Hetrogeneous Multi-Deployment Strategy Effect on
Maximizing the Lifetime Routing in Wireless Sensor Network

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Abstract: In the last few years, a significant increasing interest in the Wireless Sensor Networks (WSN) is noticed. A great challenge in WSN is the limitation of power in sensor nodes batteries, hence developing energy efficient solutions is a key issue for prolonging the lifetime of these networks. CMAX and OML are power efficient routing heuristics that have been proposed to maximize sensor networks lifetime. All the researches that evaluate these two heuristics, agreed on the superiority of OML over CMAX heuristic. In this work, in order to better represent real life terrains, four different types of single distributions were studied. In three-dimensional (3D) space, those distributions (Uniform, Poisson, Normal and Chi-square) were used to generate a Directed Acyclic Graph (DAG) to simulate the connectivity of random deployed WSN. For simulating Heterogeneous environments, 2-Hetro- and 4-Hetro-Distributions were implemented. Results of 2-Hetro-Distributions revealed the superiority of OML over CMAX heuristic in most of the cases. But unlike previous researches, slight improvement was shown by CMAX over OML when Chi-square_Normal (CN) distribution is used, with improvement ratio more than 7%. Also, improvement in the average lifetime equals to 38.63% is provided by CMAX when sensor nodes were deployed in a Chi-square_Poisson (CP) terrain. In 4-Hetro-Distributions, the best case for applying OML heuristic is noticed at the Normal_Poisson_Chi-square_Uniform distribution (NPCU) with improvement ratio up to 99.82% over CMAX. Results of Chi-square_Poisson_Normal_Uniform (CPNU) distribution pointed out that CMAX heuristic is providing better average lifetime than OML heuristic, with unexpected improvement ratio up to 65.48%. As evident by the results of this work, it is proven that Heterogeneity of real life terrains (i.e. multi-tone terrain changes) has a major effect on the lifetime routing in Wireless Sensor Networks (WSN).

Key words: Heuristic · Maximum Lifetime · Heterogeneous distribution · Wireless Sensor Networks

INTRODUCTION

Wireless Sensor Networks Overview: Low-cost, low-power small-sized multifunctional sensor nodes has been recently developed as a result of advances in digital electronics, wireless communication and micro-electromechanical systems (MEMS). These tiny sensor nodes, which consist of sensing, data processing and communicating components, leverage the idea of sensor networks based on collaborative effort of a large number of nodes [1]. Power consumption is thought of to be one of the most important requirements in WSNs [2]. Message routing in wireless sensor networks is done through battery operated sensors, which makes the critical applications assume that batteries are either recharged or replaced.

According to wireless sensor networks' applications, sensor nodes can be deployed in deterministic manner or randomly. In disaster relief operations or inaccessible terrains, random deployment strategy is needed. Many energy efficient routing heuristics were designed to satisfy such environments, like [3] and [4]; these heuristics were implemented using Uniform distribution.

Literature Review: Other researchers assumed that distribution type is a key issue to maximize lifetime for wireless sensor networks [5-7]. In order to better simulate real life environment they used Poisson distribution.
In [7] they discussed the use of Poisson distribution in order to solve the scheduling problem and determine which heuristic better fits the real-world systems. According to their study, they found that Poisson distribution gives a better description for real environment when compared to the task graph of shuttle space main engine.

In [5], a Multi-Dimensional Poisson Distribution Heuristic was introduced to better evaluate the routing heuristics; by taking in consideration earth's terrain and the multi-dimensional concept. This is done by affecting the placement of each sensor as well as the interconnection between sensor nodes. A major effect on the performance of different routing heuristics was gained.

Maximizing Lifetime Routing Heuristics in WSN

Sensor Network Model: For modelling Wireless Sensor Networks, a directed graph \( G = (V, E) \) is used, where \( V \) is the set of nodes and \( E \) is the set of edges between these nodes. A directed edge from node \( v \) to node \( u \) exists, if a single-hop transmission form node \( v \) to node \( u \) is possible. The current energy in transmitter sensor \( u \) is \( c_e(u) \), for each edge in the graph \( (v, u) \subseteq E \). In case of single hop transmission from sensor \( u \) to sensor \( v \), \( c_e(u) \) is represented by Equation (1)[4].

\[
c_e(u) = c_e(u) - w(u, v)
\]

where \( v \) is the destination sensor node and \( w(u, v) \) is the energy required to make a single hop transmission from sensor \( u \) to sensor \( v \), such that \( w(u, v) > 0 \) and \( c_e(u) > w(u, v) > 0 \). In [4], they assume that no energy is consumed during message reception. An adjacency matrix can be used to represent directed graphs of WSN [4-6]. The adjacency matrix of a finite directed graph \( G \) on \( n \) vertices (where \( n \) is the number of vertices in \( G \)), is the \( n \times n \) matrix such that, the diagonal entry \( a(i, i) \) is assigned by zeros, as we assume that there is no internal loops in the WSN. The existence of an edge from sensor \( i \) to sensor \( j \) is represented by a non-diagonal entry \( a(i, j) = 1 \), otherwise \( a(i, j) = 0 \). For example, Fig 1(a) shows a simple representation for sensor network \( N \). As, can be seen, the nodes are representing sensors and the edges represent the existence of single-hop communication between the sensor nodes. The adjacency matrix of the sensor network \( N \) is shown in Fig 1(b).

In [6], such representation 1D (one dimension) for sensors has been used. But in this work, basically we represent sensors using 3D (three dimension) space; each sensor is represented using three dimensions: \( X \), \( Y \) and \( Z \), in order to get more realistic results and using hybrid distributions to simulate terrains.

Statistical Distributions: Several types of statistical distribution procedures exist according to the purpose of analysis. Furthermore, almost every real life system contains such resources of randomness. In this work, all subsequent formulas of the statistical functions are given for the standard form, since the general form of probability functions can be expressed in terms of the standard distribution\(^1\).

Uniform Distribution: Most of the performed simulations in literature are based on distributing the sensor nodes randomly using uniform distribution, [3] and [4].

\(^1\)All statistical distributions were referenced from: NIST/SEMATECH e-Handbook of Statistical Methods, http://www.itl.nist.gov/div898/handbook/, June-2009.
Uniform distribution of sensors best fits the symmetric environment where the lands are flat and there are no geographical differences in terrains. Uniform is a distribution that has constant probability, which means that sensor nodes are evenly distributed. This is shown in Fig 2.

**Poisson Distribution:** Real environment is characterized by terrain changes, which is hard to be handled using Uniform distribution. That is due to the fact that the use of Uniform distribution causes sensor nodes to be evenly distributed. In order to represent the terrain changes, Poisson distribution is used, as it has the nature of best fitting the asymmetric environment [6]. Poisson distribution is appropriate for applications that involve counting the number of times a random event occurs in a given amount of time, distance, or area, etc. Therefore, Poisson distribution is used in some environmental applications, such as: detecting earthquakes, battlefields and volcanoes detection application. In Fig 3, it is clear that sensors are concentrated around the mean.

**Normal Distribution:** Another alternative way of deploying sensor nodes is the Normal distribution. Normal distribution better represents geographical differences in terrains. Unlike Poisson distribution, Normal distribution of sensors best fits the environment where the lands are not flat, but there are some symmetric geographical differences in terrains. In Fig 4, it can be noticed that sensors locations are concentrated around the mean, but in symmetric form.

**Chi-Square Distribution:** Using Chi-square distribution, sensor nodes are scattered in random manner, with concentration in some places while having few number of sensors in other places. Like Poisson distribution, Chi-square distribution represents hard terrain environments that have geographical changes. A major difference between Chi-square distribution and Poisson distribution is that in Chi-square distribution sensors are more concentrated in the left side of the mean. This leads to the fact that Chi-square distribution is used for representing an environment with terrains harder than that represented by Poisson distribution, as shown in Fig 5.

**Example of Heterogeneous Terrains Application:** One application for wireless sensor networks is avalanching predictions. This application requires random distribution for sensor nodes. In order to make full use of sensor network in this application, Chi-square distribution is used.
coverage, all the challenges that may face sensor network deployment are portrayed by mountainous terrains. In this research, we study the deployment strategy effect on the WSN routing protocol metrics. Our strategy takes in consideration real life environment such as multi-tone terrain changes (Heterogeneous Environment).

Fig 6 shows the landscape of typical environment that ranges from flat land, hilltop, cliffs, valleys, to mountains top (heterogeneous space). As we are trying to make fair comparison between the two routing protocols (OML and CMAX), major attention should be paid to the deployment strategy. To achieve this goal, we concentrate on the way that sensors network deployment is simulated. For that, the random graph that simulates sensor's position as well as the connectivity between sensor nodes is generated in a form that fits multi-tone terrain changes.

**Implementation of Heterogeneous Terrains:**
In 2-Hetro-distribution, the space of deployment for sensors is divided to two equal halves each with different type of distribution. Distributions to be discussed here include: Uniform, Poisson, Normal and Chi-square distribution. To match these four distributions into a 2-Hetro distribution, we will have 6 types of distributions those are: Uniform_Chi-square(UC), Uniform_Poisson(UP), Uniform_Normal(UN), Chi-square_Poisson(CP), Chi-square_Normal(CN) and Normal_Poisson(NP). Implementation for the Uniform_Chi-square(UC) distribution for example, will be by having Uniform distribution in the top of the graph with Chi-square distribution in the bottom. We will discuss six types of 4-Hetro-distributions, listed as: Poisson_Chi-square_Normal_Uniform(PCNU), Chi-square_Poisson_Normal_Uniform (CPUN), Normal_Poisson_Chi-square_Uniform Distribution (NPCU), Chi-square_Normal_Poisson_Uniform (CNPU), Poisson_Chi-square_U:

\[
\begin{array}{cccc}
N & P \\
C & U
\end{array}
\]

For example the order of the Four-Hetro-distribution NPCU, is meant to be: Normal distribution is implemented in the top-left quarter, with Poisson distribution in the top-right, along with Chi-square distribution implemented in the bottom-left quarter and finally the Uniform distribution position will be in the bottom-right quarter, as shown in Fig 7.

**Use of Three-Dimensional:** In the literature, the known method is to use 1D for representing sensor nodes. In [6] they used 3D instead of 1D sensors' representation in order to get better description for real environment. For better representation of real life terrains, we explored the use of 3D in representing sensors' positions; three dimensions X, Y and Z will be used. Connectivity between sensors in 3D space is implemented, such that; the sensor node (s) is considered to be connected to sensor (t) only if the cell in the adjacency matrix for the cross point of row (s) and column (t) holds the value 1. In 3D space, the existence of value 1 in the adjacency matrix's cell, using Poisson distribution for example, depends on satisfying the condition that; each of X, Y and Z axis should be greater than or equals to the corresponding mean value of Poisson distribution.

**Maximum Lifetime Routing Heuristics:** Due to the fact that power limitation is a great challenge in wireless sensor networks (WSN), most of the researches were proposed to maximize network lifetime. For this purpose, energy-efficient algorithms have been studied and many techniques were presented to maximize the lifetime of the network like Capacity Maximization (CMAX) heuristic and OML (Online Heuristic for Maximum Lifetime Routing, [3, 4, 6]).
CMAX Heuristic: CMAX (Capacity Maximization) is an online capacity-competitive algorithm, proposed in [3]. Using admission control, CMAX heuristic can occasionally reject messages if they are considered to be too detrimental to the network’s residual capacity. To implement heterogeneous terrains, some modifications were done on CMAX heuristic. For example, CMAX based on the Four-Hetero-distribution Normal_Poisson_Chisquare_Uniform Distribution (NPCU) is illustrated in Fig 8.

OML Heuristic: The other heuristic is OML (Online Maximum Lifetime). With OML heuristic, in order to route each message, two shortest path computations must be employed. To maximize lifetime, it is recommended to delay as much as possible the depletion of a sensor’s energy to a level below that needed to transmit a message to its closest neighbour [4]. OML is also modified to implement each of the heterogeneous distributions discussed in this work. In order to implement OML heuristic based on NPCU distribution, for example, we used the heuristic illustrated in Fig 9.
Experimental Results and Discussion

**Selecting OML and CMAX Parameters:** OML and CMAX heuristics were implemented in a single distribution, 2-Hetero-distribution and 4-Hetero-distribution using Normal, Poisson, Uniform and Chi-square distributions. In three-dimensional phase, ten sensor networks, each with 20 randomly populated sensors were implemented.

The transmission radius $T$ is set to 5. In the definition of $\rho$, the heuristic parameter $c$ was set as $= 0.001 \frac{1}{\lambda_i}$. The network lifetime was determined for $\lambda_i = 2^i$, where $i = 2$. Each single-hop transmission between two sensors was assumed to require $0.001 * d^3$ (where $d$ is the Euclidean distance between the two sensors). The initial energy is set to 90 for each sensor [4]. Our experimental results show the deployment strategy effect on WSN routing protocol metrics. Also, the study includes the dimension effect (1D and 3D) on the lifetime performance metric.

**Dimension Effect:** As shown in Table 1 and Table 2, it is clear that the number of edges is decreased when we used 3D for representing sensor nodes. Using Equation 2, Table 3 shows the percentage of the average number of edges using Poisson to the average number of edges using Uniform distribution. Note that, if the result is more than 100% then it means that average number of edges is higher when using Poisson distribution. Energy is conserved using multi-hop routing in wireless sensor networks [4]. Hence, the sensor nodes between source (s) and destination (t) are used as relays. As we have less number of edges and less choices of paths for each route, therefore we will have less power reservation.

For example to travel from source node s to destination node t, a lifetime maximization heuristic will give better lifetime for the network if it is provided more alternatives of paths to use for a single route. This leads to the fact that, when using 3D we get more power consumption (i.e. less lifetime).

According to our experiments, based on the relationship between number of edges and network lifetime, the four distributions are classified into two groups. The first group includes Chi-square and Poisson distributions, while the second group includes Uniform and Normal distributions. The first group (Chi-square, Poisson) is featured by having less average lifetime when changing the representation for sensors from 1D to 3D, which agrees with the previous works indicating that the less number of edges we have the less lifetime we get. But, unlike the first group, second group (Uniform, Normal) gives the opposite, that means when we change from 1D to 3D (knowing that the number of edges still decreases) the average lifetime is increased. We believe that the reason for such results is caused by the aspects of these distributions; symmetric and asymmetric nature.

**Single Distribution Effect on Maximizing Lifetime:**

In Fig. 10, the best average lifetime provided by OML is based on Normal distribution, which is about 27629. We believe that the reason for such results is caused by the symmetric nature of Normal distribution. The average lifetime of OML based on Uniform, Poisson and Chi-square distribution is about 7357, 2063, 842 respectively. It can be noticed that the lowest average lifetime is provided by Chi-square distribution.

![Fig. 10: Average Lifetime Using Single Distributions in 3D for OML](image-url)
As shown in Fig. 11, the average lifetime provided by OML is about 1261.9 based on Normal distribution, which is the best case for CMAX in single distributions. We believe that having this distribution with the best lifetime, as seen with OML heuristic is caused by the symmetric nature of Normal distribution. The average lifetime of OML based on Uniform, Poisson and Chi-square distribution is about 832, 605, 842 and 304 respectively. It can be noticed that the descending order of the average lifetime provided by the four distributions (i.e. Normal, Uniform, Poisson, then Chi-square) is still with the same order with CMAX heuristic, but with lower band.

Average Lifetime Routing Using Non-single Distributions: The prime goal of this work is to investigate multi-tone terrains effect on maximizing lifetime. In our simulations, it is done by having more than single distribution in the deployment graph. Also, we investigate the deployment route effect on maximizing lifetime routing heuristics. For that, we investigated non-single distributions for wireless sensor networks were implemented, including 2-Hetro-distributions and 4-Hetro-distributions.

In 2-Hetro-distribution, we will have 6 types of distributions which are: Uniform_Chi-square (UC), Uniform_Poisson(UP), Uniform_Normal(UN), Chi-square_Poisson(CP), Chi-square_Normal(CN) and Normal_Poisson(NP). Implementation for the Uniform_Chi-square(UC) distribution for example, will be by having Uniform distribution in the top of the graph with Chi-square distribution in the bottom.

In 4-Hetro-distribution, the space of deployment is divided into four quarters; each quarter has different type of distribution for network deployment. In this work, we will discuss six types of 4-Hetro-distributions, listed as: Poisson_Chi-square_Normal_Uniform (PCNU), Chi-square_Poisson_Normal_Uniform_Normal (CPUN), Normal_Poisson_Chi-square_Normal(NUPN), Poisson_Chi-square_Normal(PSN), Poisson_Chi-square_Uniform_Normal(UCN) and Poisson_Chi-square_Normal_Normal(UNN). For example, the distribution (NPCU) shown in Fig 12.

Using 2-Hetro Distributions: As we consider the multi-tone terrains with many different combination of Hetro-distributions. A 20 sensor networks are deployed to be randomly distributed using 2-Hetro-distributions in 3D space. Fig 13 shows the average lifetime for 10 sensor networks with 20 sensors in each network.
Every single reading for each network is calculated as the average for 10 networks' lifetimes. Using 3D space, Uniform distribution is positioned above the Chi-square distribution. From the figure, the average lifetime for the OML is 77% better than the CMAX. Fig 14 demonstrates that after we changed the 2-Hetro-distribution to Uniform_Normal distribution in 3D space, we found that the performance of OML heuristic is still better than CMAX heuristic, but with lower band. The improvement ratio is 70%. As we can see from Fig 15, unlike previous cases, the performance of CMAX heuristic is slightly better than OML heuristic with improvement ratio equals 7%. We believe that the reason for having larger average lifetime provided by CMAX is because of using Chi-square distribution at the top of the deployment area with Normal distribution at the bottom (distribution type effect).

In Fig 16 the average lifetime of CMAX is 38% better than the average lifetime of OML. This is one of the cases when CMAX shows superiority over OML. As a result of distribution type effect, Chi-square_Poisson (CP) distribution CMAX is preferred, with expectation for having low band of lifetime provided by both OML and CMAX when compared with other 2-Hetro-distributions. Fig 17 exposes Uniform_Poisson distribution. As can be seen, the deviation is decreased when using CMAX heuristic compared to OML. But OML is still providing much more average lifetime. The OML improvement ratio over CMAX is 22.7%. With Normal_Poisson distribution, as Fig 18 shows, the average lifetime for the OML and CMAX was about 64209.6 and 2251.6 respectively.

Among all the 2-Hetro_Distributions cases we considered, Fig 18 points out that OML heuristic records the highest band of average lifetime. With improvement ratio equals to 96.49% over CMAX. It is worthy to be mentioned here that, due to high average lifetime obtained by NP_OML, we noticed while running the case of Normal_Poisson distribution with OML heuristic, it was noticed that the runs took an extremely long time (more than 48 hours) compared to other cases. Table 4 shows the average lifetime statistics for OML and CMAX. (*) indicates the higher lifetime.
Effect of Distribution Route on Lifetime Maximization:
The Deployment Route Effect is considered in our research. For example, if an airplane is ordered to deploy sensors in a space having the NPCU 4-Hetro-distribution as shown in Fig 12. If that airplane was coming from the north, then we will use the same implementation for that space if the airplane came from the south, east or west direction. Let's go again to Fig 12, if we turned that figure to have C at the top-left quarter, N at the top-right, U at the bottom-left and P at the bottom right. As we can see, the NPCU 4-Hetro-distribution is still there, we just turned the whole figure (i.e.: the airplane is coming from the western side of the same space). But, the turned figure we just mentioned cannot be read as CNUP 4-Hetro-distribution. This is due to the fact that each of the two 4-Hetro-distributions expresses different terrains. Simply, in the first case we had the NPCU 4-Hetro-distribution, with Chi-square distribution positioned in the 3rd quarter having Normal distribution above and Uniform distribution at the right side. But in CNUP, the Chi-square distribution is positioned at the 1st corner with Uniform distribution below and Normal distribution at the right side.

Clearly, these two 4-Hetro-distributions are expressing two different terrains. Also, within the single quarter that holds the Chi-square distribution, in the first case that is shown in Fig 12, the concentration of sensors in Chi-square distribution will be in the left side (i.e.: to the west direction of the figure). But in the case of CNUP distribution, the concentration of sensors deployed by Chi-square will be in the left side, which is the South direction of the NPCU distribution.

Using 4-Hetro Distributions: Fig 19 illustrates a comparison between OML and CMAX heuristics with Poi_Ch_norm_uni (PCNU) distribution.
Table 5: Average Lifetime Statistics Using 4-Hetro-Distributions in 3D Space

<table>
<thead>
<tr>
<th>4-Hetro-Distribution</th>
<th>CMAX</th>
<th>OML</th>
<th>Difference %</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCNU</td>
<td>500.2</td>
<td>4347.7*</td>
<td>88.50%</td>
</tr>
<tr>
<td>PCUN</td>
<td>842.2</td>
<td>4343.43*</td>
<td>80.61%</td>
</tr>
<tr>
<td>CPUN</td>
<td>721.6</td>
<td>1147.8*</td>
<td>37.13%</td>
</tr>
<tr>
<td>CPNU</td>
<td>475.8*</td>
<td>164.23</td>
<td>65.48%</td>
</tr>
<tr>
<td>NPCU</td>
<td>873</td>
<td>4874.18.6*</td>
<td>99.82%</td>
</tr>
<tr>
<td>CNPU</td>
<td>1038.7</td>
<td>16218.7*</td>
<td>93.60%</td>
</tr>
</tbody>
</table>

The improvement ratio on average lifetime obtained by using OML is 88%. Even after changing the distribution type from 2-Hetro- to 4-Hetro-distribution, we still notice that OML is showing higher deviation compared to CMAX and average lifetime of CMAX is lower than OML.

With Chi_Poi Uni Norm (CPUN) distribution, although in networks 2, 3 and 4, OML lifetime is lower than CMAX, the average lifetime of OML is 37% better than CMAX. Fig 21 points out that OML heuristic gives an extremely high average lifetime when used with Norm_Poi Chi Uni (NPCU). Clearly, OML gives the largest band of lifetime, compared with all experiments included in this work. In the case of NPCU, OML showed an improvement up to 99.8% over CMAX. In this case, the average lifetime given by OML ranges between 300,000 and 600,000.

Now, we investigate the Poi Chi Uni Norm (PCUN). As shown in Fig 22, the OML still provides better average lifetime than CMAX. Improvement achieved by OML is more than 80%. But, the band of OML average lifetime is relatively low compared with NPCU in Fig 21. Fig 23 demonstrates that when the distribution CNPU is investigated, the average lifetime of OML was 93% better than CMAX. The band of lifetime given by OML ranges between five thousands to thirty thousands, which is higher than the band of PCUN shown in Fig 22.

A single modification on the deployment graph will lead us to have Chi_Poi Norm Uni (CPNU). Fig 24 illustrates unexpected results showing that CMAX is providing better average lifetime than OML. Taking into consideration that the average lifetime given by OML is 164.2 and the average lifetime given by CMAX is up to 475.8. It is true that the band of lifetime is very low for both OML and CMAX, but the improvement achieved by CMAX over OML is 65.48%. CPNU distribution is extracted by single modification on CNPU distribution. Even though, Fig 23 and Fig 24 are giving very different indications about OML and CMAX heuristics. We believe that the reason for having such conflict is the single switching (CNPU to get CPNU). Considering the two deployment cases (CP and CN) 2-Hetro-distributions; CMAX is also better than OML, this will lead to the fact that; deployment route path does affect the lifetime maximization. Table 5 shows the average lifetime statistics for OML and CMAX using 4-Hetro-Distributions, (*) indicates the higher lifetime.

CONCLUSION

This study revealed that deployment strategy does indeed have a major effect on the nature of WSN. And it does affect the performance of maximizing the lifetime of routing heuristics. In order to imitate real life environment requirements, we used in this study four different types of well known statistical techniques to distribute sensor nodes. Two heuristics OML and CMAX were implemented in 3D space.

Our experiment study using 2-Hetro-distributions shows the superiority of OML over CMAX in four deployment types, those are UN distribution by 70.22%, UP distribution by 22.74%, UC distribution by 77.67% and the best case for OML was NP distribution with improvement ratio up to 96.49%. Unlike previous researches, CMAX heuristic showed superiority over OML in two cases CN distribution and CP distribution with improvement ratio more than 7% and 38.63% respectively. With NP distribution both heuristics gave their best average lifetime; OML provided 64209.6 and CMAX provided more than 2251.

Our extensive runs show that applying 4-Hetro-Distribution results in up to 99.82% improvement ratio when using OML instead of CMAX with the NPCU distribution, which is the best 4-Hetro-Distribution case for implementing OML heuristic. In CNPU, CPUN, PCUN and PCNU, OML heuristic provided better average lifetime than CMAX, with improvement ratio equals to 93.60%, 37.13%, 80.61% and 88.50% respectively. With CPNU; unexpected results revealed that using CMAX heuristic shows superiority over OML heuristic, with improvement ratio up to 65.48%.

All previous researches, with the use of single (Uniform and Poisson) distributions in 1D space, agree on the superiority of OML over CMAX. Our results show that in some cases, using 2-Hero- and 4-Hetro-Distributions in 3D space, CMAX heuristic can provide better average lifetime over OML heuristic. This leads to the fact that, heterogeneity of real life terrains (i.e. multi-tone terrain changes) has a major effect on the performance of different routing heuristics.
REFERENCES