An Efficient Smart Weighted and Neighborhood-enabled Load Balancing Scheme for Constraint Oriented Networks

Mohammed Amin Almaiah

Department of Computer Networks and Communications
College of Computer Sciences and Information Technology, King Faisal University, Saudi Arabia

Abstract—In Wireless Sensor Networks (WSNs), uniform load or traffic distribution strategy is one of the main challenging issues, which is tightly coupled with the resource-limited networks. To address this problem, various mechanisms have been developed and presented in the literature. However, these approaches were either application specific that is designed for a specific application area such as smart building or overlay complex. Therefore, a simplified and energy efficient load-balancing scheme is always needed for the resource-limited networks. In this paper, an efficient and neighborhood-enabled load-balancing scheme is presented to resolve the aforementioned issues specifically with available resources. For this purpose, the proposed scheme bounds every member node to collect various information about neighboring nodes i.e., those nodes resides in its communication range. Moreover, if residual energy Er of sensor node is less than the defined threshold value then it shares this information with neighboring nodes. In the proposed neighborhood-enabled load balancing scheme, every sensor node Ci prefers to route packets through the optimal paths particularly those paths where probability of critical nodes is negligible i.e., path where critical node(s) are not deployed. Simulation results showed that the proposed neighborhood-enabled load-balancing scheme is better than existing approaches in terms of network lifetime (both individual node and whole WSNs), throughput, and average packet delivery ratio and end-to-end delay performance metrics.

Keywords—*Wireless Sensor Networks (WSNs); load balancing; PSO; routing protocol; low power devices*

I. INTRODUCTION

With the development of wireless technologies, Wireless Sensor Networks (WSNs) must have low cost, low power consumption, small size, easy layout, and dynamically self-organized [1]. WSNs are using widely in many different applications, such as industrial applications, health care, military defense, environmental detection, target tracking, and ecological observation, etc. [2, 3]. However, because batteries supply the energy of the sensors, its radio transmission distance will be limited. In order to solve the energy consumption and distance problems during transmission, if the sensors are too far away from the base station, the WSNs need to organize a large number of distributed nodes to form a multi-hop wireless network. In WSNS, the sensor uses multiple-hop to establish network routing. The data is transmitted back to the base station through the shortest path composed of multiple sensors [4]. In addition, in a WSN since

the wireless sensor is powered by a battery, an energy efficient and reliable load balancing is relatively important. There are many approaches to reduce energy consumption in WSNs [5, 10]. Such as load balancing among wireless sensor nodes, path selection when transmitting data, scheduling problems, sleep mechanism when there is no sensitive data, correctness of transmitting data, and so on [11,34,35].

Generally, devices Ci belongs to the Wireless Sensor Networks (WSNs) have the capacity to organize them- selves to form an operational network without human intervention specifically in remote areas. These networks consist sensor nodes Ci, base station or sink node(s) Sj, actuator (where needed) and servers etc. These devices Ci are either deployed manually (known as engineered deployment) or randomly (usually through a helicopter or other means specifically in hard areas where manual deployment is not possible) in vicinity of the underlying phenomenon needed to be observed periodically or when a particular event occurs [1]. Due to the overwhelming characteristics of these networks, WSNs are used in different application areas such as military, smart-buildings, Medicine, agriculture, etc. to assist human beings in various real life-activities or automate it completely where applicable. Every member device Ci, i.e., sensor node, prob the environment periodically or when an event is triggered and shares the collected data with the cluster head (CH) or base station(s) or server(s) through a reliable communication mechanism that is either single-hop (in case of hierarchical WSNs) or multi hop (flat WSNs) [2]. In case of hierarchical networking infrastructures, wireless communication among various devices Ci is very simple as, usually, every device Ci is deployed within wireless communication range of the concerned base station module Sj [3]. Alternatively, in later case, each device Ci has to use path or rout information, i.e., load balancing or routing table, for the reliable transmission of data and it is due to the fact that majority of these devices are deployed far away from the concern base station and are unable to communicate directly [4,33]. Multi-hop communication is an ideal mechanism to resolve challenge of limited wireless communication that is closed related to the resource limited member nodes of operational WSNs. In this regard, various load balancing and routing schemes have been presented in literature to enhance the operational capabilities of these devices Ci specifically in terms of communication range, networks lifetime and end-to- end delay.

Shortest path with minimum cost path enabled routing schemes are considered among the most reliable communication techniques. Specifically for those systems that consider timely delivery of data has more priority than connectivity of networks like intruder or malicious detection. In these schemes, shortest path are identified and every member node C_i WSNs is force to transmit data only through those path(s). One of the common problems associated with shortest path enabled schemes shortest lifespan of device C_i reside on the these shortest path which become the worst if multiple source nodes or devices share this shortest path for the transmission of packets [5], [6]. Hence, for the networks with limited resources, a uniform load balancing or traffic distribution strategy is always a challenging task specifically for the research community to resolve the aforementioned issue particularly with available resources. A well-known methodology that is multiple-path enabled load balancing schemes, which are primarily based on residual energy E_r of neighboring devices C_i, were presented to distribute net-work traffic uniformly across different communication paths [7]– [10]. In this scheme, sensor nodes can send data to t h e neighbors whose hop-count values are greater than the sender node. However, end-to-end delay and packets delivery ratio are among the common problems associated with these schemes as maximum packets are transmitted via longest paths available in the operational WSNs. Likewise, criticality aware load balancing schemes was proposed in literature, which has resolved some of the afore mentioned issues associated with multiple path enabled schemes such as net- works lifetime, average packet delivery ratio and throughput [11], [12]. However, a tightly coupled issue associated with these approaches is packet loss ratio which will increase if neighbor node with minimum reliability factor is selected as a relay node. Therefore, an efficient and reliable mechanism for energy load balancing and communication is needed to be developed to address the aforementioned issues in WSNs without any change in the infrastructure of wireless technologies.

Moreover, the research community suggests various techniques to resolve the load balancing issue of WSNs and prolong the network lifetime. Although, these techniques are efficient at some stage to manage the load balancing issue, but they have some side effects on the network performance such as high communication cost, end-to-end delay, packet lost ratio, throughput, and individual sensor devices lifespan, etc. Therefore, our proposed scheme works based on (1) utilizing the maximum of the shortest path(s); (2) conducting a smart load balancing across multiple paths (particularly those with maximum residual energy, minimum round trip time (RTT) and minimum average packet loss ratio); (3) minimum load on nodes having low residual energy Er and lowest round trip time (RTT) RTTi ; and (4) maximum load on paths with least hop count (Hc value), maximum Er and minimum Nv value; which is largely not considered in many published models, in order to improve the performance and energy efficient for the networks that have limited resources in terms of average packet delivery ratio, networks lifetime.

The proposed model will investigate the potentials of the weighted ensemble based load-balancing scheme in resolving the aforementioned issues such as end- to-end delay; packets deliver ratio, and maximum lifetime. In this paper, a weighted-ensemble based load-balancing scheme is presented for WSNs to address the aforementioned issues. In the proposed scheme, different weight-ages are assigned to various metrics of every member node such as residual energy E_r, Hop-count H_c, crucial N_v (from net- works connectivity perspective) and First Hop Neighbor Round Trip Time ($FNRTT_i$). Moreover, the proposed scheme adopts a sequential approach such that first packet is sent through the most optimal path that is computed using those metrics. Second packet is forwarded on the 2nd optimal path available in the operational WSNs.

The remaining paper is organized as follows. In subsequent section, a brief literature review is presented. In Section 3, the proposed mechanism is described in detail whereas results discussion is presented in subsequent section i.e., Section 4. Finally, concluding remarks and future directives are provided.

II. RELATED WORKS

In WSNs, which have various constraints, management of load balancing and optimized energy consumption of sensor devices are considered a vital role in enhancing the prolong network lifespan with better end-to-end delay, packet delivery, throughput, and packet loss ratio. Based on that, there is need to develop an efficient communication infrastructure of sensor devices with uniform load balancing to maximize its performance with optimal resource utilization, specifically for WSNs that have limited resources. To address this issue, many schemes have been proposed in the literature. Thus, in this section, the existing techniques of WSNs load balancing are comprehensively overviewed with their merits and demerits.

In the literature, there is an important question, How to develop an efficient load balancing scheme with minimal resources and maximum results for WSNs or IOTs? Proposing a new scheme based on a uniform load or traffic distribution approach over multi-path and multi-hop communication infrastructure to share the collected data of sensor devices in the network is a powerful solution for this issue in networks with limited resources like IOTs and WSNs. In this manner, we used both optimal-path identification scheme and gradient enabled scheme in the directed diffusion method, where server module or base station *Sj* chooses the optimal operational path; in this case, it will impose on the ordinary or member nodes Ci to utilize this path as a continuous communication link between sensor nodes. This path is used by various devices interested in transmission of data until one or more of these devices consume their on-board power completely or becomes not operational due to other reasons [13], [14]. Generally, this scheme relies on a single communication path, consequently, the lifetime of both WSNs and ordinary devices C_i is very short, that is similar to the shortest path-enabled scheme where packets are forward on this path as long as all nodes reside on it are operational. Likewise, a shortest path-enabled approach was presented to resolve coverage area problem in mobile relay node(s) [15]. A common problem associated with these schemes is the selection and reinforcement of another optimal path that is needed in scenarios where existing path is no longer available or not

reliable for further communication. This process is energy starving, time-consuming and costly for the resource-limited networks specifically WSNs and IoTs. A greedy approach enabled algorithm was used to develop a uniform load balancing to spread the traffic uniformly and enhances overall lifetime of the networks [16]. In the same way, Zheng et al., [17,18], proposed a new scheme by computing the transmission capabilities for every sensing device C_i by their neighboring devices based on processing cost, hop count H_c, residual energy E_r and round trip time (RTT_i). At the beginning, to ensure reliable wireless communication, source device assigns a neighbor device C_i with lowest H_c value over others having highest H_c values. In addition, the scheme proposes that every device C_i should find at least 4 shortest and reliable paths, and forward maximum number of packets on the most two reliable and optimal routes. Therefore, unlike previous shortest path schemes, devices C_i available in these paths do not deplete their on-board battery more rapidly than other schemes through assigning weight-age factors accurately do. Software-Defined Wireless Sensor Network (SDWSN) architecture for load balancing of IoT was proposed by Cui et al. [19]. The proposed technique uses a centralized Software Defined Network (SDN) with flexible traffic management to minimize the energy consumption of participating IoT devices in the network. Moreover, for real traffic monitoring in the network, the authors also used the Open Flow protocol framework to verify the performance of the network. Qin et al. [20] proposed the software-defined network framework for load balancing in WSNs and IoT. Furthermore, they considered the emergency control system in the urban area to verify the feasibility of the proposed scheme.. Based on the results, they found that energy based traffic spreading approach have better performance as compared to other schemes.

Additionally, another study by Yousif et al., [21], they applied a weighted optimal path for loading balancing to solve the problem of uniform traffic distribution in wireless sensor networks. Another scheme known as aware load balancing scheme was proposed [11] to improve the network lifetime with ensuring the least possible percentage of end-to-end delay and packet delivery ratio. The performance of these schemes was exceptionally well, particularly in terms of networks lifetime enhancement metric, but it has some disadvantages like longer path selection to send maximum packets with continuous rate consumes extra energy and this creates network overhead.

The literature of WSNs in terms of load balancing schemes contain various cluster-based schemes or hierarchical networking infrastructures that have been used in the recent past to address the load balancing issues for networks with limited resources such as end to end delay, packet lost ratio, throughput, and sensor devices lifespan, coverage area, etc. [9]. Most of the researchers used the LEACH protocol in their proposed models to address the issue of load balancing in WSNs. However, one of the most difficult challenges in this type of networks is the identification the optimal cluster head node (CH), which is responsible to send the collected data from sensor devices to the concerned base station. Although, LEACH protocol plays significantly will in the formation of the cluster head nodes in the network, but it has some disadvantages like dynamic cluster head nodes selection with continuous rate consumes extra energy and creates network overhead. In the same way, Zhang et al. [22] proposed a new load-balancing scheme for homogeneous networks, where both cluster head nodes (CHs) and member nodes C_i have the same features in terms of processing power and communication. The work of this scheme is based on moving the sensor nodes from CHs that have a heavy load to CHs with lowest load. The movement of sensor node is based on its location. In other word, it depends on the distance of sensor nodes, from the nearest CHs with highest volume of residual energy E_r. A load-balancing scheme based on weighted based traffic was developed to solve the networks lifetime issue that have limited resources. To solve this issue, this scheme perform by selecting the CH based on its residual energy and number of deployed nodes in its vicinity. A stochastic distribution based traffic distribution scheme was proposed by Liao et al. [23], which aimed to generate a new model based on a uniform energy consumption throughout the networks. In the same way, another schemes based on tree approach were proposed to solve the load balancing problem and to establish a reliable communication infrastructure [18]. However, the majority of these schemes are either application specific or overlay complex or expensive due to change in the existing communication mechanisms. Therefore, a reliable load balancing mechanism is needed to resolve this issue with available resources.

Theory of information enabled load balancing scheme was presented to distribute traffic uniformly through a proper scheduling of modulation and routing mechanisms [24]. Additionally, Preethiya et al. [25] have proposed mobile double cluster-head enabled particle swarm optimization approach to address uniform traffic distribution challenge in heterogeneous WSNs which is divided into four phases such as CH selection, scheduling of CHs, mobility and handover predication of a specific CH in the operational WSNs environment. However, complexity and implementation in realistic environments are among common issues associated with this approach. Zarin et al. [26] have presented a central controller node-enabled approach to distribute traffic uniformly throughout the networks where radio signals are utilized to balance energy consumption of active nodes in an operational heterogeneous WSN. A common issue with this approach is that reliable communication among mobile nodes and base station is not guaranteed. Similarly, a centralized optimal task allocation scheme is proposed to spread packets uniformly among available paths in the operational networks [27]. To realize this, linear programming and distributed optimal task allocation algorithms were integrated and utilized to minimize energy consumption of sensor nodes.

A. Problem Statement

With notable differences of existing studies [11], [7], [25], many schemes have been proposed for the load-balancing problem in WSNs. These schemes have not taken into consideration some important parameters like minimum possible average end-to-end delay and latency or maximum packet delivery ratio in order to ensure a reliable and optimal load-balancing scheme with an ideal wireless communication.

In addition, Existing load balancing schemes were either performed on CH level, particularly in cluster based infrastructures, or in multiple path based scheme usually through Er, as in flat networks, but a generalized load balancing methodology, that is applicable in different networking infrastructures and topologies, is not addressed yet. Therefore, the proposed work will be focused on the development of a reliable neighborhood-enabled load balancing and communication scheme and its implementation in real environment of the resource-limited networks. Furthermore, the proposed scheme should be suitable and implementable in various topological infrastructures of WSNs. Additionally; the proposed work should thoroughly investigate criticality or importance of device C_i particularly from networks connectivity perspective. Criticality of various nodes in the operational WSNs is depicted in Fig. 1 where communication activity of sensor nodes A, B, C and D are primarily dependent on the availability of sensor node H. Therefore, a reliable communication mechanism is needed to be developed which should bound each and every sensor node transmit packet to a non-critical nodes (if available). For example, sensor nodes E, G, F and I should be forced to avoid transmission of packets via sensor node H as alternative routes are available for these nodes in Fig. 1.
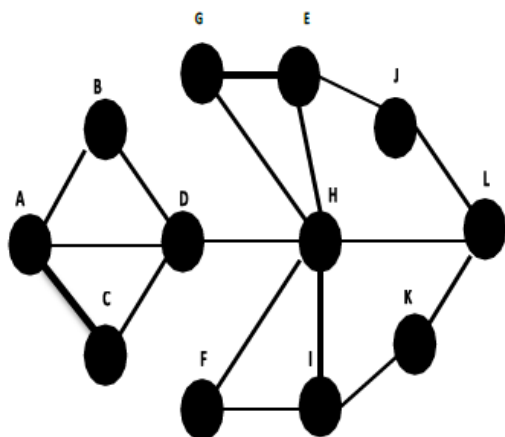

Fig. 1.   Importance of Ordinary Sensor Nodes from Networks Connectivity Perspective.

III. COMPUTATIONAL MECHANISM OF SENSOR NODES CRITICALITY FACTOR (NV)

Importance (criticality factor from the networks connectivity perspective) of a sensor node C_i $WSNs$ is a one-step process that is criticality of a member C_i is computed only once i.e., when the networks deployment process is complete. Generally, the base station module is responsible to compute criticality factors of each and every member node C_i and share it with these nodes. For this purpose, various concept of graph theory (preferably planner graph) are used to compute this factor. Higher value of a sensor node C_i criticality factor N_v is an indication of how important that node is from the WSNs connectivity perspective? For example in Fig. 1, criticality factor value N_v of sensor node H is higher than other nodes as a certain portion of the underlined network (i.e., A, B, C and D) are completely dependent on its active- ness for the transmission of packets. Moreover, this factor play a vital role

to distribute traffic in a biased but efficient manner (from residual energy E_r perspective). Therefore, the proposed load balancing mechanism should be smart-enough to minimize traffic flow on paths or neighboring sensor nodes C_i, which have higher values of criticality factor than other nodes in the operational WSNs. A detailed description of the methodology that is used to calculate criticality of sensor nodes $C_i \in WSNs$ is given below.

A. Calculation of Levels in WSNs

The computation process of a sensor node C_i criticality factor is initiated with the calculation of levels in WSNs preferably before and after removal of the concerned node C_i. For this purposed, a well-known technique called logical networks abridgment (LNA) is adopted which is used to generate loop-free description of the underlined WSNs [28]. Moreover, the concept of planner graph is utilized to develop a proper sketch of the deployed WSNs as shown in Fig. 2 where various level are identified such as level-1, level-2, etc. Usually, the deployed WSNs physical infrastructure is represented by Level-1, which is 1st level which is generated through the planner graph concept. An active sensor node Ci and communication link between two neighboring nodes in WSNs corresponds to a vertex and an edge in a graph respectively. A closed ring in the underlined graph should be a vertex in the next level as shown in Fig. 2 where an edge in the next level is subjected to neighborhood. A sensor node's levels calculation process is assumed to be completed **iff** a graph with no loop or cycle, a closed proximity of three or more nodes, is generated as represented in green at level-3 in Fig. 2. Level-2 graph is generated from level-1 where every vertex belongs to this level corresponds is created only if there is a cycle in level-1 graph and an edge is drawn **iff** there exist a pair of vertices belong to level-1 reside in closed proximity or neighbors. Moreover, these pair of vertices should belong to a similar bi-connected graph. In scenarios where these cycles do not belong to the same bi- connected graph then.

1) An edge in level-2 is drawn if and only if these cycles have a common vertex or node, which is known as cut- node in graph theory.

2) If these cycles do not have any common node(s), then edge should not be added.
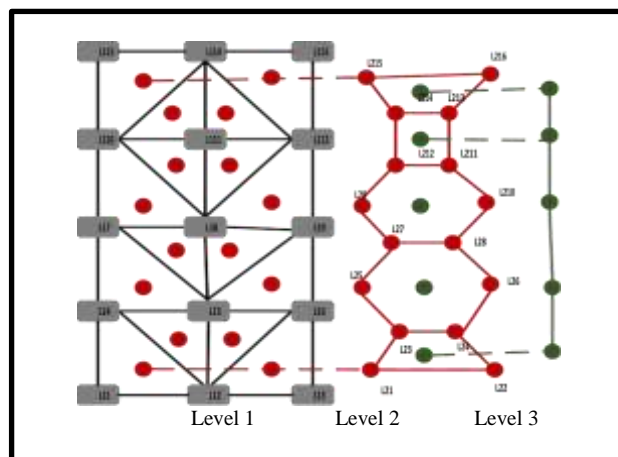

Fig. 2.   Sensor Node Criticality Metric Computation Mechanism.

The development process of Level-2 from Level-1 is identical to that of a dual graph where a vertice, which is surrounded by at-least three vertices (preferably to form a ring or cycle), is considered as a vertice in the next level exterior nodes are excluded and interior nodes are considered as shown in Fig. 2. Similarly, Level-3 vertices and edges are formed using this procedure. This process of levels computation is repeated until a loop free structure (a planner graph with no cycles) of the underlined graph is obtained as shown in green in Fig. 2.

After computing number of levels in the entire WSNs, the next phase is calculate these levels for each and every member node $Ci \in WSNs$. For this purpose, a sensor node for which levels are to be computed is assumed to be removed (temporarily) from the WSNs. For example in Fig. 1, if levels are to be computed for sensor node say 'A', then this node is assumed as removed or non-member from this network which becomes as shown in Fig. 3. Then the above mentioned process for whole networks levels computation is repeated for this network. In this way, levels of whole networks and member nodes are computed.
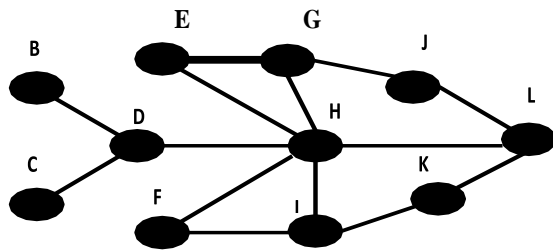

Fig. 3. Level Computation of an Individual Sensor Node.

B. Criticality of Member Sensor Nodes: Calculation Methodology

Criticality metric of a sensor node plays a vital role in prolonging the WSNs connectivity and, hence, enhancing their lifespan. Criticality metric of sensor nodes C_i WSNs is computed using the following formula.

$$v_n = \frac{N_B}{N_A} \times \frac{L_B + C}{L_A + C} \qquad (1)$$

Where V_n is the criticality factor of nth sensor node in an operational WSN. N_B and N_A represents number of nodes in network before and after removing n^{th} node respectively. For example, there are twelve nodes in WSNs as shown in Fig. 1. Whereas eleven nodes remains after removing sensor node A from the underlined WSN as shown in Fig. 3. Likewise, L_B and L_A represent levels in WSN before and after removing that node respectively. For example in Fig. 4, both networks have same number of sensor nodes i.e., five. Networks-A is a flat network with single level i.e., each node has a single path of communication. However, in network-B, each sensor nodes has two different paths available for communication. Removal of a node, as described above in level calculation mechanism, from a deployed WSN is used to examine how networks connectivity is effected if that particular node consumes it on-board battery completely. For example, if we remove sensor node C from both networks then nodes belong to network-A will not able to communicate with each other whereas those belong to network-B are able to communicate, as alternative path is available as shown in Fig. 4. Once criticality metric of

every sensor node C_i is completed then the base station S_j module shares these values with its member sensor nodes. Thus, each and every sensor node stores criticality values of its neighboring devices along with other information.
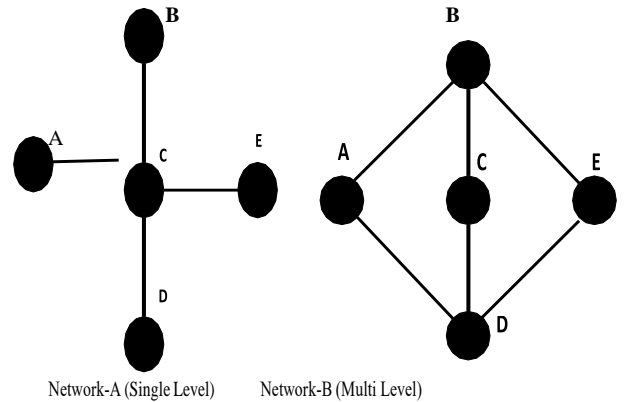

Network-A (Single Level)   Network-B (Multi Level)

Fig. 4. Effects of Levels on the Networks Connectivity.

IV. PROPOSED NEIGHBORHOOD-ENABLED LOAD BALANCING SCHEME FOR WSNs

A neighborhood-enabled load-balancing scheme, which is specifically designed for the wireless sensor networks, is presented to distribute traffic uniformly across all available paths in an operational network where every sensor node is bounded to send packet via reliable and non-critical paths or nodes. To achieve this goal, various routing metrics related to the neighboring nodes are used such as hop-count H_c, residual energy E_r, Round Trip Time (RTT) and sensor node criticality N_v.

A. Hop-Count Discover Phase

Hop-count information plays a vital role in resolving the ping-pong (multiple transmission of same message again and again) between neighboring node in operational WSNs environment. For example, a sensor node will discard a message received from neighboring device whose hop-count value is less than its own. In this phase, a control packet, Msg_{hd}, is generated and broad casted by the base station module S_j, with value of $H_c = 0$ as base station is ultimate destination of all packets, which is received by its neighboring nodes. These nodes update their H_c according, that is $H_c = 1$, and broad-cast an updated version of that message Msg_{hd}, i.e., with value of $H_c = 1$, after its back-off time expires. Back-off timer is used to minimize the collision probability of these messages.

$$T_b(C_i) = rand(0-1000) + min(H_c(C_i), \delta) \qquad (2)$$

The idea of adding an Hc value or δ with the generated random number is to further minimize (or avoid if possible) the packets collision probability of neighboring nodes as usually, these nodes have different Hc values. However, in scenarios where back-off timer Tb of two or more neighboring nodes are similar, then these nodes Ci should re-compute their back-off timer Tb accordingly. Moreover, parameter δ is an application dependent value whose values are different for different topological infrastructures such as in flat networks its value is in between 5 and 15 whereas between 2 and 5 for the hierarchical WSNs. This process is repeated by each and every

member sensor node Ci WSNs until *Hc* value is collected by every member device in the WSNs.

Moreover, every sensor node C_i keeps a record of it neighboring nodes along with their hop-count values. For this purpose, a simple table is maintained where this information is recorded from time to time. Separate session is not needed for this purposed rather it is performed as sub part of hop-count discovery phase. For example, when a sensor node receive message Msg_{hd} that contains information about it source such as hop-count and MAC-ID. Every sensor node records this information in a table, which is used to identify optimal and reliable neighboring nodes for the transmission of packets.

B. Finding Optimal Neighboring Nodes

In the proposed setup, an optimal neighboring node C_i *WSNs* is defined as a sensor node with maximum residual energy E_r and minimum possible (hop-count H_c, criticality N_v & Round Trip Time (RTT) values. In next phase, these nodes find two optimal neighbors or paths, preferably with minimum hop-count H_c, lowest RTT_i value, minimum N_v value and maximum residual energy E_r. These paths are used in the biased way (such as forwarding maximum traffic on most optimal path i.e., 70% whereas 30% on other path) to increase average packet delivery ratio and decrease the overall packet lost ratio and end-to-end delay of packets in an operational WSN. It is to be noted that packet delivery ratio is improve if majority of the packets are sent via most optimal path. Moreover, it is quite likely that packet loss ratio is minimize due to forwarding packets over a most reliable path or neighbor.

In order to identify optimal neighboring node(s), different weight-ages are assigned to the hop-count H_c, residual energy E_r, RTT and Criticality N_v values. Initially, maximum weight-age is assigned to the hop-count and criticality N_v metrics of various neighboring nodes to forward maximum packets or traffic through the shortest and less critical path. Moreover, specifically at this stage, residual energy E_r of all neighboring nodes are similar, therefore, it will not affect the optimal neighbor's' selection process irrespective of higher or lower weight-age value assigned to it. Optimal neighboring node selection process is subjected to the following (3):

$$Opt_{Neighbor}=Min(W_1 \times H_c+W_2 \times N_v+W_3 \times E_r+W_4 \times RTT_i) \qquad (3)$$

Whereas *W1, W2, W3, W4* are the weight-age factor assigned to the aforementioned metrics. In proposed setup, initially these values were assigned i.e., *W1* = 30%, *W2* = 40%, *W3* = 10% and *W4* = 20%. N_v value represents the criticality of a member node from the resource limited networks connectivity factor i.e., how important is a particular node C_i as far as WSN's long term connectivity is concerned. As described above that a higher value of criticality N_v associated with a node is an indication that a certain portion of the underlined WSN either partially or completely rely on this node i.e., if it becomes non-active (by consuming its on-board battery) then the portion of WSN will be disconnected or will not be able to communicate properly with the base station module S_j. Moreover, $Opt_{Neighbor}$ is the node C_i with (probably) a shortest path to the destination module i.e., base station.

Initially, packets generated by various source nodes C_i are distributed uniformly between two optimal neighboring nodes i.e., 50% packets forwarded through $Opt_{Neighbor}1$ and $Opt_{Neighbor}2$ respectively. However, the proposed scheme should avoid (if possible) critical nodes even though these are the most optimal neighbors. A neighboring sensor node C_i is assumed to be critical **iff**

1) Certain portion(s) of the underlined WSNs are either partially or completely dependent on that neighbor for the transmission of packets.
2) It acts as the shared optimal path among various nodes in the WSNs.
3) It has consumed approximately 80% of its on-board battery.

Moreover, if two or more neighboring nodes have a similar optimal value, then the selection process is random. Forwarding packets on most reliable path, a path with zero critical node, results in enhancing lifespan of the underlined constraint oriented networks. Additionally, the WSNs become connected for maximum possible duration without changing in the technological infrastructure.

The weight-age ratio presented in equation. 3 is maintained by every sensor node C_i until one or more of its neighboring nodes consume 75% of their on-board batteries. 75% threshold value is selected due to the fact that this node will be active for maximum possible duration. This node is now dedicated to forward data or packets of those nodes that have no other path(s) or neighbor(s) toward the base station module S_j. As soon as a sensor node C_i broadcast a message which indicates it critical condition i.e., that it has consumed 75% of the available power, then neighboring node(s) re-adjust their packets forwarding schedule or methodology accordingly. In this scenario, criteria for finding optimal neighboring nodes is revised in equation 3 by adjusting their weight-age factors such as residual energy E_r is assigned highest weight-age followed by nodes criticality value N_v. These weight-ages are adjusted as follows. *W1* = 10%, *W2* = 30%, *W3* = 40% and *W3* = 20%. Now, maximum packets are routed through those neighbors, which have maximum possible residual energy E_r and minimum criticality value N_v. This re-adjustment policy not only resolves end-to-end delay issue that is linked to the WSNs but at the same time improve their lifespan considerably.

C. Neighborhood-Enabled Load Balancing Algorithm

Generally, criticality of a sensor node C_i is high if it has maximum number of neighboring nodes particularly those nodes that have the capacity to communicate directly with it. Thus, it is quite likely that criticality of node C_i *WSNs* is strongly correlated to its congested neighborhood. A node with maximum neighbors has a higher probability to forward a slightly higher ratio of packets than other nodes, i.e., node(s) with minimum neighboring nodes. Therefore, critical node(s) consume their on-board battery more rapidly than other nodes due to the heavy load. Therefore, a trade-off metric is implemented to relieve these nodes either partially or completely (if possible) with an acceptable performance degradation ratio in terms of transmission delay, energy

consumption etc. The proposed load-balancing algorithm, which is presented below as Algorithm. 1, bounds every sensing device to thoroughly evaluate its neighborhood in terms of criticality, reliability, power capacity and distance before initiating a communication session.

D. Computational Complexity of the Proposed Load Balancing Scheme

Computational complexity is an evaluating metric that is used to describe the potentials and requirements of an underlined algorithm, in terms of time and space, to resolve a specific problem. Complexity of an algorithm has a direct co-relation to its time and space requirements.

V. RESULTS OF SIMULATION AND DISCUSSION

In this section, a detailed analysis of the simulation results is presented to evaluate the performance of the proposed neighborhood-enabled load balancing algorithm in terms of end-to-end delay, packet delivery-ratio, uniform load balancing (where possible), energy efficiency and residual energy (E_r). The proposed LBS is compared with the field proven techniques i.e., the shortest path algorithm, energy based traffic spreading approaches [8], [29], opportunistic routing [30], and vulnerability aware routing [11], [12]. These algorithms were implemented in OMNET++ [31], an open source simulation environment that is specifically designed for the resource-limited networks. It is to be noted that similar processing and communication power, on-board batteries, a single gateway module were used both for the proposed and existing schemes. Moreover, these schemes were tested using different topological structures such as graph based topology, tree based, random-top, and random- center. Additionally, channels or paths delay factors; both path loss ratio and interference are assumed to be constant for the WSNs. A WSN whose nodes (preferably n in this case) are distributed randomly in a deployment area of 500m * 500m as shown in Table I. Moreover, we have assumed that a sensor node either communicates directly with the base station module **iff** it resides in closed proximity of the base station or through various relay nodes using multi-hop communication. Additionally, for simplicity the capacities of on-board battery and transceivers are similar to the wasp- mote agriculture pro-board capacity [32] i.e., 52000 mAh and 400 meters respectively. To streamline the proposed neighborhood-enabled load balancing scheme applicability in the realistic environments of WSNs, well-known ratios are used both for packets transmission and reception i.e., $P_{TX} = 91.4mW$ and $P_{RX} = 59.1mW$ respectively. More- over, initial hop-count of ordinary nodes C_i is equal to (   ). In the proposed scheme, every node C_i is needed to inform its neighbor's **iff** its residual energy E_r is less than the defined threshold value i.e., 85% in this case. In proposed setup, the distance between various nodes C_i is kept around 400 meter. Moreover, criticality factor of WSNs and individual sensor nodes is computed only once i.e., precisely after the deployment process. As described above, this process is performed by the gateway or base station module.

The proposed scheme were thoroughly examined against various fields proven schemes (preferably load balancing and routing) in term of residual energy E_r, lifetime, end-to-end delay, average packet delivery ratio and sent or forwarded packets.

A. Uniform Energy Consumption

The proposed scheme was designed and developed not only to distribute traffic uniformly across the networks (WSNs), specifically via reliable communication path(s), but at the same time generated traffic is distributed in such a way that each and every node consume approximately similar power i.e., their residual energy is approximately similar (preferably of neighboring nodes). The proposed scheme performance is far better than existing schemes as shown in Fig. 5.

TABLE I.   HOMOGENEOUS WSNs SIMULATION PARAMETERS SETUP

| Parameters	Values
WSN Deployment Area	500m * 500m
Sensor Node	40, 200, 300, 500
Base Station	One
Initial Energy (E_s)	52000 mAh
Residual Energy (E_r)	E_s-$E_{consumed}$
Packet Transmission Power Consumption (P_{TX})	91.4 mW
Channel Delay (Ch_{delay})	10 millisecond
Packet Receiving Power Consumption (P_{RX})	59.1 mW
Idle Mode Power Consumption	1.27 mW
Sleep Mode Power Consumption	15.4 μW
Transceiver Energy (T_i)	1 mW
Transmission Range (T_r)	200m
Receiving Power Threshold (RTS_n)	1024 bits
Packet Size (P_{size})	127 bytes
Hop Count (H_c) of Base Station	0
Initial Hop Count (H_c) of Sensor Nodes	
Initial Criticality Value (V_n) of Sensor Nodes	0
Maximum Distance between Nodes	100m
Sampling Rate of sensor nodes	30 Seconds
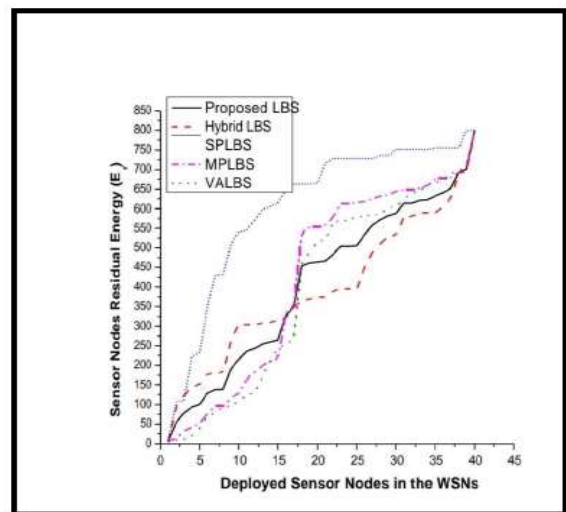
Fig. 5.   Residual Energy of Sensor Nodes belong to the Operational WSNs.

Algorithm 1 Proposed Neighborhood-enabled Load Balancing Algorithm

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Require: Forwarding of Data that is Collected by Sensor Nodes

Ensure: Return Optimal Neighbor or Path

1: $E_r \leftarrow$ **100%**
2: $V_n \leftarrow \infty$
3: $H_c \leftarrow 0$
4: $RTT_i \quad 0$
5: **Local Function** ()
6:       Packet $\leftarrow$ Either Generated or Forwarded
7:       **if**($E_r > 25\%$) **then**
8: $P_{opt} = OptimalNeighbor$ - $1(number of neighbors)$
9:       **else**
10: $P_{opt} = OptimalNeighbor$ - $2(number of neighbors)$
11:       Packet $\leftarrow$ (P_{opt})
12:   **end Local Function**
13 : **OptimalNeighbor-1** (number)
14:       $NCvalue \leftarrow 0$
15:       $N_{opt} \leftarrow \infty$
16:       $w1 \leftarrow 30\%$
17:       $w2 \leftarrow 40\%$
18:       $w3 \leftarrow 10\%$
19:       $w3 \leftarrow 20\%$
20:       **for** I $\leftarrow$ 0 to number **do**
21: $C_{cur} \leftarrow w1(H_c)_i + w2(N_v)_i + w3(E_r)_i + w4(RTT)_i$
22:       **if** ($C_{cur} < N_{opt}$) **then**
23:         $N_{opt} \leftarrow C_{cur}$
24:       **elseif** ($C_{cur} = N_{opt}$) **then**
25:         $N_{opt} \leftarrow \text{rand}(N_{opt}, C_{cur})$
26:       **end if**
27:       **end for**
28:       **return** N_{opt}

29:   **END NEIGHBORDISCOVERY-1**

30: **OptimalNeighbor-2** (number)

31:       $NCvalue \leftarrow 0$
32:       $N_{opt} \leftarrow \infty$
33:       $w1 \leftarrow 10\%$
34:       $w2 \leftarrow 30\%$
35:       $w3 \leftarrow 40\%$
36:       $w3 \leftarrow 20\%$
37:       **for** I $\leftarrow$ 0 to number **do**
38:       $C_{cur} \leftarrow w1(H_c)_i + w2(N_v)_i + w3(E_r)_i + w4(RTT)_i$
39:       **if** ($C_{cur} < N_{opt}$) **then**
40:         $N_{opt} \leftarrow C_{cur}$
41:       **elseif** ($C_{cur} = N_{opt}$) **then**
42:         $N_{opt} \leftarrow \text{rand}(N_{opt}, C_{cur})$
44:       **end for**
45:       **return** N_{opt}

46: **END NEIGHBORDISCOVERY-2**

47:   **end**

B. WSNs Lifetime

A prolonged lifetime of the resource-limited networks, WSNs and IoTs, is a challenging issue up to date. In literature, various mechanisms have been proposed to address this issue. It is evident from Fig. 6 that the proposed scheme is ideal solution for WSNs as it outperform the existing schemes. The WSNs lifetime is enhanced by the proposed scheme that is subjected to strong emphasis of the proposed neighborhood-enabled load balancing scheme on the avoidance (if possible and applicable only) of critical nodes during the communication activity. Moreover, as WSNs lifetime is subjected to the lifespan of individual nodes. Therefore, a brief analysis of an individual node lifetime is presented in Fig. 7. Lifetime of both individual node and whole WSNs is inversely proportional to the sampling rate i.e., a highest sampling interval leads to the minimum lifespan of WSNs.
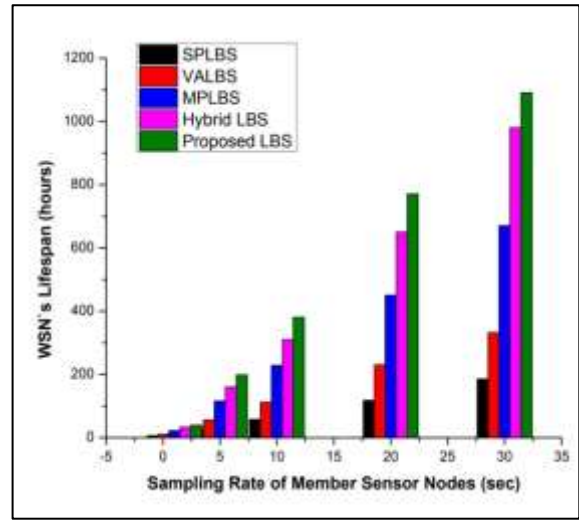

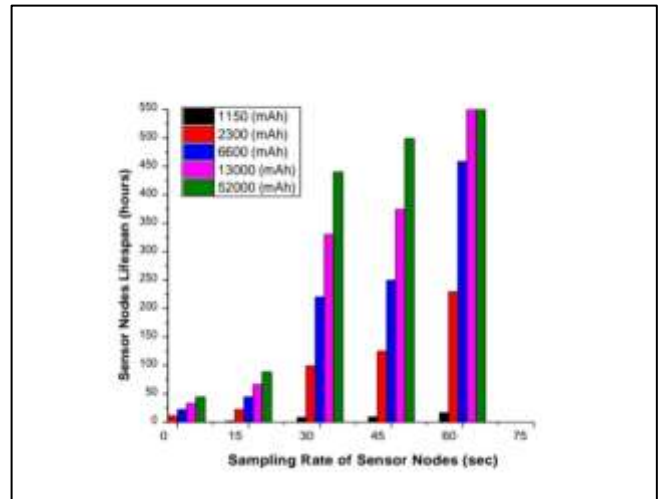Fig. 6. Lifetime Comparison of the Proposed Neighborhood-Enaod-Enabled LBS and Field Proven Algorithms.

Fig. 7. Sensor Nodes Capacities on different Standard of Waspmote On-board Batteries i.e., 1150, 2300, 6000, 13000, and 52000 mAh.

C. End-To-End Delay

End-to-End delay is a basic measure to evaluate the performance of a load-balancing scheme specifically in the resource limited networks environments. A comparison of the pro- posed neighborhood-enabled LBS and existing algorithms in terms of average end-to-end delay performance metric is presented in Fig. 8, which shows that the proposed scheme has the lowest possible end-to-end delay metric than existing schemes specifically on various WSNs densities that number of member nodes. The proposed LBS achieves this milestone by selecting an appropriate path for an individual packet by considering different parameters of the neighboring nodes such as criticality factor, residual energy, and hop count etc. Additionally, Fig. 8 shows that end-to-end delay factor is directly proportional to the networks size, channel delay, queuing delay, transmission delay, receiving delay, and the location of source and destination devices.

D. Average Packet Delivery Ratio

Average packet delivery ratio is another important performance metric that is utilized to evaluate various load balancing schemes in the realistic environment of WSNs. Fig. 9 shows the comparison of average packet delivery ratio of the proposed neighborhood-enabled LBS with the existing schemes, which shows that the proposed scheme has maximum possible average packet delivery ratio. Moreover, these results were verified on various WSNs infrastructures such as different number of nodes C_i and topologies. It is to be noted that the proposed neighborhood-enabled LBS algorithm achieves the highest ratio by utilizing a smart neighbor (preferably relay node) selection criteria and thus reducing the packet loss ratio.
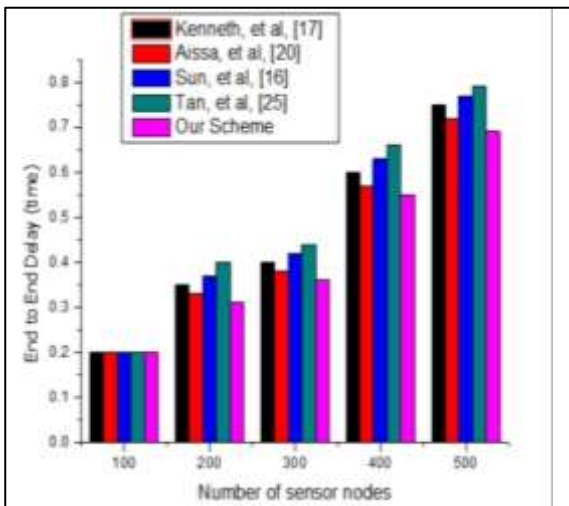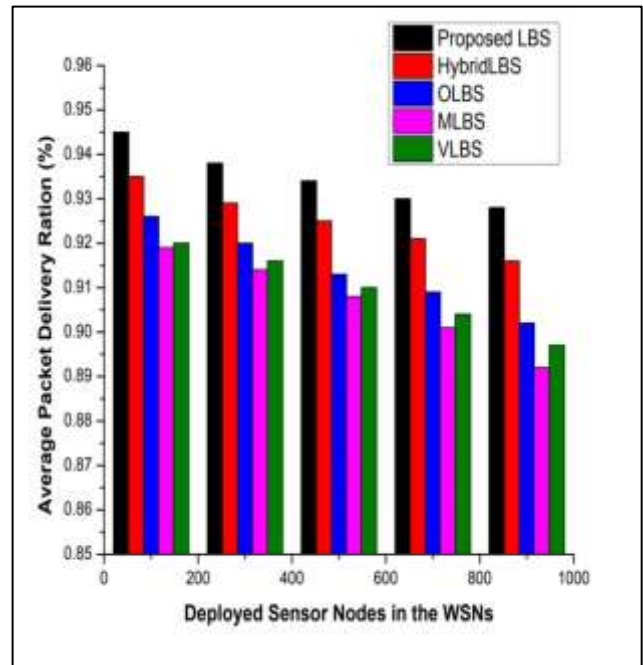
Fig. 9. Average Packet Delivery Ratio Analysis Statistics of the Proposed and Existing Load Balancing Schemes.

E. Throughput Analysis

An alternative evaluation metric is the throughput that is defined as total number of successfully delivered packets to the base station module in the WSNs. A load-balancing algorithm is considered as efficient and reliable **iff** it has achieved maximum throughput with available resources. The proposed scheme performs better than existing scheme in different realistic scenarios of the WSNs as shown in Fig. 10. The proposed neighborhood-enabled LBS has achieved the milestone of maximum possible throughput by bounding every node C_i to send packet(s) via most reliable and preferably shortest path(s) or neighbors.
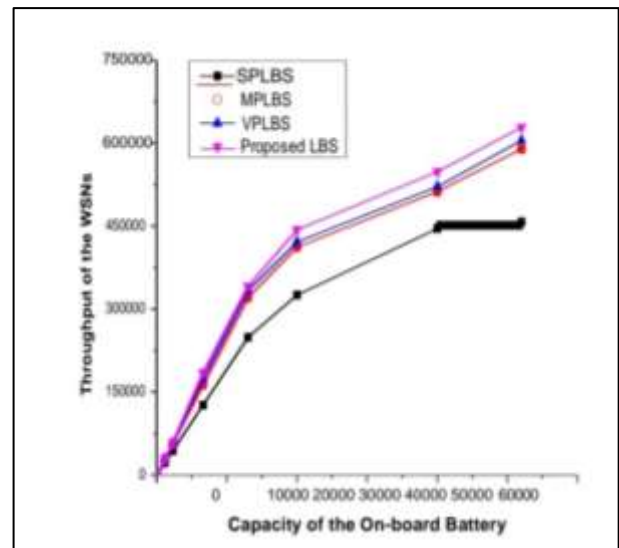
Fig. 8. End-to-End Delay Analysis Statistics of the Proposed and Existing Load Balancing Schemes.

Fig. 10. Throughput Analysis Statistics of theProposed and Existing Load Balancing Schemes.

VI. CONCLUSIONS

In this paper, a neighborhood-enabled load-balancing scheme was presented for wireless sensor networks to resolve various issues associated with the existing schemes. Moreover, the proposed scheme did not compromise on other performance metrics such as end-to-end delay, lifetime, average packet delivery ratio and throughput of the concerned WSNs. The proposed neighborhood-enabled load balancing scheme assigns different weight-ages to various metrics or parameter of every neighboring node such as residual energy E_r, Hop-count H_c, crucial N_v (from networks connectivity perspective) and first hop neighbor round trip time ($FNRTT_i$). Moreover, the proposed load-balancing scheme adopts a sequential approach such that first packet is sent through the most optimal path that is computed using those metrics and next packet is forwarded on the 2nd optimal path available in the operational WSNs. Simulation results have verified the exceptional performance of the proposed load balancing scheme against the existing LBS approaches particularly in terms of end-to-end delay, average packet delivery ratio, lifetime (both individual and whole WSNs) and throughput.

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