CHAPTER 4

THE DESIGN OF 3D EUCLIDEAN DISTANCE

4.1 Introduction

Wireless Sensor Networks (WSNs) are composed of a large number of sensor nodes that cooperatively monitor physical or environmental conditions and transmit the gathered data to the sink node. The WSNs have garnered much attention from the academic arena to assess their growing applications in several essential domains in recent years. For instance, the sensor nodes in WSN can be used to observe a physical phenomenon, such as temperature monitoring in some areas. Although WSNs continuously sense and report information within a dynamic setting, the energy supply for each sensor node is limited. Deriving the 3D Euclidean Distance between two nodes involves computing the square root of the sum of the squares of the variances between the corresponding values in the cluster. The 3D Euclidean Distance refers to a clustering algorithm that considers the energy between the neighbour node of correlated degree (ζ) and the topological features, mainly to enhance the network connectivity in WSNs.

The 3D Euclidean Distance was applied in this study to construct clusters. The 3D Euclidean Distance connects all source nodes to another node in order to maximise data, while minimising the distance that connects each coordinator node to the cluster. The correlation degree that densely deploys sensor nodes can generate data with correlated degree (ζ). Hence, the distance between the nodes determines the degree of correlation. Due to high distance in the network topology, sensor observations are highly correlated with the degree of correlation, which increases with the decreasing internode separation. A correlation degree relies on the parameter of the phenomenon. As such, this study proposes a scheme that 3D Euclidean Distance based on degree correlation of the data in WSN. The sensing nodes are used to sense the physical attributes in order to report their position coordinates (x, y, and z) and the sensed value to the nearest node degree. Another set of nodes, categorised as the degree nodes, is responsible to generate correlated degree of the received data and transmit the coefficients of regression to the parent node degree.

The query from the sink node receives data collected by the sensor nodes degree that is generated by the root node of the degree in each cluster to compute the attribute value at any location within the boundary. With such correlation degree design, the number of transmissions of sensor node is significantly reduced. Under correlation degree, the forwarder set selection and the clustering algorithm prioritise low correlated nodes in order to increase the level of diversity, while ensuring that the neighbouring nodes are close enough to each other so that the forwarded packets would be heard and duplicates avoided.

4.2 Correlation Degree

This study derived a correlation degree dynamic and scalable snoring node structure for data collection, as well as a cluster head (CH) in WSNs. In order to achieve excellent network connectivity of WSN, its applications require degree-dense deployment of sensor nodes that should lead to a single event being recorded by several nodes. This causes the sensor observations to have correlation degree (Villas, Boukerche, De Oliveira, De Araujo, & Loureiro, 2014). Correlation nodes, upon being close, tend to detect similar values. However, such closeness, based on the 3D Euclidean Distance between the different nodes that might detect similar values, depends on both application requirements and event parameters. In two different and unrelated application areas mobility measurement and correlation of degree voting theory and propose our parameters as a test for deciding whether 3D Euclidean distance is a suitable should use in the network connectivity of the clustering in wireless sensor networks. Some applications are more critical and less tolerant to discrepancies in the sensed values on the observed phenomenon, thus requiring the closer nodes that notify sensed data in the correlation region to be smaller. Other applications may be more tolerant to discrepancies in the sensed values, despite not demanding the closer nodes to report the sensed data in the correlation region to be greater. This is because; the correlated node behaviour has an important role in the network performance of wireless network. The 3D Euclidean Distance between two nodes in either the plane or n-dimensional space measures the length of a segment that connects the two nodes. In this study, CHs were selected correlated degree at first and then adjusted based on the sensor node to remain the distance. Hence, the applications are restricted to highly correlated environments and the construction of sensor node takes several rounds in the cluster, justify because it will consume more energy whereby the message may change to misbehaviour nodes.

4.2.1 Correlation Region

In a highly correlated region, the correlations between sensor nodes are determined predominantly only by their degree of distance (Villas et al., 2014). The approach defines a weight for each sensor node when data are sent, which depends on the distance from CH to target sensor node. This defines a correlation region as an area where the values sensed by the sensor nodes are considered similar to the application. Hence, a single reading within this region is sufficient to represent it. The size of the correlation region varies according to both application and event type. When a node sends data to another node that is initially correlated and receives no acknowledgement, that node will increase its correlation degree range, and this can be an effective measure since many nodes with high degrees also have high centrality by other measures, until the minimum amount of neighbours is discovered. For parameters that change significantly at a short range, the sink node should decrease the size of the correlated region; this event has to be notified by the closer nodes. When the parameters do not change significantly at short range, the sink node can increase the size of the correlated region, After clustering the nodes that detected the same event, each node checks the cell it belongs to in the event area. Each section is represented by an ordered pair (0, 1), as depicted as illustrated in Figure 4.1.

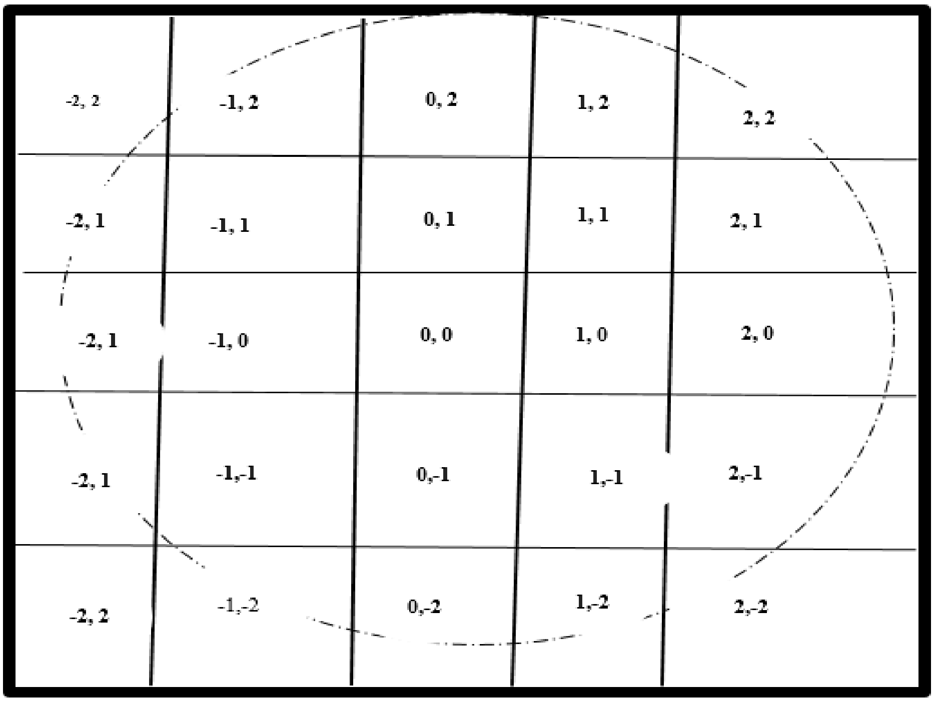

Figure 4.1: Correlation Region

The nodes can be classified based on their roles in the created correlations infrastructure:

- Neighbour node: An orange node that is currently detecting one or more events. If its sensed data are redundant, it will not report the gathered data.
- Representative node: A blue node blue is detecting an event and is reporting the gathered data to a coordinator representing itself and all nodes with similar readings.
- Coordinator: A yellow node that is also detecting an event and is responsible for gathering all the data events sent by representative nodes, aggregating them and sending the result to the sink node.

- Aggregator: A green node that aggregates data from two or more sources representative or coordinator nodes and forwards the aggregated data. It might or might not be detecting an event.
- Relay: A black node that forwards data to the sink.
- Sink: A red node interested in receiving data from a set of coordinator nodes.

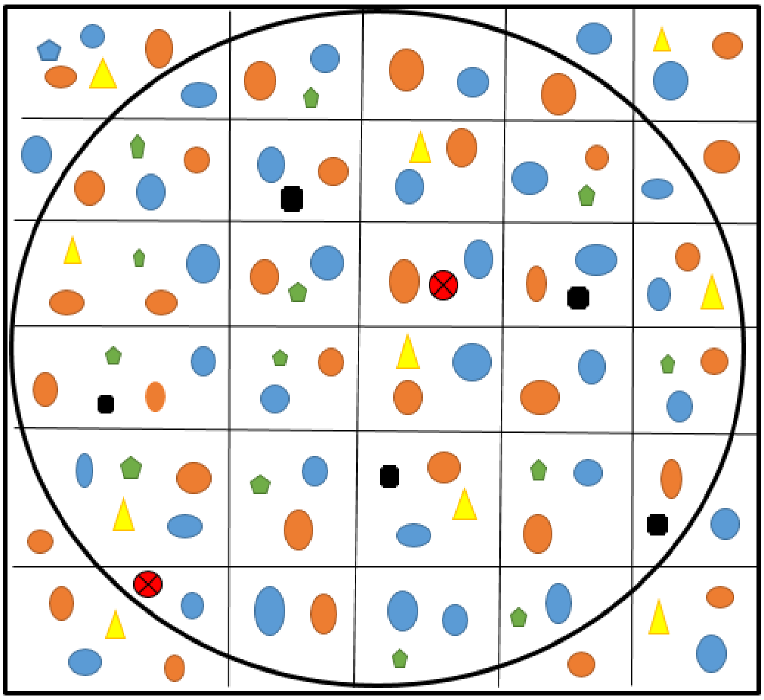

Figure 4.2: Neighbouring nodes

This method builds a sensing and correlated degree (ζ) using the shortest sensors in 3D Euclidean Distance that connect all coordinator nodes to the sink node, while maximising data and reducing distances that connect each coordinator node to the sink. First, a single neighbour node is selected at each cell of 2D Euclidean Distance for each notification. Figure 4.2 illustrates the neighbouring nodes in the event region. The neighbouring nodes selected from the set of neighbour nodes refer to nodes with fewer notifications loss ratio the nodes belonging to the same CH. If there is a tie, the neighbouring node will become the node with higher energy level to transmit data packets containing energy level field.

4.3 Formula 3D Euclidean Distance Based on Correlation Degree

The Pythagorean Theorem can be used to calculate the distance between two nodes in the same plane, in order to determine the degree of correlation. The degree of correlation depends on the misbehaviour node in network variation parameters of the phenomenon, as displayed in Figure 4.3 (where points $(x1, y1)$ and $(x2, y2)$ are in 2D Euclidean distance).

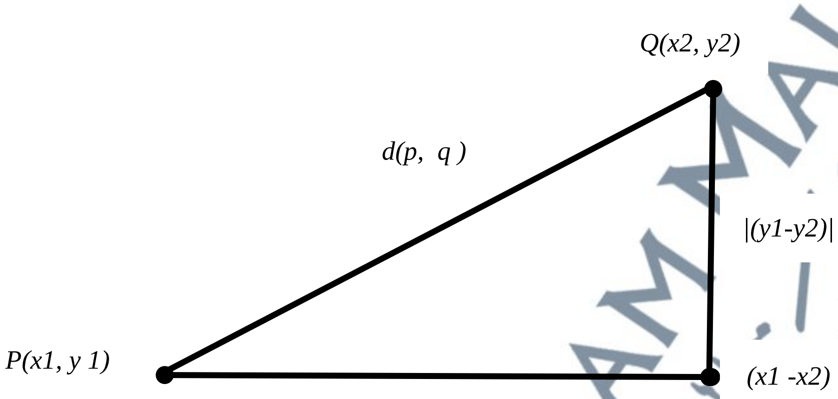

Figure 4.3: Pythagorean Theorem

In order to ensure that a point in the grid is within range, the distance pseudocode is given in Figure 4.4.

Distance (x, y, x2, y2, range)

If (x2 - x = 0 and y2 – y= 0)

    Return False

Else

    Distance = $\sqrt{(x2 - x)^2 - (y2 - y)^2}$

    If (Distance <= range)

        Return True

    Else

    Return False

Figure 4.4 The Pythagorean Theorem to determine the distance

The distance formula applies the Pythagorean Theorem to determine the distance of two nodes. The algorithm uses the x-y coordinates of the broadcasting node, whereas a neighbouring node to determine the sides of the triangle. Next, the hypotenuse is computed. If the hypotenuse does not exceed the nodes broadcasting range and the node is currently awake, then the node becomes a valid neighbour. After that, the node is added to the list of neighbours of the broadcasting node.

Most studies used 2D Euclidean Distance to test the target area. However, in the real environment, the area to be monitored is not always flat. In some applications where the third dimension and the height should not be neglected, 2D Euclidean Distance monitoring becomes insufficient. Among the applications that require 3D Euclidean distance monitoring include home automation, precision agriculture, fruit tree plantation, olive groves, and environmental monitoring. The 3D Euclidean Distance area monitoring differs from the 2D Euclidean Distance, as recent studies are coping with the former. The goal of both 2D and 3D Euclidean Distance monitoring is to ensure the required coverage of an area, a barrier or a point of interest, and to maintain network connectivity so that at least a path from each sensor node is deployed to the sink (Boufares, N., Khoufi, I., Minet, P., Saidane, L., & Saied, 2015).

The goal of this study, in particular, is to ensure full 3D Euclidean Distance area coverage while maintaining network connectivity. Hence, each detected event in the 3D Euclidean Distance area can be reported to the sink. This study anticipated that the 3D Euclidean Distance in network clustering of WSN meeting these properties (Boufares, N., Khoufi, I., Minet, P., Saidane, L., & Saied, 2015). Many researchers have focused mainly on theoretical studies, especially on 3D Euclidean Distance in WSNs, in which the best node placement is predetermined to gain the desired outcomes. Nonetheless, some studies had been based on autonomous and static sensor nodes to design network clustering.

The sensing nodes sense the physical attribute and report their position coordinates (x, y, z), while the sensed value to the nearest degree node. This defines the distance between nodes $i \, and \, j$ by the 3D Euclidean Distance between (x, y, z), where $x(x_1, x_2), y(y_1, y_2), z(z_1, z_2)$. The distance between points (x_1, y_1, z_1) and (x_2, y_2, z_2) in 3D Euclidean Distance is presented in Figure 4.5.

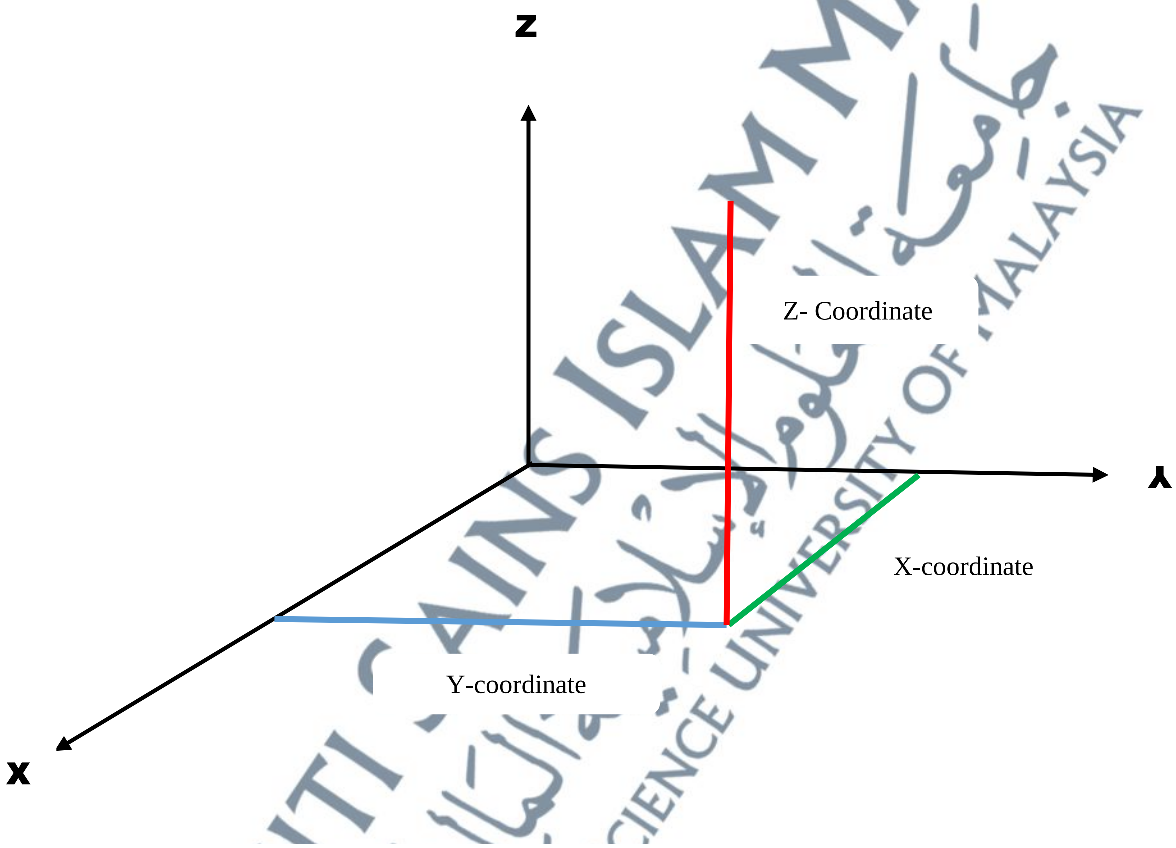

Figure 4.5: The 3D Euclidean Distance

In order to solve and calculate the result, which refers to the required distance between two points, the correlated degree (ζ) has to be determined. The expected value of 3D Euclidean Distance found between points $P \, and \, Q$ is $d(P, Q)$. The distance formula in 3D Euclidean Distance is given in Equation 4.1 in ζ values of correlated degree (ζ).

$$d(P,Q) = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 (z_2 - z_1)^2} \tag{4.1}$$

The node degree is determined by calculating the distance between the nodes in correlated degree (ζ), with other nodes within its communication radius. A predefined communication radius of all the nodes defines the distance between two nodes via 3D Euclidean distance. The correlated degree (ζ), considers the average of degree distance deviation between each node and its neighbours within a predefined communication range. Therefore, the large or the smallest value of degree implies small distance variation between a node and its neighbours, indicating a high correlation degree with its neighbours.

4.4 Correlated Degree Calculation

The distance formula in 3D Euclidean Distance is quite similar to that in 2D Euclidean Distance. The distance formula in 3D Euclidean Distance is the square root of the sum of squared differences of x, y *and* z coordinates of both points. In 3D Euclidean Distance, there is a standard Cartesian coordinate system (x, y, z) starting with a point that is known as the origin, which is composed of three mutually perpendicular axes; $x-$axis, $y-$axis, and $z-$axis. For instance, two sets of coordinates in 3D Euclidean Distance Cartesian coordinate system, (x_1, y_1, z_1) and (x_2, y_2, z_2) are used to calculate the distance between the three nodes or points.

4.4.1 3D Euclidean Distance Formula

The distance between two nodes or points refers to the length of the path that connects them. The shortest path distance is a straight line. In 3D Euclidean Distance, the distance between nodes or points (x_1, y_1, z_1) and (x_2, y_2, z_2) is determined. In calculating the distance of vectors in R^3, the distance formula for points in 3D Euclidean Distance is required.

Theorem.1. Assume that the coordinate of vertex P is (x, y, z). The distance, d between points $P(x_1, y_1, z_1)$ and $Q(x_2, y_2, z_2)$ in R^3 is given.

The above formula is used to calculate the distance between the two nodes in 3D Euclidean Distance. Proof of Theorem 1. The next section presents the calculation of correlated degree (ζ) by employing methods similar to those for Theorem 1. In order to prove the special case of Theorem 1, points $P = (x_1, y_1, z_1)$ and $Q = (x_2, y_2, z_2)$ satisfy the following condition.

Next, the expected value of 3D Euclidean Distance can be found between points $P \; and \; Q$, wherein $d(P,Q)$ refers to 3D Euclidean Distance. The distance formula in 3D Euclidean Distance is presented in correlated degree $= \sqrt{(P,Q)}$. The proof of the distance formula in 3D Euclidean Distance is as follows (Theorem 2). For vector $v = (x, y, z)$ in R^3, the magnitude or length of v is Equation 4.2:

$$v = \sqrt{x^2 + y^2 + z^2} \tag{4.2}$$

Evidence

Theorem 1 has been proven in the previous section. The distance, d between two points, $P = (x_1, y_1, z_1)$ and $Q = (x_2, y_2, z_2)$, in R^3 is similar to the length of vector $A - B$, where vectors B and A are defined as $A = (x_1, y_1, z_1)$ and $B = (x_2, y_2, z_2)$. Hence, since $A - B = (x_2 - x_1, y_2 - y_1, z_2 - z_1)$, then $d = \|A - B\| = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$. Figure 4.6 illustrates Theorem 1.

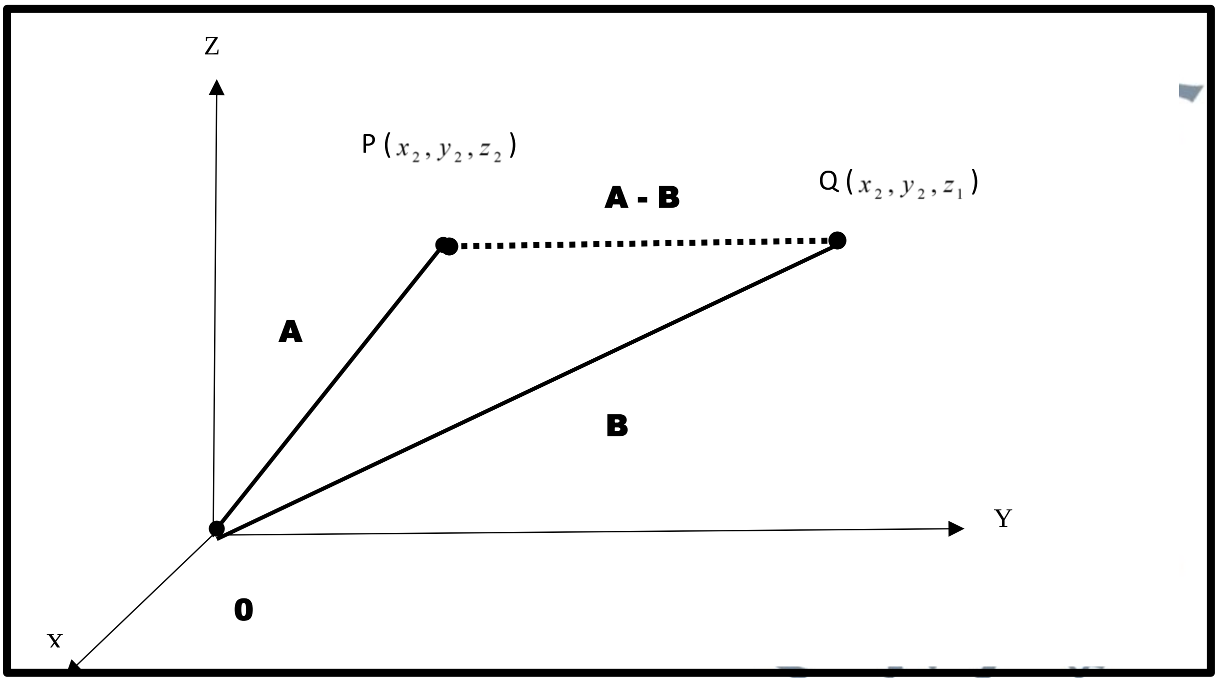

Figure 4.6: 3D Euclidean Distance

4.4.2 The distance between nodes

Each sensor node within the network runs the following algorithm, as preceded by iterations while dismissing node synchronisation. Let a_i represent any sensor node and (x_i, y_i, z_i) be its coordinates. Each node sends its position to perform neighbourhood discovery. Next, each sensor node is able to determine its 1-hop and 2-hop neighbours, apart from computing its new position based on the forces exerted on it by its 1-hop and 2-hop neighbours. Let d_{ij} denote the 3D Euclidean Distance between sensor nodes a_i and a_j. D_{ij} is given by $\sqrt{(x_j - x_i)^2 + (y_j - y_i)^2 + (z_j - z_i)^2}$. The conventional localisation algorithm in 3D WSN uses the estimated distances between the unknown node and some known anchor nodes to calculate the position of the unknown node. Each unknown node has to communicate with at least four neighbouring anchor nodes to obtain the correlated degree (ζ) values. Using a formula, an unknown node can estimate its distance to each anchor node. If there are four or more anchor nodes, the unknown node can use the estimated distance to predict its coordinates.

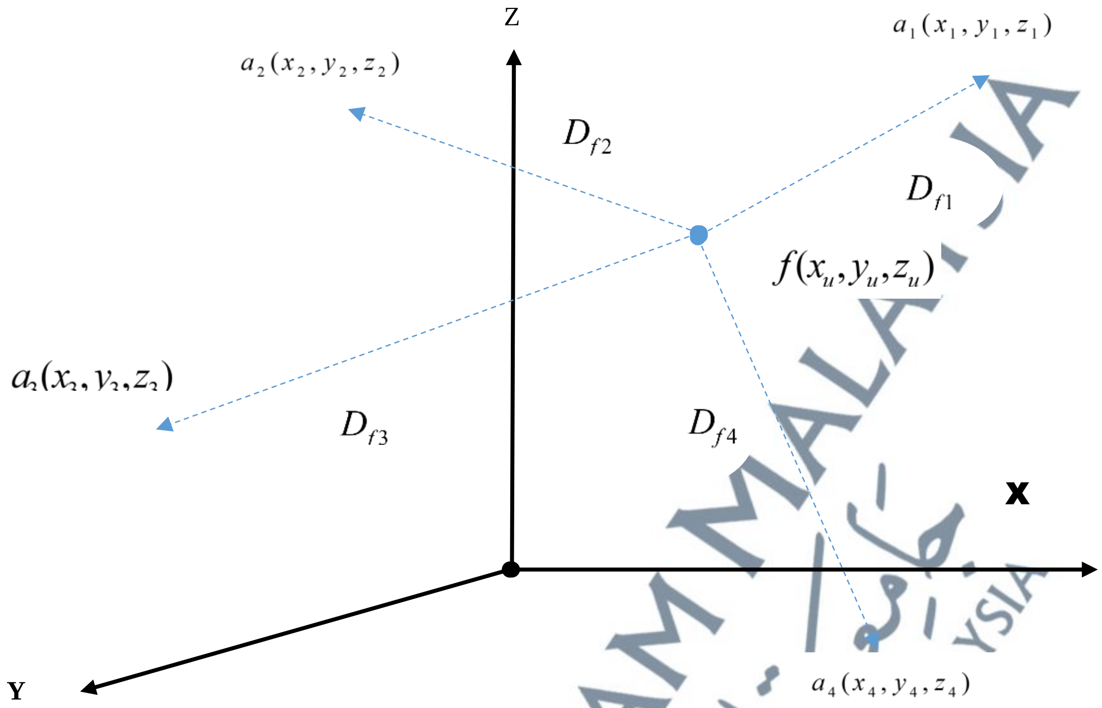

Figure 4.7: The 3D Euclidean Distance

As displayed in the example illustrated in Figure 4.7, the known coordinates of the four anchor nodes $a_1, a_2, a_3\ a_4$ are (x_1, y_1, z_1), (x_2, y_2, z_2), (x_3, y_3, z_3) and (x_4, y_4, z_4), respectively. Every sensor node and a representative sensor node are selected in each merged CH. As these three parameters are measurements in WSNs, sensor nodes can be classified into three types of representative sensor nodes; distance, packet, and energy. The cluster-based networks are applied to select the representative sensor nodes by the undirected graph, whereby the sensor node set is composed of all sensor nodes in the WSN, whereas the edge set consists of all links in the WSN. The antenna of the sensor node is an omnidirectional antenna, with a communication radius as the set of sensor nodes is found within the circle of the communication radius. The coordinates of the unknown node f are (x_f, y_f, z_f). The distances from node f to the four anchor nodes a_1, a_2, a_3, a_4, respectively, are D_{u1}, D_{u2}, D_{u3}, and D_{u4}. Due to estimation errors in these distances, there will also be estimation errors in node f coordinates.

It is common to not to have a solution to Equation 4.3 due to distance estimation error. Rather, the coordinates are estimated as follows:

$$(x_f, y_f, z_f) = \underset{(x_{ff} y_f, z_f)}{\arg\min} \sum_{i=1}^{4} \left| (x_{a_i} - x_f)^2 + (y_{a_i} - y_f)^2 + (z_{a_i} - z_f)^2 - d_{if}^2 \right| \tag{4.3}$$

Since Equation 4.3 is nonlinear equation, an error in distance estimation may result in a larger error in coordinate estimations, especially when node f is not at or near the centre of the region surrounded by the anchor nodes.

The estimated coordinates to measure the distance between four parameters (a_1, a_2, a_3, a_4) of node f can be calculated by solving the following system of nonlinear equations. For any two nodes f and (a_1, a_2, a_3, a_4), their 3D Euclidean Distance is determined as follows:

$$D_{a_i f} = \sum_{i=1} a_{if} (x_i - x_f)^2 + (y_i - y_f)^2 + (z_i - z_f)^2 \tag{4.4}$$

The distance can be expressed by the minimum hop between two nodes and also by the shortest path distance between two nodes or any other distance, such as the 3D Euclidean distance. Equation 4.3 and 4.4 can be applied to calculate the estimated position of unknown target nodes. Hence, mean points (x, y, z) are all on the circle with the radius given in Equation 4.5.

$$D_{a_i f} = \frac{\sum a_{if} (x_i - x_f)^2 + (y_i - y_f)^2 + (z_i - z_f)^2}{\sum a_i} \tag{4.5}$$

4.4.3 Correlation Coefficient (CC)

Assume that WSN in 3D Euclidean Distance is made up of a_1, a_2, a_3, a_4 and f as the anchor node. Consider distance is (D), packet transfer (β), and energy (ℓ). Thus, $D_{a_i f}$ denotes the measured distance between node f and a_1 until a_4 as in Equation 4.6. In order to measure the correlated degree (ζ) based on certain parameters, such as distance (D), packet (β), and energy (ℓ), $(x_{a_i} - x_f)^2 + (y_{a_i} - y_f)^2 + (z_{a_i} - z_f)^2$ should be between one-hop neighbour nodes using the 3D Euclidean Distance method. $x, \; y, \; z$ represent the coordinates of the nodes in 3D Euclidean Distance f and a_1, a_2, a_3, a_4.

$$D_{a_i f} = \sum_{i=1} a_{if} (x_{a_i} - x_f)^2 + (y_{a_i} - y_f)^2 + (z_{a_i} - z_f)^2 \tag{4.6}$$

The correlated degree (ζ) is measured based on Correlation Coefficients (CC), which measure the strength between parameters and correlations in Equation 4.7.

$$\begin{aligned} \beta &= (\beta_{a_i} - \beta_f)^2 + (\beta_{a_i} - \beta_f)^2 + (\beta_{a_i} - \beta_f)^2 \\ D &= (D_{a_i} - D_f)^2 + (D_{a_i} - D_f)^2 + (D_{a_i} - D_f)^2 \\ \ell &= (\ell_{a_i} - \ell_f)^2 + (\ell_{a_i} - \ell_f)^2 + (\ell_{a_i} - \ell_f)^2 \end{aligned} \tag{4.7}$$

The CC is often referred to as the 3D Euclidean Distance correlation test by using a statistical formula that measures the strength between parameters and correlations. In order to determine how strong a correlation is between three parameters, the coefficient value that may range between nodes has to be identified. The three variables are often given coordinates x, y, and z with parameter D_{n_1}. Figure 4.8 displays the correlation between the parameters are related, as represented by values x, y and z in 3D Euclidean distance. The distance is given first, and then, the CC method of determining correlated degree (ζ) is presented. In Relatively small sample is provided in the following examples.

The CC measures the strength of a correlation. The coefficient value can range from 0.0 to 1.0 (Leroux, 1998). A negative coefficient value reflects the negative correlations between the parameters (distance, packet, and energy), or as one value increases, the other decreases. On the contrary, positive range means positive correlations between the parameters above, or both values increase or decrease together.

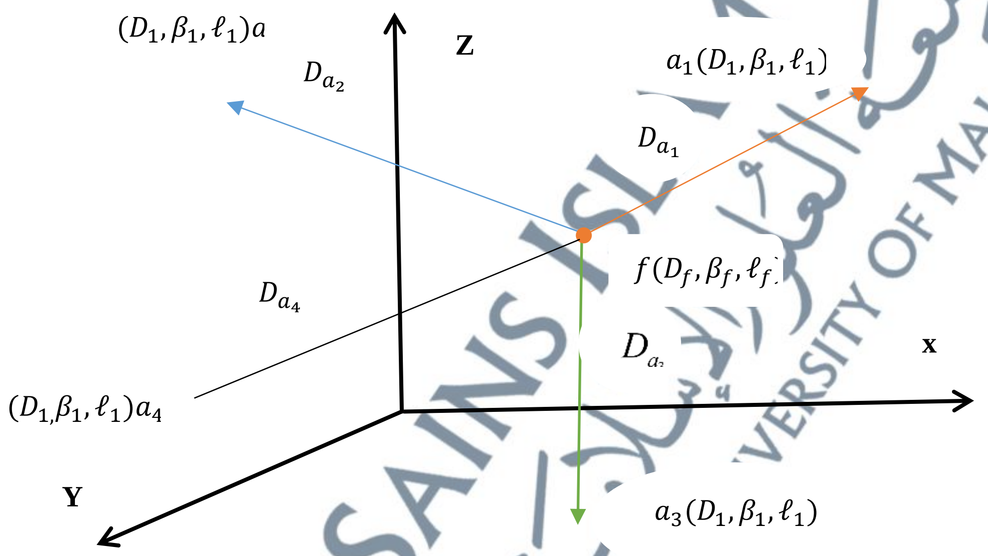

Figure 4.8: 3D Euclidean Distance

The CC is defined as follows. Suppose four nodes (a_1, a_2, a_3, a_4) each have values of distance (D), packet (β), and energy (ℓ), whereby distance is measured between f and parameters D, β, and ℓ, respectively. Let node f be the CH of nodes (a_1, a_2, a_3, a_4), which are within the cycle of communication radius, r. Equation 4.8 presents the CC of nodes within node f :

$$\zeta_{a_{i_i} f} = \frac{\sum (D_{a_i} - D_{a_i f})^2 (\beta_{a_i} - \beta_{a_i f})^2 (\ell_{a_i} - \ell_{a_i f})^2}{\sqrt{\sum (D_{a_i} - D_{a_i f})^2 \sum (\beta_{a_i} - \beta_{a_i f})^2 \sum (\ell_{a_i} - \ell_{a_i f})^2}} \quad (4.8)$$

where the summation is across all f possible values of (a_1, a_2, a_3, a_4), respectively. A method of computing the correlated degree (ζ) is elaborated next with an example. Following this, a discussion is presented on the meaning and the interpretation of CC.

The correlated degree value can be determined from the parameters D as distance, β as packet, and ℓ as energy in Equation 4.8, while the sum these values. Then, the sum of the square all parameters values are calculated to gain the sum of the square all parameters$\sum(D, \beta, \ell)$. Because, the products of each pair of three parameters and values are computed, in which the sum of these is three parameters. Then, these values can be used to determine where refers to the number of nodes. Finally, the Correlations coefficient based on the three parameters of formal correlated degree value can range from 0.0 to 1.0.

4.4.3.1 Calculation Based on Correlated Degree Value

The following depicts the calculation of correlated degree, for instance, in a WSN if a number of nodes f have (a_1, a_2, a_3, a_4) neighbouring nodes, respectively. If (a_1, a_2, a_3, a_4) are close to another node, this node can represent its neighbours in the domain using 3D Euclidean Distance, as given in Equation 4.6. This representative node is called CC based on the correlated degree node in Equation 4.9. Assume node f has (a_1, a_2, a_3, a_4) neighbouring nodes. The CC of f is distance D. The parameters of its neighbouring nodes (D, β, ℓ) are used to calculate the correlated degree (ζ). For correlated degree (ζ) variable, D, β, ℓ must range from 0.0 to 1.0.to measure the relationship of the node in 3D Euclidean distance. If CC is close to 0.0, regardless positive or negative, it implies little or no relationship between the three parameters.

$$\zeta_{a_i f} = \frac{\sum (D_{a_i} - D_{a_i f})^2 (\beta_{a_i} - \beta_{a_i f})^2 (\ell_{a_i} - \ell_{a_i f})^2}{\sqrt{\sum (D_{a_i} - D_{a_i f})^2 \sum (\beta_{a_i} - \beta_{a_i f})^2 \sum (\ell_{a_i} - \ell_{a_i f})^2}} \quad (4.9)$$

where CD is Correlated Degree,

$\sum D$ is Distance,

$\sum \beta$ is Packet,

$\sum \ell$ is Energy,

$\sum D^2$ is the sum of squared D parameter distance,

$\sum \beta^2$ is the sum of squared β parameter packet,

$\sum \ell^2$ is the sum of squared ℓ parameter energy, and

$\sum D \beta \ell$ is the sum of all parameters for paired scores.

Table 4.1: Data *f* Nodes

Nodes	**Distance (D)** *(meters)*	**Packet (β)** *(bytes)*	**Energy(ℓ)** *(Joules)*	D^2	β^2	ℓ^2	**Sum of 3 parameters**
a_1	100	16	200	10000	256	40,000	320,000
a_2	70	24	300	4900	576	900,000	504,000
a_3	50	40	400	2500	1600	160000	800,000
a_4	90	33	250	8100	1089	62500	742,500
Total	310	113	1150	25500	3521	1,162,500	2,366,500

Table 4.1 presents the calculation of Correlation Coefficients (CC). The values of four nodes for (D), (β) and (ℓ) are tabulated in the first three columns. The fourth column

shows the squares of each (D) value in the first column, while the sum of the third column is $\sum D^2 = 25500$. The fifth column displays the sum of the squares of (β) values of the second column, while the sum of the fifth column is $\sum \beta^2 = 3521$. The sixth column has the sum of the squares of (ℓ) values of the second column, while the sum of the sixth column is $\sum \ell^2 = 1162500$. The final column of the table show cases the products of (D), (β) and (ℓ) values of the first, second, and third columns, respectively. For example, if the first entry is $100 \times 16 \times 200 = 3200$, the sum of the seventh column is $\sum D\beta\ell = 2366500$.

Based on Table 4.1, the correlated degree (ζ) value can be determined from the parameters distance (D), packet (β), and energy (ℓ), while the sum these values yields $\sum D$, $\sum \beta$ and $\sum \ell$. The squares of each (D), (β) and (ℓ) values are calculated to gain $\sum D^2, \sum \beta^2$ and $\sum \ell^2$. Next, the products of each pair of D, β and ℓ values are computed, in which the sum of these is $\sum D\beta\ell$. These values can be used to determine $(D_{a_1a_2a_3a_4})(\beta_{a_1a_2a_3a_4})(\ell_{a_1a_2a_3a_4})$, where N refers to the number of nodes, as follows. Next, ζ value is calculated as given in the following:

$$D_{a_i} = \sum D^2 - \frac{(\sum D)^2}{N}$$

$$= 25500 - \frac{(310)^2}{4}$$

$$= 25500 - \frac{96100}{4}$$

$$= 25500 - 24025$$

$$= 1475$$

$$\beta_{a_i} = \sum \beta^2 - \frac{(\sum \beta)^2}{N}$$

$$= 3521 - \frac{(113)^2}{4}$$

$$= 3521 - \frac{12.769}{4}$$

= 3521 – 319225

328.75

$$\ell_{a_i} = \sum \ell^2 - \frac{(\sum \ell)^2}{N}$$

$$= 1162500 - \frac{(1150)^2}{4}$$

$$= 1162500 - \frac{1322500}{4}$$

= 1162500 – 330625

= 831875

$$D\beta\ell_{a_i} = \sum D_{a_1,a_2,a_3,a_4}\beta_{a_1a_2a_3a_4}\ell_{a_1a_2a_3a_4} - \frac{(D_{a_1a_2a_3a_4}\beta_{a_1a_2a_3a_4}\ell_{a_1a_2a_3a_4})}{N}$$

$$= 2366500 - \frac{(310)(113)(1150)}{4}$$

$$= 2366500 - \frac{4028450}{4}$$

= 2366500 – 1007112

= 1359388

Upon calculating these expressions, both CC and regression line can be identified.

The correlated degree (ζ) is determined as follows:

$$\zeta = \frac{D_{a_1a_2a_3a_4}\beta_{a_1a_2a_3a_4}\ell_{a_1a_2a_3a_4}}{\sqrt{D_{a_1a_2a_3a_4}\beta_{a_1a_2a_3a_4}\ell_{a_1a_2a_3a_4}}}$$

$$= \frac{1359388}{\sqrt{1475 \times 32875 \times 831875}}$$

$$= \frac{1{,}359{,}388}{6351231.27}$$

$$= 0.214035$$

The CC between the three parameters of formal correlated degree force is, ζ = 0.214. This indicates positive correlations between the three parameters. A perfect positive relationship yields a CC of 1.0, while 0.0CC for nil correlation between energy (ℓ), packet(β), and distance(D). The relationship here, thus, seems to be a relatively large one as it exceeds 0.2, but considerably less than a perfect association between the three parameters.

4.5 Summary

In this chapter, a correlated degree is derived based on 3D Euclidean Distance and CC. Three parameters, namely distance, packets, and energy, had been selected to measure the ζ value due to its high flexibility and ability to support long-range, large-scale, and highly-distributed applications. The calculations displayed revealed that the correlations had a drastic influence on the topological properties of networks. An assortment of networks tends to form highly connected groups of nodes with correlated degree, whereby the value increases in line with average path length and CC.

The calculation depicted in this section was applied in Enhancement Clustering Algorithm, as elaborated in Chapter 5 to assess the selection strategies. The calculation of correlated degree is further verified to determine the impact of network connectivity on the selected parameters in light of the neighbouring nodes. The details are discussed in the next chapter.