Ring Topology Optimization for Wireless Sensor Network: A New Heuristic Method

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Abstract —The development of telecommunication network has opened the possibility to the birth of new applications that make human life becomes more productive. This application is packaged into an Internet of Things (IoT) concept that requires wireless sensors for its implementation. The more wireless sensors needed would necessitate the need for a mature planning concept. One of the models used to design is TSP. TSP still has some obstacles and is open for development, especially the scenario of finding the lowest cost. In this study, heuristic methods are proposed as one solution with a given algorithm. Based on the test results, this algorithm can be little bit better compared to Ant Colony Optimization for bigger number of nodes as well for the number of small nodes, it matches the brute forces mechanism.

Index Terms—*TSP, WSN, Ant Colony, Heuristic*

I. Introduction

WIRELESS technology is growing rapidly in telecommunication network today. It can be explained by the development of wireless technology generation that is always supported by continuous research. The movement of wireless technology is now getting closer to 5G, some countries / companies / consortium racing to be the first in implementing 5G. 5G infrastructure offers many advantages and new service possibilities which supports the involved connections with smart cities such as: Internet of Things, Clouds of Things, and Advanced Artificial Intelligence [1]. Wireless Sensor Networks (WSNs) is an emerging technology which apply Internet of Things (IoT) technology to the smart city concept, IoT has so many useful functions to solve a city problem such as: traffic monitoring system, earthquake detection, and environmental condition monitoring system. A wireless sensor networks is a set of individual nodes which organized each other into a cooperative network [2]. WSN is kind of research topic which make many researchers interested, one of key challenges in WSN is related with unit power consumption.

In wireless sensor networks there is a need for topologies with low power consumption because a sensor may have limited battery life [3]. Zhi *et al* [4] proposed algorithm considers energy efficient based on *ring topology* with multi-hop clustering routing. This algorithm performs better in reducing the energy consumption of nodes and increasing the lifetime of WSNs pretends remaining energy when choosing cluster heads and uses multi-round clustering instead of clustering in every round. Younis *et al* [9] also proposed an algorithm for energy-efficient, using clustering nodes in ad-hoc sensor networks, the algorithm periodically selects cluster heads according to a hybrid of their residual energy and a secondary parameter, such as node proximity to its neighbors or node degree. Heinzelman *et al* [10] proposed an architecture called low-energy adaptive clustering hierarchy (LEACH) for microsensor networks that combines the ideas of energy-efficient cluster-based routing media access together

Communication between sensor using ring topology is not only because it has low power consumption, but also from their characterized which every sensor unit connect with two neighbors for communication which direction either clockwise or counter-clockwise. Suppose the sensor communication can prevent from disconnection of single node failure, because when one side is failure, the data could be sent again using opposite direction.

Designing a ring topology can be approached using a Traveling Salesman Problem (TSP) model. In TSP model, the salesman must search the shortest route to visit all the encouraged cities (nodes), whereas it can only be visited by once, and the travelling of the salesman must be ended in his starting city. So from this description of travelling the salesman, the journey path will be modeled as a ring topology with has a minimum distance cost.

Therefore, in these paper, we proposed a method which is approach to find a smallest cost in TSP modeling route, also with their implementation to create a ring topology for Wireless Sensor Network's (WSN).

The rest of this paper is organized in sections as follows. In Section II will be described about literature surveys which is explain the state of the art of studies on ring topologies in new directions. Section III presents proposed algorithm for solving TSP model with their performance and also its comparison with other method

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such as: Brute force and Ant Colony. Lastly, in the Section IV presents analysis result and conclusion.

II. Related Works

The traveling salesman problem (TSP) is kind of widely studied of NP-hard combinatorial optimization. Its problem is quite simple, but challenging many researchers to find the best heuristic method to solve TSP.

The most trusted method is called Brute Force Algorithm, which is try all the combinatorial of each node, then select a path with the minimum cost. Today, this algorithm is the only method that can achieve an absolute minimum value to TSP model. Brute force algorithm has a formula (n-1)!/2 which is "n" symbolized from the node/city. For the example to find the shortest route of 100 nodes, there will be $4.67x10^{155}$ ring topology combinatorial. This complexity cannot be solved manually even the most powerful computation machine today, still cannot solved it in the tolerant times.

Therefore, the wise solution is using a heuristic method. Many researchers develop this method to solve TSP. Pasquier J. L. *et al* [5] explain about the comparative three metaheuristics: Genetic Algorithm (GA), Ant Colony Optimization (ACO) and Simulated Annealing (SA). Ant Colony Optimization can reach an optimum value, but it takes longer time in computational time than does a Genetic Algorithm.

Junedul Haque [6] proposed the Solution of Traveling Salesman Problem (TSP) Using Genetic, Memetic Algorithm and Edge assembly Crossover. The result on different parameter like group size and mutation percentage, when mutation percentage is increased the distance value will be decreased.

Khan *et al* [7] using Multilevel Graph Partitioning Scheme to reduce the complexity of the TSP traveling salesman problem through k-mean partitioning algorithm which divides the main problem into multiple partitions graph in a very less time.

There is also [8] which has contributed to define its heuristic mechanism to get the lower cost of forming the ring topology as well as compared to ant colony. Nevertheless, it still has issue on time consumption for computing.

Shortly a new heuristic method is still needed to find optimum value, as close as the value which Brute force algorithm made, with shorter in computational time.

III. Proposed Algorithm

From the section II, it can be concluded that TSP has not been solved enough yet. Many researchers proposed their algorithm in the hope of producing a path to the ring topology with values as close as possible to the brute force method. The idea is also proposing the algorithm by having the same expectations with many other researchers.

The main idea of our algorithm is connecting nodes which has low cost to build a big ring. In Fig. 1, it is presented a flowchart which can help to understand the workflow of the algorithm clearly. By connecting the only low cost links it hopes that the total cost will be the lowest as well. Assuming that we have a matrix which represent the distance cost of the nodes. To make a shortest path/link on given node by connecting a node which has minimum cost.

To get a group of minimum cost, we have to sort a given value on the matrix with ascending scheme. Sorting all given cost will be the essential step to start this algorithm so it will be the foundation of the calculation. Cost in this step represents value of each link provided. This method used as the guidance to the way of creating the shortest link.

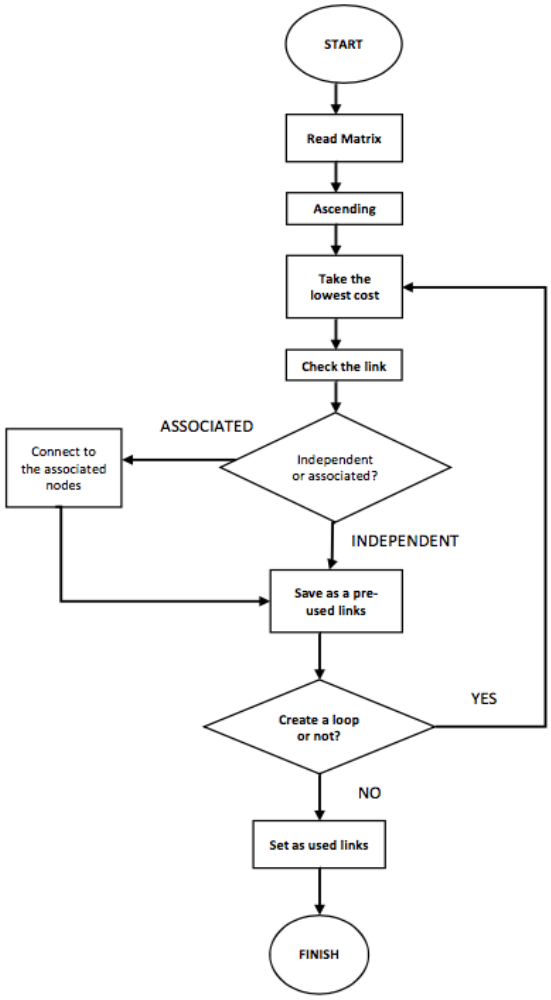

Fig. 1. A proposed algorithm flowchart

Ascending sort means the link is listed by the minimum to the maximum number. The next lowest cost of the link will be utilized to define the connection either it is connected to previous nodes or performs new separated links. This step is continued to the last possibility of connecting links until the final ring formed.

Some notes to this algorithm are: If the next node read has an associated with other previous nodes, so it has to be determined whether the node will create a close circuit (loop) or not. If the next node is independent from any associated nodes, so it can be kept as the link of nodes.

This algorithm can guarantee that all nodes is visited by once, because if it is found a link that associated to previous link, so it will be discarded. The work flow of this proposed algorithm can be easily figured out by this example matrix as well the solution for Travelling Salesman Problem to get an optimum ring topology.

Matrix on Table I describes a cost distance node to node, for example from node A to B the cost is 25 and from node D to F the cost is 15. Based on the matrix above, then it should be created a shortest path to form a ring topology. For the first step, all the data matrix will be sorted as ascending method which is shown on Table II.

TABLE I. DISTANCE MATRIX DATA

	A	B	C	D	E	F
A		25	2	42	19	9
B	25		31	8	90	2
C	2	31		95	16	27
D	42	8	95		25	15
E	19	90	16	25		70
F	9	2	27	15	70	

TABLE II. DISTANCE MATRIX DATA

Cost	2	2	8	9	15	16	19	25	25	27	31	42	70	90	95
Link	AC	BF	BD	AF	DF	CE	AE	AB	DE	CF	BC	AD	EF	BE	CD

From the Table II, it is known that the most minimum cost is 2 which is for the link node A-C. The next step will be B-F, then B-D, after that A-F. When it is checked for D-F, node F has been related to node B and Node A. If the decision is to connect node D and F, it forms circle without connecting all nodes. That is why link from node D to F should be rejected. This step will be repeated until the ring topology is formed. The above steps give the path to form ring topology illustrated in Fig. 2 with a minimum value of 62.

Fig. 2. Complete ring topology based on proposed algorithm

IV. IMPLEMENTATION

To know the effectiveness of this algorithm, it is better to compare with another algorithm which ever made by other researchers. One of the algorithm that can be compared is an ant colony algorithm. Comparison to Brute Force needed to know the lowest cost from certain ring topology which is used as foundation. Nevertheless, it has challenge due to the computation time so in this comparison, it is used only several data. Ant colony is used to perform comparison due to the similar heuristic method exploited to step closer to the minimal cost regard to time consumption for computing. Another algorithm that also used as part of comparison is [8]. In [8], also used a similar mechanism which is comparing the algorithm that has been proposed to the Ant Colony so it can be seen the pros and cons.

To get a fair comparison, the matrix of cost need to be defined which describes the cost of links from one node to others. Fig. 3 shows the data matrix used in simulation. The similar matrix is used to test each algorithm used in this study. This matrix is formed for 25 nodes which has random cost that varies from the lowest to the highest value while for brute force, it is only used for 14 nodes. While it finishes with the 25 nodes of implementation, then it is expanded until the number nodes of 50.

Nodes	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
A	0	930	993	1138	218	458	1194	637	234	577	529	371	1288	1038	426	193	767	1396	230	428	1074	302	41	432	795
B	930	0	1748	857	510	901	1022	785	659	421	130	399	754	771	477	460	953	834	941	944	450	888	979	779	730
C	993	1748	0	564	795	901	1076	749	795	612	441	669	428	787	980	742	1440	431	816	214	901	1211	1062	109	825
D	1138	857	564	0	768	1460	481	930	49	948	381	806	644	571	170	1100	1127	891	1098	622	560	892	849	545	393
E	218	510	795	768	0	1380	583	534	434	516	1133	949	1243	817	959	1278	591	357	913	361	548	526	1290	408	1231
F	458	901	901	1460	1380	0	946	552	549	658	1030	929	856	185	1487	1053	754	687	708	325	677	1180	654	1112	502
G	1194	1022	1076	481	583	946	0	754	1372	928	816	930	963	639	776	503	869	1337	1145	773	776	658	161	855	430
H	637	785	749	930	534	552	754	0	1257	856	769	616	1168	555	542	532	459	512	985	303	992	311	1216	401	612
I	234	659	795	49	434	549	1372	1257	0	390	757	321	758	1064	502	1052	256	312	838	757	847	373	594	474	1172
J	577	421	612	948	516	658	928	856	390	0	681	363	710	706	412	955	842	1170	480	627	587	1218	1528	1021	105
K	529	130	441	381	1133	1030	816	769	757	681	0	928	394	756	491	1578	1042	1246	441	332	656	832	1112	59	658
L	371	399	669	806	949	929	930	616	321	363	928	0	675	140	871	467	1346	1523	51	972	626	524	82	919	1168
M	1288	754	428	644	1243	856	963	1168	758	710	394	675	0	927	103	867	556	1053	1027	181	291	524	733	737	1049
N	1038	771	787	571	817	185	639	555	1064	706	756	140	927	0	1358	792	470	1045	803	676	156	1438	1064	316	50
O	426	477	980	170	959	1487	776	542	502	412	491	871	103	1358	0	998	712	950	501	1165	498	635	1257	759	12
P	193	460	742	1100	1278	1053	503	532	1052	955	1578	467	867	792	998	0	832	396	891	752	1271	776	1283	273	20
Q	767	953	1440	1127	591	754	869	459	256	842	1042	1346	556	470	712	832	0	1282	1045	1039	1656	674	421	1167	209
R	1396	834	431	891	357	687	1337	512	312	1170	1246	1523	1053	1045	950	396	1282	0	553	414	755	629	871	1328	70
S	230	941	816	1098	913	708	1145	985	838	480	441	51	1027	803	501	891	1045	553	0	477	554	534	928	896	917
T	428	944	214	622	361	325	773	303	757	627	332	972	181	676	1165	752	1039	414	477	0	779	458	155	969	590
U	1074	450	901	560	548	677	776	992	847	587	656	626	291	156	498	1271	1656	755	554	779	0	480	1191	264	764
V	302	888	1211	892	526	1180	658	311	373	1218	832	524	524	1438	635	776	674	629	534	458	480	0	669	1429	752
W	41	979	1062	849	1290	654	161	1216	594	1528	1112	82	733	1064	1257	1283	421	871	928	155	1191	669	0	1087	945
X	432	779	109	545	408	1112	855	401	474	1021	59	919	737	316	759	273	1167	1328	896	969	264	1429	1087	0	238
Y	795	730	825	393	1231	562	430	612	1172	105	658	1168	1049	50	12	20	209	70	917	590	764	752	945	238	0

Fig. 3. Data matrix for 25 nodes combination

Test is run for every algorithms using the similar matrix to find the lowest cost to perform ring algorithm. Based on the test, data can be gathered to know the performance of each algorithm. First test exploits the similar heuristic method used in ant colony algorithm and the proposed one. Based on the test, it shows that at the first ten nodes to perform ring topology, ant colony and the proposed algorithm have the similar value. It means both of them have the similar performance for small number of nodes.

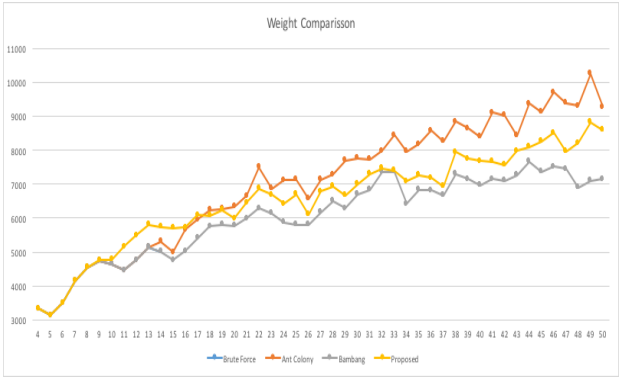

Fig. 4. Comparison brute force, ACO [8], Bambang [8], and proposed algorithm

Interesting condition need to be considered for the next seven nodes, where both algorithms have different value. The proposed algorithm is still less effective to form ring topology of seventeen nodes. However, the more interesting condition is performed for the next several number of nodes until the end of the test. The proposed algorithm has a better value for the number of nodes upper than seventeen. Fig. 4 shows that this condition can be continued for several nodes ahead.

Performance of the algorithm still can be evaluated by considering the time execution. It is figured out at the Fig. 5 where the time execution of the proposed algorithm leading among others. The proposed algorithm only takes for about 0.029 second to form ring topology of 50 nodes while [8] need to compute for about 2500 second. Ant Colony has a better time computation compared to [8] but it still under the proposed algorithm for the task of computing time.

Algorithm shown in [8] is leading to find the minimum value to perform ring topology but it has drawback on time execution. However, the proposed algorithm still less effective to perform ring topology regarding to [8] but it has pretty good efficiencies on time execution. The test is not finished by comparing ant colony algorithm and the proposed one. It still need to compare the proposed algorithm with the brute force which is known as mechanism to find the absolute minimum value to form the ring topology. This test also utilizes the same matrix used for the test of ant colony and the proposed algorithm.

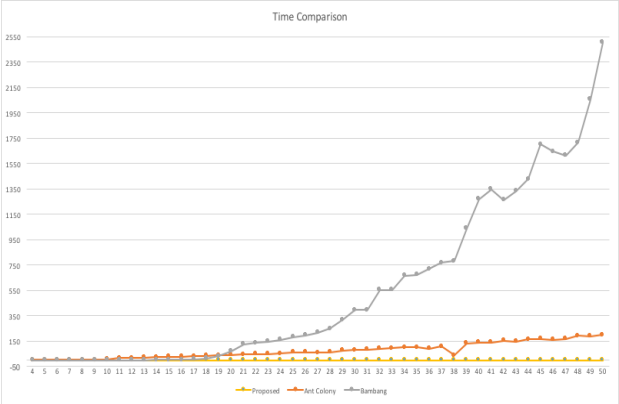

Fig. 5. Time comparison for several algorithms

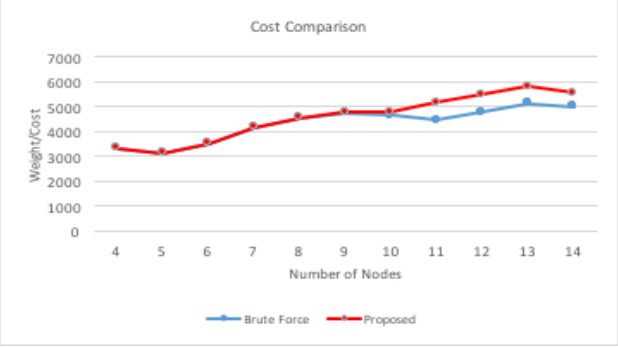

Fig. 6. Comparison brute force and proposed algorithm

Fig. 6 shows that the proposed algorithm has the similar value to form ring topology for nine nodes. The difference value, starts to perform when it forms the ring for the next five number of nodes. It only compares fourteen nodes due to the time consumption for computing to run the brute forces. The proposed algorithm still need to be improved because at the end of node it has trend to decline close to the value of brute forces.

The idea behind the proposed algorithm to collect all the minimum values to form a ring topology from given number of nodes has a quite good result. It can lead ant colony algorithm and still can be enhanced to get lower value close to the brute forces.

By evaluating the data above then it can be simply looked that the proposed algorithm has the pros for its time computing. Then it also tried to verify its pros for executing by handle similar task using another bigger data matrix. For this task, then it generates statistically random 100 x 100 matrix so it can be utilized to form as many as 100 nodes.

For the difference data matrix from the previous test, the proposed algorithm takes 0.049 second to form 60 nodes and it increases become 0.13 second to form 100 nodes.

V. Conclusions

The idea of forming a ring topology using heuristic mechanism on the proposed algorithm give a better cost relative to ant colony while it still less effective to the Bambang *et al*. The proposed algorithm lead to perform a better time execution comparing to others. It has a big opportunity to still lead compared to ant colony algorithm for big number of nodes utilized to form a ring topology. Moreover, it still open to exploit the opportunity to find it best cost because it still has distance to brute force mechanism. Moreover, the data matrix that used in the simulation is still limited for two kind of data matrix.

In the future, the development could still be run for a better cost to close the brute force while it can sacrifice some of the time to catch it. It also need to test using another data matrix to know the average performance compared to other algorithms.

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