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A Reliable Communication and Load Balancing Scheme for Resource-Limited Networks

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ABSTRACT Sensor-cloud infrastructure provides a storage platform for the massive sensed data, that is flexible and re-configurable, for various application areas which are monitored through the resource-limited networks such as wireless sensor networks (WSNs), ad hoc networks, and Internet of things (IoT). Due to their overwhelming characteristics, these networks are used in different application areas to assist human beings in their daily-life activities. However, these networks have different challenging issues such as reliability in communication and processing, storage of the massive data, efficient utilization of on-board battery, maximum lifetime achievement, minimum possible average packet loss ratio, and reliable routing mechanisms. Although various communication and load balancing mechanisms have been proposed in the literature to resolve this issue, however, these schemes are either application specific or overlay complex. In this paper, a reliable communication and load balancing scheme for the resource-limited networks is presented to resolve these issues, particularly with available resources. To achieve these goals, the proposed scheme bounds every sensing device C_i to compute the transmission capabilities of its neighboring devices that is residual energy E_r, hop count H_c, round trip time (RTT_i), and processing cost. Initially, to guarantee reliable wireless communication, a source device prefers a neighboring device C_i with minimum H_c value over those having maximum H_c values. Moreover, this scheme bounds every device C_i to find four shortest & reliable paths and forward maximum packets on two of these paths preferably on the most reliable and optimal route. Therefore, unlike the traditional shortest path scheme, devices C_i reside on these paths do not deplete their on-board battery more rapidly than others. To further improve the reliability of the proposed scheme, the assigned weight-age factors are fine-tuned if one or two of the neighboring devices C_i consume 80% of their on-board battery, that is now maximum weight-age is assigned to the residual energy E_r and minimum to H_c value respectively. Simulation results show the exceptional performance of the proposed reliable communication and load balancing scheme against the field-proven schemes in terms of average packet delivery ratio, average throughput, end-to-end delay, and overall network lifetime.

INDEX TERMS Reliable communication, reliable load balancing, resource-limited networks, classifier, WSNs.

I. INTRODUCTION

Generally, Sensor-Cloud infrastructure was proposed to manage various devices, i.e., sensor nodes and actuators, which are deployed randomly to monitor a particular activity. The sensor-cloud infrastructure was formed through the integration of resource-limited networks with cloud computing mechanisms to enhance the operational capacities of these networks in various application areas [1]. Sensor-cloud resolves some common issues associated with

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the resource-limited networks that are storage and processing of the massive data. Sensor-cloud enables these networks to collect a massive amount of data by linking the gateway of the resource-limited networks with that of cloud computing. Networks gateway is used to collect data from various sensor nodes or devices deployed in fields which are then transmitted to the cloud computing gateway where this data is stored [2].

Resource-limited networks consist of sensor nodes, actuators, base stations, access points, and servers, etc., which are either deployed manually or randomly in close proximity of the underlying phenomenon [3]–[6]. Usually, these networks are used to prob the environments periodically and sensor nodes, i.e., $C_i \in WSNs$, share their collected data with server(s) or base station(s) using reliable wireless communication mechanism(s) either directly (single hop) or multi-hop [7]. In the former case, the communication is very simple and reliable as each sensor node or device C_i can communicate directly with its concerned server or base station module S_j in an operation resource-limited network. However, in later case, the communication is rather complex as each device C_i has to use valuable information such as load balancing mechanism or neighboring device's information to establish a reliable transmission link with the receiver module [8]. Additionally, lifetime is still a challenging and open research problem as many to one (m:1) communication infrastructure is adopted in the resource-limited networks where sensor nodes or devices C_i reside in the vicinity of the base station consume their power more rapidly than other nodes and result in energy hole [9], [10].

To resolve these issues, various routing and load balancing schemes have been present in literature. The shortest or least-cost path-based routing scheme is considered among the reliable communication infrastructures, which are used in scenarios or applications where timely delivery of the collected data has a higher priority than the overall network's lifetime such as in military or intruder detection [11]. These schemes bound every device C_i to transmit data via the shortest available path without considering the residual energy E_r of sensor nodes C_i reside on this path. Although these schemes perform exceptionally well in a targeted application area, however, a tightly coupled issue with these schemes is that sensor nodes or devices C_i deployed on these paths, i.e., the shortest or least-cost paths, consume their on-board battery more rapidly than other devices in an operational network and result in network partitioning. This scenario becomes more complex if different devices share a common shortest path which is quite common in the resource-limited networks [12]. Therefore, a uniform and reliable load balancing or traffic distribution strategy are needed to be developed specifically for the resource-limited networks such as wireless sensor networks (WSNs), internet of things (IoT) and ad hoc networks. In literature, various load balancing and traffic distribution strategies have been presented to resolve the aforementioned issue i.e., lifetime and energy efficiency. Multiple path-based load balancing schemes were presented to distribute or spread the traffic uniformly across different communication paths in the operational networks [13]–[16]. The majority of these schemes are based on the residual energy E_r and hop count H_c, reliability, etc., of neighboring devices C_i preferably active devices. Although, these techniques have prolonged lifetime of the resource-limited networks but at the same time, various performance metrics were compromised such as average end-to-end delay, packet delivery ratio, and congestion. These problems occur as the majority of packets are forwarded on the longest path in operational networks. Furthermore, criticality aware load balancing schemes were presented, which have resolved some of these issues such as lifetime, packets delivery ratio and latency [7] up to some extent. However, a common problem with this approach is the complexity associated with the computational process of sensor nodes criticality factor that is computed using logical network abridgment and the concept of graph theory. Although this step is required only once during the entire lifetime of WSNs, however, the computational complexity is very high which makes its realization questionable in a realistic environment of WSNs [17].

Apart from flat networks, hierarchical communication infrastructure was presented in the literature to address various issues associated with resource-limited networks such as limited communication & processing power of ordinary devices C_i, an excessive burden on the ordinary nodes, and efficient utilization of the available power [18]. However, failure of cluster head (CH) or simultaneous communication of member devices C_i with a particular CH, the selection process of CH, the ratio of CH and ordinary node C_i are common issues associated with these networking structures. Hence, a light-weight and reliable communication mechanism, that is specifically designed for the resource-limited networks, is needed to be developed which can resolve the aforementioned issues without changing the existing technological infrastructure.

Therefore, a reliable communication and load balancing scheme should be more energy and performance efficient (particularly in terms of average end-to-end, lifetime and packet delivery ratio) that is achieved through:

- maximum utilization of the shortest or least-cost path(s)
- Intelligent load balancing on multiple available paths i.e., from shortest to longest paths
- minimum load or traffic on sensor nodes C_i having low residual energy E_r and lowest round trip time (RTT) RTT_i
- maximum load or traffic on those paths where sensor nodes C_i with the least hop count (H_c) values and maximum E_r values are deployed.

These parameters are largely not considered in many published models which are specifically developed for the resource-limited networks. In this paper, a reliable communication and load balancing scheme for the resource-limited networks are presented to resolve the aforementioned issues with available resources. Every device C_i is bounded to collect and store valuable information about its neighboring devices which is used to distribute its traffic according to the neighborhood statistics and application requirements. The main objectives of the proposed scheme are described below.

1) Increasing lifetime of the resource-limited networks through a weighted ensemble-based load balancing scheme where maximum traffic is routed through the shortest paths as long as the residual energy E_r of every sensing device C_i is greater than a defined threshold value. The traffic distribution strategy is revised if residual energy E_r of a single device C_i becomes less than the defined threshold value.
2) Maximize overall throughput of an operational network through an intelligent and weighted based load balancing and communication infrastructure.
3) Minimize average end-to-end delay by bounding every sensing device C_i to route maximum packets on the shortest but reliable path(s).
4) Maximize average packet delivery ratio which is attained through efficient utilization of the available power.

The remaining paper is organized as follows. In subsequent sections II, a brief literature review is presented which is followed by a brief description of the problem statement. In section IV, a brief description of the proposed scheme working mechanism is presented. In section V, a detailed description of the proposed communication and load balancing strategy with mathematical modeling is presented. In the subsequent section, various simulation parameters and results are discussed in detail. Finally, concluding remarks and future directions are given.

II. LITERATURE REVIEW

Sensor-cloud are used in different application areas of the resource-limited networks such as disaster relief, environmental monitoring, military, agriculture, health care and telemetry etc. [19]. An efficient and reliable load balancing scheme, that is specifically designed for the resource-limited networks and is useful in scenarios where direct communication with the receiver(s) is not possible, is a challenging task which has attracted researcher both from academia and industry. To resolve this issue, various load balancing or traffic distribution strategies were presented in the literature. A brief literature overview (particularly those schemes which are closely related to the proposed work) is presented here.

Uniform traffic distribution over multiple available paths is an ideal solution for the resource-limited networks. To realize this idea, a gradient-based optimal path identification scheme was proposed and used in the directed diffusion where a base station or server module S_j selects an optimal path and forces ordinary nodes C_i to use this path as a permanent transmission link until one or more node(s) deplete their on-board battery completely [20]. As this scheme relies on a single communication path, consequently, its lifetime is very short, that is similar to the shortest path approach particularly in situations where multiple source nodes share a common shortest path. Moreover, the selection and reinforcement of another optimal path is an energy starving and time-consuming process. A greedy growing algorithm based load balancing scheme was proposed by Kim *et al.* [21] to distribute the overall network traffic uniformly and enhances the lifetime of the operational networks. Similarly, a biased load balancing strategy was described by Touray *et al.* [22], to distribute the traffic among multiple paths in the WSNs and IoT. These techniques were well suited in application areas where longer connectivity of the underlying network has a higher priority than collected data. Moreover, these techniques have a relatively lower average packet delivery ratio and higher end-to-delay than the shortest path based schemes. A nature-inspired transmission strategy with multiple path is presented by Liu *et al.* [23] to identify communication paths for every individual device C_i. A common problem associated with this approach is a single point of failure i.e., failure of parent node leads to the partitioning of networks and, likely, important information or data is not captured or communicated. A tree-based load balancing scheme was presented to increase the underlying network's lifetime by forcing each leaf node to select one of its parent nodes as a router/relaying node. This selection process is based on their E_r and the average packet delivery ratio parameters [24]. Shah and Rabaey [25] have presented an energy-aware probabilistic traffic distribution scheme for the ad hoc networks, which has considerably improved the overall network's lifetime. Likewise, Schrugher and Srivastava [26] have thoroughly investigated the performance of different load balancing schemes -stochastic, stream-based, and energy-based- and their impact on the lifetime of networks and concluded that energy-based traffic spreading scheme performs exceptionally well than other schemes. A weighted optimal path-based load balancing scheme is described in [27] to resolve the uniform traffic distribution problem. Additionally, a critically aware load balancing scheme is presented in [7] to enhance the network's lifetime with the least possible end-to-end delay and maximum packet delivery ratio. Although, these techniques perform exceptionally well particularly in enhancing networks lifetime, however, at the same time compromised on partially prolonged average end-to-end delays and latencies as the majority of packets are forwarded on a comparatively longer path.

An Ant-based load balancing and routing scheme is presented where a pseudo-random path discovery process is adopted to improve the pheromone trail and balance overall energy consumption throughout the network [28]. Moreover, an opportunistic broadcast scheme is used to minimize the control overhead energy consumption. Likewise, an energy gauge node-enabled load balancing scheme is presented to distribute traffic or load uniformly in the operational resource-limited networks [29]. However, ratio and proper deployment position of energy gauge nodes are among the common issues associated with this approach. A path distance-enabled load balancing scheme was presented by Aissa *et al.* [30]. However, this scheme is effective within a closed building infrastructure.

Apart from flat networks, cluster-based or hierarchical schemes were proposed in the literature to resolve the aforementioned issues, i.e., lifetime, coverage area, packets delivery ratio, end-to-end delay, etc,. However, a challenging issue with these networks is the rotation or selection process of cluster head (CH) nodes, which are responsible to share the collected data of sensor nodes with the concerned base station. To resolve this issue, Zhang *et al.* [31] presented a proper load balancing scheme for homogeneous networks, where ordinary nodes and CHs have similar processing and communication power. In this scheme, sensors nodes are moved from a heavy loaded CH to a CH with minimum load. These movements are based on the distance of sensor nodes, i.e., from nearest CHs, and CHs with maximum residual energy E_r. A weighted based traffic or load balancing scheme was presented to address the constraint oriented network's lifetime issue. In this scheme, CH selection is based on two parameters, i.e., the number of deployed nodes in its closed proximity and residual energy of CH. A fuzzy, three-tier multi-hop and unequal clustering-enabled optimized routing scheme is presented to form energy-efficient networking infrastructures [32]. Multiple attributes based load balanced and optimized clustering approach is proposed to enhance the lifetime of the operational WSNs [33]. However, complexity is a common issue associated with these schemes. A stochastic distribution based traffic spreading scheme was presented by Liao *et al.* [34] to generate a uniform energy consumption model throughout the networks i.e., resource-limited networks. Similarly, tree-based schemes were presented to address the load balancing issue and to form a reliable communication infrastructure with available resources [24]. However, the majority of these schemes have various issues, i.e., application specificity, overlay complex, and expensive due to change in existing technological infrastructure. Therefore, reliable communication infrastructure is needed to resolve these issues, particularly with available resources.

III. PROBLEM STATEMENT

With the notable exception in references([7], [13]) as described in previous sections, a reliable communication and load balancing mechanism, particularly with minimum possible average end-to-end delay and maximum average packet delivery ratio, is not taken into account.

In literature, load balancing was either performed at CH level, i.e., in cluster-based or hierarchical networking infrastructures, or multiple paths based that is usually through E_r, as in flat networks, but a generalized load balancing methodology, that is applicable in different application scenarios and topologies, is not addressed yet.

The research work presented in this paper is needed to be focused on the development of a reliable communication & load balancing infrastructure that will resolve the aforementioned issues specifically with available resources and without changing the existing technological infrastructure(s).

IV. RESEARCH METHODOLOGY

To resolve the aforementioned issues associated with resource-limited networks, a particular research methodology should be used which reveals scientific methods, contribution, and quality to the research community. It will be based on the numerical analysis of the experimental results; relies on methodologies like (a) mathematical modeling; and (b) simulations. Our methodology will consist of:

- Development and implementation of reliable communication and load balancing infrastructure for the resource-limited networks.
  1) Selection of the optimal paths or neighbors from the pool of available resources which is based on their residual energy E_r and hop count H_c.
  2) The proposed load balancing scheme will minimize average end-to-end delay while maximizes the average packet delivery ratio of an operational network.
- Simulations: The essential methodology to assess the proposed technique on a large-scale network, specifically WSNs & IoTs networks, real-time simulation environment will be used.

V. PROPOSED APPROACH: A RELIABLE COMMUNICATION AND LOAD BALANCING MECHANISM

In this section, a detailed description and working methodology of the proposed scheme are presented to resolve the majority of the issues associated with the resource-limited networks particularly those which are described in the introduction section such as end-to-end delay, average packet delivery ratio, lifetime, and throughput. For this purpose, weighted-enabled traffic distribution and communication strategy are proposed where different weight-ages are assigned to various factors used such as residual energy E_r, hop count H_c, and round trip time RTT_i.

Initially in hop count H_c discovery phase, a control packet, Msg_{hd}, is broad-casted by the base station module S_j, with value of $H_c = 0$, which is received by every sensing node C_i reside in its closed proximity i.e., withing communication range of S_j. These nodes C_i update their H_c values accordingly and broad-cast an updated version of Msg_{hd}, i.e., with value of $H_c = 1$. To minimize the probability of collisions, back-off timer based approach is adopted where every node C_i holds its packets until back-off timer is expired. Back-off timer is selected randomly using equation 1.

$$\text{Back-off}Timer(C_i) = rand(0 - 100)microsec \qquad (1)$$

Once, the back-off timer is expired device C_i broad-cast an updated Msg_{hd} which is received by neighboring devices. This process is repeated until each node or device $C_i \in Networks$ obtains its H_c value.

In next phase, every node C_i finds at-least four optimal neighbors or paths -preferably with minimum hop count H_c, the lowest round trip time (RTT) value, maximum residual energy E_r and cost function $Cost_{C_{i,i+1}}$- which are used in biased ways to improve average packet delivery ratio and decrease packet loss ratio & end-to-end delay in an operational network. The biased way helps enhance lifetime and average packet delivery ratio by assigning the maximum possible weight-age factor to the H_c value, which forces the traffic to flow on the shortest path(s). Optimal neighboring nodes C_i are found using equation 2.

$$\text{Opt-Nbr}(C_i) = \omega_1 * \max(E_r) + \omega_2 * \min(RTT) + \omega_3 * \min(H_c) + \omega_4 * \min(Cost_{C_{i,i+1}}) \quad (2)$$

where ω_1, ω_2, ω_3 and ω_4 represent different weight-ages assigned to these factors respectively. $Cost_{C_{i,i+1}}$ represents the transmission and receiving cost of neighboring node C_i which is needed by a relaying node to forward a packet successfully. This function is computed using equation 3

$$Cost_{C_{i,i+1}} = \frac{\{E_{C_{i,i+1}}\}^{\alpha}}{\{E_r^{C_i}\}^{\beta}} \quad (3)$$

where, $E_{C_{i,i+1}}$ is the power (energy dissipated) needed to transmit a packet from device or node C_i to C_{i+1}.

$E_r^{C_i}$ represents the residual energy of device or node $C_i \in WSNs$. The α and β are the priority variables that are used to enhance the lifetime of an operational constraint oriented network. The transmission energy E_{TX} of a neighboring node or device C_{i+1} is computed using equation 4.

$$E_{TX}(m, d) = m * E_{C_{i,i+1}} + m * d \quad (4)$$

where, m represents number of bits in a packet and d is the distance between sender and receiver nodes or devices. Likewise, receiving energy E_{RX} (power needed to receive a packet) of a neighboring node C_{i+1} is computed using equation 5.

$$E_{RX}(m, d) = m * E_{C_{i,i+1}} \quad (5)$$

In the start, maximum weight-age is assigned to the neighboring nodes C_i with minimum hop count H_c value. This biased mechanism is used to ensure the transmission of maximum packets on shortest possible path(s) whereas minimum weight-age is assigned to the remaining parameters, i.e., E_r and RTT in an operational network. A biased weight-age assignment strategy is presented as follow that is $\omega_1 = 5\%$, $\omega_2 = 15\%$, $\omega_3 = 70\%$ and $\omega_4 = 10\%$. Minimum weight-age is assigned to residual energy E_r of neighboring devices C_i as on-board energy of every device are the same specifically once nodes are deployed. Before initializing the transmission process, every node selects two optimal neighbor(s) from four i.e., to ensure maximum transmission on these shortest paths.

In the start, generated packets are uniformly distributed between two optimal neighboring nodes i.e., 50% traffic flows through $Opt_{Neighbor_1}$ and 50% via $Opt_{Neighbor_2}$. Forwarding the majority of packets on the shortest possible path(s) leads to the overall improvement in the average packet delivery ratio and sufficiently decrease the end-to-end delay of packets in an operational network. Moreover, packets transmitted on the shortest path is an energy-efficient approach as the minimum possible nodes C_i are involved in the communication process. However, a major issue associated with the shortest path is the rapid energy consumption process of nodes reside on this path, which becomes more severe if this path is shared by multiple devices C_i. The proposed scheme resolve this issue by selecting two paths instead of one and thus reducing the rapid energy consumption process nodes C_i reside on the shortest path. 50% ratio is maintained until one or more neighboring nodes C_i, particularly those reside on the shortest path, consume 80% of their on-board batteries. Another issue associated with the shortest path based approach is the selection and reinforcement of another path that is resolved by keeping four different optimal paths.

If one or more of these nodes consumed 80% of their on-board battery, then selection criteria for the optimal neighboring node(s) is revised in equation 2 by assigning maximum weight-age to residual energy E_r and minimum to H_c i.e., $W_1 = 60\%$, $W_2 = 15\%$, $W_3 = 10\%$ and $W_4 = 15\%$. In this case, most of the traffic or packets are forwarded on other paths particularly, the remaining two, which was selected in phase-I. Forwarding packets on alternative paths certainly enhances the lifetime of an operational resource-limited network as neighboring nodes C_i with minimum residual energy E_r are ignored or avoided. Moreover, the proposed scheme enables an operational constraint oriented network as a whole or individual node C_i to achieve maximum average packet delivery ratio and throughput as (initially) maximum traffic or packets flow through the shortest path(s). Energy E consumption ratio of a node C_i packets transmitted on the shortest path(s) to multiple or energy-based path(s) is very low as the minimum possible nodes C_i or resources are needed to complete a communication cycle i.e., packet delivered to the base station. Likewise, the proposed scheme is an ideal solution for application areas where the minimum possible end-to-end delay is needed with the maximum lifetime of an operational network. End-to-end delay is defined as a combination of the processing, propagation, transmitting, and receiving delays of different nodes C_i, which serve as a source, destination, or relay in an operational constraint oriented network. The propagation delay is controlled by the forwarding packet on the path with minimum round trip time (RTT) as weight-age is assigned to it in equation 2. Additionally, as a packet(s) are forwarded on the optimal (preferable shortest path(s)). Therefore, the end-to-end delay is minimum for the proposed scheme as the minimum number of nodes C_i operate cooperatively to achieve a common goal, i.e., successful delivery of packet(s) to destination module S_j.

The reliable communication and load-balancing algorithm are presented below where C_i and S_j represent sensor node(s) and base station modules respectively in an operational constraint oriented network. A node C_i proximity or neighborhood is based on the received signal strength indicator (RSSI) value from neighboring nodes. The proposed algorithm creates a routing table which is based on neighboring nodes or devices C_i statistics i.e., E_r, H_c, RTT_i and $Cost_{C_{i,i+1}}$ values. To transmit or forward a packet, the following criteria are ensured by device $C_i \in WSNs$.

1) Packet should be sent or forwarded to an optimal neighboring node (preferably C_i that is selected in equation 2).
2) Packets should be routed to an optimal node C_i which has maximum residual energy E_r value.
3) Load balancing technique should avoid (if possible) neighboring nodes with higher H_c & $Cost_{C_{i,i+1}}$ or lowest residual energy E_r values.
4) If two or more neighboring nodes have similar value (which is computed using equation 2) then a random selection process is preferred.
5) Packet shouldn't be sent to a neighboring device C_i with minimum H_c value and its residual energy E_r value is less than 20% provided that other paths (s) are available.

Two functions, SensorNode() and NeighborDiscovery(), are used to find optimal nodes or devices in a constraint oriented network. In the SensorNode function, a packet that is either generated - created by node C_i itself- or a received from a neighboring node that resides in its closed proximity is used to call NeighborDiscovery() function. NeighborDiscovery() function is used to find an optimal neighbor(s) in an operational network by thoroughly examining various factors such as residual energy (E_r), hop-count (H_c), RTT_i and $Cost_{C_{i,i+1}}$. Weight-ages are assigned to these metrics according to equation 2 as described in the previous section. Moreover, these weight-ages may be assigned according to the application requirements i.e., if minimum delay, in the transmission of packets from source to destination, is needed then H_c has a maximum weight-age which bounds source device C_i to forward the packet(s) on the shortest path. However, if long term networks connectivity is mandatory- which is usually in agriculture and environmental monitoring applications- then these parameters are adjusted according to the proposed plan, i.e., optimal paths. Hence, the proposed communication and load balancing approach is applicable in different application scenarios by adjusting their weight-age factors accordingly.

Algorithm 1 Proposed Reliable Communication and Load Balancing Algorithm for the Resource-Limited Networks Such as WSNs and IoTs

Require: Thorough Analysis of Neighboring Node(s) $C_i \in WSNs$
Ensure: Optimal Neighboring Node(s) ($C_i \in WSNs$)
Candidate Node(s) $C_n \leftarrow C_i$ with strong RSSI Value
$E_r \leftarrow$ **100%**
$Opt_{nbr} \leftarrow \infty$
$H_c \leftarrow 0$
SensorNode ()
  Packet$\leftarrow$ Generated or Forwarded
  $Opt_{nbr} = NeighborDiscovery(number, E_r(C_i))$
  Packet$\rightarrow$ (Opt_{nbr})
end SensorNode
NeighborDiscovery (number,$E_r(C_i)$)
  $Opt_{current} \leftarrow \infty$
  if ($E_r(C_i) > 20\%$) **then**
    $\omega_1 \leftarrow$weight-age-I
    $\omega_2 \leftarrow$weight-age-II
    $\omega_3 \leftarrow$weight-age-III
    $\omega_4 \leftarrow$weight-age-IV
  else then
    $\omega_1 \leftarrow$weight-age-V
    $\omega_2 \leftarrow$weight-age-VI
    $\omega_3 \leftarrow$weight-age-VII
    $\omega_4 \leftarrow$weight-age-VIII
  endif
  for i $\leftarrow$ 0 to number **do**
    $Opt_{current} \leftarrow \omega_1 * E_r + \omega_2 * RTT + \omega_3 * H_c + \omega_4 * Cost_C$
    if ($Opt_{current} < Opt_{nbr}$) **then**
      $Opt_{nbr} \leftarrow Opt_{current}$
    elseif ($Opt_{current} = Opt_{nbr}$) **then**
      $Opt_{nbr} \leftarrow$rand($Opt_{nbr}, Opt_{current}$)
    end if
  end for
    return Opt_{nbr}
 end NeighborDiscovery
end

VI. RESULTS AND PERFORMANCE EVALUATION

In this section, a detailed description of the simulation results is presented to verify the proposed scheme performance against well-known and field-proven algorithms available in the literature. Different evaluation metrics are considered based on their tight coupling to the existing communication infrastructure such as throughput, average packet delivery ratio, end-to-end delay, and a lifetime of an operational resource-limited network. These algorithms were implemented in OMNET++, an open-source simulation environment that is specifically designed for the constraint oriented networks (such as WSNs and IoTs), using similar deployment and performance metrics. Initially, a random topological infrastructure with embedded propagation delay is adapted to mimic the real deployment process of the resource-limited networks, i.e., WSNs and IoT. Moreover, path loss ratio and interference parameters were kept constant for the whole network as these parameters are beyond the scope of the proposed reliable load balancing and communication infrastructure. In table 1, a brief description of various parameters, which are used to realize the proposed scheme, is presented. To comply with a real node or device deployment and lifetime issues, we have used standard battery powers that are available for different development platforms such as libelium, Intrinsic, etc.

The proposed scheme is compared with field-proven techniques such as vulnerability aware routing scheme [7],

TABLE 1. Simulation parameters.

Parameters	values
Deployment Area	1000m * 1000m
Sensor Nodes or Devices	50, 100, 500, 1000
Base Station	One
Initial Energy (E_i)	52000 mAh
Residual Energy (E_r)	E_i-E_c
Packet Transmission Power Consumption (E_{TX})	91.4 mW
Channel Delay (Ch_{delay})	10 milliseconds
Packet Receiving Power Consumption (E_{RX})	59.1 mW
Idle Mode Power Consumption	1.27 mW
Sleep Mode Power Consumption	15.4 μW
Transceiver Energy Consumption (T_i)	1 mW
Transmission Range (T_r)	500m
Receiving Power Threshold (RTS_n)	1024 bits
Packet Size (P_{size})	128 bytes
Hop Count (H_c) of Base Station	0
Initial Hop Count (H_c) of Sensor Nodes	∞
Maximum Distance between Nodes	300m
Sampling Rate of sensor nodes	10,20 and 30 seconds
Topological Infrastructure	Static and Random
Traffic Type	CBR and UDP

shortest path algorithm & energy-based traffic spreading approaches [14], [35], and opportunistic routing [36]. These schemes were thoroughly examined using different performance metrics such as end-to-end delay, average packet delivery ratio, throughput, and a lifetime of the operational constraint oriented networks. Moreover, operational statistics or capabilities of both devices or nodes C_i and networks were kept the same for these schemes, i.e., proposed and those available in the literature.

A. END-TO-END DELAY

Usually, for resource-limited network infrastructure, a load balancing scheme with the lowest possible end-to-end delay ratio (which includes processing, sender, receiver, and propagation delay) is preferred over scheme(s) with a higher ratio in different realistic scenarios or environments. Hence, a newly developed scheme (such as the proposed) is needed to have the minimum possible end-to-end delay without compromising on other important performance metrics particularly, the lifetime. The proposed scheme achieves this goal by forwarding the majority of packets on the shortest path(s) if possible in the operational constraint oriented networks. A comparative analysis of the proposed load-balancing scheme and those available in literature in terms of end-to-end delay metric is shown in Figure. 1. It is evident from Figure. 1 that the proposed scheme performs exceptionally well against its rival schemes under different nodes or devices scalability in the operational networks.

B. AVERAGE THROUGHPUT

The throughput of a network is defined as the ratio of successfully delivered packets to the intended destination device(s), i.e., the base station in this case. This metric becomes more important specifically in scenarios where deployment mechanisms of nodes or devices are random. A load-balancing scheme is preferred to be implemented in a realistic environment(s) of constraint oriented networks if and only if it

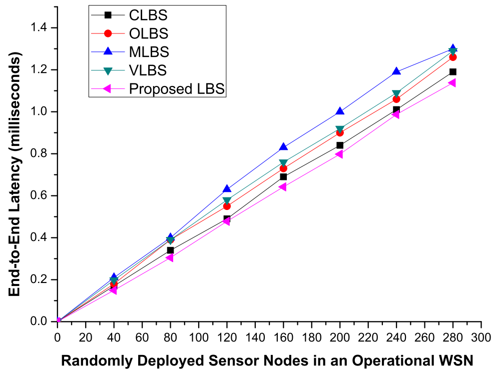

FIGURE 1. Proposed load balancing and existing schemes performance in terms of end-to-end delay with different scalability.

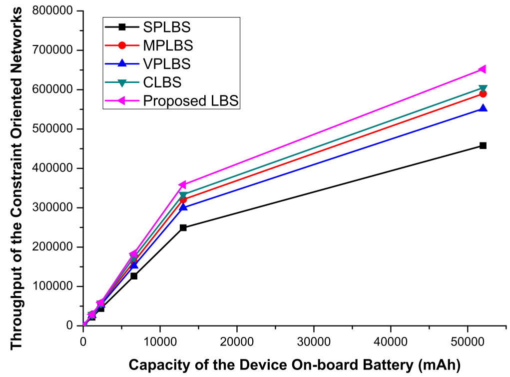

FIGURE 2. Proposed load balancing and existing schemes performance in terms of average throughput.

has maximum average throughput with a minimum possible delay. In this connection, the proposed load balancing scheme is compared with existing schemes are shown in Figure. 2, which depicts the exceptional performance of the proposed scheme under different power sources, i.e., device on-board battery capacity.

C. AVERAGE PACKET DELIVERY RATIO

Packet delivery ratio is defined as the ratio of successfully delivered packets to the generated or transmitted in an operational network. This ratio is directly proportional to the average throughput of the networks. Therefore, a load balancing or routing scheme with maximum possible average packet delivery ratio is an ideal solution specifically in resource-limited devices networking environment. The proposed load-balancing scheme performance in terms of average packet delivery ratio with existing schemes is compared using different scalability ratios of operational devices C_i in constraint oriented networks as shown in Figure. 3. It is evident from Figure. 3 that the proposed scheme has a better average packet delivery ratio than its rival schemes.

D. LIFETIME OF INDIVIDUAL DEVICE AND WHOLE NETWORK

The lifetime of the resource-limited networks is a mature area and its primary goal is to prolong the operational capabilities of both individual and whole networks. The proposed scheme

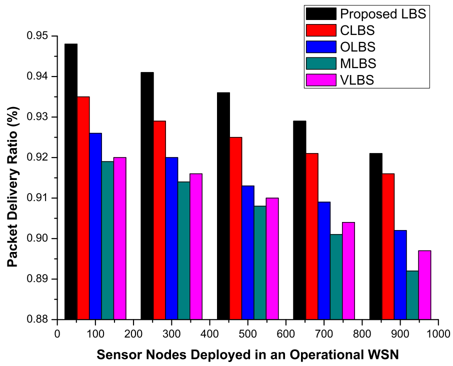

FIGURE 3. Proposed load balancing and existing schemes performance in terms of average packet delivery ratio.

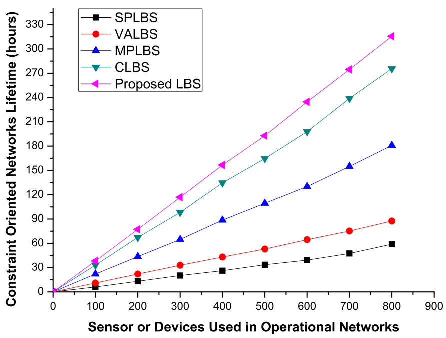

FIGURE 4. Proposed load balancing and existing schemes performance in terms of networks lifetime.

performance, particularly in terms of lifetime, is examined thoroughly using networks with different scalability ratio. Figure 4 shows that the networks with the proposed load balancing scheme have a prolonged lifetime than its rival schemes. Moreover, the proposed load balancing scheme performs better than existing schemes in prolonging the lifetime of the individual node as shown in Figure. 5.

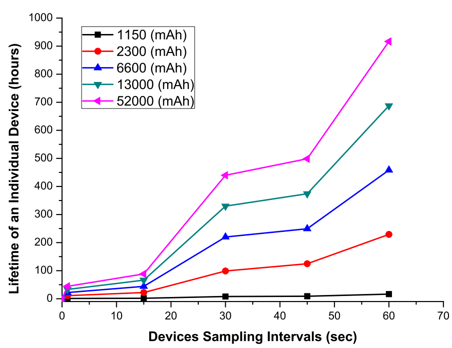

FIGURE 5. Proposed load balancing and existing schemes performance in terms of individual device(s) lifetime.

E. RESIDUAL ENERGY E_r OF ACTIVE DEVICES

Average residual energy metric E_r of various member and active devices C_i demonstrates the effectiveness of an algorithm's uniformity in terms of traffic distribution in an operational network. The proposed communication and load balancing scheme has distributed the traffic uniformly across the network as shown in Figure. 6. In the proposed scheme,

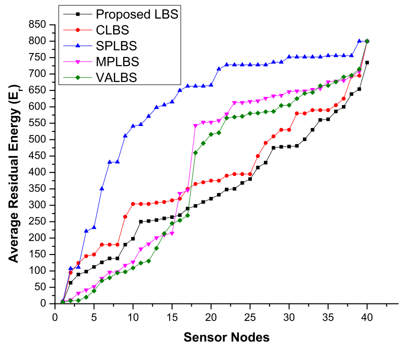

FIGURE 6. Comparison of the average residual energy of networks with different densities.

the average ratio of the residual energy E_r is directly proportional to network densities.

VII. CONCLUSION AND FUTURE WORK

With recent advances in technology particularly sensors and actuators, the resource-limited networks have been used in different application areas such as the military, medicine, agriculture, transportation, smart building & cites. Usually, the operational capabilities of these networks in the real environment is subjected to the efficient utilization of the available onboard batteries. These batteries are mostly not rechargeable either due to their deployment positions or circuitry. Therefore, a robust load balancing and communication scheme is needed to be developed to resolve these issues without compromising on various performance metrics such as end-to-end delay, average packet delivery ratio, average throughput, and network lifetime. In literature, various load balancing mechanisms have been presented to address these issues either with or without changes in the technological infrastructure. However, these schemes were either application-specific or overlay complex. In this paper, a reliable communication and load balancing scheme for the resource-limited networks was presented to resolve the aforementioned issues with the available resources. To achieve this goal, the proposed scheme calculated the transmission capabilities of the neighboring devices using their residual energy E_r, hop count H_c, round trip time RTT_i, and processing cost. Initially, every device C_i is bounded to find four optimal paths to transmit their packets such that neighboring devices C_i with minimum H_c value were preferred over those devices which have maximum H_c values and route maximum traffic on two shortest possible path(s). Therefore, unlike the traditional shortest path scheme, devices C_i resided on the shortest paths did not consume their energy more rapidly than other devices as only 50% traffic is routed on it. The weight-age factors were fine-tuned if one or more neighboring devices C_i have consumed 80% of their on-board battery, that is maximum weight-age was assigned to the E_r and minimum to the H_c values respectively. Simulation results have verified the exceptional performance of the proposed weighted ensemble-based communication and load balancing scheme against field-proven schemes in terms of average packet delivery ratio, average throughput, end-to-end delay, and overall network lifetime.

In the future, we will extend the operational capabilities of the proposed weighted ensemble-based scheme to the dynamic networking infrastructure, i.e., where sensor nodes or base station(s) or both are mobile.

1) CONFLICT OF INTEREST

All authors declare that they have no conflict of interest.

2) ETHICAL APPROVAL

This article does not contain any studies with human participants or animals performed by any of the authors.

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