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Samuel Asferaw Demilew, Dejene Ejigu, Georges da Costa, Jean-Marc Pierson. Novel reliable range-free geo-localization algorithm in wireless networks: Centre of the smallest communication overlap polygon (CSCOP). 3rd International Black Sea Conference on Communications and Networking (BlackSeaCom 2015), IEEE, May 2015, Constanta, Romania. pp.181-185, 10.1109/BlackSeaCom.2015.7185111 . hal-04050081

**HAL Id: hal-04050081**

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Submitted on 29 Mar 2023

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**To cite this version** : Demilew, Samuel Asferaw and Ejigu, Dejene and Da Costa, Georges and Pierson, Jean-Marc *Range-free selective anchor node center of the smallest communication overlap polygon localization algorithm in wireless networks.* (2015) In: 12th edition of IEEE AFRICON 2015, 14 September 2015 - 17 September 2015 (Addis Ababa, Ethiopia).

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# Novel Reliable Range-free Geo-localization Algorithm in Wireless Networks: Centre of the Smallest Communication Overlap Polygon (CSCOP)

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***Abstract*— This paper presents a novel range-free geo-localization algorithm in wireless networks. The algorithm does not require ranging devices. It uses node connectivity to estimate the location of unknown (location unaware) nodes based on two or more anchor (location aware) nodes. The algorithm works in two steps. In the first step, the True Intersection Points (TIPs) that constitute the vertices of the smallest communication overlap polygon (SCOP) of the anchor nodes' communication ranges are found. The second step estimates the location of the unknown node at the center of the SCOP which is formed from these TIPs. The performance is evaluated through MatLab simulation and compares favorably to state-of-the-art algorithms: Centroid, improved version of CPE and Mid-perpendicular localization algorithms. The results show that the proposed algorithm outperforms state-of-the-art algorithms in location accuracy which is a serious drawback of range-free localization methods when compared to range-based.**

***Keywords*— *range-free; localization algorithm; anchor nodes; true intersection points; communication overlap polygon***

## I. INTRODUCTION

In today's society location information is becoming as important as time information. However, determining where a given wireless node physically locates is a challenging task, yet very essential for many applications. The common and easiest method is installing battery- hungry Global Positioning System (GPS) receiver on each wireless node despite the fact that small wireless devices are usually energy-constrained [1, 2]. Hence, the problem of localization needs to be addressed in a manner which also considers power consumption.

In this paper, we propose a range-free which is a node connectivity-metric based method for localization of unknown nodes in outdoor environments by using the inherent radio-frequency (RF) communications capabilities of wireless nodes. Unlike other range-free localization algorithms which need three or more anchor nodes, our algorithm works with two or more neighbor anchor nodes. These anchor nodes transmit periodic beacon signals and unknown nodes use simple node connectivity metric to localize themselves.

The core principle of our localization algorithm is to find the SCOP that forms the communication range overlap of anchor nodes, then to take the center of this polygon as the estimated position of unknown node $N_x$. To achieve this, it introduces the concept of TIPs to pinpoint the vertices of the SCOP. Then, the position of the unknown node is centroid of vertices (or TIPs) of this SCOP.

The performance of the proposed algorithm is compared with the well-known Centroid [3], improved, simplified and distributed version of CPE (improved CPE) [7, 8] and Mid-perpendicular [9, 10] algorithms to show its superiority in the level of location accuracy which is a serious drawback of range-free localization methods when compared to range-based methods [1, 2].

The rest of the paper is organized as follows: Section II reviews related works. Section III presents the localization technique of the proposed algorithm. Section IV provides a MatLab performance evaluation of the proposed algorithm; finally, Section V offers a conclusion and a future work.

## II. RELATED WORKS

The rapid increase in the number of wireless nodes and their applications in recent years has greatly raised research attention in wireless node localization. Wireless node localization methods can be broadly classified into two classes: range-based and range-free method [5]. A range-based method, as its name indicates, uses additional dedicated ranging devices, like timers, signal strength receivers, directional antennas and/or antenna arrays to locate nodes. This method may give a fine-grained result putting strict requirements on signal measurements and time synchronization; however, these requirements result in high power consumption of scarce battery.

On the other hand, range-free localization methods do not require an additional battery hungry ranging devices for distance/angle measurements among nodes; instead they use node connectivity and appropriate range-free localization algorithms. As a result, they do not consume high battery power which makes them more appropriate to energy constrained wireless nodes localization; however, they usually give coarse-grained accuracy. Due to their poor precision, research focuses on techniques to improve their accuracy. Range-free localization methods can be further classified into two groups: local and hop-counting methods [5].

In the local methods, an unknown node collects the location information of its neighbor anchor nodes to estimate its own location. For instance, in the Centroid Algorithm which is proposed in [3], each wireless node estimates its location as the centroid of the locations of its neighboring anchor nodes. This algorithm can give good accuracy if anchor nodes are regularly positioned [9, 10]. However, if the anchors are not positioned regularly, it gives low accuracy.

Later, He et al. proposed the APIT technique in [6] that divides the network environment into triangular regions between anchor nodes. Then, every sensor node determines its relative location based on the triangles and estimates its own position as the center of gravity of the intersection of all the triangles where the node may reside. Nevertheless, APIT demands long-range anchor node stations and expensive high-power transmitters.

To advance the accuracy of the Centroid Algorithm, the Convex Position Estimation (CPE) Algorithm was first proposed [4] by Doherty et al. The authors present an optimization concept to locate the unknown node. The core principle of this algorithm is to find the smallest rectangle that bounds the overlapping communication range of anchor nodes. Then it takes the center of this rectangle as the estimated location of the unknown node, $N_x$. Here, the problem is how to find the smallest rectangle. The authors recommend an abstract optimization model to get the smallest rectangle.

Since the resource-constrained unknown node is unable to do huge and complex calculations demanded by the optimization process, the original CPE algorithm is a centralized method. As a result, all unknown nodes are required to send the collected node connectivity information to a centralized controller first. Then, the centralized controller computes the position of each unknown node and transmits the estimated positions back to the corresponding unknown nodes. This causes high traffic and bottlenecks. In other words, the original CPE algorithm scales poorly when the network is large.

Nevertheless, researchers [7, 8], have proposed an improved, simplified and distributed version of the original CPE algorithm. To find the smallest rectangle, unlike the original CPE, the improved version of CPE algorithm forms an Estimated Rectangle (ER) which bounds the SCOP. The center point of ER is the estimated location of the unknown node. Unlike both original CPE and its improved version that look for a rectangle which bounds the SCOP, our novel proposed algorithm finds SCOP itself. This helps our algorithm (CSCOP) to improve the localization accuracy.

To advance the precision of Centroid and improved version of CPE algorithms, other researchers [9, 10] have proposed Mid-perpendicular algorithm. The core principle of this algorithm is to get center of anchor nodes' communication overlap using mid-perpendicular lines on the three sides of a triangle formed from the three anchor nodes. The cross point of the three mid-perpendicular lines is considered as the estimated position. As anchor nodes increase in number beyond three, any three of them can give estimated position; hence, as many as $C_n^3$ estimated locations of the unknown node can be generated, where $n$ is number of anchor nodes. Then, the algorithm regards the average of all these positions as the final estimated position. As a result, this algorithm is computationally complex.

A second type of range-free localization method is hop-counting (also known as DV-Hop) method. It was first proposed by Niculescu and Nath in [11]. In this method each unknown node requests its neighboring anchor nodes to give their estimated hop sizes and then attempts to get the smallest hop count to its neighbor anchor nodes. Then, every unknown node estimates its distances to neighbor anchor nodes using the hop count. Finally, the unknown nodes apply trilateration to estimate their location depending on the estimated distances to three appropriate neighbor anchor nodes. There are several follow-up studies on DV-Hop method [12] but our focus is on the first type of method.

## III. Center of the Smallest Communication Overlap Polygon (CSCOP) Localization Algorithm

Regardless of their accuracy, Centroid, original CPE, improved CPE and Mid-perpendicular are popular localization algorithms. However, accuracy is an important parameter for most location based applications (LBAs). Looking critically, these popular algorithms give relatively low accuracy when compared to the location accuracy demanded by most LBAs. To improve this shortcoming, we propose our localization algorithm called Center of the Smallest Communication Overlap Polygon (CSCOP).

CSCOP localization algorithm works in 2 steps: i) pinpointing the SCOP where the unknown node resides; ii) then, estimate the location of unknown node at the center of this pinpointed SCOP. Now the problem is how to pinpoint the SCOP.

### *1) Pinpointing the Smallest Communication Overlap Polygon (SCOP)*

Like Centroid, original CPE, improved CPE, Mid-perpendicular and other related algorithms, we assume all anchors have the same communication range. However, unlike other related algorithms which assume an unknown node $N_x$ has at least 3 neighbor anchor nodes, CSCOP assumes at least 2. To illustrate the principle of pinpointing the SCOP, let us look at Fig. 1 below:

In Fig. 1, the unknown node $N_x$ has 3 neighbor anchor nodes: ($A_1$, $A_2$ and $A_3$). As these are its neighbor anchors, unknown node $N_x$ actually locates inside the SCOP of anchor nodes (the shaded area in the figure). Hence, any range-free localization algorithm, to be reliable and with better location accuracy, has to always estimate the location of unknown node

inside this shaded region which we call the SCOP. Hence, we have to find SCOP first.

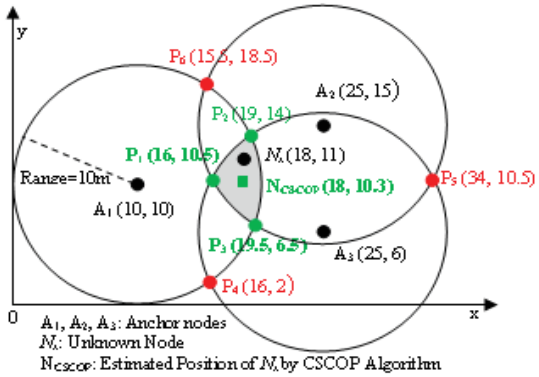


Fig.1. Pinpointing SCOP

In Fig. 1, we have 3 anchor nodes which mean 3 circles with radii equal to their communication range R. To pinpoint the SCOP, we perform the following 2 steps:

First, using (1), we solve each circle's Intersection Points (IPs) with every other circle. The IPs of 2 circles can be 1, 2 or infinity. If it is infinity, the two circles are identical which means they are one and the same circle. Hence, 2 different circles of neighbor anchor node intersect either at 1 point (as in Fig. 2(*a*)) or at 2 points (as in Fig. 3(*a*)).

$$\begin{cases} (x - x_i)^2 + (y - y_i)^2 = R^2 \\ (x - x_j)^2 + (y - y_j)^2 = R^2 \end{cases} \qquad (1)$$

Where ($x_i$, $y_i$) and ($x_j$, $y_j$) are the positions of the two anchor nodes involved in the calculation of IPs; $R$ is communication range of anchor nodes (or radius of a circle). For example, if we take $A_1$ and $A_2$ anchors in Fig. 1, they intersect at points $P_3$ (19.5, 6.5) and $P_6$ (15.5, 18.5). Totally, in Fig. 1, we have 6 IPs ($P_1$, $P_2$, $P_3$, $P_4$, $P_5$ and P6) of anchor nodes $A_1$, $A_2$ and $A_3$.

Second, once we have identified IPs, we have to farther identify TIPs which make vertices of SCOP from False Intersection Points (FIPs) those which do not among these IPs using (2).

$$(x_{IPi} - x_j)^2 + (y_{IPi} - y_j)^2 \le R^2 \qquad (2)$$

Where ($x_{IPi}$, $y_{IPi}$) and ($x_j$, $y_j$) are the coordinates of the IPs and anchor nodes' location respectively and $R$ is communication range of anchor nodes. Using (2), we check the distance between each of these IPs at a time to each anchor's position whether it is less than or equal to R (radius) or not. If IP's distance to each anchor is less than or equal to R, that IP is taken as a TIP. If not, it is considered as a FIP. For instance, among these 6 IPs in Fig. 1, points $P_1$, $P_2$ and $P_3$ are classified as TIPs and $P_4$, $P_5$ and $P_6$ are classified as FIPs. Since we are interested in the TIPs, we take only $P_1$, $P_2$ and $P_3$ as they form the vertices of the SCOP.

Now, let as look at the possible range of TIPs in different scenarios in the following figures: Fig. 2 shows that two or more anchor nodes can have a single TIP which is at the same time the SCOP of the anchor nodes. In such a scenario, the estimated and the real location of the unknown node $N_x$ is the same, 0% location error. This can be true in theory but in reality it is difficult to achieve 100% accuracy.

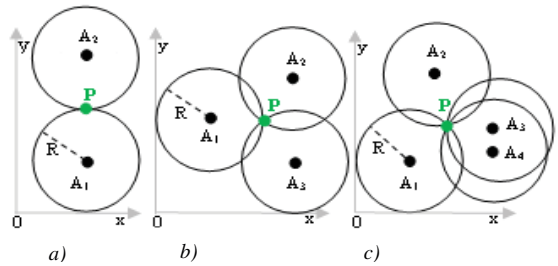


Fig. 2. Senario-1: SCOP with one TIP regardless of increase in number of anchor nodes from *a)* to *c)*

Fig. 3(*a*), 3(*b*) and 3(*c*) show the number of TIPs can be just two regardless of the number of neighbor anchor nodes. In Fig. 3(*c*), the two TIPs are formed from the intersection points of the two farthest anchor nodes: $A_1$ and $A_2$, but not $A_3$. More importantly in Fig. 3(*c*), we can note that this algorithm excludes anchor nodes that will not contribute to TIPs, for example anchor node $A_3$. Moreover, Fig. 2(*a*), Fig. 3(*a*) and 3(*c*) show us this algorithm can also work with only 2 anchor nodes.

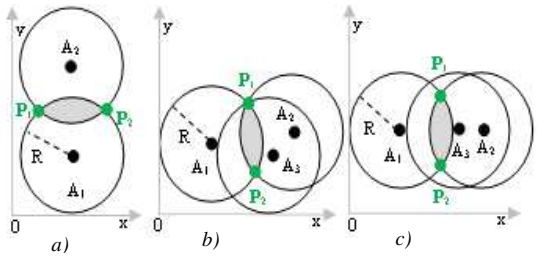


Fig. 3. Senario-2: SCOP as two TIPs

Unlike Fig. 2 and Fig. 3, Fig. 4(a) and 4(b) show us as the number of neighbor anchor nodes increase, the number of TIPs may also increase.

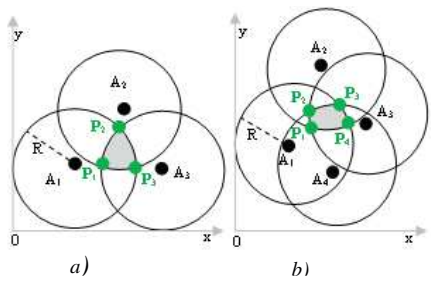


Fig. 4. Senario-3: SCOP with more than 2 TIPs

In general, looking at Fig. 2 to Fig. 4, the TIPs can be: i) just a point as shown in Fig. 2 (Senario-1), ii) two points as in Fig. 3 (Senario-2) or iii) more than two points as in Fig. 4 (Senario-3). Hence, TIPs may range from 1 to $k$ where $k$ is the

number of neighbor anchor nodes. In other words, the number of TIPs is less than or equal to the number of anchor nodes.

*2) The Center of the Smallest Communication Overlap Polygon*

Once we pinpoint SCOP by identifying the TIPs as its vertices, then we can estimate the location of the unknown node as the center of the SCOP (or TIPs). Assuming finally we have $n$ number of TIPs: $P_1$, $P_2$....$P_n$ identified by using (2), then, unknown node $N_x$ locates itself at the centroid of these $n$ numbers of TIPs as in (3):

$$\begin{cases} x_{CSCOP} = \left(x_{TIP1} + x_{TIP2} + \ldots + x_{TIPn}\right)/n \\ y_{CSCOP} = \left(y_{TIP1} + y_{TIP2} + \ldots + y_{TIPn}\right)/n \end{cases} \quad (3)$$

Where ( $x_{TIP1}$ , $y_{TIP1}$ ), ( $x_{TIP2}$ , $y_{TIP2}$ ). . . ( $x_{TIPn}$ , $y_{TIPn}$ ) are coordinates of TIPs and $n$ is the number of TIPs. The result $x_{CSCOP}$ and $y_{CSCOP}$ is the position of the unknown node, $N_x$.

Fig. 5 summarizes the program procedure of CSCOP localization algorithm.

**Algorithm:** Center of the Smallest Communication Overlap Polygon (CSCOP)

During a period $t$, unknown node $N_x$ obtains the positions of $k$ neighbor anchors ($A_1$, $A_2$ …, $A_k$).
($x_i$, $y_i$) is a coordinate point, Intersection Point (IP), True Intersection Point (TIP)
$x_{cscop} \leftarrow 0$; $y_{cscop} \leftarrow 0$
**for** $i \leftarrow 1$ to $(k\text{-}1)$
    $A_i$ is chosen. ($x_i$, $y_i$) is the position of $A_i$.
    **for** $j \leftarrow (i+1)$ *to* $k$
        $A_j$ is chosen. ($x_j$, $y_j$) is the position of $A_j$.
        IP[($x_i$, $y_i$)] ← calculated as (1) based on anchors $A_i$ and $A_j$
            C1 = C1+1
    **end for**
**end for**
**for** $i \leftarrow 1$ *to* C1
    13 IP$_i$ is chosen ($x_i$, $y_i$) is coordinate of IP$_i$
    **for** j← *1to k*
        $k_j$ is chosen ($x_j$, $y_j$) is the position of $k_j$
    TIP[($x_i$, $y_i$)] ← calculated and checked as (2) based on IPs computed
    C2 = C2 + 1
**end for**
**for** $i \leftarrow 1$ to C2
    **do** $x_{cscop} \leftarrow (x_{cscop}$+TIP ($x_i$)) ; $y_{cscop} \leftarrow (y_{cscop}$ + TIP($y_i$))
**end for**
$x_{cscop} \leftarrow x_{cscop}$/C2; $y_{cscop} \leftarrow y_{cscop}$ / C2
**return** $x_{cscop}$ and $y_{cscop}$

Fig. 5. Procedure of CSCOP Localization Algorithm

## IV. PERFORMANCE EVALUTION

In this section accuracy performance of our localization algorithm, CSCOP, is compared with the state-of-the-art algorithms. In the simulation, MATLAB is used with ideal scenarios: ideal radio propagation without interference or path loss, no frame collisions and no mobility for nodes. To make anchor nodes within a radio communication range of the unknown node, the simulation area is configured as a square with side length "2 × range" and the unknown node is placed at the center of the simulation area. We assume that the unknown node $N_x$ has communicated with the anchor nodes and knows their locations. Using respective algorithms Centroid [3], improved CPE [7, 8], Mid-perpendicular [9, 10] and our CSCOP, unknown node $N_x$ computes its estimated location. Metric "location error % radio range" is used to quantify the accuracy of these algorithms, where the "location error % radio range" is calculated as the percentage of location error by the node radio range. The location error is the distance between $N_x$'s estimated and real location; the unit is in meter.

Table 1 lists the parameters used in the simulation. "Random simulation number" refers to the number of simulations with different geographic distributions of anchor nodes. Although the number of neighbor anchor nodes ranges from 2 to $k$ for CSCOP and 3 to $k$ for others, we consider a maximum of 8 anchor nodes for our simulation purpose (in reality, their number may not reach 8). To reduce subjectivity, for each number of anchor nodes, the random simulation number is set to be 10,000.

TABLE I. Simulation Parameters for Performance Evaluation

| List of Parameters | Values |
|---|---|
| Simulation Area | 40m × 40m Square Area |
| Node Radio Communication Range | 20 meters |
| Radio Propagation | Ideal, no path loss, no interference |
| Real position of $N_x$ | $N_x$(20m, 20m) |
| Number of Anchor nodes "$k$" | 2 or more for CSCOP |
| | 3 or more for others |
| Random Simulation Number | 10,000 |

To have a comprehensive view on localization accuracy performance of the algorithms, the simulation results on average, maximum and minimum location error values are presented in the following figures:

Fig. 6 presents the average location error performance of these algorithms. In the figure, it can be seen that our new CSCOP algorithm out performs other algorithms. Besides, unlike other algorithms it also works with two anchor nodes.

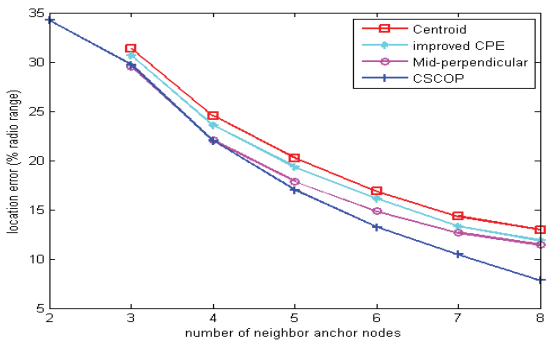


Fig. 6. Average location error (% radio range)

In the figure, when the number of anchor nodes increases, the performance of our algorithm increases more significantly

than the others. For instance, it showed high accuracy improvement in the case of more anchor involvement (5, 6, 7 and 8 anchors) than from less anchor involvement (2, 3 and 4 anchors). This is because as more anchor nodes are involved, SCOP gets reduced in size (or TIPs, which are vertices of SCOP, become closer and closer to the unknown node). For example, when we go from Fig. 4(a) to Fig. 4(b), we notice that SCOP (shaded region) decreases in size as the number of anchor nodes increase from 3 to 4. The same is true when more anchor nodes involve. This indicates that CSCOP localization algorithm is a reliable algorithm especially for crowd or swarm wireless node localization. In general, the accuracy performance improvement from Centroid algorithm to our CSCOP algorithm is more significant than from Centroid to other state-of-the-art algorithms.

The maximum and minimum location error value of these algorithms is presented in Fig. 7. The figure indicates the minimum location error for all four algorithms is near to zero. On the other hand, the maximum location error is relatively higher; almost two times the average value. To know where most of the location error probability lies (whether around minimum, average or maximum), we need to look for error probability distribution.

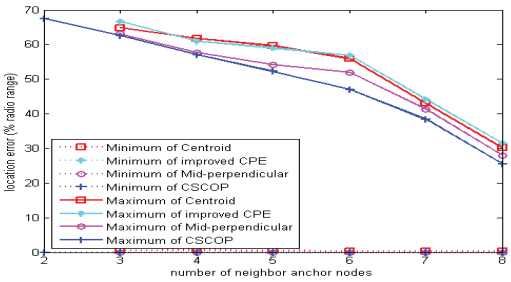


Fig. 7. Maximum and minimum location error in (%) of radio range

Fig. 8 shows the location error probability distribution in case of 8 anchor nodes. It is generated by using the MATLAB statistics toolbox normal fit function. For all three algorithms, the figure indicates while average location error occurs most frequently, maximum location error occurs with probability nearly 0. This figure also shows our algorithm outperforms other related state-of-the-art algorithms in minimum, average and maximum location errors.

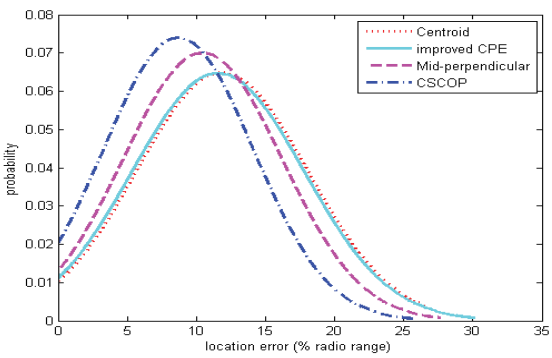


Fig. 8. Probability distribution of location error (8 neighbor anchor nodes)

## V. Conclusion and Future Work

In conclusion, location accuracy performance evaluation results in Section IV show our algorithm (CSCOP) out performs other state-of-the-art algorithms. Unlike other related algorithms, CSCOP first finds SCOP itself; as a result, it always locates the unknown node inside the SCOP, improving accuracy, which makes it a relatively reliable and accurate localization algorithm. It improves the accuracy since the vertices of SCOP (or TIPs) are closer to the real position. As the number of anchor nodes increase, we get nearer TIPs to the unknown node. This in turn improves the accuracy since the TIPs are closer to the real position. Furthermore, this algorithm, in addition to improving location estimation of the unknown node $N_x$, it also defines the smallest boundary where this node resides which is the SCOP, formed from TIPs as its vertices.

We are currently working on how to make this algorithm simpler and more computation and energy efficient.

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