a deployed WSN that comprises all of the sensor nodes of various services, $X = S_i^1|S_i^2|\ldots S_n^N$ randomly dispersed in a coverage region (presumed smart area). Essential data sinks or BS are also considered in the sensing area. After the fixture of all sensing nodes and the required BS, they are presumed to be immobile. Furthermore, we categorize the heterogeneity of the sensor nodes based on their services in a smart environment. They are regular (R), periodic (P), and emergency (E) services, which means they do not have equivalent abilities, such as reception/transmission range, processing, energy capability, and so on. By optimizing energy utilization, sensor nodes may employ power management to regulate the data transmission power level that depends entirely on the receiver's distance [40,41]. Wireless connections are preferred for all communications. Communication is established among various deployed nodes only if the interested nodes are within the reachable, communicative range of others. In this model, because the transmitting power is predefined, each node can determine the distance of its neighbors based on the Minkowski metrics.

4.3. Energy Model Configurations

The energy scheme employed in this research is similar to those planned in the standard LEACH approach. The energy expenses experienced by the analog-digital electronics (ADE) units, power unit, processing unit, and memory unit of sensory nodes are added together to determine the overall cost of sending n-bit data along with a distance, D. The cost of using multiple paths (ϕ) or free space (Ψ) depends on whether the distance among two communicative nodes is more or less than a distance specified threshold. In addition to those assumptions, a 1 Mb/s data transmission speed with 914 MHz core frequency is considered for the transmitter of regular services in smart city infrastructure. The costs of data reception per n-bit data are estimated as the digital and analog component energy expenses. The energy used by individual network components can be defined as follows.

CHs energy consumption encompasses the energy required to create the cluster and additional tasks allocated to such a CH position. Primary roles of selected CH include selection announcements, aggregation of sensed data, determination of an alternate route in case of route failure, and relaying of the essential data from mn to BS and vice versa.

$$\xi = \sum_{R=1}^{n} [e_{sel} + e_{adv} + e_B + e_{SD} + e^A_{(T_x)} + e^A_P] \tag{1}$$

$$e_{sel} = \left[(\frac{\eta}{\mathbb{T}}) \times (e_{(T_x|R_x)_{elc}} + d^2_{BS}.\psi) + ((\frac{h(N-1)}{\mathbb{T}}) \times \alpha) \right] \tag{2}$$

$$e_{adv} = e_{(T_x|R_x)_{elc}} \times \eta \tag{3}$$

$$e_B = e_{(T_x|R_x)_{elc}} \times \eta \times N_{mn} \tag{4}$$

$$e_{SD} = [f \times N_{mn} \times \Psi \times e_{(T_x|R_x)_{elc}}] \tag{5}$$

$$e^A_{T_x} = \left[(\frac{\varphi}{\mathbb{T}}) \times (e_{(T_x|R_x)_{elc}} + d^2_{BS}.\psi) + ((\frac{h(N-1)}{\mathbb{T}}) \times \alpha) \right] \tag{6}$$

Similarly, the data perceiving from external environs, transmission, and reception activities are concerned with each mn's roles. Thus, each mn's total energy depends on the energy spent for set-up, receiving, and transmitting required data. Algorithm 1 shows the Distribution and Computations of clustering.

Algorithm 1 CRS algorithm for Clustering selection and Routing.

Input: M_d, mn_i, X
Output: Ranking, CH selection, and Intra-Cluster Routing
$\forall mn_i$
  BS_i sends B_{sig};
END $\forall$
$\forall BS_i$
Upon receiving $Bsig$ from BSi;
  mn_i sends $Back_{sig}$;
END $\forall$
$\forall mn_i$
Upon receiving $Back_{sig}$;
BS_i computes R_i;
$R_i = \sum_{(i=1)}^{n} (M_d + X)$,
$where M_d < mean mn_{i_(T_x)} [Rad] \{R_1, R_2, R_3, \ldots R_n\} \epsilon \mathbb{Z}_i$
END $\forall$
$\forall \mathbb{F}^{th} frame$
$While(condition : (T_x(R_i || CH_i))$
  Select CASE (current slot);
   $CASE\_1 : Slot\_0$
    $R_i \&\& CH_i gains knowledge on \mathbb{Z}_i$;
   BREAK;
   $CASE\_2 : (T_x(R_i))$
    $sends \varphi to CH_i$;
    $IF \varphi exceeds ST$
     $Ri forwards \varphi to 1 - \mathfrak{H} || 2 - \mathfrak{H} Rn$;
   $ENDIF$
  BREAK;
  $CASE\_3 : (T_x(CH_i))$
   $broadcast\ \varphi\ to\ Ri$;
  BREAK;
 END CASE;
 $Current\_slot \leftarrow Next\_slot$;
$END \mathbb{F}^{th\smile} frame$

5. CRS Distribution and Computations

The unique CRS protocol uses the dispersed responsibilities of both CH and BS in the smart city environment. The BS allocates balanced transmission slots and determines each cluster's services (R, P, or E). In contrast, CHs assign balanced transmission slots to each of its mn. Because the services are dynamic in smart cities, the transmission slots are customizable. For this, we have adapted the DD-TDMA scheduler, which highly suits the desired scenario. The upcoming discussions delineate further information about this scheduling technique.

The configuration stage in CRS involves the formation of clustering and selection of CHs and mn of the corresponding clusters. Each mn in a cluster function is a potential contender to be chosen as the CH. During the transmission stage, sensed data are collected from all the mn within their respective slot, and then the CH processes the aggregated data to send them to the BS through single or multi-hop transmission.

CRS's objective is to form clustering as per the service, determine optimal CH among potential nodes with heterogeneity factors, and ultimately route the data across the network with perfect load balancing and energy efficiency through DD-TDMA. In addition to these features, alternative routes are identified dynamically as an FT strategy for managing possible communication failures. A vital element of this approach is a streamlined categorization of nodes, selection procedures of CH, and inter- and intra-cluster routing that depends on each active node's service weight-age and residual energy. To route packets across clusters in the event of communication failure due to potential faults, each CH re-routes the packets to its neighbors based on the rank determined by BS and shares the same during the allocation of transmission slots. As noted previously, service-based clustering is determined by three factors, and the smart city administrator redefines those factors. It is crucial to comprehend a few definitions to understand the integrated functionalities of the clustering and routing system.

1. Regular Services: Public service routinely provided on a need or condition basis. The least weight-age has been assigned to this kind of service and is proactive and reactive.
2. Periodic Services: The provision of service at pre-arranged intervals with or without users' requests and the performance of work that is scheduled ahead of time. Moderate weight-age has been assigned to this type of service and is of the reactive type.
3. Emergency Services: Critical services that need immediate action under high priority to cope with crises when they arise. High weight-age is preferred for this type of service and is of a bold type.

Service-oriented clustering in CRSs intends to save time for cluster formation, neighbor node discovery, and CH selection. The knowledge provided here is significant during the selection of the CH and throughout the development of the complex network architecture. The values of the weight-age of each service are fixed in terms of percentage (50: 75: 100 for R: P: E, respectively), which is constant throughout the network operations. After the clustering process as per the weight-age, the heterogeneity communication among different clusters is handled through BS. Here, the communication range of BS is assumed to be greater than the range of CH. Algorithm 1 depicts the clustering process.

$$BS^{i}_{T_x} > CH^{i}_{T_x} > mn^{i}_{T_x} \tag{7}$$

Upon completion of the clustering process, each node sends a beacon signal to its fixed area BS, wherein, as a response to the beacon signal, BS assigns ranking order to each node in the respective cluster. The ranking strategy is based on the "first reach, first assign" basis, which states that the first reached beacon at BS is assigned as *rank*_1 node, whereas the second arrived as *rank*_2. This ranking process halts when all the nodes in the cluster are assigned with ranking order. Moreover, upon completing the ranking process, the *rank*_1 node advertises itself as the CH to all other nodes in the cluster through broadcasting. Now, the BS allows transmission slots based on the DD-TDMA scheduling scheme. The allotment completely depends on Minkowski distance, ranking, and type of services. It is a specialized version of both Manhattan and Euclidean distances, and its formulation is depicted in Equation (8). The nodes from different coverage ranges are identified through Minkowski distance. Two or more nodes are allocated with the same slots if their transmission radius is less than the Minkowski distance. Figures 4 shows the Service-oriented clustering in a smart city and Figures 5 shows Inter-clustering slot configuration.

$$R_{i_{T_x}}[Rad] < \sum_{k=1}^{n} \left[|R_i^S - R_i^D|^{R_i^S} \right]^{\frac{1}{R_i^S}} \tag{8}$$

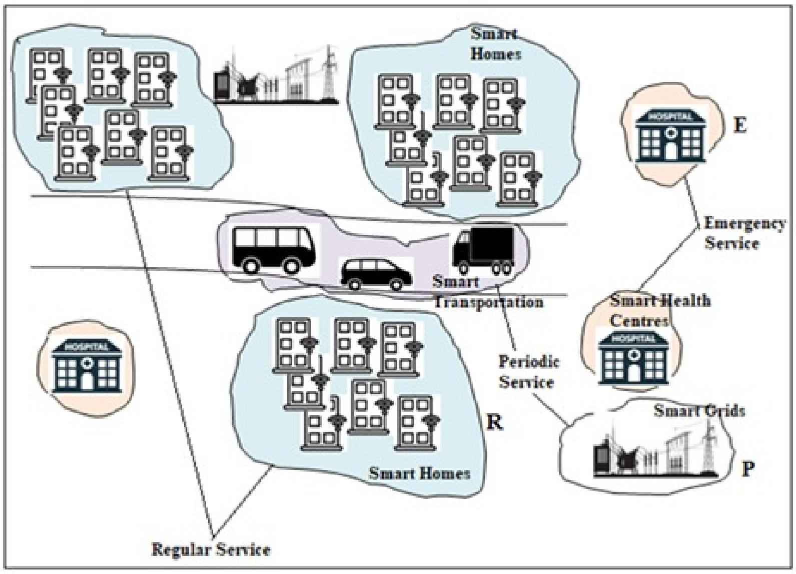

Figure 4. Service-oriented clustering in a smart city.

Ranked nodes	Alloted Slot	@Slot_0	1-hop route	2-hop route
R1,R4,R6	1	R1,...Rn	R1→(R2 | |R5 | |R8) R4→(R3 | |R5) R6→(R7 | |R3)	R1→(R7 | |R9) R4→(R2) R6→(R8)
R5,R7	3	R1,..,Rn	R5→(R4 | R6) R7→(R2 | R8)	R4→(R9) R6→(R3)
....				
Rn	N	R1,..,Rn	....	....

Figure 5. Inter-clustering slot configuration.

DD-TDMA [42] is an enhanced TDMA scheduler that relies on the local neighborhood data to arrange slots to prevent collisions. Here, if multiple nodes are in differing coverage regions, they may also broadcast in the same slot. Thus, it optimizes the load balance through the network. The entire communication is categorized into two levels: homogeneous and heterogeneous. All the homogeneous communications are done at the intra-cluster level, whereas the heterogeneous communications are handled through the inter-cluster level where various types of nodes communicate. The maximum of single-hop communication is fixed for intra-cluster transmission until the data packet does not exceed the predefined slot period.

The first slot of each transmission frame is open to all the deployed nodes to gain network knowledge, including BS and the nearest deployed node (ID, energy status, positional coordinates, and service type). Subsequently, different sets of ranking nodes are allocated to different slots. Finally, the intermediate slots between ranking nodes' slots are assigned to a CH to manage load distribution and ensure the reliability of any broadcast transmissions.

The heterogeneous communication is carried among different service-based CHs. Similar to the communication procedures of the intra-cluster level, the $slot\_0$ is made open to all the CHs to gain knowledge on the deployed network (such as nearest CH, BS position, and energy status of nearby CHs). Different sets of CHs are allocated to different slots. The intermediate slots between allotted slots of CHs are assigned to the BS to manage load distribution and ensure the reliability of any broadcast transmissions.

The reactive and proactive routing procedures begin at intra-level and inter-level clustering once the BS sends updated routing information throughout the smart city environment. Whenever the particular nodes' transmission exceeds the predefined time slot, it can route the excess data packets through known 1-hop or 2- hop communicative nodes. Similarly, with the CH, the aggregated sensor data are routed during their allotted time slots, and if the transmission process exceeds the time limit, the excess packets are routed through the nearby CH identified at *slot*_0 session. The three intra-cluster routing strategies cases are depicted in Figures 6 to 11.

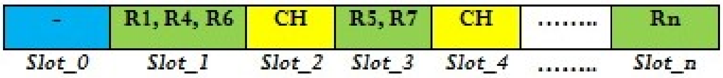

Figure 6. Transmission frame of intra-cluster slot allocations.

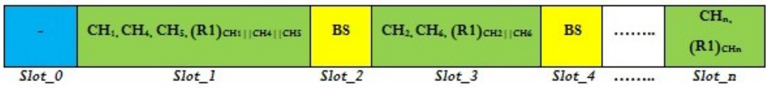

Figure 7. Transmission frame of inter-cluster slot allocations.

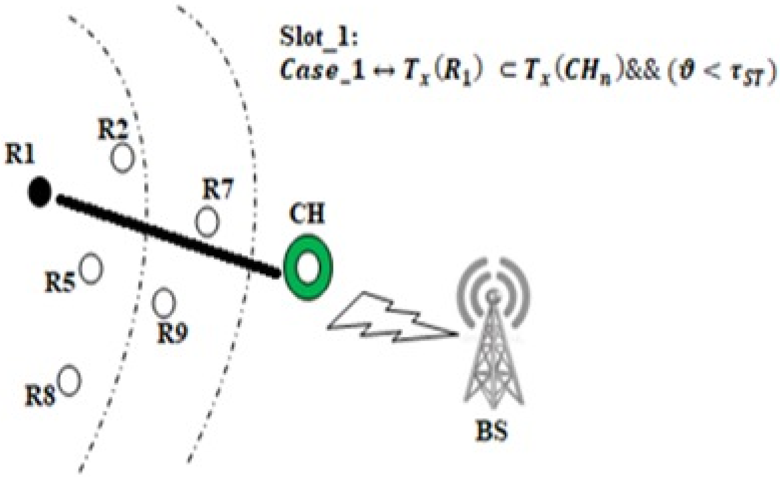

Figure 8. $Case_1$ of intra-cluster routing.

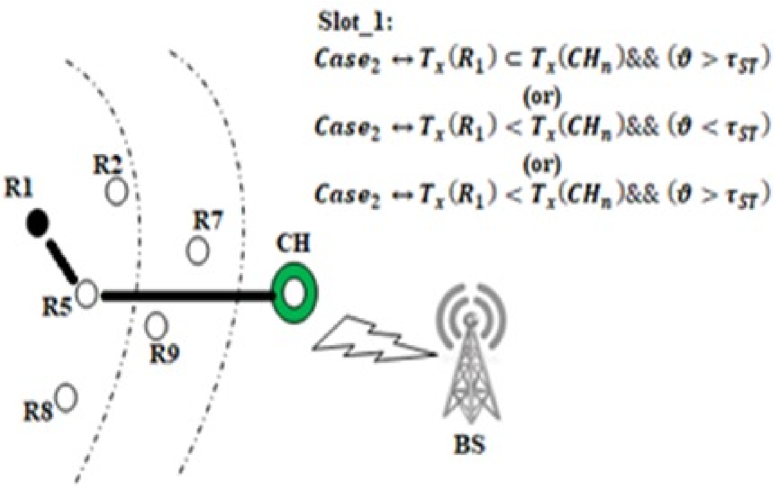

Figure 9. $Case_2$ of intra-cluster routing.

All the CHn transmission slots are allocated with its R1 node to route the data packets whenever the particular CH fails during the transmission due to potential faults. Thus, this procedure ensures complete and reliable data transmission. The selection of intermediate nodes to route the excess data packets is processed through Minkowski computations and residual energy.

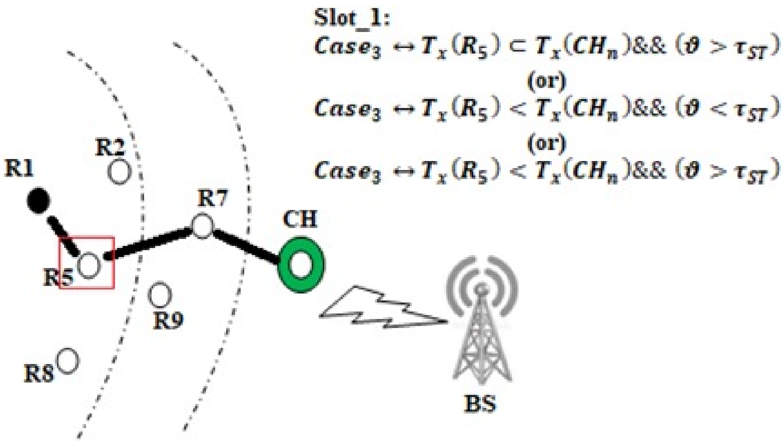

Figure 10. $Case_3$ of intra-cluster routing.

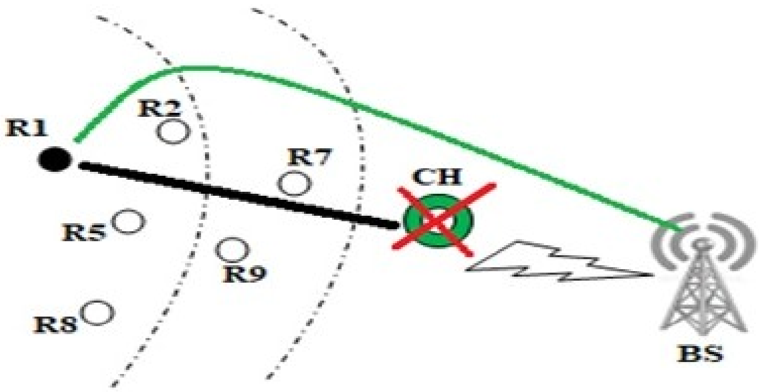

Figure 11. FT routing during inter-cluster transmission.

6. Outcome Analysis

According to the research, the proposed CRS protocol was evaluated compared to prevailing algorithms, including recent LEACH-C [43] and standard LEACH [15]. As a result, the CRS protocol is more effective than any of those compared protocols, particularly when considering network lifespan, and it is ideal for IoT-based smart infrastructures. Initially, the experiment is examined for two scenarios that vary in the count of deployed nodes. Scenario-1 comprises 2:6:150 propositions of nodes (i.e., 2 BS, 6 clustering regions, and 150 sensing nodes). Similarly, scenario-2 comprises 4:8:200.

We used inter-cluster (between the clusters) and intra-cluster (within the cluster) routing strategies and loaded balancing conceptual paradigms to examine the CRS algorithm's energy efficiency and other QoS metrics. All the generalized processes, such as slot allocation per frame, CH selection, cluster management, and data transmission for all three services, are conducted at experimental rounds.

In the standard LEACH procedure [15], cluster segmentation and CH selection are common evidence for maximum homogeneous network energy source utilization. In contrast, the proposed CRS accommodates all three essential services common in smart cities and renders an efficient transmission process across the heterogeneous network. One of the prominent procedures of CRS is clustering that is processed based on service type. The choice of the CH selection for each cluster is based on the weight-age factors such as service priority, ranking strategy, and residual energy. Next, every member node of each cluster communicates according to the DD-TDMA scheduling. CRS primarily uses energy sources to transmit sensed data rather than cluster formation, control overheads, etc.

There are significant differences between CRS and S-LEACH, especially at clustering stages. The S-LEACH employs a dynamic cluster that is refreshed after each round, with CH selection happening between rounds. The cluster creation mechanism causes reliable connectivity and essential information exchange that use enormous energy. In contrast, CRS is based on nodes' service type and transmission period at inter and intra-level clusters using optimal energy sources. When they are formed, clustered regions stay unchanged throughout the network's operations, but enhancements are allowed only for newly updated nodes. As you can see in Figures 12 and 13, the proposed CRS saves a significant proportion of node energy. Furthermore, the CH selection method relies on weight-age factors accumulated over time, enabling each node a potential CH.

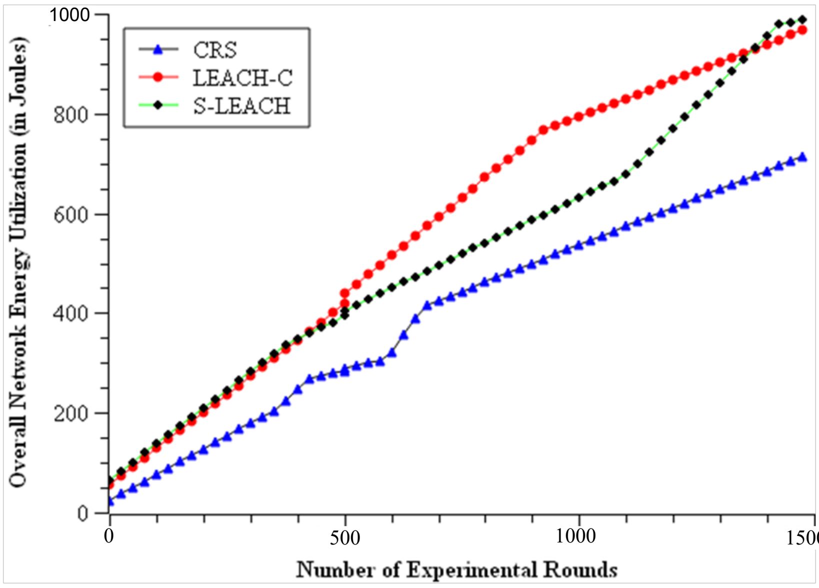

Figure 12. Overall energy utilization vs. experimental rounds (intra-cluster level).

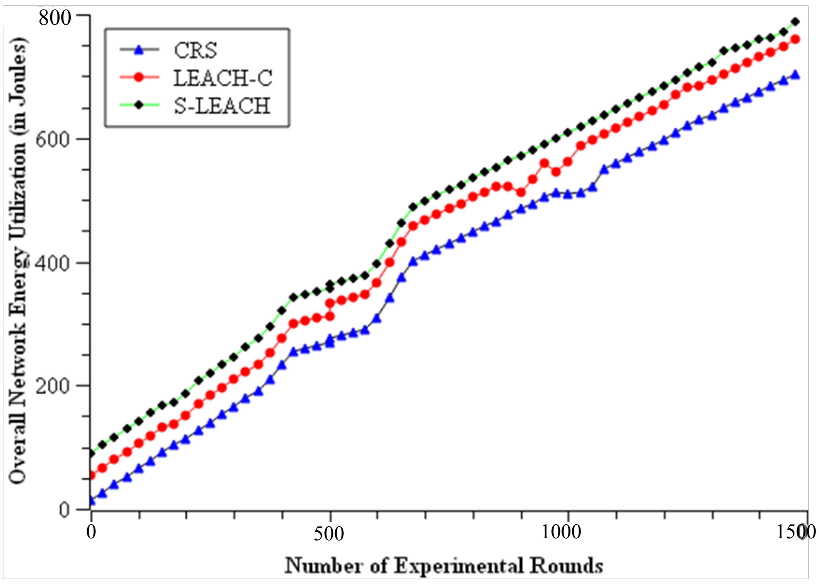

Figure 13. Overall energy utilization vs. experimental rounds (inter-cluster level).

CRS protocols' efficiency in energy consumption is much superior to that of S-LEACH and LEACH-C protocols. CRS and LEACH-C pose a similar set of stages, including cluster formation, selection of CH, and data routing. CRS consumes much less energy than LEACH-C and S-LEACH during the cluster formation and CH selection stages. In Figure 14, the average energy used for the cluster formation process is shown for scenarios 1 and 2 with transmission ranges of 50 and 100 meters, respectively. Similarly, Figure 15 depicts the average energy used for the CH selection process. The second evaluation metric is based on the total count of packets generated by various sensing nodes and delivered to the BS via corresponding CH. CRS seems to have a greater percentage of packet reachability ratio to the BS than either LEACH-C or S-LEACH, which have similar network lifespans. The CRS manages its communication hops to minimize packet losses due to collision and increases the packet reachability ratio to the CH/BS.

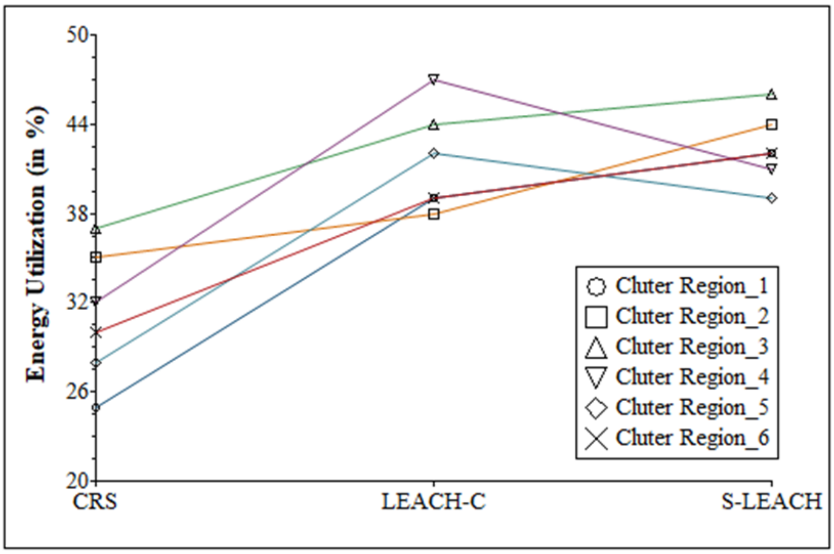

Figure 14. Average energy utilization for cluster formation.

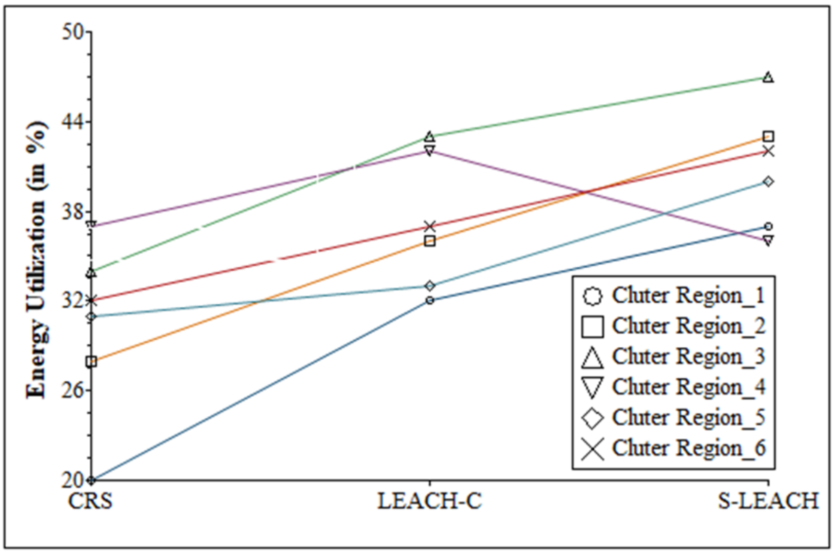

Figure 15. Average energy utilization for CH selectioon.

The experiments were conducted by varying the network size based on two scenarios, where scenario-1 constitutes 2:6:150 [BS: CH: mn] propositions of nodes and scenario-2 includes 4:8:200 [BS: CH: mn]. Furthermore, Figures 16 and 17 demonstrate that, throughout the case of CRS, the sensing node survival rate is much higher than that of S-LEACH and LEACH-C. Thus, our suggested approach is successful for massive network deployments.

Figure 18 illustrates the throughput in homogeneous routing at the intra-cluster level and heterogeneous routing at the inter-cluster level. When compared to S-LEACH and LEACH-C, CRS is also shown to provide better throughput. This is because each cluster is segregated based on service type and process specific to similar data types. Moreover, unless the transmission data packets of the nodes exceed the time slot, it is presumed to transmit its sensor data to the corresponding CH directly. Thus, the overall delivery of packets with minimal loss is an application through the proposed protocol. Residual energy and connection level are primary factors in attaining an optimum throughout. The CH is randomly chosen among active nodes in S-LEACH with no parameter/criteria. Another significant issue is that all nodes are assumed to prefer only zero-hop communication (direct communication) in LEACH. Thus, it is not realistic and suitable for large-scale infrastructure.

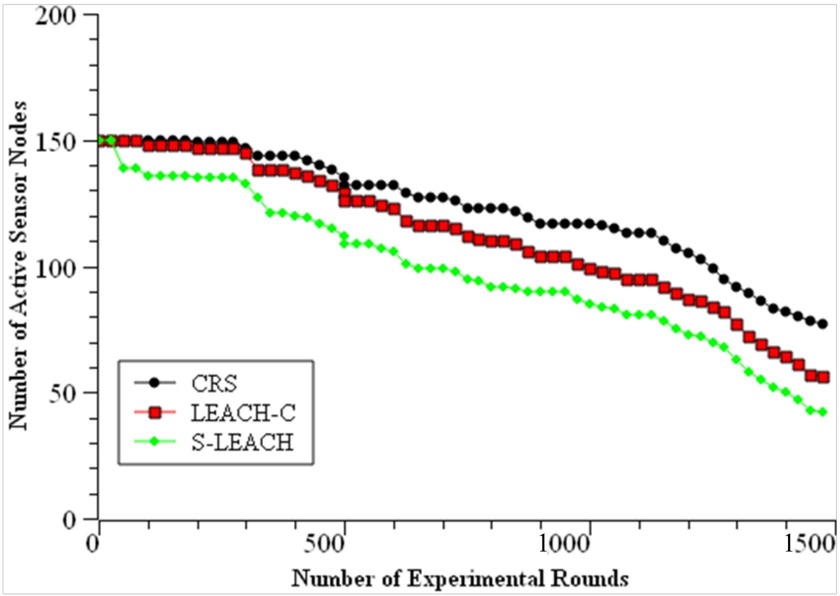

Figure 16. Active sensor nodes based on service types vs. experimental rounds (scenario-1).

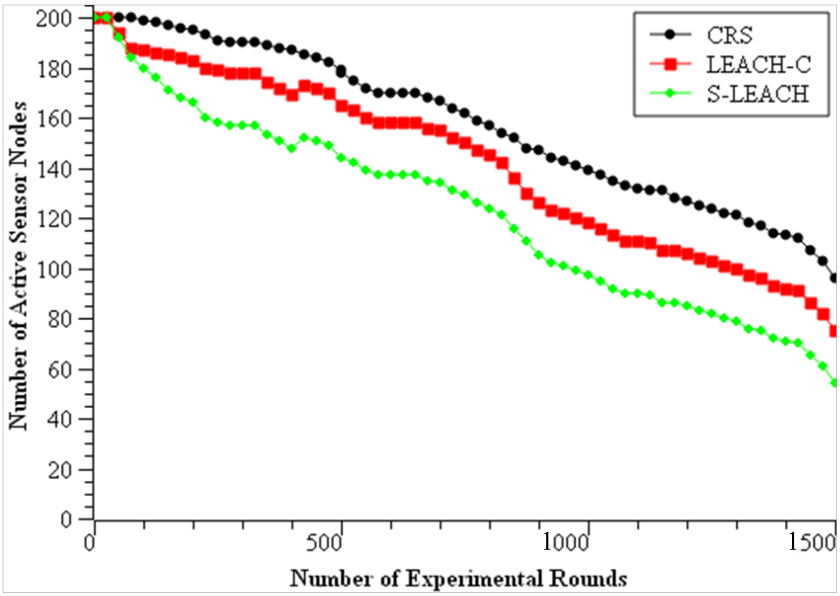

Figure 17. Active sensor nodes based on service types vs. experimental rounds (scenario-2).

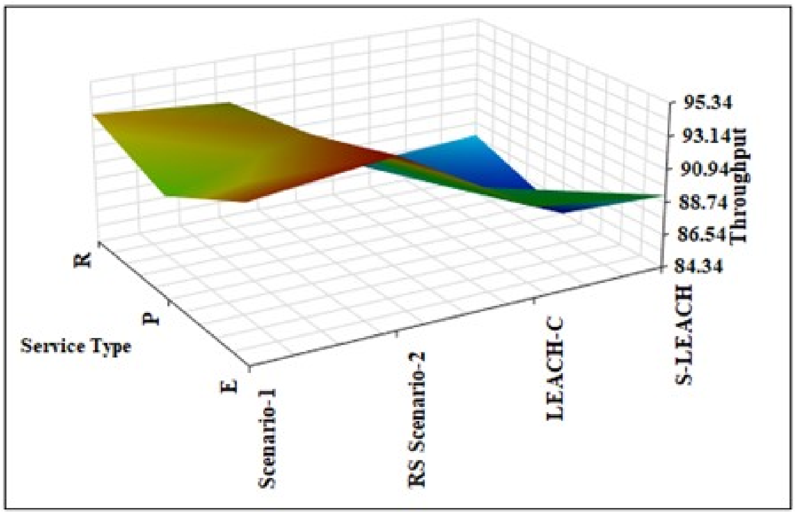

Figure 18. Throughput vs. experimental rounds.

Figure 19 compares the number of stable connections among active nodes throughout the network operations. The results exhibit the stable connectivity for the proposed CRS, almost 100% in every round. Whereas, for LEACH-C and S-LEACH, it is observed as 96% and 88%, respectively. Because the transmission limit for each cluster is constant, it ensures the data reachability of every node falls under the reception coverage of other nodes. LEACH-C aims to avoid isolated nodes, certain nodes that do not interconnect well because of gateway nodes, which may shorten the network's lifespan.

Due to its dynamic cluster formation strategies, it guarantees a high level of connection. CRS service-oriented clustering and CH selection based on ranking strategy enable routing topology creation more efficiently. For LEACH-C, the size of the area varies, leading to the increased count of hop utilization even with higher transmission capacity. These data show that the transmission route developed by CRS is better than that of S-LEACH and LEACH-C. Further, the gap might be more significant in situations for which the transmission capabilities are expanded.

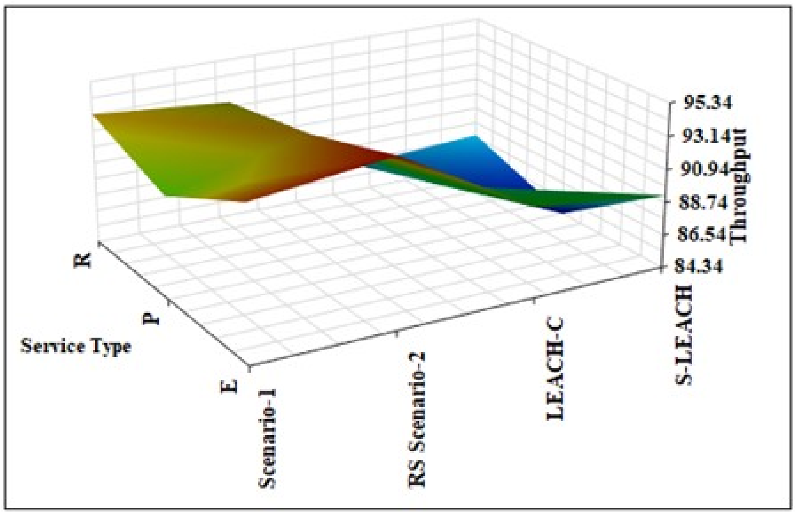

Figure 19. Average number of connected nodes (in 3-service types).

Another way to quantify how well the mn and CHs are distributed concerns the mean hop count between CH and BS, which is determined as the ratio of total hop-count between the CH and BS to the total count of CHs in the deployed region. For all three protocols, the mean hop-count from mn to the sink is compared.

Figure 20 shows that the CRS protocol's mean hop count decreased by 1%, whereas LEACH-C and S-LEACH increased by 2% throughout the experimental rounds. This recorded observation is due to the adaptation of CRS protocol to the DD-TDMA's slot adjustments based on the generation of data packets and thus forms an optimized clustering environment.

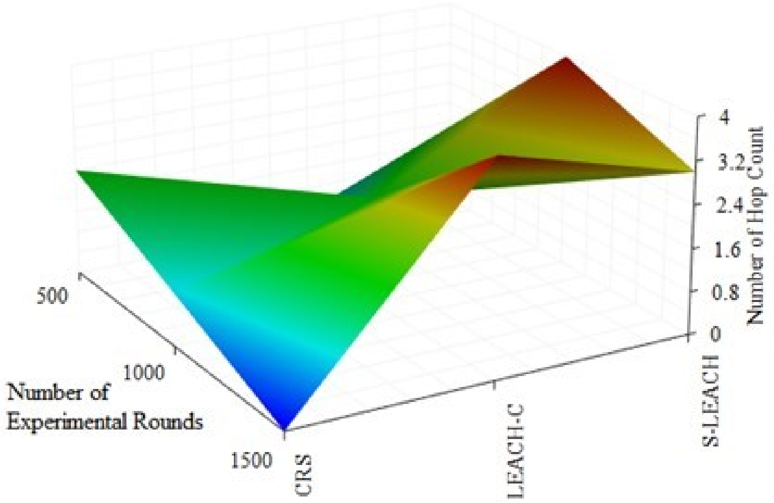

Figure 20. T: Number of hop counts vs. number of experimental rounds.

In addition to processing several comparative analyses, CRS, S-LEACH, LEACH-C also vary in the packet reachability ratio from specified clusters to the BS, using various energy levels of the nodes with varying experimental rounds. The packet reachability ratio of the CRS protocol is much higher than for the other two protocols. S-LEACH's energy efficiency does not improve because the energy expenditures in managing cluster nodes are more than the energy consumed during the data transmission period. A further cause for node energy loss is the extended transmission lengths that start from mn to CH and then to BS.

7. Conclusions

The CRS protocol addresses clustering and routing as interlinked issues. The performance of routing in the CRS protocol is compared with the S-LEACH and LEACH-C protocols. The assessment criteria include the number of stable connections among nodes throughout the network operations, energy consumption efficiency, and network lifespan. To ensure even communication loads on the network, DD-TDMA scheduling is used. The network lifetime was improved using the CRS method, which displayed almost 100% stable connection in every cycle/round. For LEACH-C and S-LEACH, these were observed as 96% and 88%, respectively.

Furthermore, the sensing node survival rate is greater for the smart infrastructure through CRS than for S-LEACH and LEACH-C. The experimental findings show that the suggested method will be effective in micro and complex network systems, especially in smart city infrastructures. Further, in the future, we plan to examine the same strategy with maximum heterogeneity services.

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Abbreviations

The following abbreviations are used in this manuscript:

BS	Base Station
CH	Cluster Head
CRS	Clustering and Routing Strategy
DD-TDMA	Deterministic Distributed Time Division Multiple Access
FT	Fault-Tolerant
IoT	Internet of Things
LEACH-C	Low-Energy Adaptive Clustering Hierarchy—Centralized
me	Member Node
MTTF	Meantime To Fail
NP	Non-Deterministic Polynomial
QoS	Quality of Service
RAD	Radius
S-LEACH	Standard Low-Energy Adaptive Clustering Hierarchy
UN	United Nations
WSN	Wireless Sensor Network

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