Operator Calculus Approach for Route Optimizing and Enhancing Wireless Sensor Network

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***Abstract*—Route optimization is one of important feature in wireless sensor networks in order to enhancing the life time of WSNs. Since Centrality is one of the greatest challenges in computing and estimating the important node metrics of a structural graph, it is necessary to calculate and determine the importance of a node in a network. This paper proposes an alternative way to optimizing the route problems which is based on multi-constrained optimal path (MCOP) and operator calculus approach. A novel routing protocol called Path Operator Calculus Centrality (POCC) is proposed as a new method to determine the main path which contains high centrality nodes in a wireless sensor network deployment. The estimation of centrality is using the operator calculus approach based on network topology which provides optimal paths for each source node to base station. Some constraints such as energy level and bit error rate (BER) of node are considered to define the path centrality in this approach. The simulation evaluation shows improved performance in terms of energy consumption and network lifetime.**

***Keywords*—Wireless Sensor Network, Multi-constrained Optimal Path, Centrality, Path Centrality, Operator Calculus.**

I. Introduction

One of the important aspects in wireless sensor networks (WSNs) is routing protocol. Contrary to traditional ad hoc networks, routing in WSNs is more challenging due to their inherent characteristics. First, resources are very constrained in terms of energy supply, capability and transmission bandwidth. Second, it is hard to design a global scheme as Internet Protocol (IP). In addition, IP cannot be applied to WSNs since address updating in a large-scale and dynamic WSN may result in very heavy overhead. Third, it is hard for routing to manage with unpredictable and frequent topology changes due to the limited resources, particularly in a mobile sensor environment. Fourth, data aggregation by sensor nodes generally creates in a high probability of data redundancy, which should be considered by routing protocols. Fifth, most applications of WSNs need the only communication scheme of many-to-one, for example from multiple sources to one particular sink, rather than multicast or peer to peer. Finally, in time-constrained applications of WSNs, data transmissions should be achieved within a certain period of time. However, energy preservation is more important than quality of service (QoS) in all sensor nodes are constrained with energy which is directly related to network lifetime.

Selection of cluster heads (CHs) based on optimal probability for load distribution of energy within sensor nodes is proposed in homogeneous clustering protocol called Low Energy Adaptive Cluster Hierarchy (LEACH) [1]. Furthermore, conception of hierarchical and multi-hop clustering disseminates energy load more evenly. It is noticed that localized schemes work well when compared with centralized algorithm in clustering based approaches. On the basis of energy distribution among sensor nodes, WSNs are categorised into homogeneous and heterogeneous networks. Some clustering routing protocols such as LEACH [1], Power-Efficient Gathering in Sensor Information System (PEGASIS) [2], and Hybrid Energy-Efficient Distributed Clustering (HEED) [3] are designed for homogeneous networks. Whereas, stable Election Protocol (SEP) [4] and Distributed Energy-Efficient Clustering (DEEC) [5], Learning Automata-based Energy Efficient Heterogeneous Selective Clustering (LA-EEHSC) [6] deal with heterogeneous networks. Geographic and Energy Aware Routing (GEAR) [7] routes a packet towards targeted region through geographical information and energy awareness of nodes. For such process either their exist a closer neighbor or all neighbor are farther away from destination. For closer neighbors from the destination, GEAR picks a next-hope node among all neighbors closer to the destination.

In WSNs, data are transmitted in multihop scheme where the sensor node forwards the collected information to another node which is closer to the destination, in this case the base station (BS). There are numbers of data dissemination algorithms and routing protocols which are designed to transport the sensed data to the base station (BS) with minimum energy consumption. However, the growing interest in real time applications such as reporting imaging data in hostile area, disaster monitoring and intrusion detection necessitates the appearance of other new and more significant requirements. These requirements comprehend guaranteeing certain network bandwidth, end-to-end delay and delivery ratio. Although, the severe constraints of the wireless sensor network (WSN) produce great issues and challenges that hinder supporting these QoS requirements. These constraints are supporting multiple classes of traffic, delay energy trade-offs, reliability vs. redundancy, multipath routing constraints, and network congestion [8].

Most of the existing routing algorithm takes place according to the criterion of the shortest path from a given source node to destination. However, in Social Network Analysis (SNA), both the node with high degree and the node with high betweenness centrality, which are commonly called the central nodes of networks, are very important to the frequent data transmission due to heavier load. As consequent, energy consumption of those central nodes is greater than that of other sensor nodes, which leads to unbalanced energy consumption. Once the central node runs out of its energy, WSNs would decrease its performance and break down the network connectivity.

In order to avoid the central nodes using up their energy too early, we propose a routing based on operator calculus [9] approach in this paper, which takes into account the energy and the bit error rate (BER) on weighted wireless sensor networks, where the weight values are estimated based on betweenness centrality of nodes. The simulation results show that the proposed routing algorithm outperforms comparators as regards extending the network lifetime and balancing the energy consumption in WSNs.

Centrality is an indispensable concept in Social Network Analysis (SNA). It is used to determine the importance of a node in a network. Essentially, it is estimated by computing the number of shortest paths that traverse a certain node. Historically various centrality indices have been used, including degree centrality, closeness centrality, graph centrality, stress centrality, and betweenness centrality. There are some new variants of centrality indices which have been proposed, such as beyond centrality by Shavitt and Singer [10], edge betweenness centrality by Cuzzocrea *et al*. [11], delta-betweenness centrality by Plutov and Segal [12], path centrality by Alahakoon *et al*. [13], and its variations of shortest-path betweenness centrality by Brandes [14].

Degree centrality of a node v is estimated by the number of nodes adjacent to v. Closeness centrality of a node v is an inverse sum of distances from v to all other nodes in the network graph. Betweenness centrality presents a possible centrality measure for distinguishing the importance of a node v within the network. The concept of centrality is used in vehicular networks for access-point deployment and discovering link criticality. Moreover, according to Sitanayah *et al*. [15], centrality is used for routing and load balancing in the WSN field.

Siddiqi *et al*. [16] presented that route optimization is another important feature of WSNs. Route optimization is used for finding the optimum paths from the source node to the base station or the sink node that respect given constraints.

The contribution of this paper is an alternative routing protocol for WSNs by wise use of path centrality based on the operator calculus approach. We determine the main path to the base station for each remaining sensor node in the network. Moreover, to the best of our knowledge, there is no similar centrality measure based on the operator calculus approach applied in a routing protocol of WSNs.

The rest of this paper is organized as follows. Section II reviews related work. Section III discusses the proposed work. Results and analysis are discussed in Section IV, and the conclusion of the paper is presented in Section V.

II. Related Work

Depending on the routing strategy, Bechkit et al. [17] proposed an adequate link cost definition. In the basic approaches, the goal was to reduce the hop count towards the Base Station (BS) or the sink node. The link cost is define to be one and the path cost, which is calculated as the sum of link costs, provides the hop count from the source node to the BS. Since the energy dissipation and the end-to-end delay are related to the path length, the use of shortest paths in terms of hop count minimizes the energy consumption and the end-to-end delay.

In energy-aware routing issues, some metrics were exploited in the literature [18], [19], [20]. When the energy consumption through the link is used as metric, the total consumed energy to reach the BS is reduced. This proposed approach called Short Path-power routing [18] or Minimum Total Energy (MTE) routing [19]. The authors in [18] proposed a SP-power routing algorithm based on the energy dissipation through a link as metric, they proposed also a SP-cost routing where the cost function was inversely proportional to the remaining energy. They presented finally a SP-power-cost routing to optimize a combination of the energy dissipation and the remaining energy level. Route establishment were based upon the Dijkstra algorithm. When using the SP-power routing strategy in static WSN, all the packet traffic is routed on the same minimum energy paths even the tree update is adaptive or periodic, nodes of these paths may exhaust quickly their energy. Eventhough, when they based on the remaining energy as metric, the paths to the BS may change and, consequently, the time to the first node failure is improved.

Authors in [19] proposed a link metric which integrates the reception transmission energy amount, the initial energy level and the remaining energy level of both the source node and the destination one. The distributed Bellman-Ford algorithm was employed in order to build the shortest path tree (SPT) based on the defined metric. In [21], the authors proposed an energy dissipation estimation model to calculate the link metrics. They were used the principle of Prim and Dijkstra to construct the SPT to prolong network lifetime while using clustering scheme.

In [22], the authors proposed an adaptive routing tree protocol for WSN where the setup phase is based on the SPT with a learning-based adaptive update. The authors proposed two strategics: the energy-aware one where they used the residual energy level of the source node to calculate the link cost and the congestion aware strategy where they calculate the link costs depending on the current transmission queue length of the source node.

Several routing protocol for WSNs such as Quadrature-LEACH (Q-LEACH) [23] has been proposed for homogeneous networks which enhances LEACH. Whereas, in Q-LEACH, network is partitioned into sub-regions and hence, clusters formed within these sub-regions are more deterministic in nature. Thus, sensor nodes are well distributed within a specific cluster and results in efficient energy consumption. Concept of randomized clustering for optimized energy drainage is applied in each region.

In WSN, sensor nodes perform transmit the processed data to a base station (BS) or the sink node over a wireless channel using single hop or multiple hops. While the propagation loss exponent is in high level, multi-hop communication should be employed to counter the high path loss occur. When nodes use multi-hop communication to reach the BS, the closer nodes to BS have a higher load of relaying packets as compared to other nodes.

However, most of sensor networks nodes are in static mode. Consequently the nodes closer to the cluster head (CH) or the BS will get overloaded constantly. On the other hand when the WSNs use single hop communication to access the BS, the farther nodes have the highest energy consumption due to long distance communication.

Also sensor networks are densely deployed, so problems related to scalability at MAC layer as well as at routing Layer are severe. It has been proposed in literature that to overcome above said problems sensor nodes can be organized into clusters and in each cluster, cluster head is responsible for communication with sink as well as with its member nodes. However clustering has its own problems and limitations like how to select a cluster head and rotation of cluster head. Here, it has been proposed that Different centrality measures like degree, closeness, Eigenvector, betweenness, network flow centrality can be used to resolve single hop, multihop or clustering related issues.

Authors in [8] proposed a Grid-based Multipath with Congestion Avoidance Routing protocol (GMCAR) as an efficient QoS routing protocol which is suited for grids sensor networks topology. They employed the idea of dividing the sensor network topology into grids. Inside each grid, one of the sensor nodes is selected as a master node which is responsible for transmitting the data generated by any node and for routing the data received from other master nodes in the neighbor grids. For each master node, multiple diagonal paths that connect the master node to the sink are stored as routing entries in the routing table of that node. The novelty of the proposed protocol lies behind the idea of incorporating the grids densities along with the hop count into the routing decisions.

Authors in [24] offered nodes' connectivity and energy and also provide a cluster-based method for decreasing of energy consumed by sensor nodes with clusters' field size dynamically adjusted in a dinamic changed network environment.

Authors in [25] proposed an energy-balance routing algorithm for extending the network lifetime for wireless sensor networks with scale-free characteristic. In order to avoid the nodes with high traffic using up their energy too early and prolong the network lifetime, the new routing strategy adopts the shortest path routing algorithm on weighted wireless sensor networks, where the weight values are calculated based on betweenness centrality of the nodes.

III. The Proposed Algorithm

In this section, the proposed routing algorithm is presented and some assumptions have been made for the sensor nodes as well as for the wireless sensor network. Hence the assumptions and properties of the network and sensor nodes are:

- Sensor Nodes are uniformly randomly deployed in the network.
- There is one Base Station (BS) or Sink node.
- Nodes always have the data to send to the base station (BS).
- Nodes are location-unaware, i.e. not equipped with GPS-capable antenna.
- All nodes have similar capabilities in terms of processing and communication and of equal significance. This motivates the need for extending the lifetime of every sensor.

A. Operator Calculus Approach

This section gives a short review on operator calculus approach [9]. The previous work [26] provides deep definitions on operator calculus theory [9] that we used. The main idea underlying the operator calculus approach is the association of graphs with algebraic structures whose properties reveal information about the associated graphs. In particular, by constructing the 'nilpotent adjacency matrix' associated with a finite graph, information about self-avoiding structures (paths, cycles, trails, etc.) in the graph are revealed by computing powers of the matrix [27].

We represent a WSN as a graph $G = (V, E)$, where V is the set of sensor nodes (SNs) and E is a set of edges. Every edge associates two nodes which are within communication range of each other; i.e., the nodes are adjacent in the graph. Two sensor nodes are said to be connected if there is an edge or a path between them. If every pair of nodes is connected then it is a connected graph. In general, a WSN topology is an undirected graph. For simplicity, in this work, we assume that the graph is connected. In a topology of a WSN with a base station (BS), the paths from all sensor nodes to the base station or sink node establish a rooted tree, where the sink node is the root of the tree. Any node w on a path from a node v to the root is an ancestor of v. If w is an ancestor of v, then v is a descendant of w. In a tree, v is the parent of w and w is the child of v if an edge (v, w) exists with $d(v, Sink) < d(w, Sink)$.

A 5-nodes graph and a portion (submatrix) of its associated constrained path-identifying nilpotent adjacency matrix can be seen in Figures 1 and 2, respectively. For example, we want paths from v_1 to v_3 that satisfy constraints C = (40,27,30,40).

The $\mathfrak{C}$-constrained path-identifying nilpotent adjacency matrix Ψ represents an algebra homomorphism via

$$\omega_{v_i} \mapsto \sum_{\ell} \langle v_i|\Psi|v_\ell\rangle. \tag{1}$$

This extends inductively to the full algebra $\mathcal{A}_{\mathfrak{C}} \otimes \Omega_n$ by linear extension of

$$\omega_{\mathbf{p}.v_i} \mapsto \omega_{\mathbf{p}} \sum_{\ell} \langle v_i|\Psi|v_\ell\rangle. \tag{2}$$

Dirac notation is extended to $(\mathcal{A}_{\mathfrak{C}} \otimes \Omega_n)^{|V|}$ by linear extension of

$$\langle \xi^{\mathbf{a}} \omega_{\mathbf{b}} | := \xi^{\mathbf{a}} \omega_{\mathbf{b}} \langle \mathbf{b}_{|\mathbf{b}|} |. \tag{3}$$

Four step paths from v_1 to v_3 satisfying $w \leq \{40, 27, 30, 40\}$ are :

1) $\upsilon^{\{13,24,16,33\}}\ \omega_{\{1,2,6,4,3\}}$
2) $\upsilon^{\{15,20,18,33\}}\ \omega_{\{1,2,6,5,3\}}$
3) $\upsilon^{\{27,22,29,22\}}\ \omega_{\{1,4,6,5,3\}}$

The minimum cost is $\upsilon^{\{13,24,16,33\}}$ with path $\omega_{\{1,2,6,4,3\}}$. And the highest cost but still satisfy the constraints given is $\upsilon^{\{27,22,29,22\}}$ with path $\omega_{\{1,4,6,5,3\}}$.

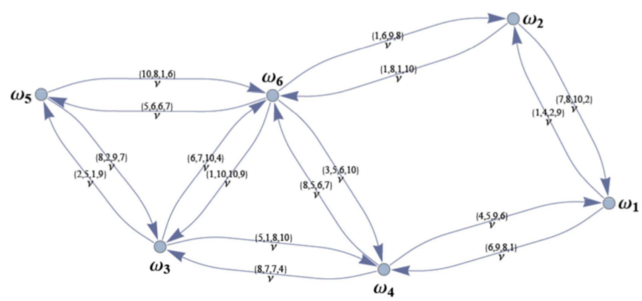

Fig. 1: A 5 nodes graph.

$$\Psi = \begin{pmatrix} 0 & \overset{\{1,4,2,9\}}{\nu}\omega_{\{2\}} & 0 & \overset{\{6,9,8,1\}}{\nu}\omega_{\{4\}} & 0 & 0 \\ \overset{\{7,8,10,2\}}{\nu}\omega_{\{1\}} & 0 & 0 & 0 & 0 & \overset{\{1,8,1,10\}}{\nu}\omega_{\{6\}} \\ 0 & 0 & 0 & \overset{\{5,1,8,10\}}{\nu}\omega_{\{4\}} & \overset{\{2,5,1,9\}}{\nu}\omega_{\{5\}} & \overset{\{6,7,10,4\}}{\nu}\omega_{\{6\}} \\ \overset{\{4,5,9,6\}}{\nu}\omega_{\{1\}} & 0 & \overset{\{8,7,7,4\}}{\nu}\omega_{\{3\}} & 0 & 0 & \overset{\{8,5,6,7\}}{\nu}\omega_{\{6\}} \\ 0 & 0 & \overset{\{8,2,9,7\}}{\nu}\omega_{\{3\}} & 0 & 0 & \overset{\{10,8,1,6\}}{\nu}\omega_{\{6\}} \\ 0 & \overset{\{1,6,9,8\}}{\nu}\omega_{\{2\}} & \overset{\{1,10,10,9\}}{\nu}\omega_{\{3\}} & \overset{\{3,5,6,10\}}{\nu}\omega_{\{4\}} & \overset{\{5,6,6,7\}}{\nu}\omega_{\{5\}} & 0 \end{pmatrix}$$

Fig. 2: Sub-matrix of 5 nodes constrained path-identifying adjacency matrix.

The proposed algorithm, called path operator calculus centrality (POCC) which is inspired by betweenness centrality, estimates the number of optimum paths traverse a given node. A node with high value of centrality is more probably to be installed on the main paths, instead shortest paths, between multiple node pairs and therefore more information needs to be relayed through this node. In addition, this node takes an important part in the connectivity of the network.

The POCC of a vertex v in a graph $G = (V, E)$ with V vertices is estimated as follows:

1) For each pair of vertices (s, t), calculate the optimum paths between them, in this case the total maximum of energy and the minimum of bit error rate (BER).
2) For each pair of vertices (s, t), define the fraction of optimum paths that traverse vertex v.
3) Sum this fraction over all pairs of vertices (s, t).

For the shake of understanding, this work has assumptions as follows:

- The base station (BS) or the sink node is located at the center of network.
- Sensor nodes (SN) have different of energy level and Bit Error rate (BER).
- Range communication (R_c) and Range sensing (R_s) are remain the same for all sensor nodes (SNs).
- The calculation of Path Operator Calculus Centrality (POCC) is running at BS.

In the literature of recent studies [25], [28], [29], it is known that betweenness centrality plays an important role in the traffic on a network. For a given network, the path operator calculus centrality (POCC) of a node v is defined as:

$$POCC(v) = \sum_{s \neq v \neq t \in V} \frac{\sigma_{st}(V)}{\sigma_{st}} \tag{4}$$

where σ_{st} is the number of optimum paths going from source node s to node t, in this case t is the sink node; and $\sigma_{st}(V)$ is the number of optimum paths going from s to t and passing through node v.

Figure 3 shows a sample nodes deployment in random fashion. The size node presents the centrality score. The bigger size means bigger score. Figure 4 presents the main path in the topology which contains of the best of centrality nodes.

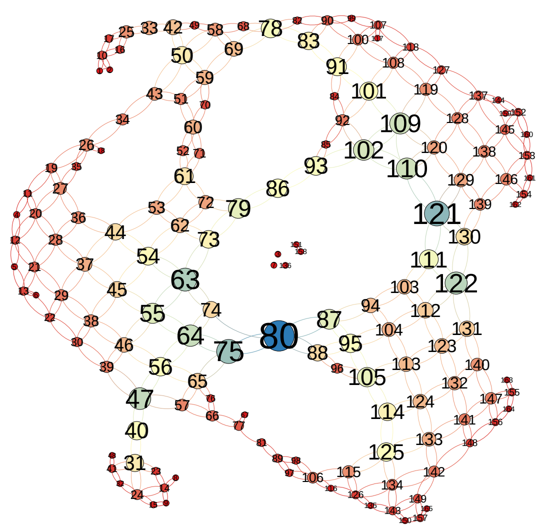

Fig. 3: Sample random deployment nodes.

Energy depletion could happen to each sensor node in a WSN which leads to dead node. Consequently, the topology changes in the network. Figure 5 and 6 depict the topology changes in a WSN. As seen in Figure 5, since node 25 is the most important node in this topology, it means that node 25 has the highest centrality score followed by its neighbor nodes (node 20, 21, 30). While node 25 is dead, not only the topology changes, but also the centrality. If the centrality score is recalculated, we will obtain the new centrality nodes as seen in Figure 6. Now, node 34 becomes the most important node in the network followed by node 30 and 29.

Table I presents the Top 10 nodes centrality of Betweenness Centraliy (BC), Closeness Centrality (CC) and Path Operator

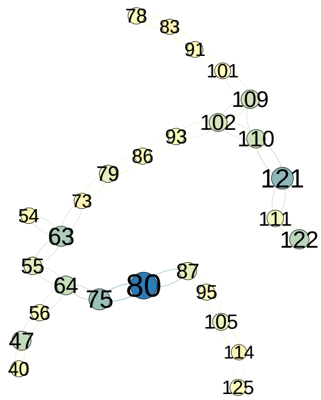

Fig. 4: Sample the main path on a WSN.

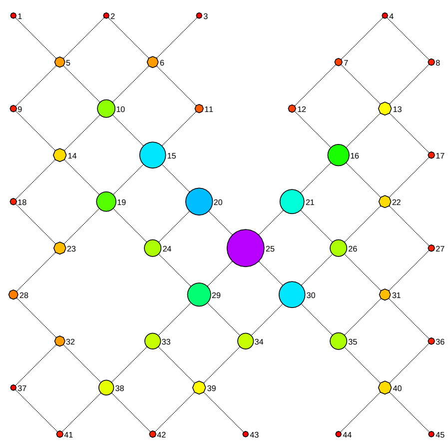

Fig. 5: Topology before updating.

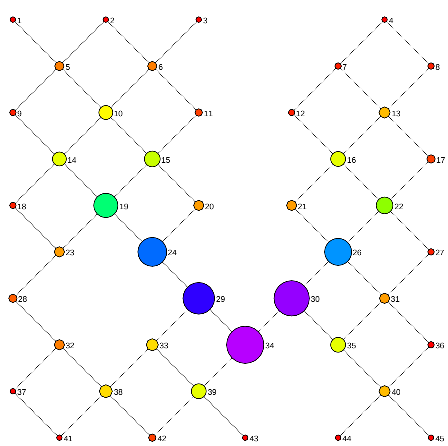

Fig. 6: Topology after updating.

Calculus Centrality (POCC) based on the topology in Figure 7 where the base station (BS) is located on the left bottom of network in grid topology manner.

B. The Routing Strategy

In network model, the number of sensor nodes is denoted by n. All sensor nodes could be treated as both sensors and routers for sensing and relaying data packets. Each wireless link is remain the same of packet delivery capacity. Due to the low data rate in WSNs, it is assumed that each node has enough ability to process and transmit or handle the data packets in its receiving buffer. Transport on the network runs in discrete time steps and is driven by inserting new data packets per time step at the source nodes randomly. And at each time step, every node transmits the data packets one step via intermediate nodes toward the base station (BS) according to the fixed routing table which defined by operator calculus strategy.

TABLE I: The top 10 nodes present the centrality measure.

BC	CC	POCC
60	1	1
69	128	2
53	8	10
61	113	7
68	121	26
76	16	18
52	2	24
77	17	32
44	127	41
70	112	50

Since we use grid topology in our deployment, the operator calculus approach offers several optimum paths for each sensor node (SN) to base station (BS). A sensor node (SN) might have several optimum paths which each path has its score. With this way, BS can classify and keep them in its table for future use such as route recovery.

However, what we have proposed here could be extended to other general cases, such as random or heterogen topology, and location of BS.

C. The Protocol Phase

The proposed protocol could be divided into three phases: Grids formation phase, routing establishment phase and maintenance phase. This section presents deeply each phase in the next section.

1) Phase of Grids Formation: A given sensing area can be illustrated as grids formation. The proposed approach uses grids topology to deploy a wireless sensor network since sensor nodes are remain the same of range communication (R_c) and range sensing (R_s).

Initially, the proposed protocol divides the sensing area logically into squared-shaped grids form. The sensor nodes are deployed in grids formation, where a sensor node is placed on a unit grid square of $10\ m \times 10\ m$ in the area of $100\ m \times 100\ m$. According to [33], the grids topology is the best reliability than the other topology. Although, there are some approaches that have been proposed which also create paths toward the sink, the proposed algorithm is distinguished for two reasons. Firstly, the idea of dividing the sensor area into grids form in order to build diagonal paths from each grid toward the BS. Secondly, the proposed mechanism, takes into account the density of sensor nodes as a decision factor in data forwarding.

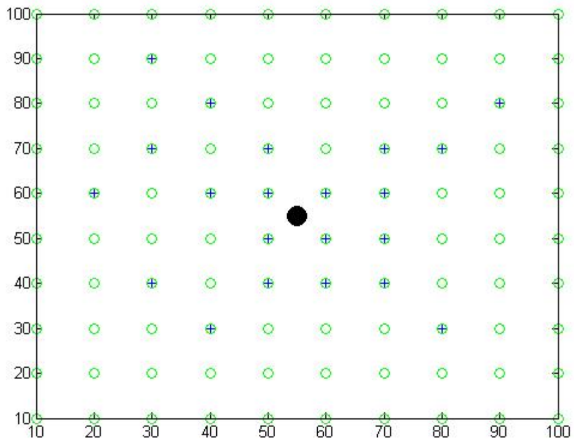

Fig. 7: Grids formation with POCC nodes.

Algorithm 1 Grids Formation

Data In: POCC Scores
for $line = 1$ **to** N **do**
  for $col = 1$ **to** N **do**
    $checkL = mod(line, 2)$
    $checkC = mod(col, 2)$
    if $(checkL = 0)$ and $(checkC = 0)$ or $(checkL = 1)$ and $(checkC = 1)$ **then**
      S(i).xd=line*10
      S(i).yd=col*10
      S(i).E=Eo
      S(i).POCC=0
      S(i).Score='value'
      S(i).type='Normal'
  */*Define Advance nodes*/*
  for $i = 1$ **to** N **do**
    Identification of Normal nodes.
    Assign POCC Score for each sensor nodes.
    if S(i).Score > Treshold **then**
      S(i).POCC=1
      S(i).type='Advance'

In order to ensure the connectivity, the grid size must satisfy the relation $R = R_s = R_c$; where R is the grid size, R_s and R_c are the sensing and the communication range of sensor respectively. This ensures that each sensor node is capable of communicating with any node in any neighbor grids.

Figure 7 shows the grid formation of deployed sensor nodes based on Algorithm 1. There are two types of nodes in this topology, i.e. normal node (N) and advanced node (A). Normal node is a common sensor node, and on the other side, advance node is a node which is selected by base station (BS) based on POCC score.

The difference between the proposed algorithm with the others is in defining advance node and cluster head (CH) or master head. Most of routing algorithms select the advance node randomly. However, the proposed routing algorithm selects the advance node based on its POCC value according equation as follows:

$$Adv(i). = \begin{cases} 1, & \text{if } S(i).POCC > Thresh \\ 0, & \text{Normal} \end{cases} \quad (5)$$

Then for each advance node selected, it will have energy greater than normal nodes defined by:

$$S(i).E = E_0 \times (1 \times \alpha) \quad (6)$$

where E_0 is initial energy for all nodes and α is value for heterogenity of energy.

2) Phase of Routing Establishment: Once sensor nodes deployed, the base station (BS) performs centrality estimation of each node based on the operator calculus. In this case, the constraints which take into account in determining the centrality index are the energy and bit error rate (BER) level of sensor nodes (SN).

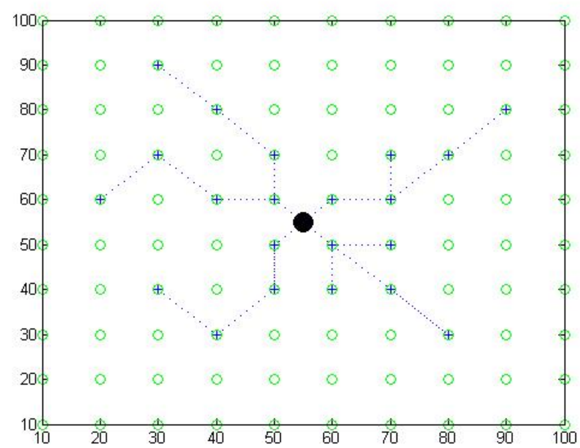

Fig. 8: The main path formation.

Since BS runs procedure of path operator calculus centrality (POCC) estimation, it produces the optimum paths for each sensor node (SN) to reach destination, in this case the sink node.

After the grids formation phase is done, the next phase is routing establishment (see Algorithm 2. First, since BS has all information for resources, including POCC score, BS sends setup message to sensor nodes. While a sensor node (SN) receives a setup message, it will check $Node\_ID$. If $Node\_ID$ is true, it will keep the values of format message then records its parent and child nodes. Otherwise, sensor node (SN) forwards the setup message.

POCC establishes the main paths from all advance nodes which defined by BS. In this case, BS sends setup message by multicast to all advance nodes. Figure 8 shows the main path or the central path of network which contains advance nodes with POCC score higher than threshold.

The cluster tree is formed by keeping track of the parent-child relationship among Advance nodes, and it is guaranteed to be connected as new child nodes are selected from neighbors of existing Advance nodes. The cluster tree network in this case is a multi-hop. As nodes join to the network, the nodes with which they communicate during the network association process is defined as the parent, the joining node becomes the child of the parent node. For example, see Figure 7 and 8, node 14, located at (40,20), becomes child of the parent node 24, located at (40,30), since node 24 is the shortest parent node of node 14.

Algorithm 2 Path Establishment

BS sends setup message to SNs.
while a SN receives a setup message, it will check $Node\_ID$ **do**
  if $Node\_ID$ = True **then**
    SN keeps its information.
    SN records its parent and child nodes.
  else forward the setup message.

3) Phase of Maintenance: In WSN, maintenance phase is more difficult than the other phases due to the nature of deployment. However, it might be possible to reprogram the deployment phase, consume resources and add uncertainty.

While a failure node do occurs, an error message sends to BS, then BS will perform a local search in its routing table to re-select a new Advance node and re-create a new path. Furthermore, see Algorithm 3.

Algorithm 3 Path Recovery

while a SN detected a broken link since it failed to transmit a data packet. **do**
  for each S(i) **do**
    if S(i).E = 0 **then**
      if S(i).type = 'Advance' AND S(i).POCC = 1 **then**
        Send error message to BS.
        BS performs a local search to find the optimum path in the second class.
        BS re-selects a new Advance Node.

In the proposed protocol, the maintenance phase supports the network longevity. The energy to be consumed with k-bit data transmitted to a target node for the distance of d can be expressed as:

$$E_{Tx}(k,d) = \begin{cases} k * E_{elec} + k * \varepsilon_{fs} * d^2, & d < d_0 \\ k * E_{elec} + k * \varepsilon_{fs} * d^4, & d \geq d_0 \end{cases} \tag{7}$$

Where the threshold distance d_0 is: $d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$

The energy to be consumed with the k-bit data received by a sensor node is: $E_{Rx}K = k * E_{elec}$.

Equation 7 defines the energy consumption during data transmission is obtained from two transmission models; ideal transmission model for a transmission distance less than the threshold distance ($d < d_0$) and multi-access interference model for a transmission distance bigger than the threshold distance ($d \geq d_0$). Furthermore, E_{elec} is the energy consumed in the communications module and required by amplifiers in two different types of transmission modes.

The proposed algorithm assumes that each node has a limited radio enough to directly reach its neighbor only in 1 hop, with this way, it could save the energy.

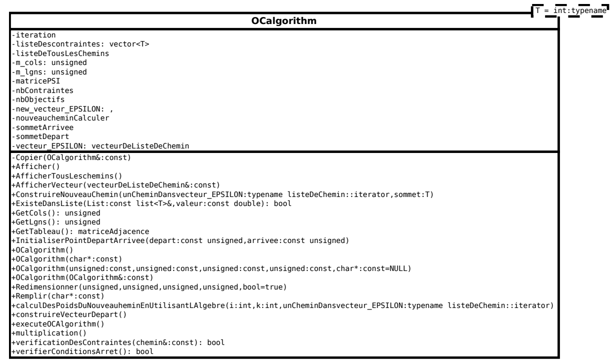

Fig. 9: Class Operator Calculus.

IV. Results and Analysis

The operator calculus algorithm were implemented in C++ on a PC Desktop 2.13 GHz with 4 GB running on Linux. Figure 9 depicts the class of operator calculus algorithm. Table II shows the parameter simulation used in this scenario. The network environment with the field size of $100\ m \times 100\ m$ in which 100 sensor nodes are installed. The BS is located in the center of sensing area. In order to show the efficacy of the proposal POCC, four main routing algorithms are used as benchmarks i.e. LEACH [1], SEP [4], Z-SEP [34], and TEEN [35]. The simulation results have been compiled and compared, running a simulation for 10 times. The performance measured in this scenario are alive node, dead node, packets to BS, average energy and network lifetime, as seen in the Figure 10, 12, 15 and 17. In general, as seen in Table III, it is clear that POCC, when compared with other routing algorithms, performs quiet good. In terms of number of alive node, SEP routing algorithm is the lowest, followed by LEACH, Z-SEP and TEEN respectively. In this scenario simulation, POCC has the highest in terms of number of alive node. Moreover, the rank result is remain the same in terms of average energy residual. However, in terms of average packets to base station, LEACH sends the lowest number of packets to the sink, followed by SEP, TEEN, and Z-SEP respectively. POCC produces more number of packets than the others to send to the base station, due to it provides a reliable path to the BS and keep the connectivity between nodes.

TABLE II: Global Simulation Parameters

Parameter	Value
Simulation Area	$100\ m \times 100\ m$
Number of nodes	100
Initial energy	0.5 J
Energy aggregation (E_{DA})	5 nJ/bit
E_{elec}	50 nJ/bit
ε_{fs}	10 pJ/bit/m^2
ε_{mp}	0.0013 p/bit/m^4
Cluster Head Prob.	0.1
Heterogenity Prob.	0.1
α	2
Data packet size	4000 bit
Data Aggregation	0.6
Routing Algorithm	LEACH, SEP, Z-SEP, TEEN, POCC
Simulation Round time	10000

TABLE III: Statistics Data Comparison

	LEACH	SEP	Z-SEP	TEEN	POCC
Alive Nodes	15.33	14.5	20.86	21.99	30.26
Dead Nodes	84.67	85.5	79.14	77.31	69.74
Packet to BS	39550	59850	183200	127200	234700
Avg. Energy (J)	0.05323	0.04568	0.07472	0.08060	0.14970

A. Alive and Dead Node

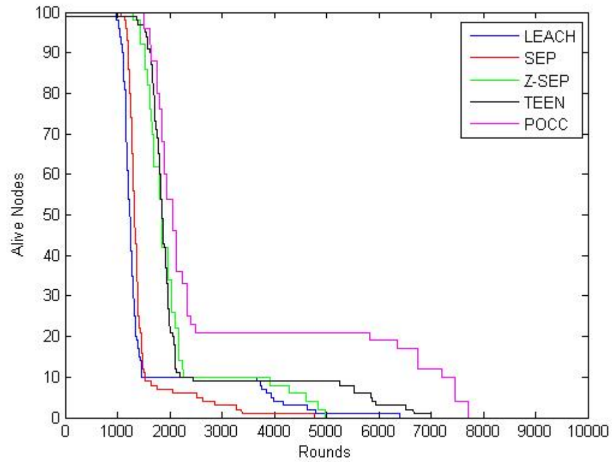

Fig. 10: No. of alive nodes vs No. of rounds during simulation.

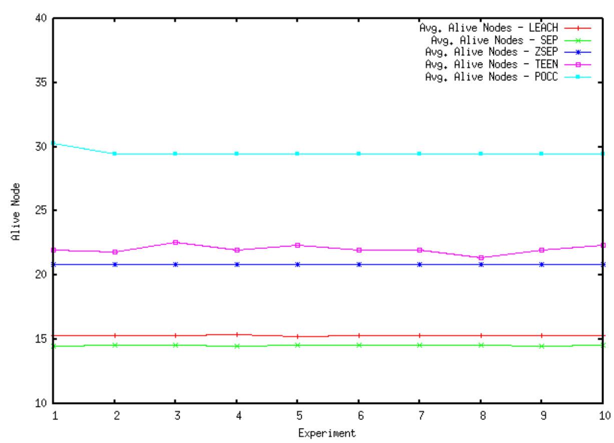

Fig. 11: Average of alive nodes recorded at the simulation experiment.

Figure 10 shows the alive and dead nodes during the simulation. In general, the proposed algorithm outperforms the comparators. As seen in the figure, LEACH, SEP, Z-SEP and TEEN have alive nodes decrease along with round time simulation. On the other side, the proposed routing algorithm, POCC, can keep all sensor nodes alive till close to 1500 rounds times of simulation. The same things with Figure 12, Figure 13 presents the dead nodes during the simulation period. Due to random method of comparator algorithms when selecting the advance node and cluster head (CH) in one round, it makes

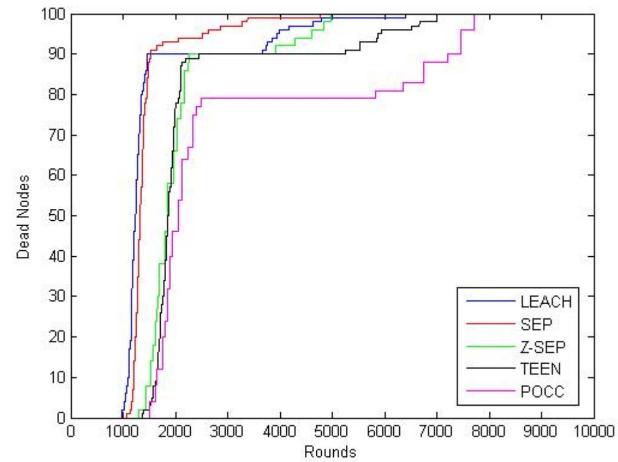

Fig. 12: No. of dead nodes vs No. of rounds during simulation.

the selected nodes drain its energy quickly since it relays all the packets to BS only in one big hop. Such as LEACH, SEP and Z-SEP, they choose the cluster heads arbitrary in size and some of the cluster members are could be located far away. Due to this dynamic cluster formation, the farther nodes suffers through high energy drainage and thus, network performance degrades.

It is clear to see that network lifetime is improved quiet significantly when compared with other algorithms, i.e. LEACH, SEP, Z-SEP and TEEN, POCC performs much better. In this case the network remains alive almost 7800 rounds assuring network lifetime to be more optimized. Furthermore, it is also obvious that stability period is also enhanced i.e., first node dies around 1500 rounds whereas, in routing algorithms like LEACH, SEP, Z-SEP and TEEN, this value is much lower.

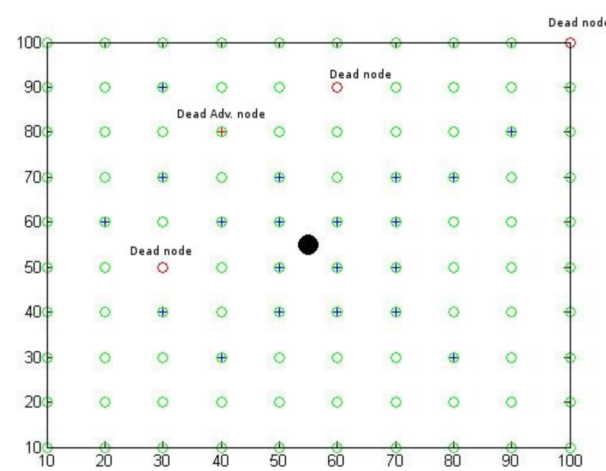

Fig. 13: Topology when advance and normal nodes dead occur.

Figure 13 and 14 depict the condition while advance node and some normal nodes are dead and the average of number of dead nodes recorded during the experiments, respectively.

All the results have been performeed over 10 runs in order to respect a confidence interval of 95%.

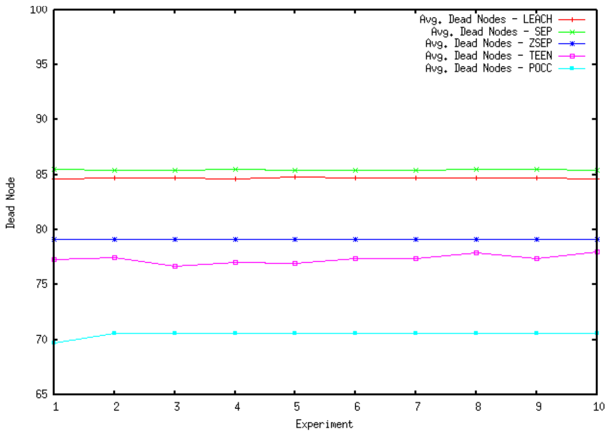

Fig. 14: Average of dead nodes recorded at the simulation experiment

B. Packet to Base Station

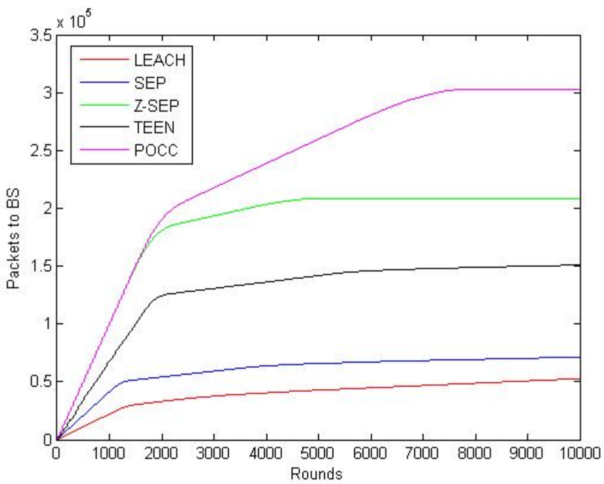

Fig. 15: No. of packets to BS vs No. of rounds during simulation.

Figure 15 and 16 present the average number of packets transmit to the sink node. Figure 17 and 18 depict the average energy level of sensor nodes vs No. of round simulation. Since the proposed algorithm has more advance nodes which already defined by the BS based on its centrality score, then they have more energy level than the normal nodes. On the other hand, the comparator algorithms use a probability to define an advance node. In addition, protocols such as LEACH and TEEN, they don't choose a node became cluster head twice during the simulation.

C. Average Energy

We have compared the proposed POCC with LEACH, SEP, Z-SEP and TEEN at initial energy E_0 = 0.5 J. POCC selects

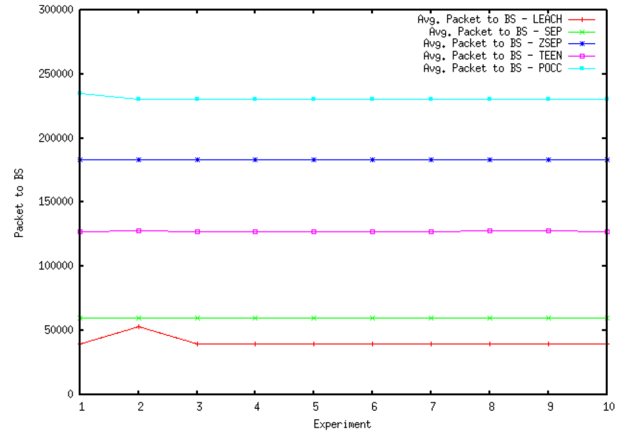

Fig. 16: Average of packet send to the BS recorded at the simulation experiment.

the respective cluster head on the basis centrality index which results optimum path for clusters communication for cluster head (CH) to BS. This shows that POCC has greater lifetime of network field in comparison to other routing algorithms. As all the operations are performed by the BS which takes decisions for selection of a sensor node as cluster head. Hence, the results are better in the proposed algorithm as compared to other routing approaches.

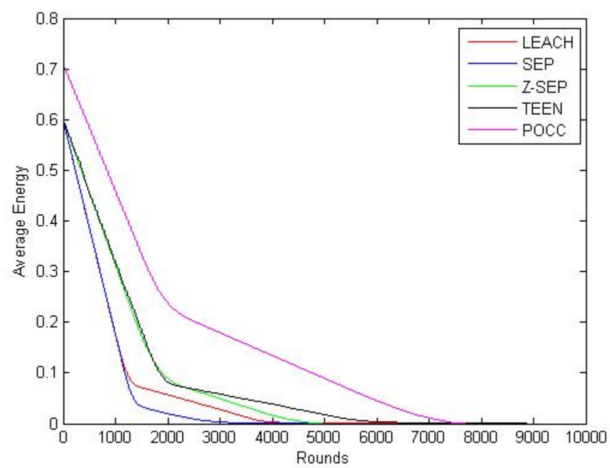

Fig. 17: Average of energy vs No. of rounds during simulation.

D. Network Lifetime

Some energy-aware works [30], [31], [32], [36] and [37] are designed to adequately prolong the longevity of WSNs.

Network lifetime is refers to time until the first sensor node in a WSN runs out of its energy. When a node dead occurs in the network, then it will not be the part of the network. If a dead node occurs in the earlier, it may affect to the lifespan of the network and drag toward the early dead of all nodes.

Table IV provides the average of the time when the first dead node of each routing algorithm occurs in the topology. It

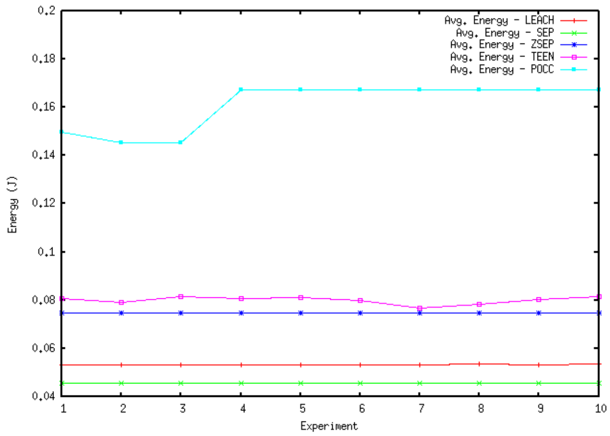

Fig. 18: Average of energy recorded at the simulation experiment.

TABLE IV: Network Lifetime

Protocol	First Dead Node at (r)
SEP	1109
Z-SEP	1286.75
LEACH	998.25
TEEN	1427.75
POCC	1573.75

shows that LEACH has the shortest network lifetime and then followed by SEP, Z-SEP and TEEN. The proposed algorithm, POCC, has the longest network lifetime since it applies the optimum path based on operator calculus.

The reasons for all of this phenomenons are, first, since POCC employs operator calculus approach which is concern with energy level when defining an optimum path from source to BS, it means that POCC used only single hop between each sensor node and multi-hop to transmit a packet data. With this way, each node only consume a small energy to transfer a packet data 1 hop to its parent or neighbor. Second, POCC keeps the density and the connectivity between each sensor node since a sensor node has some feasible paths to its destination.

V. Conclusion

In this study, we proposed a routing algorithm which is based on operator calculus to keep connectivity, coverage and energy aware approach to improve nodes' energy dissipation and enhancing the network lifetime. It can be shown from simulation results that a sensor network based on connectivity and path centrality has longer lifetime. For the next research in the future, other factors such as obstacles, load balancing, stability, reliability or other social network analysis should be concerned in order to enhancing the reliability and fault tolerant of proposed scheme.

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