ENHANCEMENT OF TRANSMISSION RANGE ASSIGNMENT FOR CLUSTERED WIRELESS SENSOR NETWORKS

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ABSTRACT

Transmitter range assignment in clustered wireless networks is the bottleneck of the balance between energy conservation and the connectivity to deliver data to the sink or gateway node. The aim of this research is to optimize the energy consumption through reducing the transmission ranges of the nodes, while maintaining high probability to have end-to-end connectivity *to the network's data sink. We modified the approach given in [1] to achieve more than 25% power saving through reducing cluster head (CH) transmission range of the backbone nodes in a multihop wireless sensor network with ensuring at least 95% end-to-end connectivity probability.*
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KEYWORDS

Wireless sensor networks, wireless ad hoc networks, clustering, transmission range, connectivity.

1. INTRODUCTION

In the literature follow, clustering mechanism in wireless networks means dividing network's nodes into groups which are called clusters. Each cluster has a single cluster head (CH) which collects and summarizes data flow from ordinary cluster's nodes and forwards it to the Gateway nodes which are shared between two or more clusters.

The main advantages of clustering in wireless sensor networks (WSN) 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 [1][2]. Ordinary nodes in clusters elect their CHs via CH candidacy announcements performed by each node according to a probability scale which is computed by individual nodes and it considers the effect of hop distances to the sink on the relative traffic loads at different locations of the network [3-5].

In clustering protocols, the main aim is the successful delivery of network data to the gateway. However, there are two main related concepts. If the transmission range of CH-to-CH is too short (not long enough), it will drain low transmission power, but leads to network partitioning in which some CHs cannot communicate, and hence causes failure of data delivery process to the gateway [5]. On the other hand, if the transmission range of CH-to-CH is too long (not short enough), it will ensure the successful delivery of network data to the gateway, but requires high transmission power and difficult modulation schemes [3][4]. 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.

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In previous studies [6][7], 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. Furthermore, in [8], a Local Minimum Spanning Tree (LMST) algorithm was proposed with less demanding solution. The authors of [1] analyze end-to-end connectivity with respect to deployment density of network's nodes and provide an analytical solution. Inspired with the work of [1], we modified their algorithm by using a simpler mathematical approach for computing the average anguler deviation ($\bar{\boldsymbol{\theta}}$) and the next hop distance ($\boldsymbol{d_{Next}}$). The modified approach reduces CH-to-CH transmission ranges and provides more conserving CH transmission power while maintaining high probability of end-to-end connectivity to the gateway.

The remainder of this paper is organized as follows. Section 2 describes the used mathematical approach for assigning the minimum transmission range. Section 3 provides numerical results and comparison of the original approach in [1]. Finally, Section 4 concludes the paper.

2. MINIMUM TRANSMISSION RANGE COMPUTATION

We follow the approach in [1] to compute the minimum transmission range by increasing *R* until obtaining 95% end-to-end connectivity probability (*Prob*) for a CH node located at a distance *d* from the gateway as shown in Algorithm 1. Where R_0 is the initial value of *R* and ΔR is the range increment.

Algorithm 1 Algorithm to compute R

1: $R \leftarrow R0$;
2: $[prob] \leftarrow connect\ (\lambda, d, R)$;
3: **while** $prob < M$ **do**
4: $R \leftarrow R + \Delta R$;
5: $[prob] \leftarrow connect\ (\lambda, d, R)$;
6: **end while**
7: **return** R

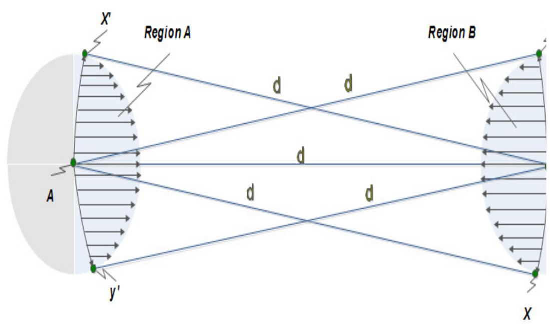
The procedure (***connect***) returns *prob*, which is obtained by using algorithm 2. Hence, the probability of end-to-end connectivity to the gateway for a given CH node density λ, and a communication range *R* of CH-to-CH is calculated by the procedure *connect* as shown below.

Algorithm 2 Procedure $connect(\lambda, d, R)$

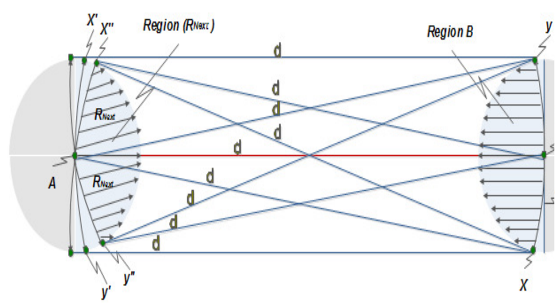
1: prob $\leftarrow$ 1;
2: K $\leftarrow$ 0;
3: $\bar{r} \leftarrow E[r] = \frac{\int_0^R 2\pi r^2 \lambda\, e^{-\lambda\pi(R^2-r^2)}}{1-e^{-\lambda\pi R^2}}$;
4: while d > R do
5: K $\leftarrow$ K + 1;
6: $\alpha \leftarrow 2\sin^{-1}(R/2d)$;
7: $\beta \leftarrow \frac{(\pi-3\alpha)}{2}$;
8: $\bar{\boldsymbol{\theta}} \leftarrow \mathbf{0.5}\,\beta$;
9: $\mathbf{d_{Next}} \approx \mathbf{d} - \bar{\mathbf{r}}\cos\bar{\boldsymbol{\theta}}$;
10: d $\leftarrow d_{Next}$;
11: s $\leftarrow$ (2d + R)/2;

$a \leftarrow \sqrt{s(s-d)^2(s-R)}$;
$Area_1 \leftarrow d^2\alpha/2 - a$;
$Area_2 = \frac{R^2\beta}{2}$;
$Area\,(R_{Next}) = 2\,(\,Area_1 + Area_2\,)$;
if K == 1 then
prob ← $(1 - e^{-\lambda Area(R_{Next})})$prob ;
else
$(R_{new}) \leftarrow ((2K-3)\bar{r} + 2R)\bar{r}\,\bar{\theta}$;
prob ← $(1 - e^{-\lambda Area(R_{new})})$prob ;
end if
end while
if d > 0 then
K ← K + 1;
end if
return prob

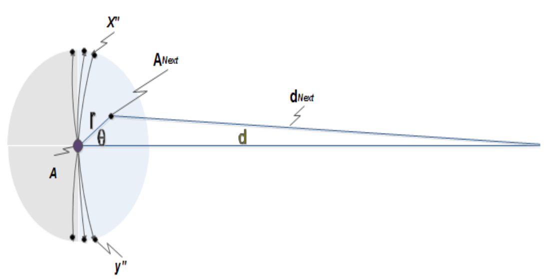
The idea of algorithm 2 in [1] is to get the shortest hop distance between the next hop node of ***A*** (denoted by A_{Next}) and the gateway ***B***. where, node ***A*** is originally at a distance ***d*** from node ***B***, as shown in Figure 1(a). Hence, *Region A* is the intersection of *B*'s circular 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.



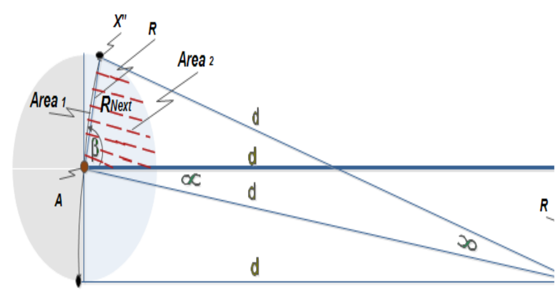
a) *Region A* and *Region B*



b) *Region* $R_{Next}(Area\ (R_{Next}))$



c) Next hop $\boldsymbol{A_{Next}}$ and new distance $\boldsymbol{d_{Next}}$



d) $Area_1$ and $Area_2$

Fig.1: Locating the next hop node towards the gateway. [1]

Figure 1(b), illustrates the determination of $Region\ R_{Next}$ (denoted as $Area\ (R_{Next})$, in line 15 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 circular arcs of radius d form points X and Y with region A (in Fig. 1(a)) at points X'' and Y'' respectively.

Therefore, when we randomly select next hop for node A in *Region* R_{Next}, it will have a new distance (d_{Next}) to gateway B less than the previous distance d. This means that the distance to gateway B (d_{Next}) monotonously decreases with increasing hop count K (see line 5 of algorithm 2) to node A and re-find a new value $d_{Next} < d$ (line 10) until $d < R$. This is clear from the inner loop of algorithm 2 (line 16 to line21). Also this loop updates the probability (*Prob*) of end-to-end connectivity over K hops at each iteration.

Hence, we can obtain the probability to find at least one node in $Area\ (R_{Next})$ to be the next first hop of A (A_{Next}) as ($\mathbf{1 - e^{-\lambda Area(R_{Next})}}$), (line 17 in algorithm 2). $Area(R_{Next})$ is represented by dashed lines in Figure 1(b), (line 15 in algorithm 2), and R_{Next} is represented by dashed lines in Figure 1(d). It should be noted that:

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

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

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

$$Area_1 = d^2\alpha/2 - a$$

$$\text{and, } a = \sqrt{s(s-d)^2(s-R)} \qquad (1)$$

where (a) is the area of triangle $AX''X$, and (s) is the half circumference of the triangle, (lines 11-15 of algorithm 2).

As shown in Figure 2, the area $Area\ R_{new}$ has new next hops for nodes of hop number i. where this area is presented by a simple geometrical calculation as $Area(R_{new}) \leftarrow ((2K-3)\bar{r} + 2R)\bar{r}\,\bar{\theta}$ (see line19 of algorithm 2). Then, we consider the probability to find at least one node in *Area Rnew* to update *prob* (see line 20). [1][9]

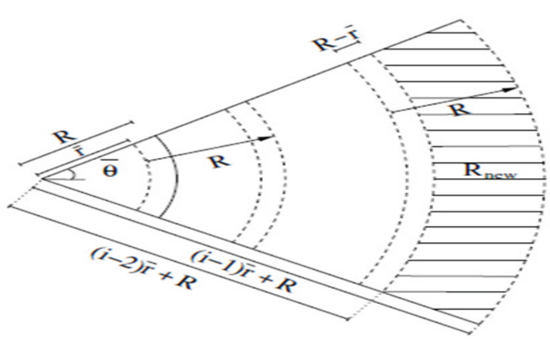


Fig. 2: Search area for next hop nodes. [1]

For an $X \times X$ network, where ($X = 1000m$), the derived terms used in algorithm 2 can be accurate enough when the range R is close to the value of distance (d) which is selected by Monte Carlo simulations to obtain the minimal range R that gives a connectivity of at least 95%, for different values of node density σ. Therefore, the best estimation is obtained when choosing the CH that is $X/2$ (d= 500m) away from the gateway for all density values [1]. Note that $\lambda = p\sigma$, where p is the CH selection probability.

2.1. Computation of d_{Next} [1]

In [1], and as shown in Figure 1(c), d_{Next} is approximated by using the following formula:

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

Where $\bar{r}$ is the expected value of the minimum radial distance, $0 < r \leq R$, which is computed by using line 3; and $\bar{\theta}$ is the average angular deviation, $0 \leq \theta \leq \beta$, which is computed in [1] by using the following formula:

$$\bar{\boldsymbol{\theta}} = \frac{\int_0^\beta \theta e^{-2\lambda\left[\frac{\theta\bar{r}^2 - \frac{\bar{r}^2}{2}\sin(2\theta)}{2}\right]} d\theta}{\int_0^\beta e^{-2\lambda\left[\frac{\theta\bar{r}^2 - \frac{\bar{r}^2}{2}\sin(2\theta)}{2}\right]} d\theta} \qquad (3)$$

2.2. Computation of d_{Next} (our approach)

As shown in Figure 3, 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:

$$d_{Next} \approx d - \bar{r}\cos\bar{\theta} \qquad (4)$$

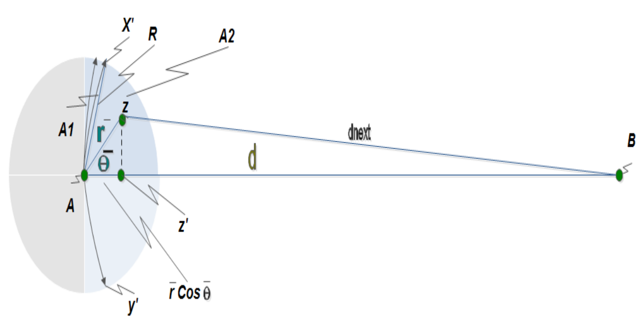


Fig.3: A_{Next} and new distance d_{Next} (our approach)

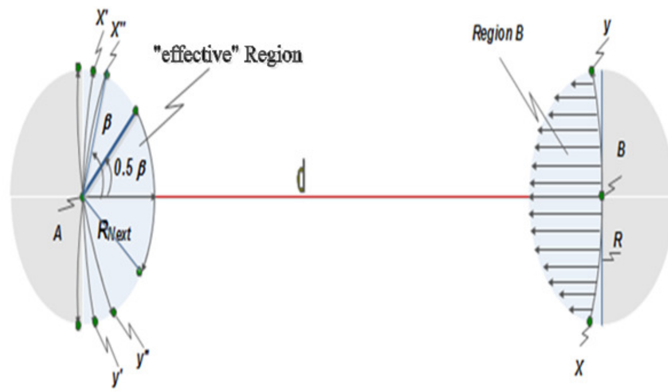


Fig. 4: Effective Region

Moreover, as shown in Figure 4, 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. Hence, the average angular deviation ($\bar{\theta}$) which was computed by equation (3) in [1] can be approximated as:

$$\bar{\theta} \approx 0.5\beta \quad (5)$$

Then we can find the transmission power by using the following formula [2]:

$$P_{AB} = R^2 \quad (6)$$

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

$$\text{Power saving \%} = \left(1 - \frac{P_{New}}{P_{Old}}\right) \times 100\% \quad (7)$$

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.

3. PERFORMANCE EVALUATION

Numerical analysis was performed to find the end-to-end connectivity probability as a function of the minimum transmission range R. The analysis were done for various node density values (σ =3×10^{-3}, 4×10^{-3}, 5×10^{-3}, and 6×10^{-3}). The CH selection probability p is taken as 0.1, corresponding to CH density values (λ= 3×10^{-4}, 4×10^{-4}, 5×10^{-4}, and 6×10^{-4}), whereas $R_o = 10m$ and $\Delta R = 1m$. Figure 5 and Figure 6 show the connectivity probability as a function of the transmission range for the approach in [1] and our approach respectively. As expected, in both figures, end-to-end connectivity probability increases as the range R increases, and also it increases as the node density 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.

Since the objective is to achieve a high end-to-end connectivity probability with a minimum transmission range, we summarized the comparison of both Figures at 95% connectivity probability for the various node density values as shown in Table 1. It is clear that our approach outperforms the approach of [1] by 19.40-28.56% power saving since we succeeded to assign lower minimum transmission ranges.

Table1. Power saving % Comparison for 95% Connectivity Prob.

Node density σ	Range R for approach [1] (m)	Range R for our approach (m)	Power saving%
0.003	98	88	19.40
0.004	84	71	28.56
0.005	74	65	22.85
0.006	67	59	22.46

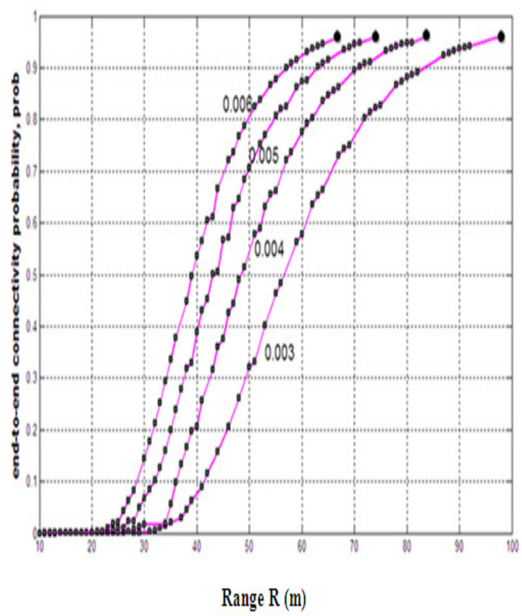


Fig.5. Connectivity Probability versus R for the approach of [1]

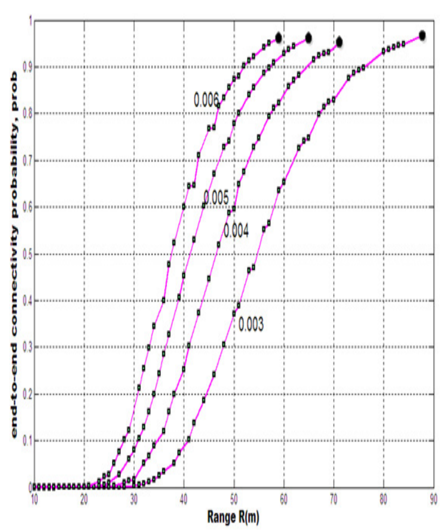


Fig.6. Connectivity Probability versus R for our approach

4. CONCLUSIONS

Transmission range assignment in WSNs is an important issue which affects the transmission power and connectivity of the nodes. Therefore, the ultimate goal is to maintain high connectivity probability with minimum transmission range so that energy conservation and data delivery are both achieved. in this paper, we followed a similar analytical approach given in [1] to assign the minimum transmission range for CH-to-CH communication with an acceptable connectivity probability.

Our approach differs from the approach given in [1] in two different aspects: 1) we used a simpler mathematical model; 2) we maintained the same connectivity with smaller transmission ranges, which means less power consumption and hence longer life time of the nodes. In summary, the numerical results demonstrate that our proposed approach is more effective in prolonging the network lifetime.

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