Transmission Range Assignment with Balancing Connectivity in Clustered Wireless Networks

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We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Computer Engineering.

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ABSTRACT

Currently, the main challenge for researchers in the field of wireless sensor networks is associated with reducing the energy consumption as much as possible to increase the lifetime of the nodes and improve the performance of the network. Furthermore, delivery of data to its destination is also an important key issue that represents throughput of the network.

On the other hand, transmission range assignment in clustered wireless networks is the bottleneck of the balance between energy conservation and the connectivity to deliver a given size of data to the sink or gateway. Therefore, this research aims to optimize the energy consumption through reducing the transmission ranges of the backbone nodes in multihop network, while maintaining high probability to get end - to- end connectivity to the network's data sink or gateway. Hence, this framework will decrease the energy used for the transmissions made by cluster head nodes, and improve the efficiency of the current clustering protocols that usually use huge transmission ranges for cluster heads (CHs) backbone in wireless sensor networks.

We modified the approach given in [1] to achieve more than 30% power saving through reducing CH-transmissions of the backbone network nodes in a multihop wireless sensor network with ensuring at least 95% connectivity probability.

Keywords: Wireless sensor networks; Adaptive transmission ranges; Clustering; Network topology.

ÖZ

Günümüzde, kablosuz algılıyıcı ağları alanındaki araştırmalarda karşılaşılan temel zorluk, ağ düğümlerinin ömrünü ve ağ performansını artırmak amacı ile enerji tüketimini azaltılmasıdır. Ayrıca, verinin hedefine ulaşması, ağın veri uretimini etkileyen önemli bir etmendir.

Öte yandan, kümelenmiş kablosuz ağlarda iletim aralığı teyini, enerji tasarrufu ve bağlanabilirlik arasındaki degiş tokuşu belirleyen en önemli etmendir. Bu nedenle, bu araştırma, yüksek bağlanabilirlik olasılığını korurken; veri iletim aralığını azaltarak enerji tüketimini optimize etmeyi amaçlar. Dolayısıyla, bu çalışma, küme başkanı düğümler tarafından veri iletimi için harcanan enerjiyi azaltır ve küme başkanı düğümler için genellikle büyük iletim aralıkları kullanmakta olan mevcut kümelenme protokollerinin verimliliğini arttırır.

[1]'de verilen yaklaşımı değiştirerek en az % 95 bağlantı olasılığını korurken, çok atlamalı kablosuz algılıyıcı ağlarında bulunan küme başkanı düğümlerin veri iletim aralığını azaltarak %30 enerji tasarrufu sağladık.

Anahtar Kelimeler: Kablosuz algılıyıcı ağları, Uyarlanabilir iletim aralığı; Kümelenme; Ağ Topoloji.

DEDICATION

"I'd like to thank from the core of my heart, to my God who make to me the way of Knowledge is easy".

I'd like to fully thank for my parents: My mother and my father (Ask God covered them by to his mercy)

To my wife and my children: Ali, Doha, Yasser, Nuha, Saja, and my small flower Safa.

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To the beast my friends; Kilan, Yasser, Talal, Ahmed, Ibrahim, Adnan, Wisam, and all other my friends, who were always beside me and supporting me with praying for me to achieve my a dream by obtaining us on the master degree from Eastern Mediterranean University (EMU).

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LIST OF ABBREVIATIONS AND SYMBOLS

A	Ordinary node
a	The area of triangle
Algo	Algorithm
A_{Next}	Next hop node of node A
B	Gateway node
BS	Base station
β	The angle for $Area_1$
CH	Cluster Head node
d	CH node distance from a gateway node
d_{Next}	New distance to gateway node
K	Hop number's distance to the node A
λ	CH node density
m	Meter
M	At least 95% probability of connectivity
$Prob$	End-to-end connectivity probability
R_A	*Region A*
R_B	*Region B*
R	CH transmission range
ΔR	Increment Range
r	The distance for the next hop to the node A
$\overline{r}$	The expected (average) value of distance r to the node A
R_{Next}	Next area
R_{new}	Area of new next hops for nodes

s	The half circumference of the triangle
σ	Node density value
θ	The angular deviation about originally distance d
$\bar{\theta}$	The average angular deviation of θ
UCR	Unequal Cluster-based Routing protocol
WSNs	Wireless Sensor Networks

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Chapter 1

INTRODUCTION

1.1 Introduction

In the scientific literature, wireless sensor networks (WSNs) consist of sensor nodes (this term refers to a "*device*") that are deployed usually to monitor, examine and study a system or an environment, then forward data to its end destination. Currently, WSNs are widely used in military, health, industrial, and consumer applications. Therefore, they are receiving much attention in the academic and research institutions [1] [2].

WSNs have two important issues: 1) energy constraints and its consumption, where energy resources in WSN depend on their batteries (short-lived and low power**)**; 2) connectivity for delivery of information to its destination that refers to the throughput of the network. Both of these issues are associated with transmission range for nodes in the network [3] [4].

Data is delivered from network's nodes to the data collection point (Sink or a gateway) over multihop paths by using clustering technology which means that the devices in wireless networks are divided into groups of nodes (called clusters). Hence, each cluster must contains a single Cluster Head (CH) node which is elected as a local controller that performs the task of compiling and summarizing the data flows from other member's nodes within a cluster [1] [4] [5].

The major advantages of Clustering technology in (WSNs) are: reducing traffic volume of data flows by forming the CH-backbone; making the network topology more simple; and alleviating overhead, collision, interference and traffic congestion. Ordinary nodes in clusters elect their CHs via CH nomination announcements performed by every node in relation to the scale of probability which is computed by singular nodes and it considers the outcome of jump distances to the sink of the comparative traffic load at various locations of the network [1] [6] [7].

In clustering protocols, the most important aim is the successful delivery of a given size of data to the sink or gateway. However, there are two main associated perspectives: If the CH transmission range (which mean clusterhead-to-clusterhead transmission range) is not long enough (too short), it will consume low power, but leads to network partitioning in which some CHs cannot communicate, and hence causes failure of data delivery process to its destination (gateway). On the other hand, if the CH transmission range is not short enough (too long), it will ensure the successful delivery of network data to its destination, but requires difficult modulation schemes and high power for data transmission. Hence, these two concepts require a tradeoff for the transmission rang so that the range should be short enough to save energy and avoid high costs of data transmission and long enough to ensure no splitting of the network and achieve high data throughput [2] [8] [9].

In previous studies, the authors proposed algorithms which assign minimum transmission range with ensuring network connectivity, but they require global information about node locations which is difficult to achieve in WSNs [10] [11].

While, the authors of [1] investigate connectivity probability (this term refers to "*the probability of end -to- end connectivity*") according to deployment density for nodes in the network and provide an analytical solution. Inspired with the work of [1], we modified their algorithm by using simpler mathematical approaches to decrease CH transmissions ranges and provide more conserving CH transmission power while maintaining high connectivity probability of data to the sink or gateway.

1.2 Problem definition and motivation

The limitations of energy resources and power consumption in data transmissions are important issues in the wireless networks. Hence, most devices in wireless sensor networks are limited in energy resources because they depend on their batteries which have shorter life time with longer transmission ranges. Furthermore, ensuring the delivery of a given size of data is also very important because it represents the throughput of the network. Therefore, these two issues make transmission range assignment in clustered wireless networks the bottleneck of the balance between energy conservation and the connectivity of delivering data to the sink or gateway node, and this requires reducing transmission ranges of CHs as possible to provide more conserving CH transmission power while maintaining high connectivity probability to the data sink or gateway.

1.3 Research aims

The aim of this research is to optimize the energy consumption through reducing the Cluster Head (CH) transmission range of the backbone nodes in a multihop wireless network, while maintaining high probability of connectivity to the data sink or gateway in the network.

1.4 Thesis outlines

This thesis consists of five chapters. Chapter two presents literature review and theoretical background which contain the clustering mechanism in WSNs, and numerical analysis to compute CH transmission range with high connectivity probability. Chapter three shows the modified transmission range assignment algorithms to reduce CH -to- CH transmission ranges and provides more conserving CH transmission power by using simpler mathematical models. While chapter four shows the implementation and results for the original and our approaches. Finally, chapter five presents conclusions and suggestions.

Chapter 2

THEORETICAL REVIEW

2.1 Literature review

In wide-area wireless networks, data collection point is either Sink which is a processing center or gateway which is the basis for a link to the network infrastructure. Hence all data collected by network's nodes via multihop paths is delivered to this collection point. This leads the researchers to divide the networks nodes in to Clusters which are groups of nodes with data flows as shown in Figure 2.1. [2] [3]

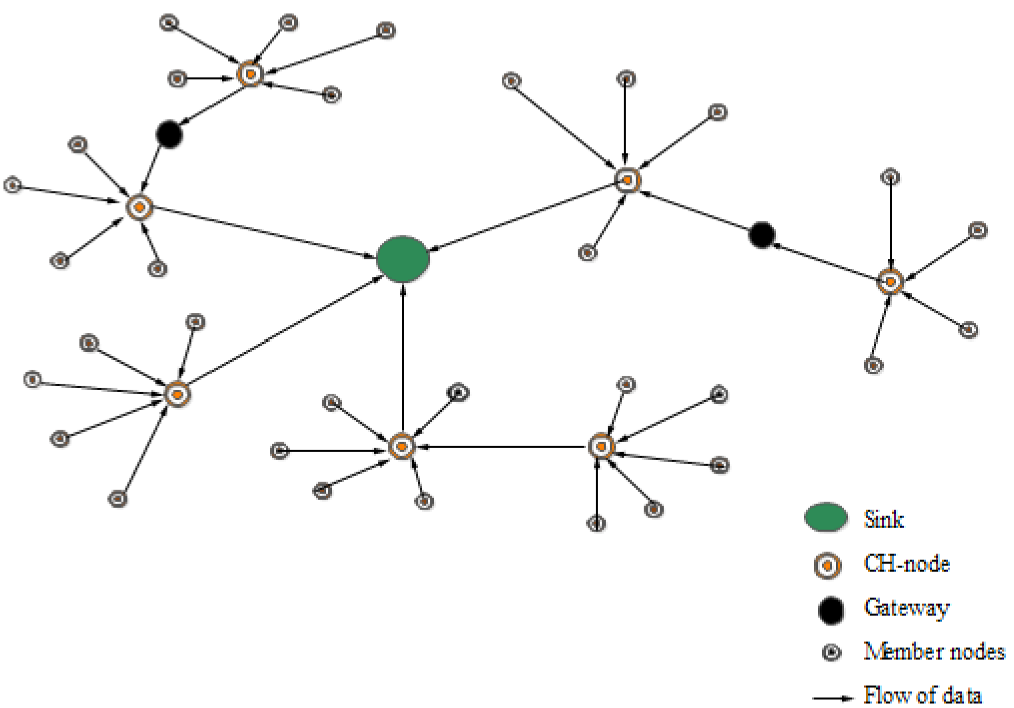


Figure 2.1: Clustered architecture [2]

Hence, each cluster has three types of nodes.

1) Single node as clusterhead (CH): collects and summarizes data flow from their ordinary nodes and then forwards data collection to the next hop.

2) Gateway nodes: shared between two or more clusters and they are considered as bridges among clusters in the network.

3) Member (normal) nodes: relay the data and connected only with CH in its cluster, where the number of ordinary nodes represents the size of the cluster in the network.

2.2 Clustering mechanism

In wireless networks, clustering mechanism has many advantages:

1) Reduction the data flows: ordinary nodes in each cluster linked to its CH, which collect, summarize data delivered, remove the redundancy of data, and forward the information to the next hop [1] [12].

2) Formed backbone network: CH and gateway nodes can form the backbone of network; this will make network topology more simple and alleviating overhead, Collision, interference and traffic congestion. The blue dashed lines represent the CH- backbone topology for WSN, as shown in Figure 2.2 [1] [6] [7].

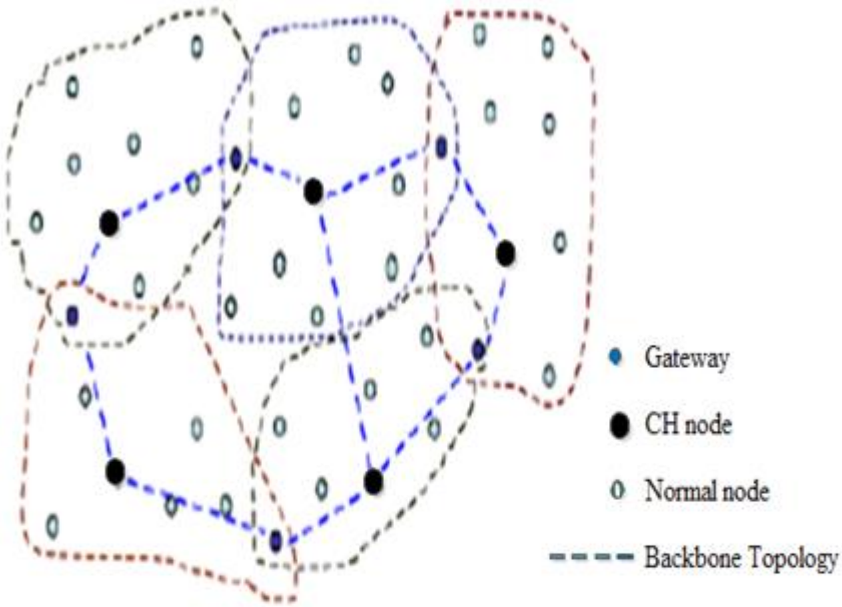


Figure 2.2: Backbone topology for clustering network. [6]

3) More stability for network topology: Only some part of the network can be affected by changing the network nodes [2] [3].

4) Easing hotspot problem: The CHs located closer to the sink die faster than those farther, because the nearest loaded by traffic data flows, therefore an unequal cluster-based routing (UCR) protocol in clustering network is used to minimize the effect of this problem by selecting clusters sizes (which mean number of nodes in each cluster) on the basis of the density of traffic data flows at each clusterhead for network's backbone, as shown in Figure 2.3 [1] [7].

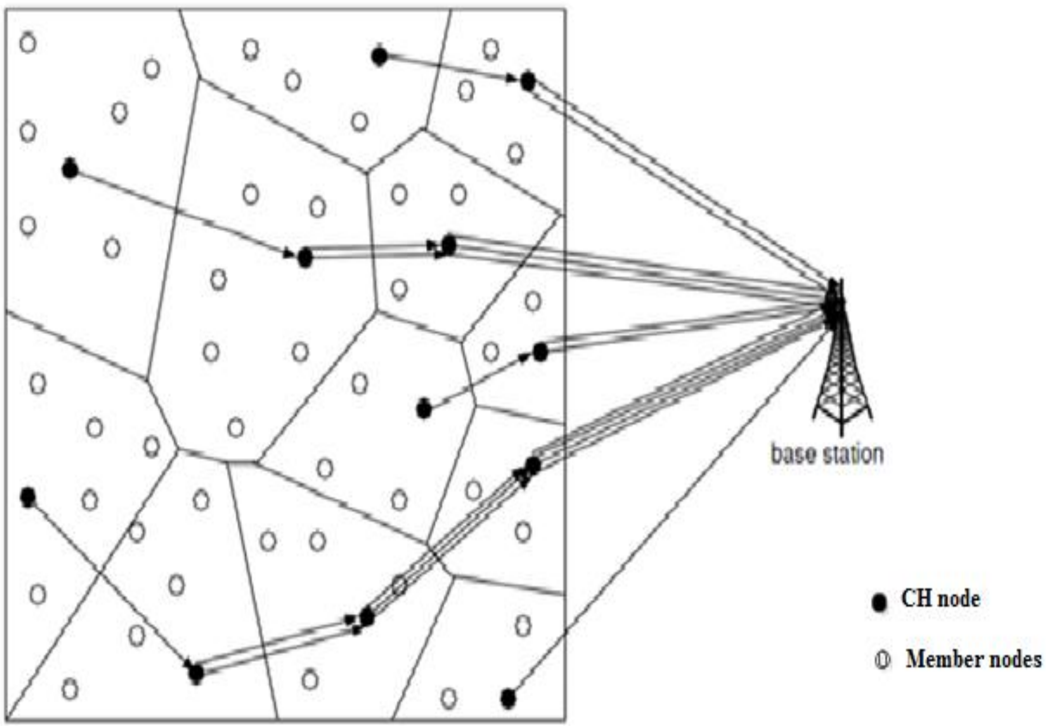


Figure 2.3: An overview UCR protocol. [7]

This Figure shows that the clusters have different sizes. So the size of cluster is decreased with decreasing the distance to the Base Station (BS) or sink; and the traffic data flows for closer CHs are alleviated.

5) Reduce energy consumption: Energy resources in wireless Sensor networks (WSN) are limited and have short lifetime because they used batteries. Therefore, clustering mechanism sported power saving by reducing transmission ranges and data flows for all nodes [1] [13].

2.3 Transmission range

Clustering mechanism for wireless networks has two concepts:

1) CH transmission range is long so that it will ensure successful delivery of network data to the gateway, but this option will need additional transmission power to achieve it and difficult modulation schemes as well. This means that inefficient using of energy, short lifetime of network, and additional cost [1] [7] [8].

2) CH transmission range is short (not long enough): so that it fails data delivery process to the gateway, this option will drain low transmission power, but it will at the same time lead to a fragmentation of the network and reduce its overall throughput [1] [9]. These two options caused the transmission range bottleneck of wireless networks. Therefore, we must select minimum transmission range to provide more energy and to avoid a fragmentation in the network. Moreover, to reduce high costs and at the same time ensures certain data delivery to the gateway**.**

2.3.1 Computing CH-CH range "*R*"

The approach in [1] computes the minimum transmission range by increasing *R* until obtaining 95% probability of connectivity (*M*) for CH node placed at a distance *d* from the gateway as shown in Algorithm 1. Where "R_0" is the original value of the range (*R)* and "Δ*R"* is the range increase.

Algorithm 1: Algorithm to compute R

$R \leftarrow R0$;

$[prob] \leftarrow connect\ (\lambda, d, R)$;

while $prob < M$ **do**

$R \leftarrow R + \Delta R$;

$[prob] \leftarrow connect\ (\lambda, d, R)$;

end while

return R

Figure 2.4: Algorithm1 [1]

Where (*R*0 = 10m) is the original value of range *(R)*, (Δ*R=1m)* is the range increase and the term "*connect"* returns *prob*, which is obtained by using algorithm 2, as shown in Figure 2.5. Hence, the probability of connectivity to the sink or gateway for a known ClusterHead node density ***(λ)*** and CH transmission range (*R)* provide the procedure *connect* with increasing hop distance *K* and decreasing a distance *d* [1]

Algorithm 2: Procedure *connect* (λ, d, R)

prob $\leftarrow$ 1;

K $\leftarrow$ 0;

$\bar{r} \leftarrow E[r] = \frac{\int_0^R 2\pi r^2 \lambda e^{-\lambda\pi(R^2 - r^2)}}{1 - e^{-\lambda\pi R^2}}$;

while d > R do

K $\leftarrow$ K + 1;

$\propto \leftarrow 2\sin^{-1}(R/2d)$;

$\beta \leftarrow \frac{(\pi - 3\propto)}{2}$;

$C \leftarrow \int_0^\beta e^{-2\lambda[\frac{\theta\,\bar{r}^2 - \frac{\bar{r}^2}{2}\sin(2\theta)}{2}]}\, d\theta$;

$\bar{\theta} \leftarrow \frac{1}{C}\int_0^\beta \theta e^{-2\lambda[\frac{\theta\,\bar{r}^2 - \frac{\bar{r}^2}{2}\sin(2\theta)}{2}]}\, d\theta$;

$d_{Next} \approx \sqrt{\bar{r}^2 + d^2 - 2\bar{r}\,d\cos\bar{\theta}}$;

d $\leftarrow d_{Next}$;

$s \leftarrow (2d + R)/2$;

$\alpha \leftarrow \sqrt{s(s-d)^2(s-R)}$;

$Area_1 \leftarrow d^2 \propto/2 - \alpha$;

$Area_2 = \frac{R^2\beta}{2}$;

$Area\,(R_{Next}) = 2\,(Area_1 + Area_2)$;

if K == 1 then

prob $\leftarrow (1 - e^{-\lambda Area\,(R_{Next})})$prob;

else

$a(R_{new}) \leftarrow ((2K - 3)\bar{r} + 2R)\bar{r}\,\bar{\theta}$;

prob $\leftarrow (1 - e^{-\lambda Area\,(R_{new})})$prob;

end if

end while

if d > 0 then

K $\leftarrow$ K + 1;

end if

return prob

Figure 2.5: Algorithm 2 [1]

The idea of algorithm 2 in [1] is to get the smallest hop distance among the next hop nodes of *A* (denoted by A_{Next}) and the gateway *B*, where, node *A* is originally with a distance (*d*) from node *B*, as shown in Figure 2.6 [1].

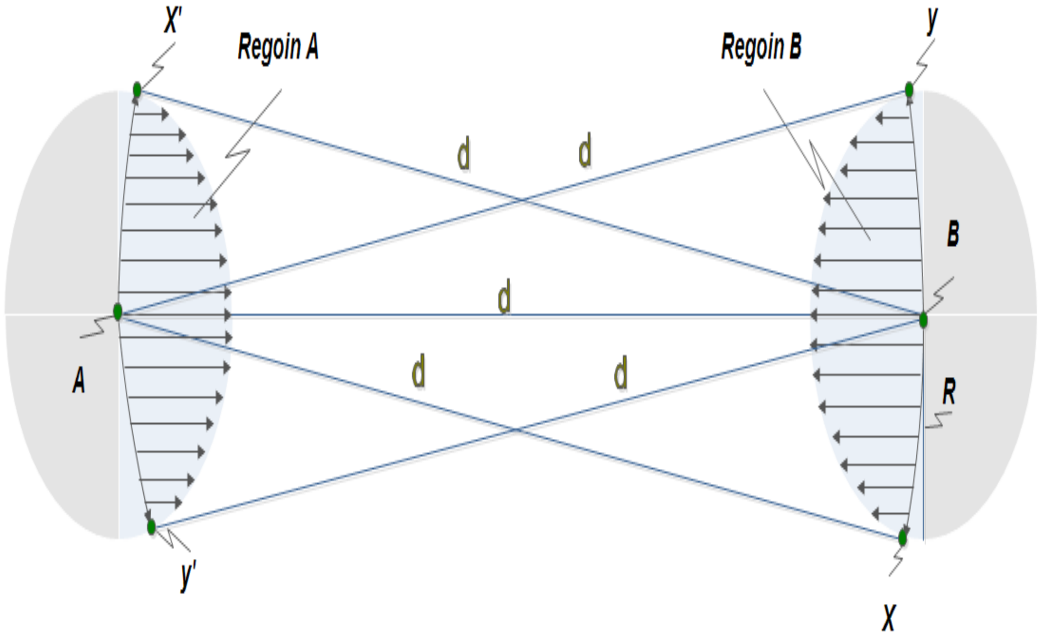


Figure 2.6: Regoin *A* and Regoin *B* [1]

Hence, *Region A* is the intersection of *B*'s circular arc of radius *d* ($X^{'}Y^{'}$) with *A*'s circular range. Similarly, *Region B* is the intersection of *A*'s circular arc of radius *d* (*XY*) with *B*'s circular range, therefore, when we select randomly next hop for node *A* (denoted by A_{Next}) in region *A* which has a new distance (d_{Next}) to gateway *B* less than the previous distance *d*. This means, the distance (d_{Next}) to the node *B* decreases with increasing hop distance *K* (see step 5 of algorithm 2) to node *A* and re- find a new distance d_{Next} less than *d* to *d* (see step 11) until $d < R$. Thus clear in the inner loop (step 17 to step 22) of algorithm2. Also this loop updates the connectivity probability (*prob*) over *K* hops. To avoid a next hop distance (d_{Next}) is larger than the previous distance, when the previous hop of node *B* is at intersections points (point x and point y) of the arc xy which bounds the Region *B*, therefore, as shown in Figure 2.7 [1].

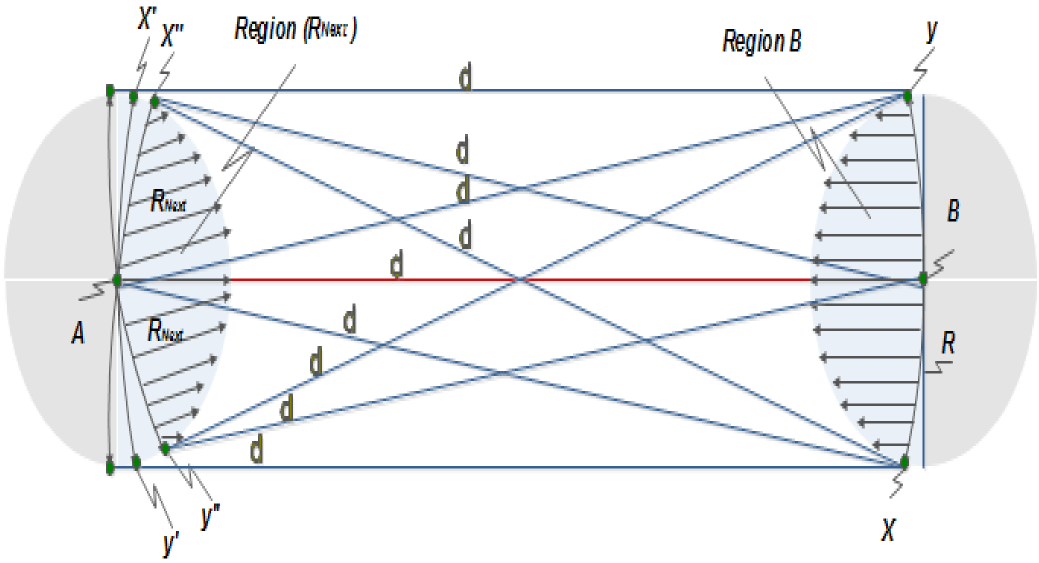


Figure 2.7: *Region* R_{Next} (Area R_{Next}) [1]

This Figure, illustrates the determination of *Region* $\mathrm{R_{Next}}$ (denoted *Area* (R_{Next}), see step 16 of algorithm2) within *Region A*, to ensure that the distance d_{Next} (which is the distance between *A*'s next hop and *B*'s previous hop) is always less than the distance *d*. Hence, the *Region* R_{Next} is created by the intersection of the arcs of radius distance *d* for point *X* and point *Y* with *Region A* (in Figure 2.6) at points *X''* and *Y''* respectively [1].

2.3.2 Computing the next hop distance $\mathbf{d_{Next}}$

The next hop (A_{Next}) of ordinary node *A* which is lying within *Region* $\mathrm{R_{Next}}$ and it has a radius r (where $0 < r \leq R$) to node *A*, and angular deviation θ (where $0 \leq \theta \leq \beta$) to the straight line between node *A* and gateway *B* as shown in Figure 2.8 and also this next hop has a distance $\mathrm{d_{Next}}$ to node *B* [1].

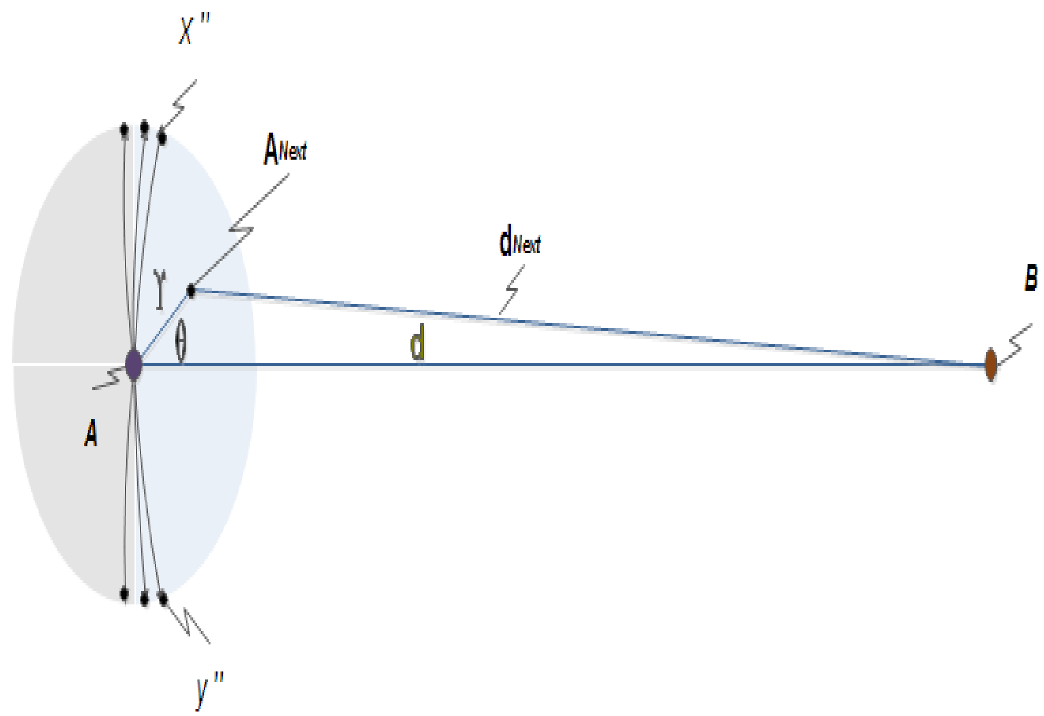


Figure 2.8: Next hop A_{Next} and a new distance d_{Next} [1]

Therefore, we can find a new distance d_{Next} for single hop A_{Next} by using cosine law as below: [14]

$$d_{Next} = \sqrt{r^2 + d^2 - 2rd\ Cos(\theta)} \qquad (2.1)$$

The locations of node have uniform distribution,therefore, the expressions r and θ are random variables and the next jump of A (A_{Next}) will depend on these two variables in a *Region* R_{Next} Fartheremore, avoid the complex of laping integrations to find individual path lengths which will occur in multihop distances. [15] Therefore, by using the approximation of the average transmission distance $\overline{r}$ which is equal to the value for each next hop over a path and then we can compute a new distance d_{Next} depending on this approximation (See step 10 in algorithm 2) as flow: [1] [14]

$$d_{Next} \approx \sqrt{\overline{r}^2 + d^2 - 2\overline{r}\, d\, cos\, \overline{\theta}} \qquad (2.2)$$

where $\overline{r}$ is the average of next hop distances to node A and $\bar{\theta}$ is the average angular deviation for θ. Therefore, we must find these two variables

1) The average propagation distance $\bar{r}$

To find the average for the next hop distances $\bar{r}$, as shown in Figure 2.9.

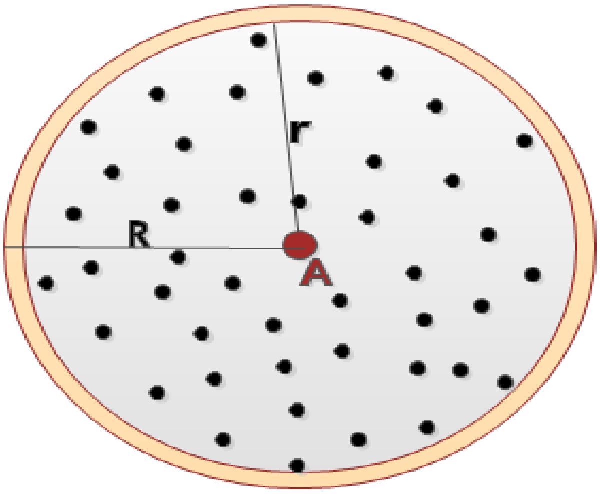


Figure 2.9: Computing the average for the next hop distances $\bar{r}$ [1]

An expected value (average) of the smaller radial distance that encircles for every node within A's circular range, as shown in Figure above, we consider no nodes within the region more than radius r and this will make radius r to be the smallest boundary radius. Also, we consider at least only one node in smallest encircle $2\pi r\, dr$ within region r. Therefore, we can represent at least one neighbour node of node A within its range in equation below: [1] [16]

$$f(r) = \frac{2\pi r \lambda e^{-\lambda\pi(R^2-r^2)} dr}{1-e^{-\lambda\pi R^2}} \tag{2.3}$$

Hence, the expected value which is equal to average distance $\bar{r}$ will be as below:

$$\bar{r} = E[r] = \frac{\int_0^R 2\pi r^2 \lambda\, e^{-\lambda\pi(R^2-r^2)}}{1-e^{-\lambda\pi R^2}} \tag{2.4}$$

where step 3 in algorithm 2 represents this equation

2) The average angular deviation ($\bar{\theta}$), we seek to obtain the average angular deviation $\bar{\theta}$ for this average distance as shown in Figure 2.10.

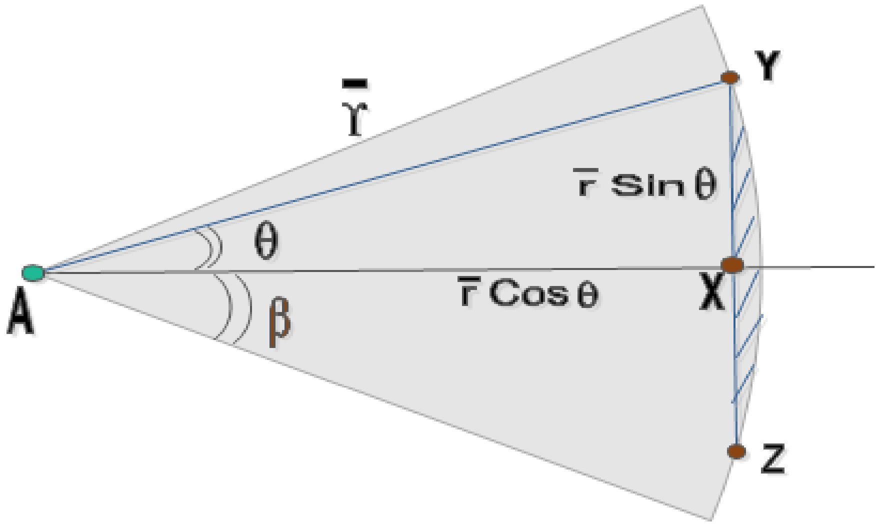


Figure 2.10**:** Computing the average angular deviation $\bar{\theta}$ [1]

We consider the node Y which has the furthest angular deviation θ towards the gateway *B*, this means there is no any node in the dashed area bounded by the line YZ and arc YZ. Therefore, this region has smaller probability and fewer likely for a furthest node (Y) to include a great angular deviation (θ) towards node B, because the distribution is not uniform on this arc. Hence, we can estimate the average angular deviation $\bar{\theta}$ (the expected value of angular deviation θ) by finding the probability of this area with the flowing relations [1] [16].

Area of half marked region = Area of arc's θ – Area of triangle *AYX*

where, Area of arc's θ = $\frac{\bar{r}^2\theta}{2}$, *and* Area of triangle AYX = $\left(\frac{1}{2}\right)\bar{r}\ cos\,\theta\ *\bar{r}\ sin\,\theta$

Area of half marked region $= \frac{\bar{r}^2\theta}{2} - \left(\frac{1}{2}\right)\bar{r}^2\,\frac{sin(2\theta)}{2} = [\,\bar{r}^2\theta - \left(\frac{1}{2}\right)\bar{r}^2\,sin(2\theta)\,]/2$

Area of overall marked region = $\bar{r}^2\theta - \left(\frac{1}{2}\right)\bar{r}^2\,sin(2\theta)$

And then, the Probability (*Prob*) of this area will be ($e^{-\lambda[\bar{r}^2\theta-\left(\frac{1}{2}\right)\bar{r}^2\sin(2\theta)]}$). Therefore, the average angular deviation $\bar{\theta}$ (steps 8 and 9 in algorithm 2) can estimated as shown below.

$$\bar{\theta} = \frac{\int_0^\beta \theta e^{-2\lambda\left[\frac{\theta\bar{r}^2-\frac{\bar{r}^2}{2}\sin(2\theta)}{2}\right]}d\theta}{\int_0^\beta e^{-2\lambda\left[\frac{\theta\bar{r}^2-\frac{\bar{r}^2}{2}\sin(2\theta)}{2}\right]}d\theta} \qquad (2.5)$$

2.4 End -to- end connectivity probability

The connectivity for wireless clustering networks is depends on the probability for each node that is located the next hop towards a gateway node, as shown in Figure 2.7, the *Region* R_{Next} (Area(R_{Next})) with the first ordinary node A is considered within it. Hence, the Poisson distribution can be achieved for nodes' number in this area which has uniformly distributed. Therefore, we can obtain the probability of connectivity to get one node only with *Region* (R_{Next}) to be next first hop (A_{Next}) as $1 - e^{-\lambda \mathrm{Area}(R_{Next})}$, (*Step 18 in algorithm 2*), [1] [16]

Where, R_{Next} is represented by dashed lines as shown in Figure 2.11. [1]

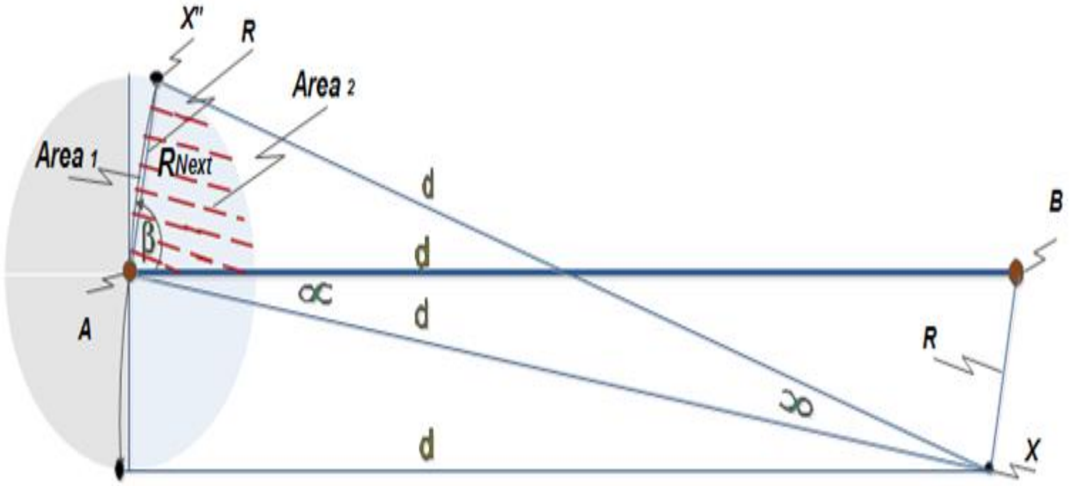


Figure 2.11: Area_1 and Area $_2$ [1]

$R_{Next} \ = \ Area_1 + \ Area_2$, *and* $\quad Area(R_{Next}) = 2 * R_{Next}$

$Area(R_{Next}) = 2[\,Area_1 + \ Area_2]$, (See step 16 of Algo.2) (2.6)

where, $Area_1$ is the area difference between the area of Section circular (*XX'A*) and triangle *AXX'*), while $Area_2$ is selected area corresponding to the circular arc of angle β, as follow: [1] [14]

$Area_1 = d^2 \propto /2 - \alpha$, *(Step 14 of algorithm 2)* (2.7)

$Area_2 = \ \frac{R^2\beta}{2}$, *(Step 15 of algorithm 2)* (2.8)

Now, we find angles $\propto$ and β and then the area (α) of triangle *AXX'* as shown below.

I-For triangle *AXX'*

$$R^2 = d^2 + d^2 - 2 * d * d\, cos(\propto) \ = 2 * d^2[1 - cos(\propto)] \quad \leftrightarrow$$

$$[1 - \cos(\propto)] = \frac{R^2}{2d^2} \ \leftrightarrow$$

$$\frac{[1 - \cos(\propto)]}{2} = \frac{R^2}{4d^2} \ \leftrightarrow$$

$$\sqrt{\frac{[1 - \cos(\propto)]}{2}} = \frac{R}{2d} \ = \ \sin(\ \propto/2) \ \leftrightarrow$$

$\propto = \ 2 * \sin^{-1}(\frac{R}{2d})$, *(Step 6 of algorithm 2)* (2.9)

II-Since, The triangle *AXX'* is an isosceles triangle and sum of its angles are π. Therefore, $\propto \ +(\alpha + \beta) + (\propto + \beta) = \pi \ \leftrightarrow \ 2\beta + 3 \propto = \pi \ \leftrightarrow$

$\beta = \frac{\pi - 3\propto}{2}$, *(Step 7 of algorithm 2)* (2.10)

III-The area (*a*) of triangle *AXX'* is found by using the half circumference (s) of this triangle, where

$\mathrm{s} \ = \frac{\mathrm{d+d+R}}{2} \ = \frac{2*\mathrm{d+R}}{2}$, ***(****Step 12of algorithm 2)* (2.11)

And,

$$\alpha = \sqrt{s(s-d)^2(s-R)}\ , \quad \textit{(Step 13 of algorithm 2)} \qquad (2.12)$$

2.5 New area search for next hop nodes

We strive to find the next jumps towards a gateway node within *Region* R_{Next} which has multiple nodes. Hence, the number of jumps becomes higher and more complex of node locations. Furthermore, recently increasing wrapped areas becomes exponential, causing hardness in an accurate computation. On the other hand, it is sensible to hardly estimate those anew areas as other hops are crossed as shown in Figure 2.12 [1] [14].

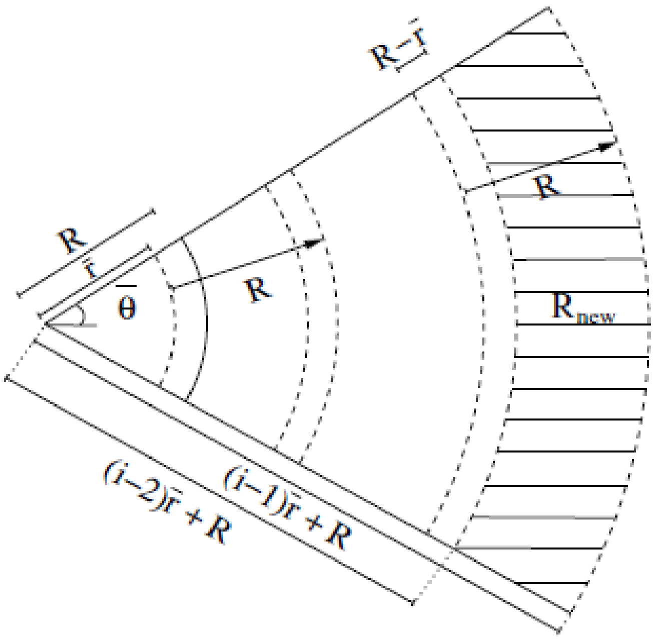


Figure 2.12: Area for next hop nodes (R_{new}) [1]

This Figure shows the *Area* (R_{new}) which contains nodes that have a new next hops to nodes of hop number (i). Hence, the circular arcs which have the same center at ordinary node *A* with gradual increase of transmission range *R*, and the average angular deviation $\bar{\theta}$ (that is found in equation 2.5). While the gradient away from the center (the node *A)* is supposed to include the average transmission incremental radius for $\bar{r} \leq R$ for every hop as a single hop propagation distance (step 3 of algorithm 2) [1] [15].

Therefore, we get the *Area* (R_{new}) which became easy by using geometrical computation, as follows: [1] [14]

$$R_{new} = [(i-1)\bar{r} + R]^2 * \frac{\bar{\theta}}{2} - [(i-2)\bar{r} + R]^2 * \frac{\bar{\theta}}{2} = [[(i-1)\bar{r} + R]^2 - [(i-2)\bar{r} + R]^2]\frac{\bar{\theta}}{2} = [[(i-1)^2(\bar{r})^2 + 2(i-1)\bar{r}R + (R)^2] - [(i-2)^2(\bar{r})^2 + 2(i-2)\bar{r}R + (R)^2]\frac{\bar{\theta}}{2} = [(i)^2(\bar{r})^2 - 2i(\bar{r})^2 + (\bar{r})^2 + 2i\bar{r}R - 2\bar{r}R + (R)^2 - (i)^2(\bar{r})^2 + 4i(\bar{r})^2 - 4(\bar{r})^2 - 2i\bar{r}R + 4\bar{r}R - (R)^2]\frac{\bar{\theta}}{2} = [2i(\bar{r})^2 - 3(\bar{r})^2 + 2\bar{r}R]\frac{\bar{\theta}}{2} = [(2i-3)(\bar{r})^2 + 2\bar{r}R]\frac{\bar{\theta}}{2} = [(2i-3)\bar{r} + 2R] * \bar{r}\frac{\bar{\theta}}{2}$$

$$\therefore \quad R_{new} = [(2i-3)\bar{r} + 2R] * \bar{r}\frac{\bar{\theta}}{2} \qquad \textit{(Step 20 of algorithm 2)} \qquad (2.13)$$

after that, we assume the connectivity probability (*Prob*) to obtain one node with Area (*Rnew*) and update this *prob* (see steps 21 and 22), as follows:

$$Prob = [1 - e^{-\lambda Area(R_{new})}] \qquad \textit{(Step 21 of algorithm 2)}$$

$$Prob = [1 - e^{-\lambda Area(R_{new})}] * Prob \quad \textit{(Step 22 of algorithm 2)} \qquad (2.14)$$

2.6 Implementation of the algorithms

Implementation of the algorithm1 requires the initial value of range R_0 (10m), the range increment ΔR(1m), and the probability of connectivity (prob) (step 2 of algorithm 1 to a gateway that we receive from the term connect (λ, *d*, *R*) by using algorithm2. Furthermore, algorithm2 needs a value of *d* along which multihop probability of connectivity which is calculated within various values of the transmission range (*R*). Hence, this range (*R*) is allocated for each clusterhead (CH) nodes and linked with deployment node density σ $(3 * 10^{-3}, 4 * 10^{-3}, 5 * 10^{-3}, and\ 6 * 10^{-3})$. Therefore, with clusterhead (CH) selection probability (P) is equal to (0.1), CH node density λ will be (0.0003, 0.0004, 0.0005, and 0.0006) respectively [1] [7] [8] [9].

Also, for an $X\times X$ network, [1] where ($X = 1000m$), the derived terms used in the algorithm 2 can be accurate enough when the resulting range *R* is close to the value of distance d that is selected by Monte Carlo simulations to obtain the smallest range (R) which allows at least 95% Connectivity probability (*Prob*), with different values of node density σ. Therefore, the best estimation is obtained for choosing the CH that is *X/*2 (d= 500m) away from the node *B* for each density value of the network nodes σ. [1]

Chapter 3

THE MODIFIED TRANSMISSION RANGE ASSIGNMENT ALGORITHM

3.1 Mathematical concepts

Depending on the basic mathematical concepts and the relationships between the circle and the straight line, we find four new mathematical cases to reduce the transmission range (R) with ensuring at least 95% end–to- end connectivity probability.

3.2 New d_{Next} law

In [1], d_{Next} is approximated by using equation $\left(d_{Next} \approx \sqrt{\bar{r}^2 + d^2 - 2d\bar{r}\cos\bar{\theta}}\right)$ (*See step 10 of algorithm 2*). While, as shown in Figure 3.1, we can use a new method to compute d_{Next}.

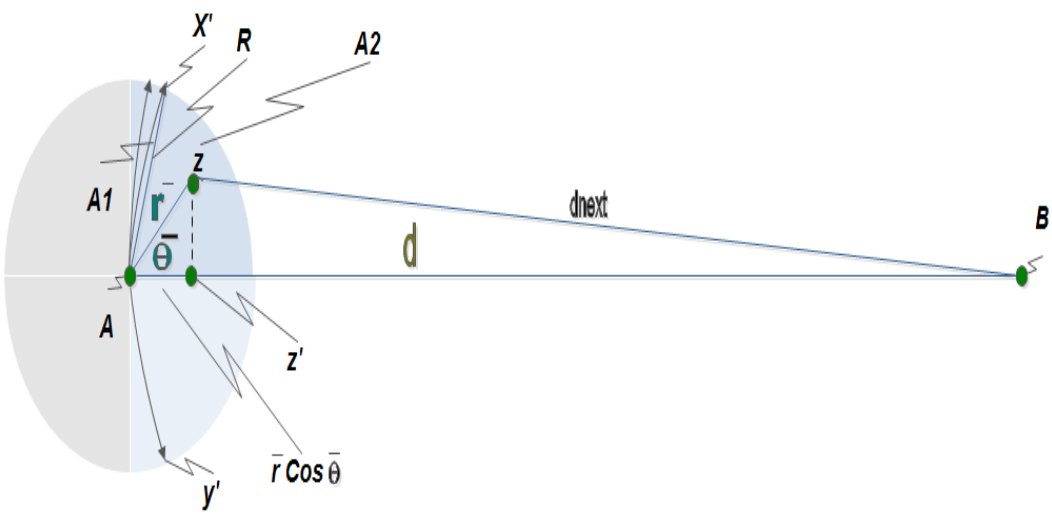


Figure 3.1: A_{Next} and a new distances d_{Next}.

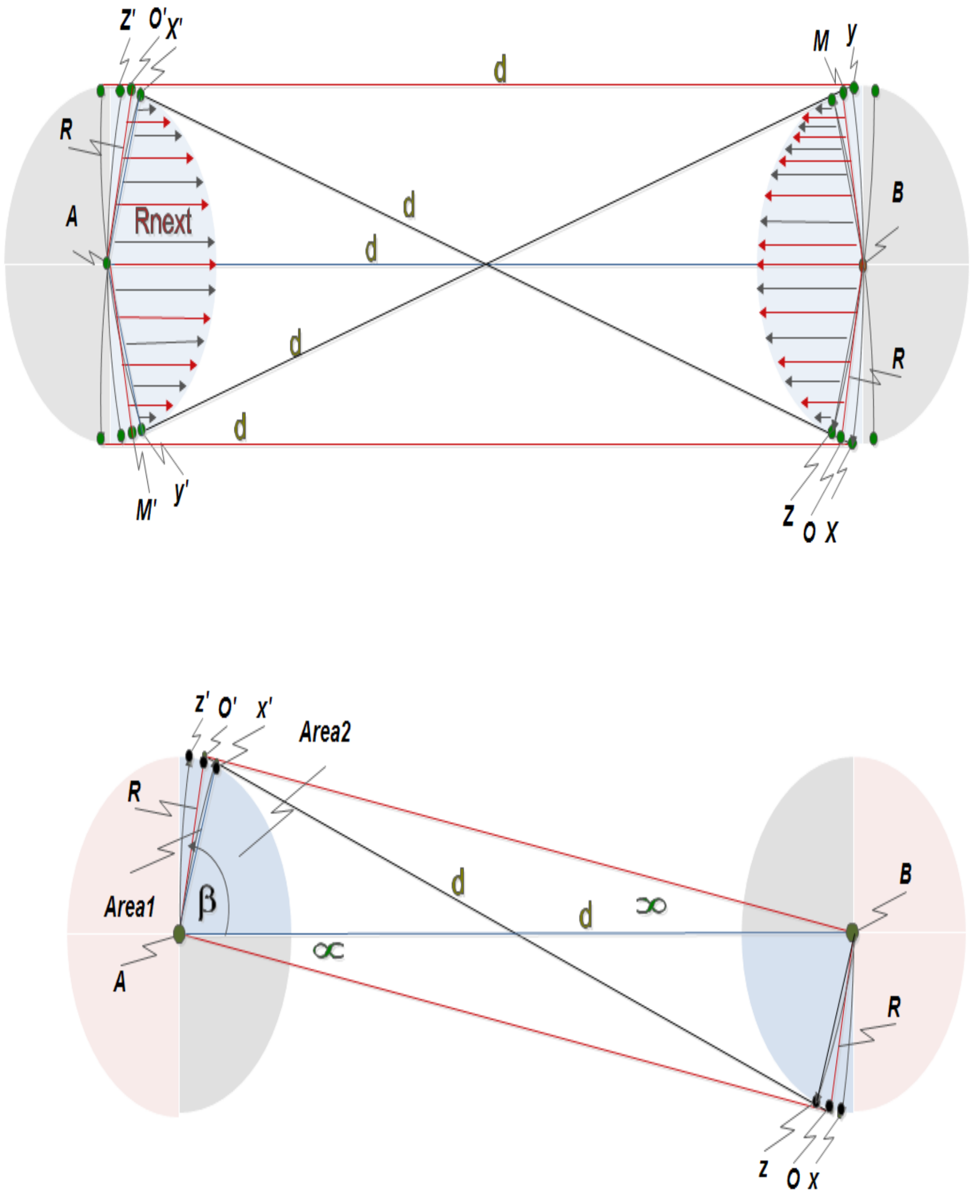
The idea is that the component of $\bar{r}$ on the straight line *AB* is ($\bar{r}\, cos\, \bar{\theta}$). Therefore we can also approximate d_{Next} as:

$$d_{Next} \approx d - \bar{r} \cos \bar{\theta} \qquad (3.1)$$

Where $\bar{r}$ is the expected value of the smallest radial distance r, ($0 < r \leq R$), and $\bar{\theta}$ is the average angular deviation of θ, ($0 \leq \theta \leq \beta$). Hence, both $\bar{r}$ and $\bar{\theta}$ are computed by using steps (3) and (9) of algorithm 2 respectively. [14]

3.3 Increasing area search (R_{Next})

In [1], *Region* R_{Next} (Which represents $Area_1$ and $Area_2$) is determined by computing angles ($\propto$ and β). While, as shown in Figure 3.2, we can use a new mathematical approach to compute angles ($\propto$ and β) by increasing the area search R_{Next}.



a)

b)

Figure 3.2: Increasing area search: (a) Area R_{Next}, (b) $Area_1$ and $Area_2$

The idea, as shown in Figure 3.2a, we consider both points *O'* and *O* which are lying on a circular arcs *Z'X''* and *ZX* respectively (that means shaft points *X''* and *X* to points *O'* and *O* respectively). Also, as shown in Figure 3.2b, we consider the straight line *BO'* is the tangent of *A's* circle at point *O'* and the straight line *AO* is the tangent of *B*'s circle at point *O*. For this case, when we choose any point on the straight line AO' which has the distance r to node A, and d_{Next} to gateway B, that will be guarantee less than d by value (r cos (β)), where $0 \leq r \leq R$. this leads to: [14]

$AO' \perp BO'$ and $BO \perp AO$

(Radius is perpendicular to the tangent of the circle from the tangency point).

Also, $AO' = BO = R$ and $OO' = AB = d$

$\therefore \Delta ABO' \equiv \Delta ABO$ (Two triangles are matching by two sides and angle). Therefore,

$\therefore m\, A\grave{B}O' \equiv m\, B\grave{A}O \equiv \propto$

Now, we can find a new law to compute angle $\propto$ and angle β from the triangle ABO' or ABO as follow: [14]

$$\propto = \tan^{-1}(R/d) \tag{3.2a}$$

$$\beta = \frac{\pi}{2} - \propto \tag{3.2b}$$

In this approach, there are two states:

1) Using a new equation (3.2a) and equation (3.2b) to compute ($\propto$ *and* β) in the steps 6 and 7 of algorithm2.

2) Using a new d_{Next} law ($d_{Next} \approx d - \bar{r}\cos\bar{\theta}$) with state (1).

3.4 Decreasing area search (R_{Next})

Region R_{Next} (Which represents $Area_1$ and $Area_2$) is determined in approach [1] to compute the angle $\propto$ and angle β. While, as shown in Figure3.3, we can use a new mathematical approach to compute these angles by decreasing the area search R_{Next}.

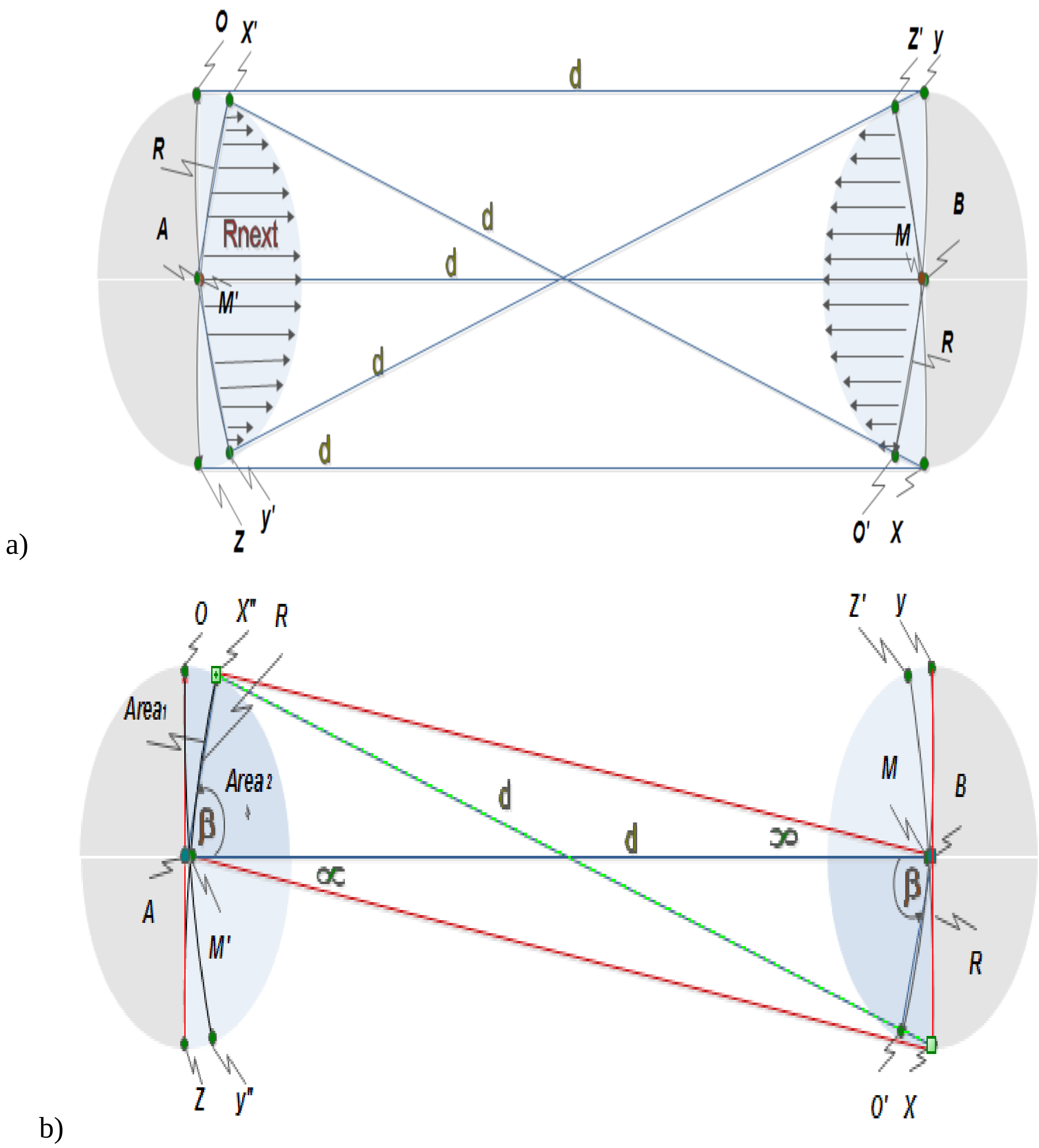


Figure 3.3: Decreasing area search; (a) Area (R_{Next}). (b) Area_1 and Area_2

As shown in Figure (3.3.a and b), we consider the arcs (*ZX''*) and (*OY''*) of the radius (*d*) around point *X* and point *Y* respectively, intersect at point *M'* that is very close to point *A*, and Similarly the arcs (*YO'*) and (*XZ'*) around points *O* and Z respectively, intersect at point *M*, that's guarantee reducing the next Region (R_{Next}) within the Region *A* (see Fig. 2.7), thus satisfies *dnext's* hop is less than the distance *d*.

In this approach, we can find a new law to compute the angles ($\propto$ and β) as shown in the figure3.3b. Hence, the idea is that we consider the straight line (BX') is tangent to *A's* circle at point *X'*, this leads us to the flow: [14]

AX' $\perp$ *BX', at point (X')*

(Radius perpendicular to the tangent of the circle from the tangency point)

And also, *XX' = AB = d, BX = AX' = R,* and $m\,A\grave{X}'B \equiv m\,A\grave{B}X \equiv \pi/2$, therefore, $\Delta\,ABX \equiv \Delta\,ABX'$, (Two sides and angle from the first triangle with two sides and angle from the second triangle).

$\therefore m\,A\grave{B}X' \equiv m\,X\grave{A}B = \propto$

And from triangle (ABX'), we can found the angles $\propto$ and β, as below.

$\propto = \tan^{-1}(R/d)$, and (3.3a)

$\beta = \frac{\pi}{2} - \propto$, (3.3b)

In this approach, there are two main states and four secondary states:-

3.4.1 Main states

1) -Using a new equation (3.3a) and equation (3.3b) in steps 6 and 7 of algorithm2

2) -Using a new d_{Next} law ($d_{Next} \approx d - \bar{r}\cos\bar{\theta}$) with state (1).

3.4.2 Secondary states

In this case, as shown in Figure 3.3b, we consider the points (M' *and* A), and the points (M *and* B) which are matching, i.e. ($M' \equiv A$), and ($M \equiv B$) respectively. Therefore, we can use equation (3.3a) and equation (3.3b) with equations (2.9) and equation (2.10) to determine $Area_1$ and $Area_2$ and find a new four states as follow:

1) Using equation 3.3b ($\beta = \frac{\pi}{2} - \propto$) only, and equation 2. 9 ($\propto = 2 * \sin^{-1}(\frac{R}{2d})$)

2) Using equation 3.3b ($\beta = \frac{\pi}{2} - \propto$), and equation 2. 9 ($\propto = 2 * \sin^{-1}(\frac{R}{2d})$) with a new d_{Next} law (equation 3.1).

3) Using equation 3.3a ($\propto = \tan^{-1}(R/d)$) only , and equation 2.10 ($\beta = (\pi - 3 \propto)/2$

4) Using equation 3.3a ($\propto = \tan^{-1}(R/d)$), and equation 2.10 ($\beta = (\pi - 3 \propto)/2$, with a new d_{Next} law (equation 3.1).

3.5 Computing an average angular deviation $\bar{\theta}$

As shown in Figure3.4

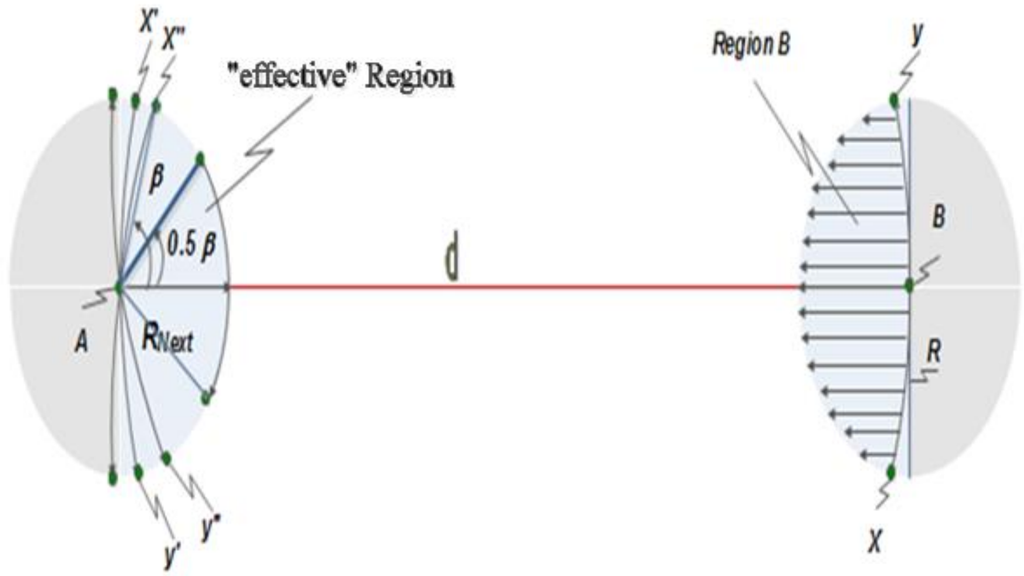


Figure 3.4: Effective region

Hence, if we choose A_{Next} to be in the indicated "effective" region of Region R_{Next}, then we can obtain the highest transmission range for a given transmission power. Moreover, the average angular deviation ($\bar{\theta}$) which was computed by equation (2.5) in [1] can be approximated as:

$$\bar{\theta} = 0.5\,\beta \quad (3.4)$$

In this approach, we got the main two advantages: the first is to avoid the mathematical complexity and the second is to provide high power saving for CH transmission range more than 30%. So that there are four states as follow:

1) Using $\bar{\theta} = 0.5\,\beta$ Instead of equation (2.5).

2) Using $\bar{\theta} = 0.5\,\beta$ with a new law of d_{Next} in equation (3.1).

3) Using $\bar{\theta} = 0.5\,\beta$ with decreasing Area (R_{Next}) i.e. $\propto = tan^{-1}(R/d)$, *and* $\beta = \frac{\pi}{2} - \propto$ *only*.

4) Using $\bar{\theta} = 0.5\,\beta$, with decreasing Area R_{Next} ($\propto = \tan^{-1}(R/d)$, and $\beta = \frac{\pi}{2} - \propto$) with a new law of d_{Next}.

Hence, all our modifications above of algorithm 2 in approach [1] will become like follows:

Algorithm 2: Procedure *connect* (λ, *d*, *R*)

$prob \leftarrow 1;$
$K \leftarrow 0;$
$\bar{r} \leftarrow E[r] = \frac{\int_0^R 2\pi r^2 \lambda\, e^{-\lambda\pi(R^2 - r^2)}}{1 - e^{-\lambda\pi R^2}};$
while $d > R$ do
$K \leftarrow K + 1;$
$\boldsymbol{\propto \leftarrow 2\tan^{-1}(R/d);}$
$\boldsymbol{\beta} \leftarrow \frac{\pi}{2} - \propto;$
$\boldsymbol{\bar{\theta} \approx 0.5 * \beta;}$
$\mathbf{d_{Next} \approx d - \bar{r}\ \cos\bar{\theta};}$
$d \leftarrow d_{Next};$
$s \leftarrow (2d + R)/2;$
$\alpha \leftarrow \sqrt{s(s - d)^2(s - R)};$
$Area_1 \leftarrow d^2 \propto /2 - \alpha;$
$Area_2 = \frac{R^2\beta}{2};$
$Area\,(R_{Next}) = 2\,(Area_1 + Area_2);$
if $K == 1$ then
$prob \leftarrow (1 - e^{-\lambda Area\,(R_{Next})})prob;$
else
$a(R_{new}) \leftarrow ((2K - 3)\bar{r} + 2R)\bar{r}\,\bar{\theta};$
$prob \leftarrow (1 - e^{-\lambda Area\,(R_{new})})prob;$
end if
end while
if $d > 0$ then
$K \leftarrow K + 1;$
end if
return prob

Figure 3.5: the modified version of algorithm 2

3.6 CH- to- CH transmission power

We can find transmission power by using the following formula: [6]

$$P_{AB} = R^2 \tag{3.5}$$

where, P_{AB}, the minimum transmission power required from node A to getaway B, and R is the transmission range in (m), and therefore we can find the Power saving percentage for minimum transmission ranges as follows:

$$\text{Power saving \%} = \left(1 - \frac{P_{New}}{P_{Old}}\right) \times 100\% \tag{3.6}$$

where, P_{Old} is the transmission power calculated by using the approach of [1], and P_{New} is the transmission power calculated by using our approach of all cases above.

Furthermore, the minimizing energy consumed in the wireless networks extend the network lifetime, but we didn’t seek to calculate it in this research.

Chapter 4

NUMERICAL RESULTS

4.1 Case1: Main approach

We follow the approach in [1] by using Matlab to obtain the minimum CH transmission ranges for various values of node density σ $(3*10^{-3}, 4*10^{-3}, 5*10^{-3}, and\ 6*10^{-3})$ with ensuring at least 95% connectivity probability (*prob*). Hence, Figure 4.1 appears the probability of connectivity (*Prob*) as a function for the CH transmission range (R) of the original approach in [1].

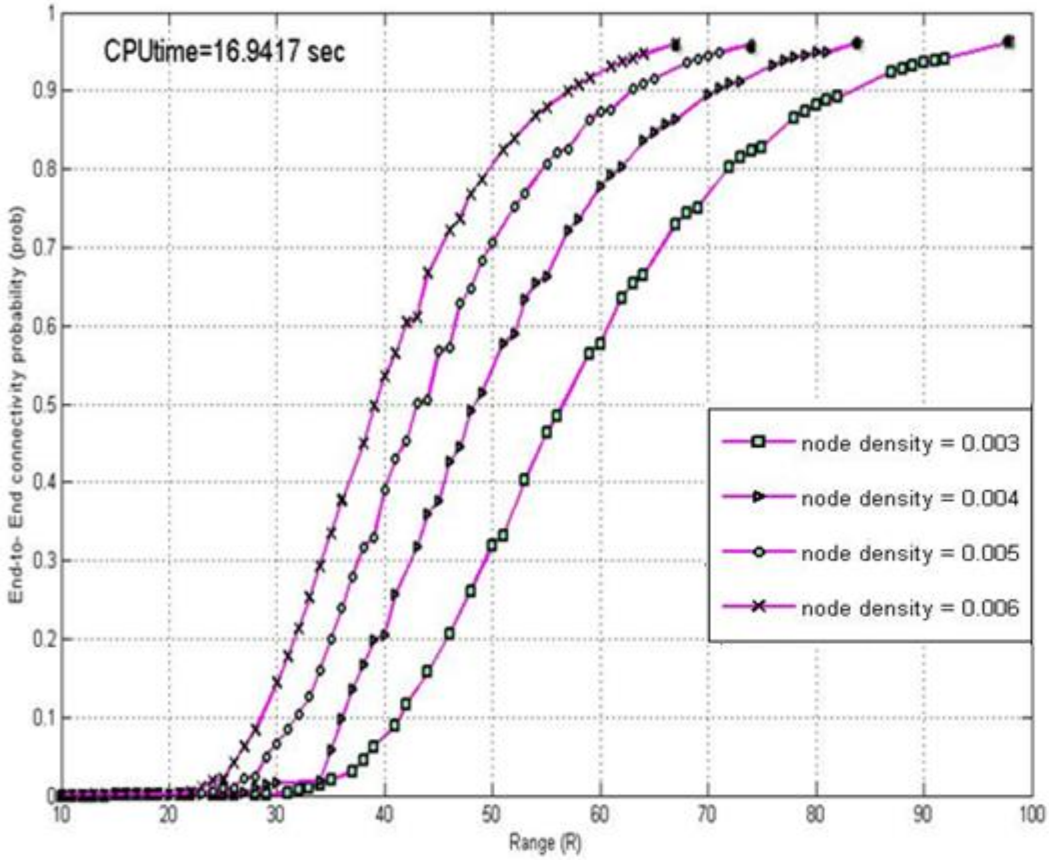


Figure 4.1: Connectivity probability versus R for the approach of [1] with different values of node density σ

As it can be seen from this figure, probability of connectivity (*Prob*) increases as the CH range (R) increases, and also it increases as the density of nodes increases, this is because when the range or node density increases, the chance of CHs to find next hop is more, and hence, communication is more assured. Also, table 4.1 shows the maximum CH transmission range for different values of node density σ with at least 95% connectivity probability.

Table 4.1: Maximum transmission range for different node density with at least 95% connectivity probability (Prob)

Node density (σ)	Range R (m)	Prob.
0.003	98	0.9618
0.004	84	0.9622
0.005	74	0.9602
0.006	67	0.9593

Hence, it can be noted that the maximum range is obtained at the lowest node density and vice versa.

4.2 Case 2: New d_{Next} law.

In this case, we used a new d_{Next} law ($d_{Next} \approx d - \overline{r}\, cos\, \overline{\theta}$) rather than the equation 2.2 ($d_{Next} \approx \sqrt{\overline{r}^2 + d^2 - 2\overline{r}\, d\, cos\, \overline{\theta}}$) in step 10 of Algorithm2. Hence, Figure 4.2 shows a connectivity probability (*Prob*) versus R with a new *dnext's* law for different density of nodes σ. Moreover, it is clear that the probability of connectivity (*Prob*) increases as the CH range (R) increases, and also it increases as the density of nodes (σ) increases.

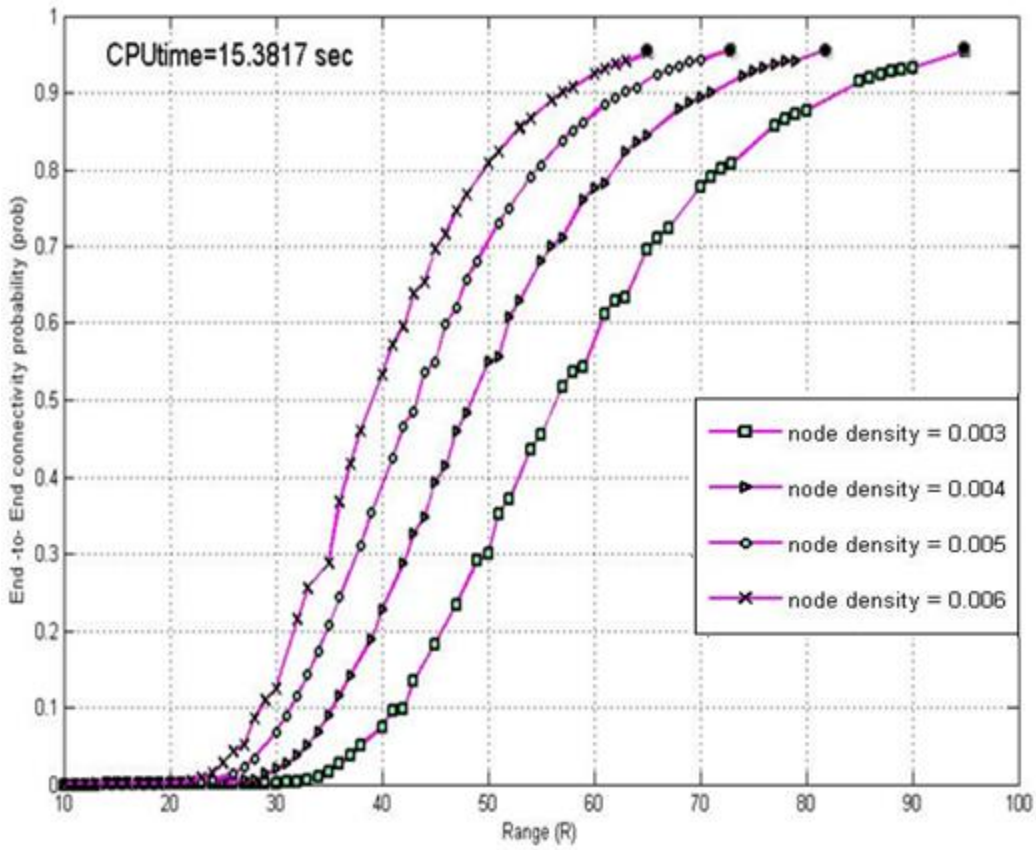


Figure 4.2: Connectivity probability versus R for a new d_{Next}'s law with different values of node density σ

Then we used equation ($P_{AB} = R^2$) and equation (Power saving%= $\left(1 - \frac{P_{New}}{P_{Old}}\right) \times 100\%$) to compute the value of power saving percentage at maximum CH transmission ranges for various node density values σ. Table 4.2 shows the power saving percentage comparison for 95% connectivity (*Prob*) between the approach of [1] and this approach.

Table 4.2: Power saving % comparison for 95% connectivity probability with a new d_{N}ext

Node density	Main results [1]		New d_{Next}'s law		Power saving %
	Range R (m)	Prob.	Range R (m)	Prob.	
0.003	98	0.9618	95	0.9542	6.03
0.004	84	0.9622	82	0.9565	4.71
0.005	74	0.9602	73	0.9570	2.70
0.006	67	0.9593	65	0.9516	5.90

It can be noted that our approach outperforms the approach of [1] by 2.70 - 6.03% power saving. Hence, high power saving is 6.03% with reducing range R (3m) for node density σ = 0.003, while low power saving % is 2.07% with reducing range R (1m) for node density σ = 0.005.

4.3 Case 3: Increasing area search (R_{Next})

In this case, there are two states as follow:

1- Using a new equations ($\propto = \tan^{-1}(R/d)$, $\beta = \frac{\pi}{2} - \propto$) to compute ($\beta$ *and* $\propto$) in steps 6 and 7 of Algorithm. (2). Figure 4.3 shows the connectivity probability (*Prob*) as a function of the CH range (*R*) for different density values σ. Moreover, it is clear that probability (*Prob*) increases as the range *R* increases, and also it increases as the density (σ) increases.

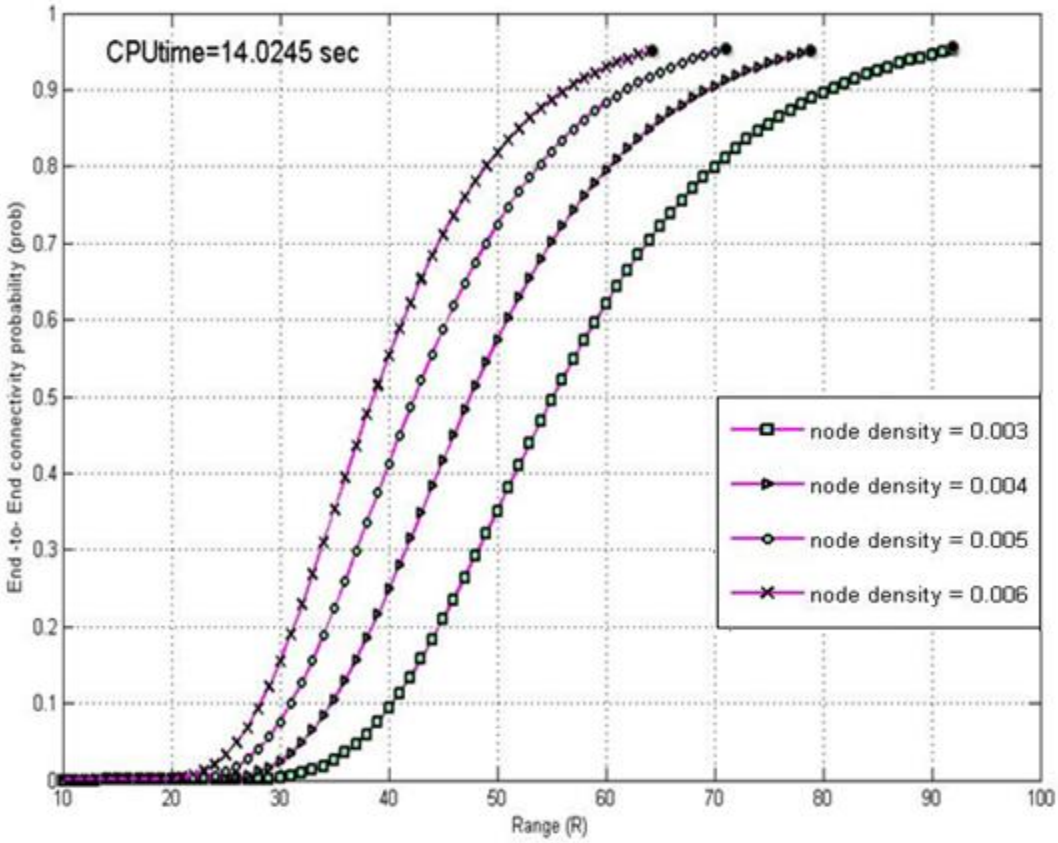


Figure 4.3: Connectivity probability versus R for increasing area with different values of node density σ

Then we used equation ($P_{AB} = R^2$) and equation (Power saving%= $\left(1 - \frac{P_{New}}{P_{Old}}\right) \times 100\%$) to compute the value of power saving percentage at maximum CH transmission range for different node density values σ. Table 4.3 shows the power saving percentage comparison for 95% connectivity (*Prob*) between the approach of [1] and this approach.

Table 4.3: Power saving % comparison for 95% connectivity probability with increasing area

Node density	Main results [1]		Increasing area: change (β *and* $\propto$) only.		Power saving,%
	Range R(m)	Prob.	Range R (m)	Prob.	
0.003	98	0.9618	92	0.9518	11.87
0.004	84	0.9622	79	0.9510	11.55
0.005	74	0.9602	71	0.9532	7.94
0.006	67	0.9593	64	0.9503	8.76

It can be noted that our approach outperforms the approach of [1] by 7.94-11.87% power saving. Hence, high power saving % is 11.87% with reducing range *R* (6m) for node density σ = 0.003, while low power saving % is 7.94% with reducing range R (3m) for node density σ = 0.005.

2- Using a new d_{Next} law ($d_{Next} \approx d - \overline{r}\, cos\, \overline{\theta}$) with state (1).

Figure 4.4 shows the connectivity probability (Prob) versus *R* for different density values σ. Moreover, it is clear that probability of connectivity (*Prob*) increases as the CH range (*R*) increases, and also it increases as the density of the nodes σ increases.

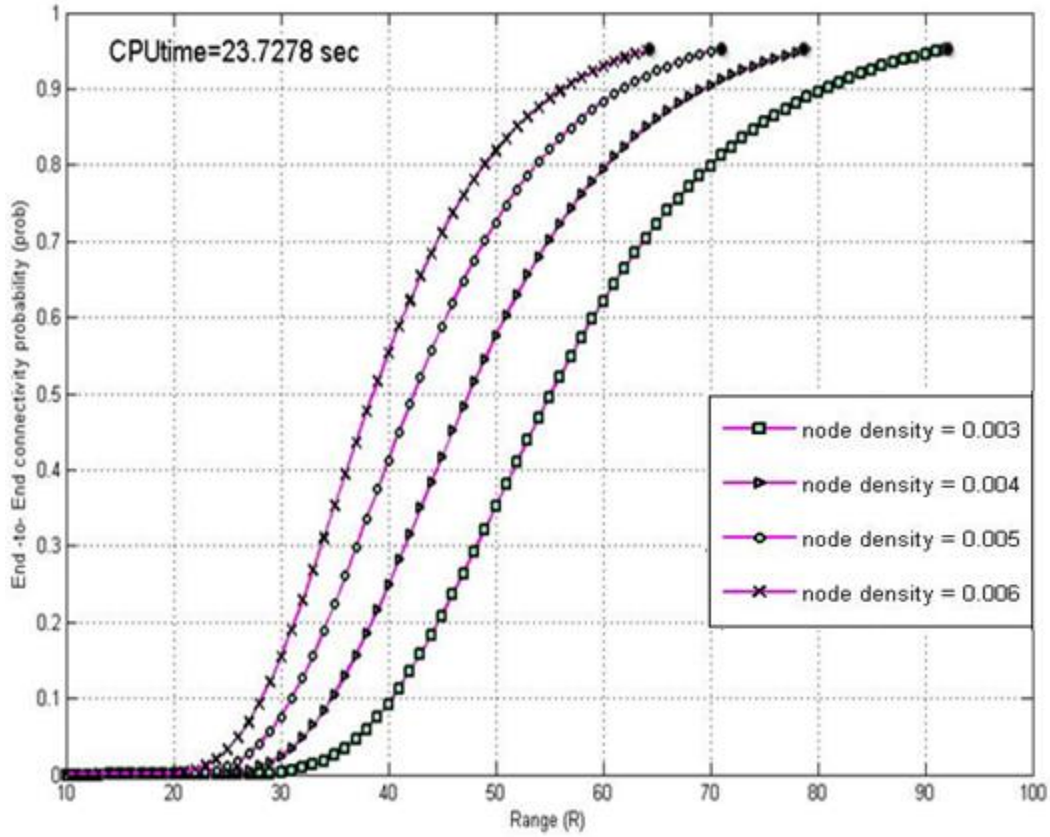


Figure 4.4: Connectivity probability versus R for increasing area with a new d_{Next}'s law and different values of node density σ

Then we used equation ($P_{AB} = R^2$) and equation (Power saving%= $\left(1 - \frac{P_{New}}{P_{Old}}\right) \times$ 100%) to compute the value of power saving percentage at maximum CH transmission range (R) for different density values σ. Table4.4 shows the power saving percentage comparison for 95% Connectivity (*Prob*) between the approach of [1] and this approach.

Table 4.4: Power saving % comparison for 95% connectivity probability with increasing area and a new d_{Next}.

Node density	Main results [1]		Increasing area: change (β *and* $\propto$) with a new dnext's law.		Power saving %
	Range R(m)	Prob.	Range R (m)	Prob.	
0.003	98	0.9618	92	0.9519	11.87
0.004	84	0.9622	79	0.9511	11.55
0.005	74	0.9602	71	0.9533	7.94
0.006	67	0.9593	64	0.9504	8.76

It can be noted that our approach outperforms the approach of [1] by 7.94-11.87% power saving. In this approach, increasing area search with a new dnext's law gives us transmission ranges (R) are lower than those in approach [1]. Also, high power saving % is 11.87% with reducing range R (6m) for node density σ = 0.003, while low power saving % is 7.94% with reducing range R (3m) for node density σ = 0.005.

Note that: Both states (1) and (2) gave us Ranges are lower than the results in [1] and more power saving.

4.4 Case 4: Decreasing area search (R_{Next})

In this approach, there are two main states and four secondary states:-

4.4.1 Main states

1- Using a new equations ($\propto = \tan^{-1}(R/d)$, $\beta = \frac{\pi}{2} - \propto$) to compute ($\beta$ $and \propto$) in steps 6 and 7 of Algorithm. (2). Figure 4.5 shows the Connectivity Probability versus the CH range (R) for different density values σ. Moreover, it is clear that the probability (*Prob*) increases as the CH range (R) raises, and also it increases as the density σ increases.

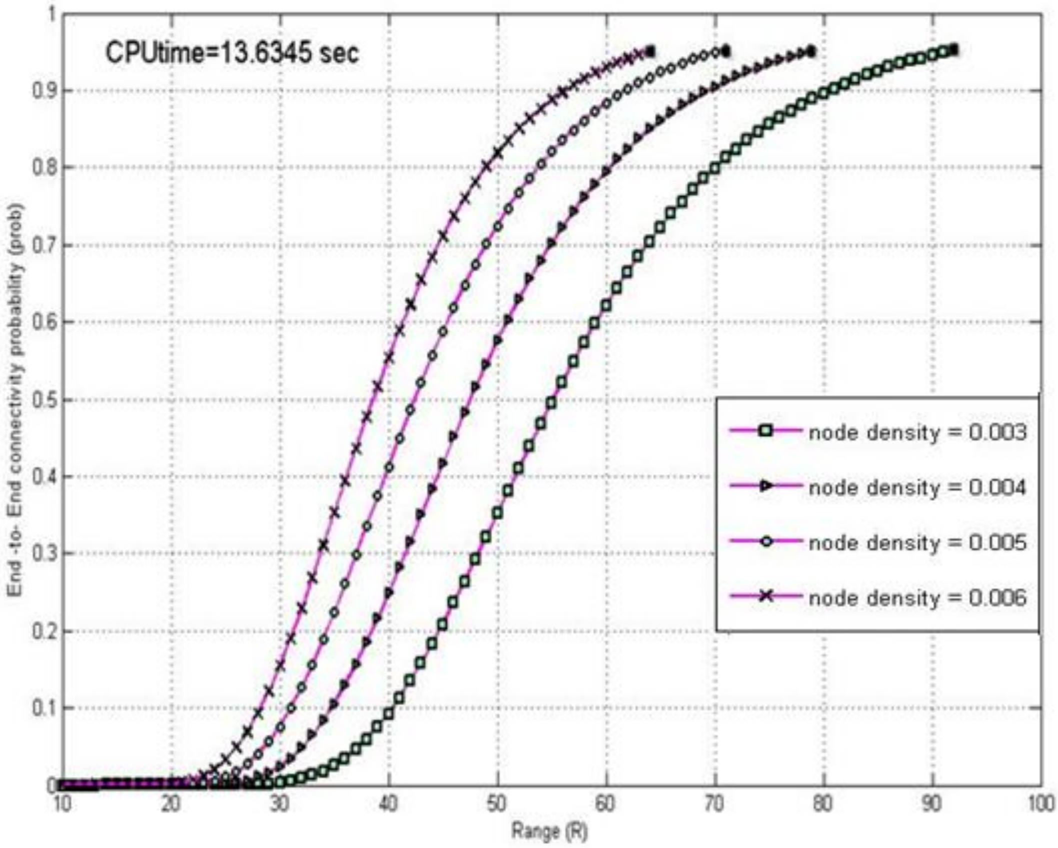


Figure 4.5: Connectivity probability versus R for decreasing area only with different values of node density σ

Then we used equation ($P_{AB} = R^2$) and equation (Power saving%= $\left(1 - \frac{P_{New}}{P_{Old}}\right) \times 100\%$) to compute the value of power saving percentage at maximum CH transmission (R) for different density values of the nodes σ. Table 4.5 shows the power saving percentage comparison for 95% connectivity (*Prob*) between the approach of [1] and this approach.

Table 4.5: Power saving % comparison for 95% connectivity probability with decreasing area

Node density	Main results [1]		Decreasing area (β *and* $\propto$) only.		power saving %
	Range R(m)	Prob.	Range R (m)	Prob.	
0.003	98	0.9618	92	0.9518	11.87
0.004	84	0.9622	79	0.9510	11.55
0.005	74	0.9602	71	0.9532	7.94
0.006	67	0.9593	64	0.9503	8.76

For this approach, decreasing area search gives us transmission ranges are lower than those in approach [1]. Also, we achieved 7.94-11.87% power saving. Hence, high power saving is 11.87% with reducing CH range R (6m) for density σ = 0.003, while low power saving is 7.94% with reducing range R (3m) for node density σ = 0.005.

2- Using a new d_{Next} law ($d_{Next} \approx d - \overline{r}\,cos\,\overline{\theta}$) with state (1).

Figure 4.6 shows the probability of connectivity (*Prob*) as a function of the CH transmission (*R*) for different density values σ. Moreover, it is clear that the probability (*Prob*) increases as the (*R*) increases, and also it increases as the density value σ increases.

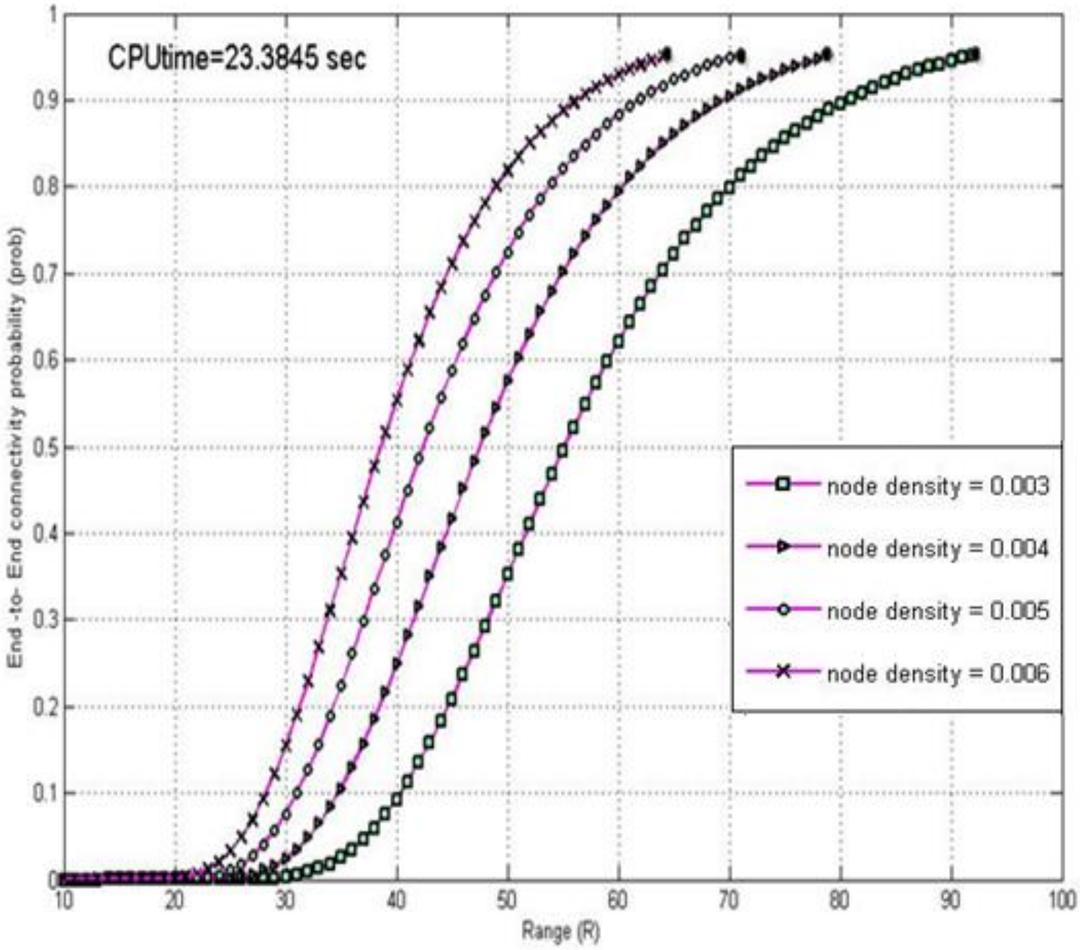


Figure 4.6: Connectivity probability versus R for decreasing area with a new d_{Next}'s law and different values of node density σ

Then we used equation ($P_{AB} = R^2$) and equation (Power saving%= $\left(1 - \frac{P_{New}}{P_{Old}}\right) \times 100\%$) to compute the value of power saving percentage at maximum CH range (R) for various density values σ. Table4.6 shows the power saving percentage comparison for 95% connectivity ($Prob$) between the approach of [1] and this approach.

Table 4.6: Power saving % comparison for 95% connectivity probability with decreasing area and a new d_{Next}

Node density	Main results [1]		Decreasing area: change β and $\propto$ with a new dnext's law.		power saving %
	Range R(m)	Prob.	Range R (m)	Prob.	
0.003	98	0.9618	92	0.9519	11.870
0.004	84	0.9622	79	0.9511	11.550
0.005	74	0.9602	71	0.9533	7.944
0.006	67	0.9593	64	0.9504	8.755

It can be noted that our approach outperforms the approach of [1] by 7.94-11.87% power saving. In this approach, increasing area search with a new dnext's law gives us transmission ranges are lower than those in approach [1]. Also, high power saving % is 11.87% with reducing range R (6m) for node density σ = 0.003, while low power saving % is 7.94% with reducing range R (3m) for node density σ = 0.005.

4.4.2 Secondary states.

Using equation 3.3b ($\beta = \frac{\pi}{2} - \propto$) and equation 2.9 ($\propto = 2 * \sin^{-1}(\frac{R}{2d})$)

Figure 4.7 shows the connectivity probability as a function of the CH transmission range R for different values of node density σ. Moreover, it is clear that the connectivity probability increases as the range R increases, and also it increases as the node density increases.

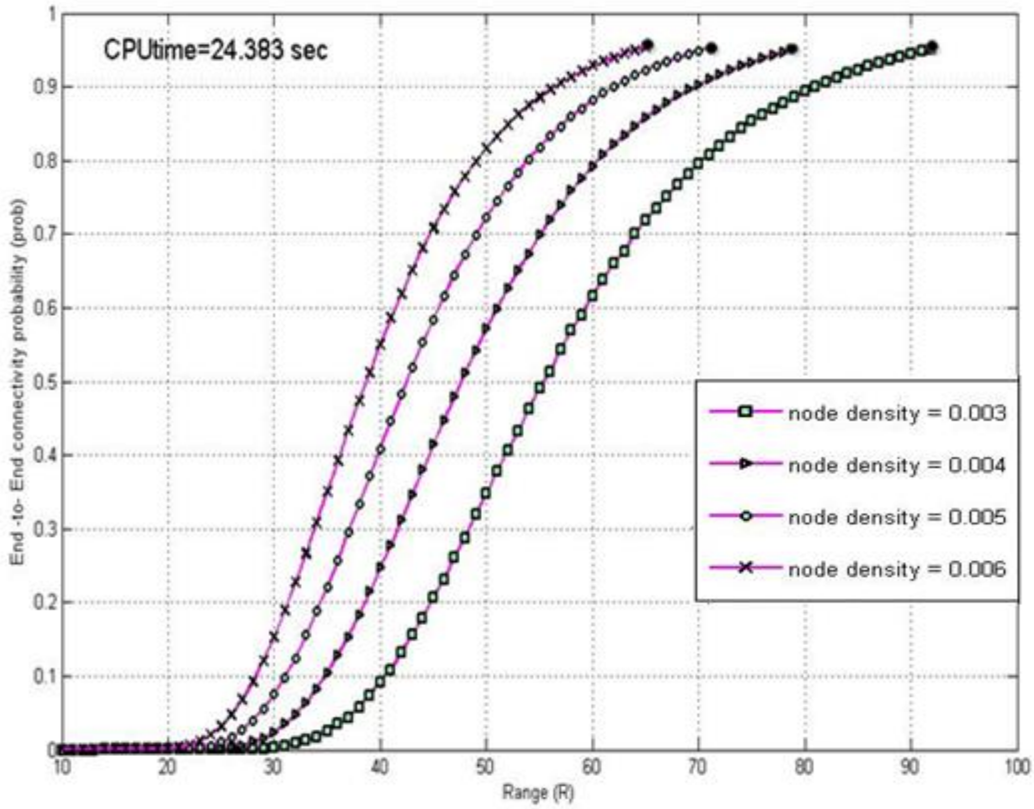


Figure 4.7: Connectivity probability versus R for decreasing area (change β) only with different values of node density σ

Hence, this Figure shows the maximum range (R) for various density values σ with probability of connectivity ($Prob$) at least 95%. Then we used equation ($P_{AB} = R^2$) and equation (Power saving%= $\left(1 - \frac{P_{New}}{P_{Old}}\right) \times 100\%$) to compute the value of power saving percentage at maximum transmission range for various density values σ. Table 4.7 shows the power saving percentage comparison for 95% connectivity ($Prob$) between the approach of [1] and this approach.

Table 4.7: Power saving % comparison for 95% connectivity probability with decreasing area (change β)

Node density	Main results [1]		Decreasing area: change β only.		\power saving %
	Range R(m)	Prob.	Range R (m)	Prob.	
0.003	98	0.9618	92	0.9510	11.87
0.004	84	0.9622	79	0.9503	11.55
0.005	74	0.9602	71	0.9527	7.94
0.006	67	0.9593	65	0.9541	5.88

It can be noted that our approach outperforms the approach of [1] by 5.88-11.87% power saving. For this approach, decreasing area search (change β) only gives us transmission ranges of CHs are lower than those in approach [1]. Hence, high power saving is 11.87% with reducing range *R* (6m) for density value σ = 0.003, while low power saving is 5.88% with reducing range *R* (2m) for density value σ = 0.006.

2) Using equation 3.3b ($\beta = \frac{\pi}{2} - \propto$), and equation 2.9 ($\propto = 2 * \sin^{-1}(\frac{R}{2d})$) with a new d_{Next} law ($d_{Next} \approx d - \overline{r}\, cos\, \overline{\theta}$).

Figure 4.8 appears the Probability (*Prob*) as a function of the CH range *R* for various values of the density σ. Moreover, it is clear that the probability of connectivity (*Prob*) increases as CH range *R* raises, and also it rises as the density value σ rises.

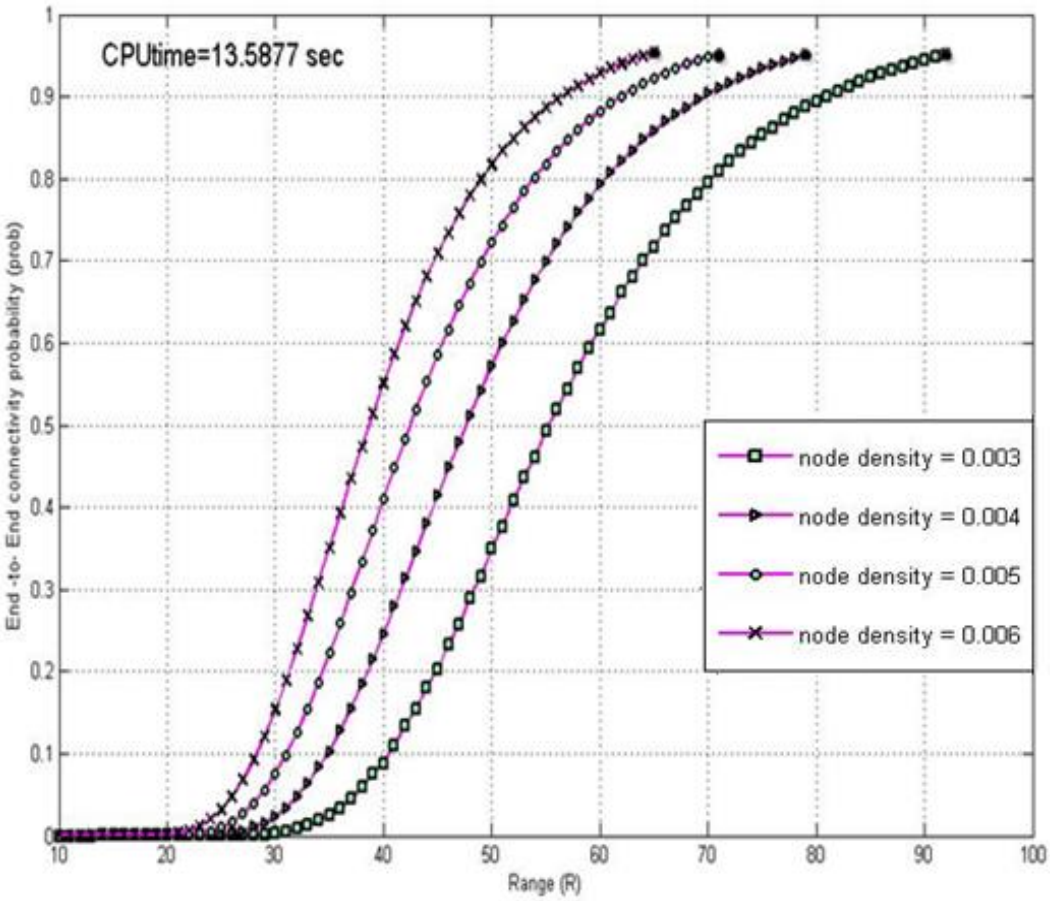


Figure 4.8: Connectivity probability versus R for decreasing area (change β) with a new d_{Next}*'s* law and different values of node density σ

Then we used equation ($P_{AB} = R^2$) and equation (Power saving%= $\left(1 - \frac{P_{New}}{P_{Old}}\right) \times 100\%$) to compute the value of power saving percentage at maximum transmission range of CH (R) for various values of density σ. Table 4.8 shows the power saving percentage comparison for 95% connectivity (*Prob*) between the approach of [1] and this approach.

Table 4.8: Power saving % comparison for 95% connectivity probability with decreasing area (change β) and a new d_{Next}

Node density	Main results [1]		Decreasing area: change β with new d_{Next} law.		power saving %
	Range R (m)	Prob.	Range R (m)	Prob.	
0.003	98	0.9618	92	0.9510	11.87
0.004	84	0.9622	79	0.9504	11.55
0.005	74	0.9602	71	0.9528	7.94
0.006	67	0.9593	65	0.9541	5.88

For this approach, decreasing area search (change β) with a new d_{Next} law gives us transmission ranges of CHs are lower than those in approach [1]. Also, we achieved 5.88-11.87% power saving. Hence, high power saving is 11.87% with reducing range R (6m) for density σ = 0.003, while low power saving is 5.88% with reducing range R (2m) for node density σ = 0.006.

3) Using equation 3.3a ($\propto = \tan^{-1}(R/d)$), and equation 2.10 ($\beta = (\pi - 3 \propto)/2$. Figure 4.9 shows the probability of connectivity as a function of the CH range R for different node density values σ. Moreover, it is clear that the connectivity probability increases as the range R increases, and also it increases as the node density increases.

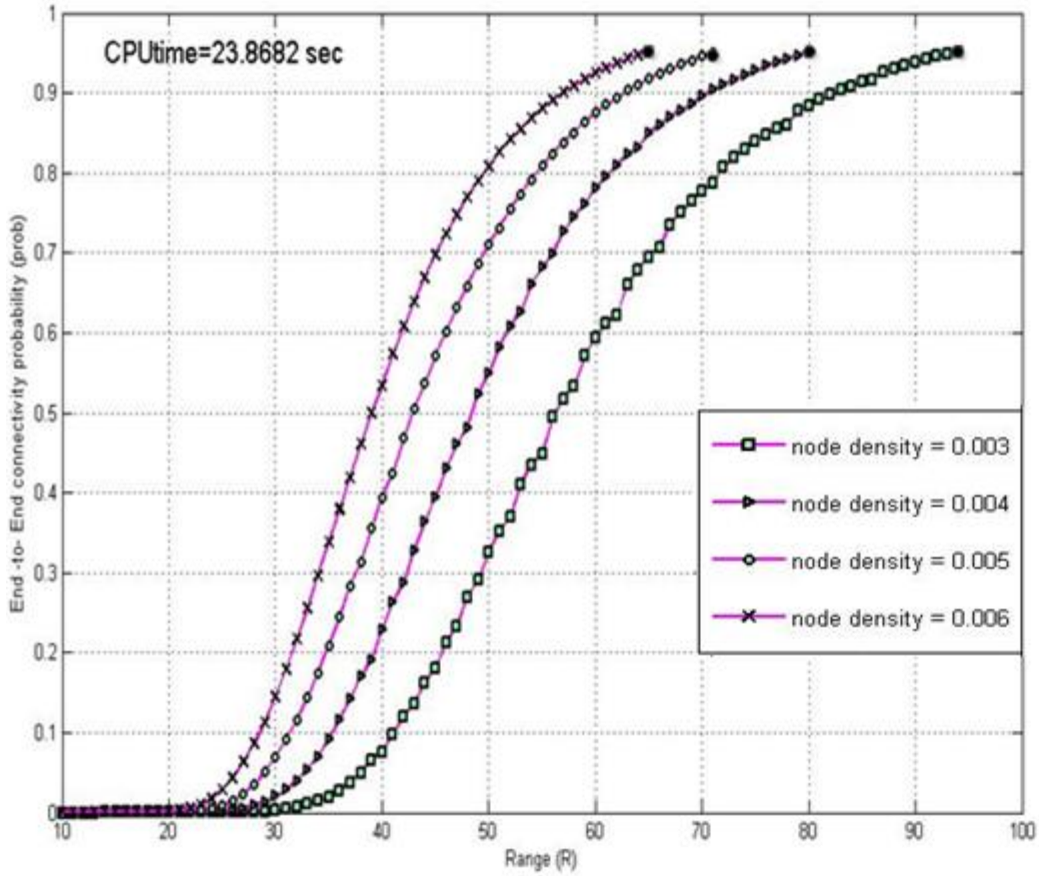


Figure 4.9: Connectivity probability versus R for decreasing area (change ∝) with different values of node density σ

Then we used equation ($P_{AB} = R^2$) and equation (Power saving%= $\left(1 - \frac{P_{New}}{P_{Old}}\right) \times$ 100%) to compute the value of power saving percentage at maximum CH transmission range for different node density values σ. Table 4.9 shows the power saving percentage comparison for 95% connectivity (*Prob*) between the approach of [1] and this approach.

Table 4.9: Power saving % comparison for 95% connectivity probability with decreasing area (change ∝)

Node density	Main results [1]		Decreasing area; change ∝ only.		power saving %
	Range R (m)	Prob.	Range R (m)	Prob.	
0.003	98	0.9618	94	0.9516	8.00
0.004	84	0.9622	80	0.9505	9.30
0.005	74	0.9602	71	0.9500	7.94
0.006	67	0.9593	65	0.9519	5.88

It can be noted that our approach outperforms the approach of [1] by 5.88-11.87% power saving. For this approach, decreasing area search (change $\propto$) gives us transmission ranges are lower than those in approach [1]. Hence, high power saving is 9.30% with reducing range R (4m) for density σ = 0.004, while low power saving % is 5.88% with reducing range R (2m) for node density σ = 0.006.

4) - Using equation 3.3a ($\propto = \tan^{-1}(R/d)$), and equation 2.10 ($\beta = (\pi - 3 \propto)/2$, with a new d_{Next} law ($d_{Next} \approx d - \bar{r}\cos\bar{\theta}$).

Figure 4.10 shows the connectivity (*Prob*) as a function of the CH range R for various density values σ. Moreover, it is clear that the probability (*Prob*) increases as the CH range R increases, and also it increases as the density value σ increases

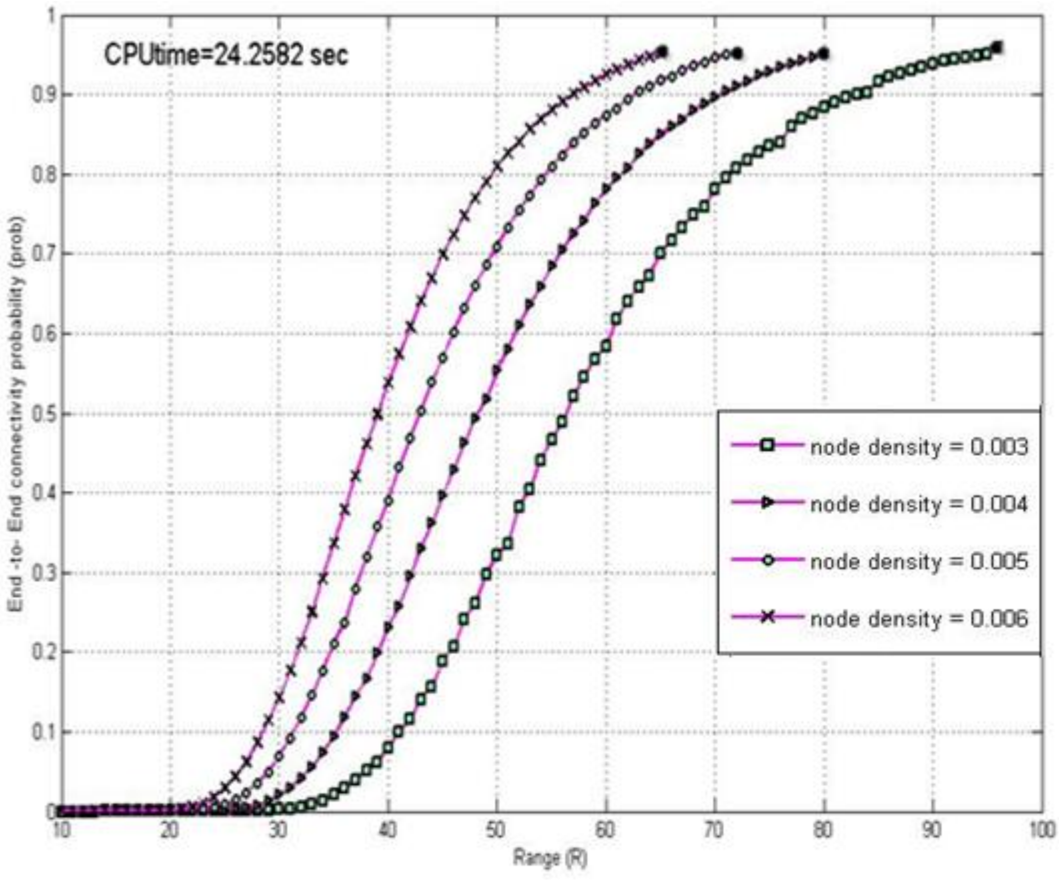


Figure 4.10: Connectivity probability versus R for decreasing area (change $\propto$) with a new d_{Next}'s law and different values of node density σ

Then we used equation ($P_{AB} = R^2$) and equation (Power saving%= $\left(1 - \frac{P_{New}}{P_{Old}}\right) \times 100\%$) to compute the value of power saving percentage at maximum CH transmission range for various values of node density σ. Table 4.10 shows the power saving percentage comparison for 95% connectivity (*Prob*) between the approach of [1] and this approach.

Table 4.10: Power saving % comparison for 95% connectivity probability decreasing area (change ∝) and a new d_{Next}

Node density	Main results [1]		Decreasing area: change ∝ with new d_{Next} law.		power saving %
	Range R(m)	Prob.	Range R (m)	Prob.	
0.003	98	0.9618	96	0.9516	4.04
0.004	84	0.9622	80	0.9505	9.30
0.005	74	0.9602	72	0.9500	5.33
0.006	67	0.9593	65	0.9519	5.88

In this approach, decreasing area search (change ∝) with a new d_{Next} law gives us transmission ranges of CHs are lower than those in approach [1]. Also, we achieved 4.04 -9.30% power saving. Hence, high power saving is 9.30% with reducing range *R* (4*m*) for density *σ* = 0.004, while low power saving is 4.04% with reducing range *R* (2*m*) for density *σ* = 0.003.

4.5 Case5: New computing the average angular deviation $\overline{\theta}$.

In this approach, we use equation ($\bar{\theta} = 0.5\,\beta$) Instead of equation (2.5) ($\bar{\theta} = \frac{\int_0^\beta \theta e^{-2\lambda\left[\frac{\theta \bar{r}^2 - \frac{\bar{r}^2}{2}\sin(2\theta)}{2}\right]} d\theta}{\int_0^\beta e^{-2\lambda\left[\frac{\theta \bar{r}^2 - \frac{\bar{r}^2}{2}\sin(2\theta)}{2}\right]} d\theta}$) to find four states as follow:

1) - Using a new law for $\overline{\theta}$ ($\bar{\theta} = 0.5\,\beta$) Instead of equation (2.5).

Figure 4.11 shows the Probability as a function of the CH transmission range *R* for different values of node density σ. Moreover, it is clear that the connectivity probability increases as the range *R* increases, and also it increases as the node density increases.

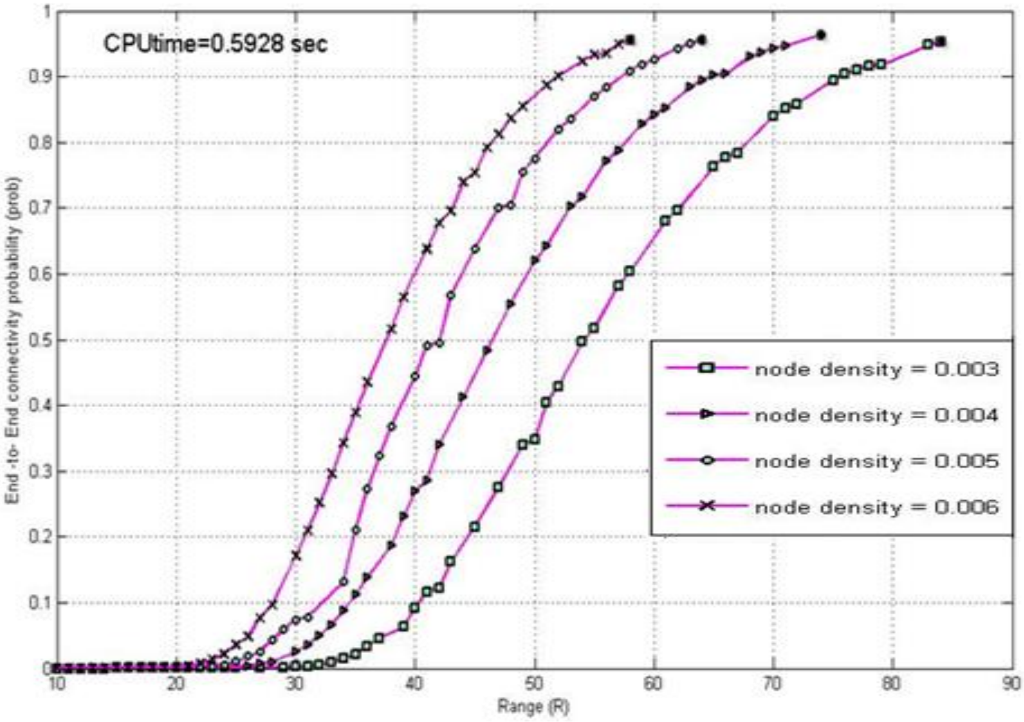


Figure 4.11: Connectivity probability versus R with using a new law for $\bar{\theta}$ and different values of node density σ

Then we are used equation ($P_{AB} = R^2$) and equation (Power saving%= $\left(1 - \frac{P_{New}}{P_{Old}}\right) \times 100\%$) to compute the value of power saving percentage at maximum CH range for various values of density σ. Table 4.11 shows the power saving percentage comparison for 95% Connectivity (*Prob*) between the approach of [1] and this approach.

Table 4.11: Power saving % comparison for 95% connectivity probability with a new law for $\bar{\theta}$

Node density	Main results [1]		Using a new law for ($\bar{\theta}$)		Power saving %
	Range R (m)	Prob.	Range R (m)	Prob.	
0.003	98	0.9618	84	0.9521	26.53
0.004	84	0.9622	74	0.9636	22.39
0.005	74	0.9602	64	0.9555	25.20
0.006	67	0.9593	58	0.9556	25.06

For this approach, using a new law for $\bar{\theta}$ gives us transmission ranges of CHs are lower than those in approach [1]. Also, achievement 22.39- 26.53 % power saving.

Hence, high power saving is 26.53 % with reducing CH range R (14m) for density σ = 0.003, while low power saving is 22.39% with reducing CH range R (10m) for density σ = 0.004.

2)-Using a new law for $\bar{\theta}$ ($\bar{\theta} = 0.5\,\beta$) with a new law of d_{Next} ($d_{Next} \approx d - \bar{r}\,cos\,\bar{\theta}$).

Figure 4.12 appears the probability of connectivity (*Prob*) as a function of the CH range R for various values of density σ. Moreover, it is clear that the connectivity (*Prob*) increases as the transmission range of CH (*R*) increases, and also it increases as the density σ increases.

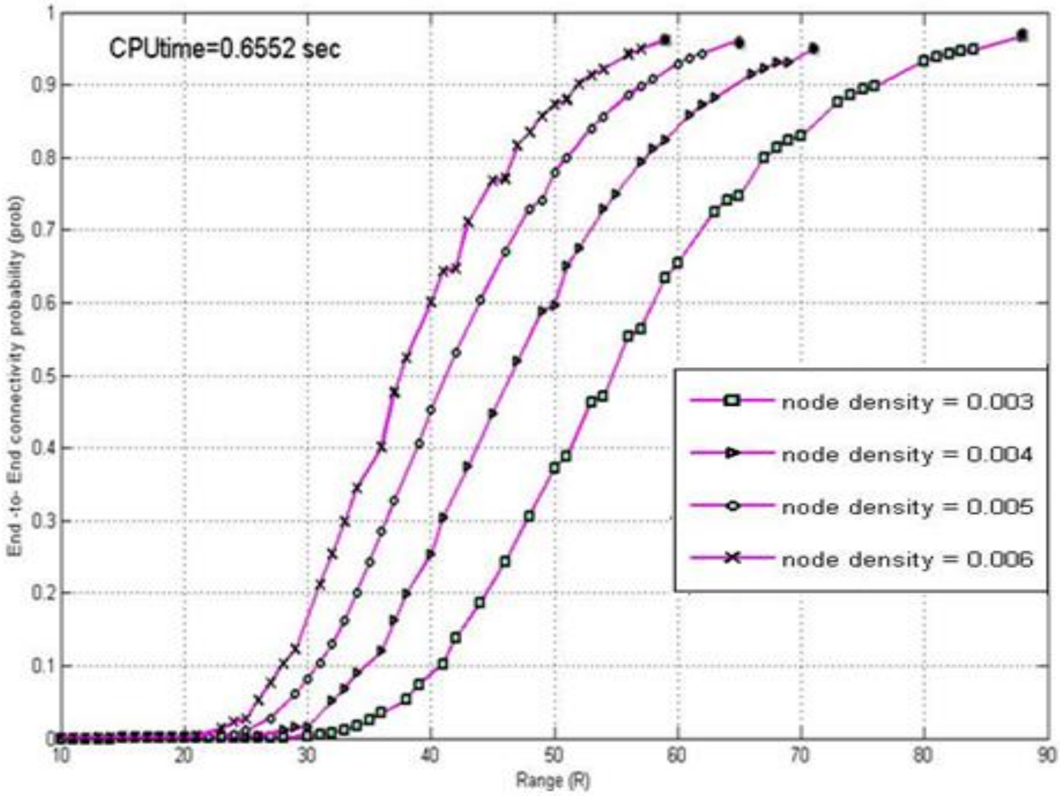


Figure 4.12 : Connectivity probability versus R with a new law for $\bar{\theta}$ and a new d_{Next} for different values of node density σ

This Figure shows the maximum CH range for various values of density σ with Connectivity (Prob) at least 95%. Then we are used equation ($P_{AB} = R^2$) and equation (Power saving%= $\left(1-\frac{P_{New}}{P_{Old}}\right)\times 100\%$) to compute the value of power saving percentage at maximum CH transmission range (R) for various values of density σ. Table 4.12 shows the power saving percentage comparison for 95% connectivity (*Prob*) between the approach of [1] and this approach.

Table 4.12: Power saving % comparison for 95% connectivity probability a new law for $\bar{\theta}$ and a new d_{Next}.

Node density	Main results [1]		Change ($\bar{\theta}$) with new law of d_{Next}		Power saving %
	Range R (m)	Prob.	Range R (m)	Prob.	
0.003	98	0.9618	88	0.9574	19.37
0.004	84	0.9622	71	0.9500	**28.56**
0.005	74	0.9602	65	0.9516	22.85
0.006	67	0.9593	59	0.9520	22.46

For this approach, using a new law for $\bar{\theta}$ with new law of d_{Next} gives us transmission ranges of CHs are lower than those in approach [1]. Also, we achieved 19.37- 28.56 % power saving. Hence, high power saving is 28.56 % with reducing CH range R (13m) for density σ = 0.004, while low power saving is 22.46% with reducing CH range R (10m) for density σ = 0.003.

3) Using a new law for $\bar{\theta}$($\bar{\theta}=0.5\,\beta$) with decreasing area search (change ∝ and β),($\propto=\tan^{-1}(R/d)$ and $\beta=\frac{\pi}{2}-\propto$).

Figure 4.13 shows the Connectivity (*Prob*) as a function of the transmission range of CH (R) for various values of density σ. Moreover, it is clear that the connectivity probability increases as the range of CH (R) increases, and also it increases as the value of density σ increases.

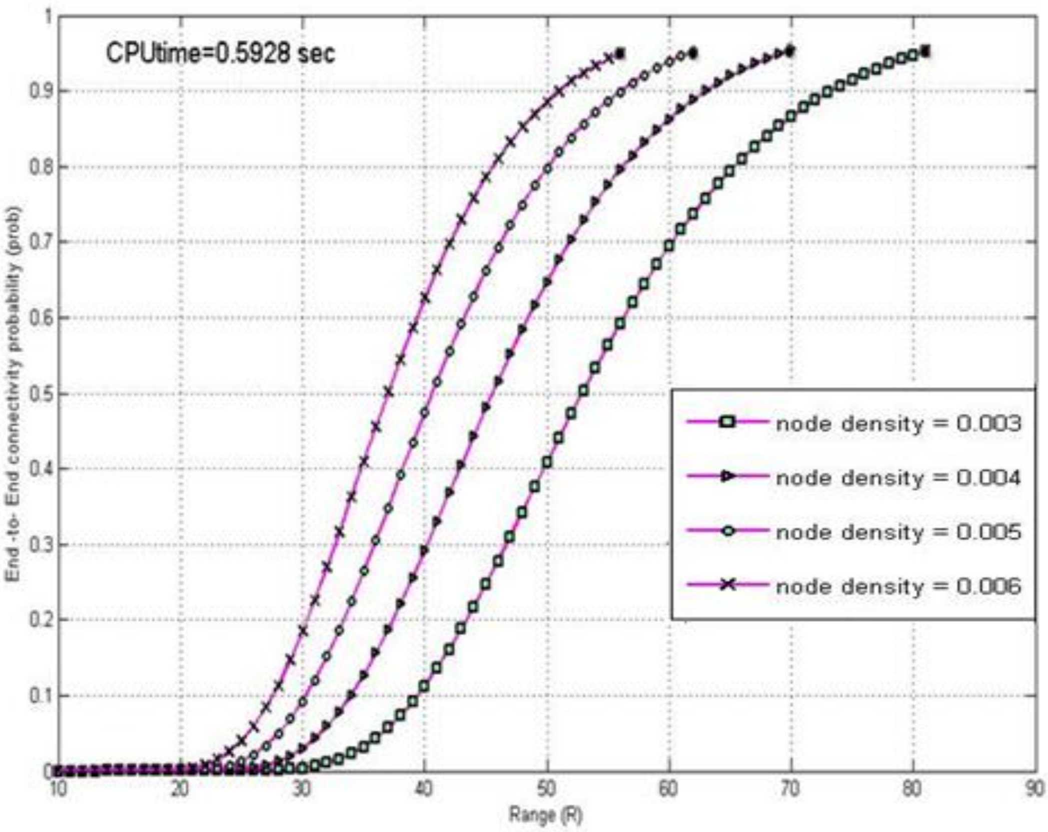


Figure 4.13: Connectivity probability versus R with a new law for $\bar{\theta}$ and decreasing area (change $\propto$ and β) for different values of node density σ

This Figure shows the maximum range for various node density values σ with Connectivity (*Prob*) at least 95%. Then we are used equation ($P_{AB} = R^2$) and equation (Power saving%= $\left(1 - \frac{P_{New}}{P_{Old}}\right) \times 100\%$) to compute the value of power saving percentage at maximum transmission range (*R*) for various values of density σ. Table 4.13 shows the power saving percentage comparison for 95% Connectivity (*Prob*) between the approach of [1] and this approach.

Table 4.13: Power saving % comparison for 95% connectivity probability with a new law for $\bar{\theta}$ and decreasing area (change $\propto$ and β).

Node density	Main results [1]		Change ($\bar{\theta}$) and area search (β and $\propto$)		Power saving %
	Range R (m)	Prob.	Range R (m)	Prob.	
0.003	98	0.9618	81	0.9520	31.70
0.004	84	0.9622	70	0.9544	30.56
0.005	74	0.9602	62	0.9528	29.80
0.006	67	0.9593	56	0.9501	30.14

In this state, using a new law for $\bar{\theta}$ and decreasing area search (change $\propto$ and β) gives us transmission ranges of CHs are lower than those in approach [1]. Also, achievement 29.80- 31.70 % power saving. Hence, high power saving % is 31.70 % with reducing range of CH (R=17m) for density σ = 0.003, while low power saving % is 29.80%with reducing range of CH (*R*=12m) for density σ = 0.005.

4) Using a new law for$\bar{\theta}$ ($\bar{\theta} = 0.5\,\beta$) with decreasing area search (change $\propto$ and β), ($\propto = \tan^{-1}(R/d)$ and $\beta = \frac{\pi}{2} - \propto$), with a new law of d_{Next}. ($d_{Next} \approx d - \bar{r}\,cos\,\bar{\theta}$).

Figure 4.14 appears the Connectivity (*Prob*) as a function of the transmission range *R* for various values of node density σ. Moreover, it is clear that the connectivity (*Prob*) increases as the range *R* of CH increases, and also it increases as the density σ increases.

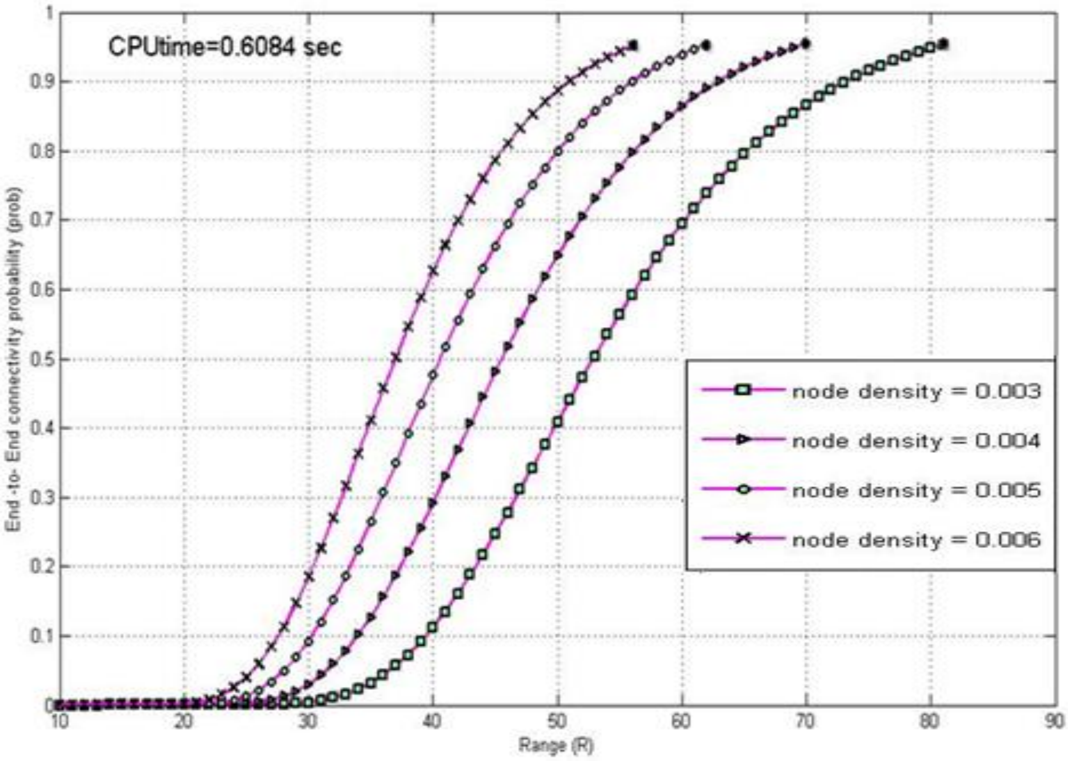


Figure 4.14: Connectivity probability versus R with a new law for $\bar{\theta}$, decreasing area search, and a new law of d_{Next} for different values of node density σ

Then we used equation ($P_{AB} = R^2$) and equation (Power saving%= $\left(1 - \frac{P_{New}}{P_{Old}}\right) \times 100\%$) to compute the value of power saving percentage at maximum CH transmission range (R) for various values of density σ. Table 4.3 shows the power saving percentage comparison for 95% Connectivity ($Prob$) between the approach of [1] and this approach.

Table 4.14: Power saving % comparison for 95% connectivity probability with a new law for$\bar{\theta}$, $d_{Next,}$ and decreasing area (β and $\propto$)

Node density	Main results [1]		Change ($\bar{\theta}$) and area search (β and $\propto$) with new law of d_{Next}.		Power saving %
	Range R (m)	Prob.	Range R (m)	Prob.	
0.003	98	0.9618	81	0.9520	31.70
0.004	84	0.9622	70	0.9544	30.56
0.005	74	0.9602	62	0.9528	29.80
0.006	67	0.9593	56	0.9501	30.14

For this approach, using a new law for $\bar{\theta}$ and decreasing area search (change $\propto$ and β) with a new d_{Next} law gives us transmission ranges of CHs are lower than those in approach [1]. Also, we achieved 29.80- 31.70 % power saving. Hence, high power saving % is 31.70 % with reducing the maximum range of CH (R=17m) for density σ = 0.003, while low power saving % is 29.80%with reducing range (R=12m) for density σ = 0.005.

4.6 Comparison for the power saving and transmission ranges

As shown in Table 4.15, we compare between all the numerical results proposed in our approaches with the approach [1] for different node density values σ, according to power saving% and reducing the maximum range value with ensuring at least 95% probability of connectivity. It can be noted that our approaches outperforms the approach of [1] by (2.70 – 31.70) % power saving through reducing value in CH transmission range (1–17) m of the backbone nodes in a multihop wireless networks.

Table 4.15: Comparison for power saving % and reducing range value (m) with 95% connectivity Prob for different values of node density σ

N	State	Power saving % for different node density				Reducing Range (m) for different node density			
		0.003	**0.004**	**0.005**	**0.006**	**0.003**	**0.004**	**0.005**	**0.006**
1	New dnext law	6.03	4.71	2.70	5.90	3	2	1	2
2	Increasing area search	11.87	11.55	7.94	8.76	6	5	3	3
3	Increasing area search with new dnext law	11.87	11.55	7.94	8.76	6	5	3	3
4	Decreasing area search	11.87	11.55	7.94	8.76	6	5	3	3
5	Decreasing area search with new dnext law	11.87	11.55	7.94	8.76	6	5	3	3
6	Decreasing area search change β only	11.87	11.55	7.94	8.76	6	5	3	2
7	Decreasing area search change β with new dnext law	11.87	11.55	7.94	8.76	6	5	3	2
8	Decreasing area search change $\propto$ only	8.00	9.30	7.94	5.88	4	4	3	2
9	Decreasing area search change ($\propto$) with a new dnext law	4.04	9.30	5.33	5.88	2	4	2	2
10	New law of ($\bar{\theta}$)	26.53	22.39	25.20	25.06	14	10	10	9
11	New law of ($\bar{\theta}$) with a new law of d_{Next}	19.37	28.56	22.85	22.46	10	13	9	8
12	New law of ($\bar{\theta}$) with decreasing area search	**31.70**	30.56	29.80	30.14	**17**	14	12	11
13	New law of ($\bar{\theta}$) and d_{Next} with decreasing area search	**31.70**	30.56	29.80	30.14	**17**	14	12	11

4.7 CPU time comparison

As shown in Table 4.16, we compared the required CPU time for our approach with the approach in [1]. It can be seen that our approach requires much less computation CPU time than the original approach of [1] through reducing CPU time from 16.94 sec to 0. 61 sec.

Table 4.16: Cputime comparison between our modified versions and original approach [1]

State	CPU time for original approach [1] (sec)	CPU time for our modified version (sec)
New law of ($\bar{\theta}$) and d_{Next} with decreasing area search	16.9417	0.6084

Chapter 5

CONCLUSION

Transmission range assignment in WSNs is an important issue which affects the transmission power and connectivity of the nodes. Therefore, the main goal is to ensure high connectivity probability ($Prob$) with minimum transmission range (R) so that data delivery and energy conservation are both done. In this thesis, we followed a similar analytical approach given `in [1] to assign the minimum transmission range with at least 95 % connectivity probability ($Prob$).

Our approaches differ from the approach for [1] in two different sides: 1) we used a simpler mathematical model; 2) we maintained the same connectivity probability ($Prob$) with smaller transmission ranges of CHs, which means more power saving and hence longer life time of the nodes.

In summary, the numerical results confirm that our proposed approaches are more effective in extend the network lifetime and achieve (2.70 – 31.70) % power saving through reducing CH transmission range (1 – 17) m of the backbone nodes in a multihop wireless sensor networks for different values of node density σ ($3 * 10^{-3}, 4 * 10^{-3}, 5 * 10^{-3}, and\ 6 * 10^{-3}$) with ensuring at least 95% connectivity probability ($Prob$) for delivery of data to its distention.

Future work

We will follow these Suggestions in the future as bellow:

- Using a simpler mathematical model to avoid the complex integrations for computing the average propagation distance ($\overline{r}$).
- Rearrangement of algorithm 2 in approach [1]. Namely exchange the positions of $\bar{\theta}$ and $\overline{r}$ to obtain a simpler mathematical models

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APPENDICES

Appendix A: Matlab code for Algo1, the transmission range (*R*) [1]

```
%%   MATLAB Code for Transmission Range assignment
% %   By ABD ALI HUSSIAN
% %   TIME STARTING WITH PROGRAMING IS 10\11\2013
t=cputime;
 sigmma= [0.003, 0.004, 0.005, 0.006];
For j = 1:4;
sigmma (j);
Array R= [];
Array Prob= [];
R=10;
P=0.1;
 Lamda = P.*sigmma (j);
d=500;
Prob =connect (lamda, d, R);
k=1;
Array Prob (k)= Prob;
Array R (k)= R;
While Prob <.95
    R=R+1;
 Prob =connect (lamda, d, R);
  If prob > Array prob (k)
      k=k+1;
   Array R (k) =R;
   Array prob (k) = Prob;
  End
  If prob>.95
   Break;
    End
End
If j==1
 Plot (Array R, Array Prob,'-ms',...
                'Line Width',2,...
                'Marker Edge Color ','k',...
                'Marker Face Color',[.49 1 .63],...
                'Marker Size',5)
  End
If j==2
 Plot (Array R, Array Prob,'-m>',...
                'LineWidth',2,...
                'Marker Edge Color ','k',...
                'Marker Face Color',[.49 1 .63],...
                'Marker Size',5.5)
  End
If j==3
 Plot (Array R, Array Prob,'-mo',...
                'Line Width',2,...
                'Marker Edge Color ',' k ',...
```

```
            'Marker Face Color', [.49 1 .63],...
            'Marker Size',5
 End
If j==4
 Plot (Array R, Array Prob,' -mx',...
            'Line Width', 2,...
            'Marker Edge Color ','k',...
            'Marker Face Color',[.49 1 .63],...
            'Marker Size',8)
End
 hold all;  % plot and save previous plot (more than curve)
 grid on;   % Turn on grid lines for this plot
End
 e = cputime-t;
 text (14, 0.95, ['CPUtime=',num2str(e),' sec'], 'Color', 'black','FontSize',14);
```

Appendix B: Matlab code for Algo.2, the Procedure *connect* (*λ, d, R*) [1]

```
Function [Prob] = connect (lamda, d, R)
%% Measurement end-to-end connectivity probability (Prob)
Prob=1;
r=0: R;  % initial value of hope redus
K=0;     % number of CH-hope distance
% rdash % average propagation distance
%%%% fun= 2.*pi.*(r.^2)*lamda.*exp(-lamda.*pi.*(r.^2));
fun= @(r) (2.*pi.*(r.^2).*lamda).*exp(-1.*lamda.*pi.*(R.^2 -r.^2));
q=integral (fun, 0, R);
z=1-exp (-1.*lamda.*pi*R^2);
 rdash= q/z;
While d>R
K=K+1;
alffa= 2.*asin (R/(2.*d));
betta= (pi-3.*alffa)/2;
%theta= 0; %angular deviation about line [AB]
%theta= 0: betta;
fun1= @ (theta) exp (-lamda.*(0.5).*(theta.*(rdash.^2) -
(0.5).*(rdash.^2).*sin(2.*theta)));
c=integral (fun1,0,betta);
fun2=@ (theta) theta.*exp (-lamda.*(0.5).*(theta.*(rdash.^2) -
(0.5).*(rdash.^2).*sin(2.*theta)));
 w= integral (fun2, 0, betta);
 thetadash= w/c;
 dnext= sqrt ((rdash.^2)+(d.^2)-2.*rdash.*d.*cos(thetadash));
d=dnext;
 s= 0.5.*(2.* d + R);
 a=sqrt (s.*((s-d).^2).*(s-R));
 Area1=abs (0.5.*((d.^2).*alffa)-a);
 Area2=0.5.*(R.^2).*betta;
 AreaRnext=2.*(Area1+Area2);
```

```
If (K==1)
    Prob= (1-exp (-1.*lamda*AreaRnext)).*Prob;
 Else
    AreaRnew=((2.*K-3).*rdash+2.*R).*rdash.*thetadash;
  Prob= (1-exp(-1.*lamda.*AreaRnew)).*Prob;
 End
End
 If (d>0)
   K=K+1;
 End
```

Appendix C: Matlab code for Algo 1, the transmission range (*R*) [our approach]

```
t=cputime;
 Sigmma= [0.003, 0.004, 0.005, 0.006];
For j = 1:4;
sigmma (j);
Array R= [];
Array Prob= [];
R=10;
P=0.1;
 Lamda = P.*sigmma (j);
d=500;
Prob =connect (lamda, d, R);
k=1;
Array Prob (k)= Prob;
Array R (k)= R;
While Prob <.95
    R=R+1;
 prob =connect(lamda, d, R);
  If prob > Array prob (k)
      k=k+1;
   Array R (k) =R;
   Array prob (k) = Prob;
  End
  If prob>.95
  Break;
  End
End

If j==1
Plot (Array R, Array Prob,'-ms',...
                'Line Width',2,...
                'Marker Edge Color ','k',...
                'Marker Face Color',[.49 1 .63],...
                'Marker Size',5)
 End
```

```
If j==2
 Plot (Array R, Array Prob,'-m>',...
              'LineWidth',2,...
              'Marker Edge Color ','k',...
              'Marker Face Color',[.49 1 .63],...
              'Marker Size',5.5)

 End

If j==3
 Plot (Array R, Array Prob,'-mo',...
              'Line Width',2,...
              'Marker Edge Color ',' k ',...
              'Marker Face Color', [.49 1 .63],...
              'Marker Size',5
 End
If j==4
  Plot (Array R, Array Prob,' -mx',...
              'Line Width', 2,...
              'Marker Edge Color ','k',...
              'Marker Face Color',[.49 1 .63],...
              'Marker Size',8)

End
  hold all; %plot and save previous plot (more than curve)
  grid on;  % Turn on grid lines for this plot

End
e = cputime-t;
  text (14, 0.95, ['CPUtime=',num2str(e),' sec'], 'Color', 'black','FontSize',14);
```

Appendix D: Matlab code for Algo. 2, the Procedure (*connect* (*λ, d, R*)) [our approach]

```
Function [Prob] = connect (lamda, d, R)
%% Measurement end-to-end connectivity probability (Prob)
Prob=1;
r=0: R;   % initial value of hope redus
K=0;      % number of CH-hope distance
% rdash % average propagation distance
%%%% fun= 2.*pi.*(r.^2)*lamda.*exp(-lamda.*pi.*(r.^2));

fun= @(r) (2.*pi.*(r.^2).*lamda).*exp(-1.*lamda.*pi.*(R.^2 -r.^2));
q=integral (fun, 0, R);
z=1-exp (-1.*lamda.*pi*R^2);
 rdash=q/z;

While d>R
```

```
K=K+1;
alffa=atan(R/d);
betta=(0.5.*pi)- alffa;
%theta=0; %angular deviation about line [AB]
%theta=0: betta;
thetadash= 0.5.*betta;
  dnext= d-rdash.*cos(thetadash);
 d=dnext;
 s= 0.5.*(2.*d+R);
 a=sqrt (s.*((s-d).^2).*(s-R));
 Area1= abs (0.5.*((d.^2).*alffa)-a);
 Area2=0.5.*(R.^2).*betta;
 AreaRnext= 2.*(Area1+Area2);
 If (K==1)
     Prob= (1-exp (-1.*lamda*AreaRnext)).*Prob;
  Else
     AreaRnew= ((2.*K-3).*rdash+2.*R).*rdash.*thetadash;
   Prob= (1-exp (-1.*lamda.*AreaRnew)).*Prob;
  End
End
 If (d>0)
    K=K+1;
   End
```