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A Note on Optimum Cluster Estimation in LEACH Protocol

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ABSTRACT In the last two decades, a plethora of energy efficient protocols based on LEACH protocol have been proposed by researchers. LEACH is one of the most prominent protocol for wireless sensor network, which is a self-configurable and energy-efficient cluster based protocol. LEACH protocol uses certain approximations and assumptions. In this paper, we tried to find what happens if these basic assumptions and approximations of LEACH are not considered. We have found that E_{elecRx} plays a vital role in deciding optimum number of clusters and E_{elecTx} has no effect on number of clusters in the network. We have also found that multi-clustering might not be required at some point and, at some point, number of optimum clusters could be as high as N (number of live nodes in the network).

INDEX TERMS LEACH, cluster size, optimum cluster size, energy efficiency, lifetime, energy model, wireless sensor network.

I. INTRODUCTION

Fall in the prices of low cost sensors have accelerated the use of sensor based monitoring of houses, factories, habitats, country borders and many other [1]. Sometimes the number of sensors (herein referred as micro sensors or node) are quite large [1]. The grouping of these sensors on basis of some criteria is called clustering. There are several advantages of clustering cited by several scholars, among which is the increased life time of the nodes and hence network [2].

Followed by LEACH [2]–[4], [4] a number of protocols have come up in the last two decades promising better life time of the nodes and hence network [5]–[25] but still we feel it is worth discussing LEACH as many descendants and extensions of LEACH have been proposed; thus to understand the newly developed protocols a thorough understanding of LEACH is desirable.

LEACH is used for development of new protocols for WSN or is used as a base for comparison purpose of developed protocols [19], [26]–[30]. LEACH protocol uses certain approximations and assumptions. In this paper the approximations made in the development of the LEACH protocol is analyzed and reworked for new insight.

This paper is organized as follow; section II describes LEACH energy dissipation model, process of cluster formation and determination of number of clusters, in section III we discuss about the proposed modification in LEACH followed by conclusion in section IV.

II. LEACH ENERGY DISSIPATION MODEL

From energy dissipation point of view, LEACH promised substantial improvements over the then existing protocols. LEACH considers three sources of energy dissipation, namely; communication, data processing and cluster formation. In this section we discuss these three sources and their mathematical representation but first we discuss the network architecture followed by LEACH.[1]

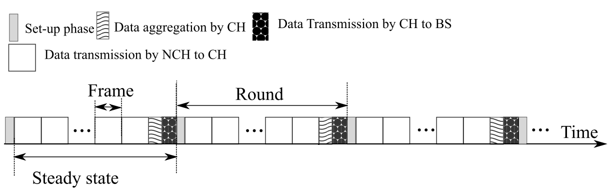

FIGURE 1. **LEACH operation.**

A. LEACH NETWORK ARCHITECTURE

All the sensor nodes which are deployed in the sensing field to be monitored, dynamically form clusters during the setup phase (as shown in fig. 1). Each cluster has a node designated as Cluster Head (CH). The other nodes are called Non-Cluster Head (NCH) nodes. The NCH nodes sense the data from their

[1]For convenience and understanding we have used the same symbols used in [2] and [3]

surrounding and send it to the CH node of the cluster to which it belongs. The tasks performed by CH nodes are as below;

1) Sense data/ physical parameters from its own environment of deployment.
2) Receive data sent to it by its cluster members in a TDMA (Time Division Multiple Access) schedule.
3) Perform data processing (data aggregation).
4) Transmit the processed data to the base station.

Base station is at a larger distance and may also be outside the sensing field. These operations are repeated periodically and follow a TDMA based schedule. In order to save energy the nodes are not always in active mode. They follow a sleep and wakeup cycle (as shown in fig. 1).

The task performed by CH are substantially more in comparison to a NCH node, that is the CH uses more energy and thus this implies that the CH node is likely to die[2] early. To avoid early death of the node, the cluster heads are rotated periodically, so that every other node gets a chance to perform the duty of a CH.[3]

B. ENERGY DISSIPATION IN COMMUNICATION

LEACH considers a simple communication model (as shown in fig. 2) where the transmitter unit has two components; transmitter electronics and the amplifier circuit. Similarly, the receiver unit has only receive circuitry. Both of these units are powered by a small battery. Here two types of path loss models are considered; free space path loss [31] and multi-path fading where the power loss factors are d^2 and d^4 respectively. Thus the energy dissipation by the free space path propagation for transmitting l bits is estimated as

$$E_{Tx-free-space}(l) = lE_{elec} + l\epsilon_{fs}d^2 \tag{1}$$

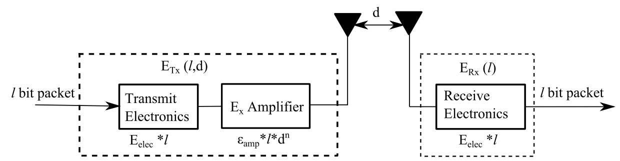

FIGURE 2. First order radio model.

and the energy dissipation by the multipath path propagation for transmitting l bits is estimated as

$$E_{Tx-multi-path}(l) = lE_{elec} + l\epsilon_{fs}d^4 \tag{2}$$

The Friss free space model is chosen if $d < d_0$ else multi path model is chosen [3]. The crossover distance d_0 [31] is estimated as;

$$d_0 = \frac{4\pi\sqrt{L}h_t h_r}{\lambda} \tag{3}$$

where $L \geq 1$ is the system loss factor not related to propagation.

[2]The energy level falls below a threshold value due to which node becomes non-operational

[3]This leads to load sharing among the nodes of the cluster

The energy dissipated in transmitting a message of length 'l' bits to a distance 'd' is estimated as below;

$$\begin{aligned} E_{Tx}(l,d) &= E_{Tx}(l) + E_{Tx-amp}(l,d) \\ &= \begin{cases} lE_{elec} + l\epsilon_{fs}d^2 & \text{if } d < d_0, \\ lE_{elec} + l\epsilon_{mp}d^4 & \text{if } d \geq d_0, \end{cases} \end{aligned} \tag{4}$$

Similarly, to receive the same length of message energy dissipated by receiver is

$$E_{Rx}(l) = E_{Rx-elec}(l) = lE_{elec} \tag{5}$$

C. ENERGY DISSIPATION IN DATA AGGREGATION

During data aggregation step, the cluster head node accepts data from its cluster member nodes and performs data aggregation operation before transmitting it to the base station. On the basis of experiments carried out and referred in [32], the value of data aggregation may be taken to be $E_{DA} = 50$ nJ/bit/signal.

D. CLUSTER HEAD SELECTION PROCESS

In order to have an extended network life time, the cluster head selection process in LEACH follows a distributed approach where the nodes are autonomous and participate in the CH selection process. Let us assume that at a given time there are k number of clusters in the network. Say after r rounds, i^{th} sensor elects itself to be a cluster head at some instance of time t. if $S_i(t)$ is an indicator factor on the basis of which it will be decided that in the recent (r mod (N/k)) rounds whether a node has been a cluster head or not. Then the probability of each node to become a cluster head after r^{th} round is

$$P_i(t) = \begin{cases} \dfrac{k}{\text{N-k} * (r \bmod \frac{N}{k})} & : C_i(t) = 1 \\ 0 & : C_i(t) = 0 \end{cases} \tag{6}$$

E. OPTIMUM NUMBER OF CLUSTERS

An optimum number of cluster heads can create an energy efficient network. If the number of clusters is less than or greater than the optimum number of clusters then in either case energy dissipation will be high, as shown experimentally in [2]. Let us assume that there are N sensor nodes distributed uniformly in a square region M x M. If the area is divided into k clusters then each cluster on an average should have $\frac{N}{k}$ nodes per cluster, out of this $\frac{N}{k} - 1$ are cluster member nodes and one is cluster head. The energy dissipated by each cluster head during a single frame (of l bits) can be estimated as:

$$E_{CH} = lE_{elec}(\frac{N}{k} - 1) + lE_{DA}\frac{N}{k} + lE_{elec} + l\epsilon_{mp}d_{toBS}^4 \tag{7}$$

In this communication it is assumed that BS is at far distance from the CH so multipath path loss is used. If this communication is within the cluster then the energy dissipated by a single node while communicating it to the CH can be estimated in following manner.

$$E_{non-CH} = lE_{elec} + l\epsilon_{fs}d_{toCH}^2 \tag{8}$$

The area occupied by each cluster (which can be of any arbitrary shape) is approximately $\frac{M^2}{k}$. Assuming that the nodes are distributed uniformly with node distribution $\rho(x, y)$ and the CH is at the center of mass of the cluster. The sum of the square of the distance from NCH to CH is

$$\begin{aligned} D[d^2_{toCH}] &= \iint (x^2 + y^2)\rho(x, y)dxdy \\ &= \iint r^2 \rho(r, \theta) r dr d\theta \end{aligned} \tag{9}$$

for simplicity lets assume that the cluster area is circular in nature. The area occupied by each cluster with radius R is πR^2 therefore value of R can be calculate as

$$\begin{aligned} \pi R^2 &= \frac{M^2}{k} \\ R &= \frac{M}{\sqrt{\pi k}} \end{aligned} \tag{10}$$

Assuming that $\rho(r, \theta)$ is constant for r and θ. The equation (9) can be rewritten as

$$\begin{aligned} D[d^2_{toCH}] &= \rho \int_{\theta=0}^{2\pi} \int_{r=0}^{\frac{M}{\sqrt{\pi k}}} r^3 dr d\theta \\ &= \frac{\rho}{2\pi} \frac{M^4}{k^2} \end{aligned} \tag{11}$$

As the density has been considered to be uniform.

$$\rho = \frac{1}{\frac{M^2}{k}} \tag{12}$$

Equation (11) can be rewritten as

$$D[d^2_{toCH}] = \frac{1}{2\pi} \frac{M^2}{k} \tag{13}$$

Now using this (8) can be written as

$$E_{non-CH} = lE_{elec} + l\epsilon_{fs} \frac{1}{2\pi} \frac{M^2}{k} \tag{14}$$

The energy dissipated inside a cluster during a single frame is

$$E_{cluster} = E_{CH} + (\frac{N}{k} - 1)E_{non-CH} \tag{15}$$

$$\approx E_{CH} + \frac{N}{k} E_{non-CH} \tag{16}$$

and on the basis of this the total energy dissipated in the network during a single frame is

$$\begin{aligned} E_{total} &= kE_{cluster} \\ &= l(E_{elec}N + E_{DA}N + k\epsilon_{mp} d^4_{toBS} \\ &\quad + E_{elec}N + \epsilon_{fs} \frac{1}{2\pi} \frac{M^2}{k} N) \end{aligned} \tag{17}$$

From this the optimum number of clusters, in a network field can be estimated by setting the derivative of E_{total} with respect to k and equating it to 0, which gives

$$k_{optimumLeach} = \frac{\sqrt{N}}{\sqrt{2\pi}} \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \frac{M}{d^2_{toBS}} \tag{18}$$

III. PROPOSED MODIFICATIONS IN LEACH

While proposing the modification in LEACH, we have the same assumption that LEACH protocol has, except in equation (16). Equation (16) without approximation can be written as

$$\begin{aligned} E_{total} &= k(E_{CH} + (\frac{N}{k} - 1)E_{non-CH}) \\ &= k(lE_{elec}(\frac{N}{k} - 1) \\ &\quad + lE_{DA}\frac{N}{k} + lE_{elec} + l\epsilon_{mp} d^4_{toBS} \\ &\quad + (\frac{N}{k} - 1)(lE_{elec} + l\epsilon_{fs} \frac{1}{2\pi} \frac{M^2}{k})) \\ &= l(NE_{elec} - kE_{elec} + NE_{DA} + kE_{elec} \\ &\quad + k\epsilon_{mp} d^4_{toBS} + NE_{elec} + N\epsilon_{fs} \frac{1}{2\pi} \frac{M^2}{k} \\ &\quad - kE_{elec} - l\epsilon_{fs} \frac{1}{2\pi} M^2) \end{aligned} \tag{19}$$

Taking its derivative with respect to k and equating it with 0 we get

$$\epsilon_{mp} d^4_{toBS} - N\epsilon_{fs} \frac{1}{2\pi} \frac{M^2}{k^2} - E_{elec} = 0 \tag{20}$$

In eq.(20) if $\epsilon_{mp} d^4_{toBS} = E_{elec}$, this equation breaks down and when $\epsilon_{mp} d^4_{toBS} > E_{elec}$ we have;

$$k^2 = N\epsilon_{fs} \frac{1}{2\pi} M^2 \left(\frac{1}{\epsilon_{mp} d^4_{toBS} - E_{elec}} \right) \tag{21}$$

and we obtain

$$\frac{N\epsilon_{mp} M^2}{2\pi} \frac{1}{k^2} = 0 \tag{22}$$

this would be true in the limit $k \to \infty$; but the number of sensor nodes is finite. Thus for the condition $\epsilon_{mp} d^4_{toBS} \leq E_{elec}$ it is proposed that k = N.

$$k = \sqrt{\frac{N}{2\pi}} \frac{\sqrt{\epsilon_{fs}} M}{\sqrt{(\epsilon_{mp} d^4_{toBS} - E_{elec})}} \tag{23}$$

solving it for the distance d_{toBS} where k is supposed to be k = N, we get

$$d_{toBS} = \left[\frac{1}{\epsilon_{mp}} \left(\frac{M^2 \epsilon_{fs}}{2\pi N} + E_{elec} \right) \right]^{\frac{1}{4}} \tag{24}$$

the same equation can be re-written as

$$K_{new} = \begin{cases} N : d_{toBS} \leq \left[\frac{1}{\epsilon_{mp}} \left(\frac{M^2 \epsilon_{fs}}{2\pi N} + E_{elec} \right) \right]^{\frac{1}{4}} \\ \sqrt{\frac{N}{2\pi}} \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \frac{M}{\sqrt{d^4_{toBS} - \frac{E_{elec}}{\epsilon_{mp}}}} : otherwise \end{cases} \tag{25}$$

writing

$$C = \sqrt{\left(d^4_{toBS} - \frac{E_{elec}}{\epsilon_{mp}} \right)} \tag{26}$$

TABLE 1. Symbols and their meaning.

Symbol	Meaning	Value
L	$L \geq 1$ is the system loss factor not related to propagation	
h_r	Height of the receiving antenna above ground	1.5m
h_t	Height of the transmitting antenna above ground	1.5m
λ	Wavelength of the carrier signal	
N	Total number of nodes	100
l	Bits of message to be transmitted	
d	Distance of communication	
d^2	Free space power loss	
d^4	Multipath power loss	
d_0	Crossover distance for selecting power loss model	86.2m
E_{Tx}	Energy dissipation during transmission	
E_{Rx}	Energy dissipation during receiving	
E_{elec}	Energy required to run the electronic circuit of T_x and R_x	50 nJ/bit
ϵ_{fs}	Energy required for free space propagation	10 pJ/bit/m^2
ϵ_{mp}	Energy required for multi path propagation	0.0013 pJ/bit/m^4
E_{DA}	Cost of data aggregation	50 nJ/bit/signal
d_{toBS}	Distance from CH to BS	
d_{toCH}	Distance from NCH node to CH	

the K_{new} becomes

$$K_{new} = \begin{cases} N : d_{toBS} \leq \left[\frac{1}{\epsilon_{mp}}\left(\frac{M^2\epsilon_{fs}}{2\pi N} + E_{elec}\right)\right]^{\frac{1}{4}} \\ \sqrt{\frac{N}{2\pi}}\sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}}\frac{M}{C} : otherwise \end{cases} \quad (27)$$

It is evident from equation (18) and (25) that optimum number of clusters is dependent on distance from cluster head nodes to base stations (d^4_{toBS}) and also on the factor $\frac{E_{elec}}{\epsilon_{mp}}$. Here distance ($d^4_{toBS}$) is the average distance between all the cluster heads and base station.

A. ESTIMATION OF AVERAGE D_{TOBS}

Cluster heads are located at different distances from the BS. Thus to estimate the average distance d^4_{toBS} to be used in (26) or (27) we proceed as follow for the configuration of the deployment used in this work. For every set up the average value of d^4_{toBS} needs to be estimated. Lets assume that there are N sensor nodes distributed uniformly in a square region of $M \times M$ and the base station is located outside the sensing filed at location (a, b) as shown in the fig 3.

The sum of the d^4_{toBS} distance from cluster heads to base station is

$$D[d^4_{toBS}] = \iint ((a-x)^2 + (b-y)^2)^2 \rho(x,y)dxdy = \iint \frac{\left((a-x)^2 + (b-y)^2\right)^2}{M^2}dxdy \quad (28)$$

further integrating from 0 to M (current sensing field dimension), we get

$$D[d^4_{toBS}] = \int_{x=0}^{M}\int_{y=0}^{M} \frac{\left((a-x)^2 + (b-y)^2\right)^2}{M^2}dxdy = \frac{28\,M^4}{45} - \frac{5\,M^3\,a}{3} - \frac{5\,M^3\,b}{3} + \frac{8\,M^2\,a^2}{3} + 2\,M^2\,a\,b + \frac{8\,M^2\,b^2}{3} - 2\,M\,a^3 - 2\,M\,a^2\,b - 2\,M\,a\,b^2 - 2\,M\,b^3 + a^4 + 2\,a^2\,b^2 + b^4 \quad (29)$$

We tried to estimate the distance of the CH to base station for a particular scenario as shown in fig. 3 where we varied the position of the base station along the straight line (50,0) to (50,175) and plotted the distance as shown in fig. 5.

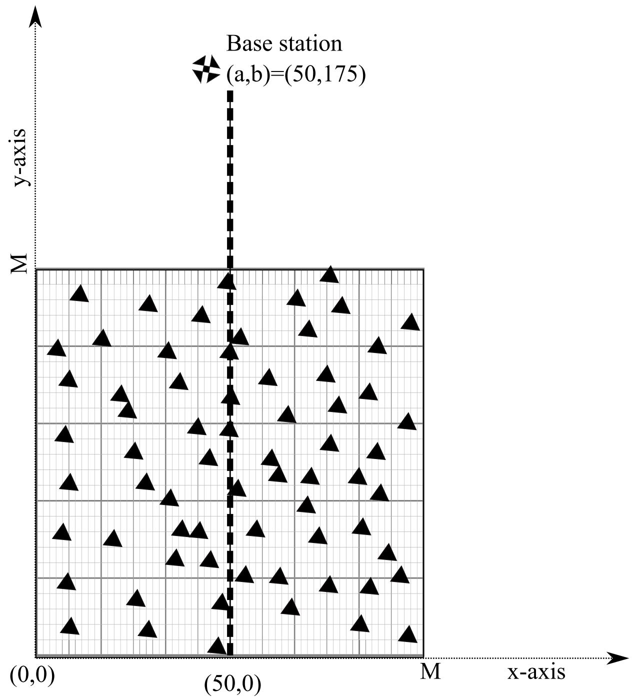

FIGURE 3. Layout of sensors and base station.

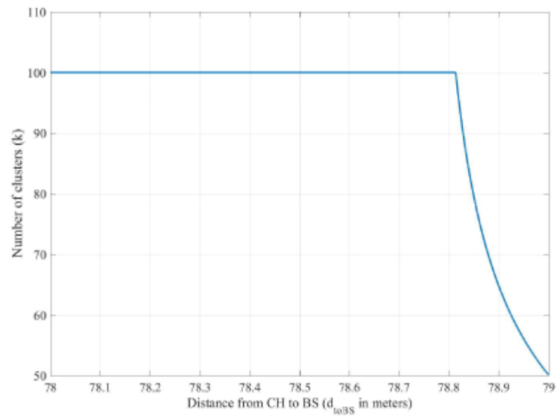

FIGURE 4. Optimum number of clusters:Here it has been observed that at d_{toBS} = 78.813 meters the number of clusters are k=N, where N is number of living nodes.

We estimated optimum number of clusters using equation (18) and (25) and tabulated it in (table 2). We also plotted the newly estimated optimum number of clusters based on eq.(25) in fig. 4 Below are our comments/ observations;

1) The modified LEACH shows higher number of cluster nodes than the number of nodes physically present in the sensing field after a crossover value of d^4_{toBS}, k should be at most equal to N. As an example for d_{toBS} = 78.511 *meters* number of optimum clusters k=2586 (using eq. 27). which is impossible under the current scenario, as the number of sensors in the sensing field are at most N=100 and that too in

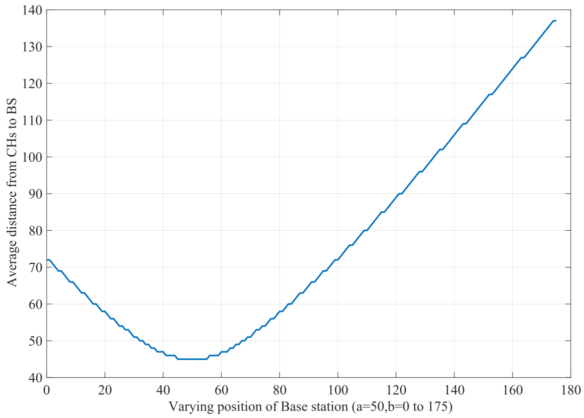

FIGURE 5. Average distance of cluster heads to base station (varying position of base station) on a linear path as shown in fig 3.

TABLE 2. Optimum number of clusters, LEACH vs proposed technique.

dtoBS (m)	KoptimumLeach		Knew	
79	5.607823	6	50.07227	51
80	5.467547	6	22.14176	23
85	4.843225	5	9.442121	10
90	4.320037	5	6.717008	7
95	3.877263	4	5.337887	6
100	3.49923	4	4.461441	5
105	3.173905	4	3.839516	4
110	2.891926	3	3.368529	4
115	2.645921	3	2.996257	3
120	2.430021	3	2.692996	3
125	2.239507	3	2.440357	3
130	2.07055	3	2.226228	3
135	1.920016	2	2.04223	3
140	1.785321	2	1.882347	2
145	1.664319	2	1.742123	2
150	1.555213	2	1.618169	2
155	1.456495	2	1.507854	2
160	1.366887	2	1.409099	2
165	1.2853	2	1.320236	2
170	1.210806	2	1.239903	2
175	1.142606	2	1.166984	2
180	1.080009	2	1.100548	2
185	1.022419	2	1.039812	2
190	0.969316	1	0.984116	1
195	0.920245	1	0.932897	1
200	0.874808	1	0.88567	1
205	0.832654	1	0.842019	1
210	0.793476	1	0.801581	1
215	0.756999	1	0.76404	1
220	0.722981	1	0.729118	1
255	0.538136	1	0.540695	1
260	0.517638	1	0.519921	1

the beginning.[4] As seen if fig. 4 at $d_{toBS} = 78.813\, meters$ k becomes 100.

2) For $d_{toBS} > 104m$ both the approaches have same number of clusters (after rounding up to integer value).
3) For $79 \leq d_{toBS} \leq 104\, m$ there is substantial difference in optimum number of clusters (ranging from 1 to 45).

We have also done a comparison plot of optimum number of clusters as per LEACH and our proposed work (as shown

[4]In the beginning only all the N nodes can be alive, with time they may die

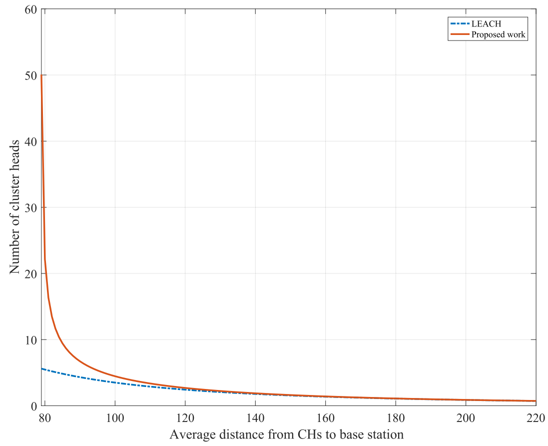

FIGURE 6. Comparison between optimum number of cluster as per LEACH and our proposed work.

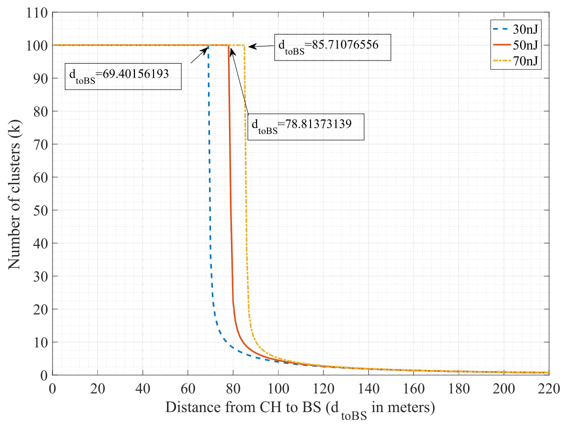

FIGURE 7. Value of k with varying E_{elecRx}.

in fig. (6). We find that there is drastic difference between the two techniques when the average d_{toBS} is between $79\ meters \leq d_{toBS} \leq 114\ meters$.

B. EFFECT OF E_{ELEC}

In LEACH it is assumed that E_{elec} is the energy required to run the T_x and R_x circuitry and here the assumption is that both circuitry consume same energy. It has been cited by several authors like [33] that both the circuitry are different and require different power levels to operate. For example as per [33] which has also been cited in [3] that in transmit mode the chip operate at 165mW and 46.5 mW in receive mode. Similarly data sheet for chip CC2420 [34] which is a Chipcon product from Texas Instruments says that the current required for receiver is 18.8mA whereas for transmitter it ranges from 8.5mA to 17.4mA. In order to differentiate between T_x and R_x power, let E_{elecTx} be the energy consumed to run transmit circuitry in single mode transmission and E_{elecRx} be the energy consumed to run receiver circuitry. Repeating the above steps with the new nomenclature we obtain the following expression, whose proof is given in appendix.

$$k_{new} = \sqrt{\frac{N}{2\pi}} \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \frac{M}{\sqrt{d_{toBS}^4 - \frac{E_{elecRx}}{\epsilon_{mp}}}} \quad (30)$$

Now it is observed that the ratio of $\frac{E_{elecRx}}{\epsilon_{mp}}$ is important. It is E_{elecRx} which has role in deciding the optimum number of clusters.

We graphically represent the value of k with different values of E_{elecRx} in fig (7). We observe that with increase in E_{elec} the same number of the optimum cluster are achieved at increased value of d_{toBS}.

IV. CONCLUSION

It has been observed that optimum number of clusters k is dependent on $C = \sqrt{(d_{toBS}^4 - \frac{E_{elec}}{\epsilon_{mp}})}$. It is also found that E_{elec} in C is E_{elecRx} which means energy dissipation by the receiver circuitry is important for estimating optimum number of clusters and hence an energy efficient clustered wireless sensor network. We have derived the expression for average distance between CHs and base station, which is required for estimating optimum number of clusters. If the effect of the factor $\frac{E_{elecRx}}{\epsilon_{mp}}$ is neglected then eq.(30) reduces to eq.(18). The analysis presented has modified the base LEACH result to include the effect of the ratio $\frac{E_{elecRx}}{\epsilon_{mp}}$ on the number of cluster heads. It is found that if the distance of cluster head nodes with base station increases there is no need of multiple clustering, a single cluster accommodating all the life nodes is sufficient. If this distance is below the breakdown point then there should be N clusters in the network i.e all the nodes should directly communicate with the base station.

APPENDIX
PROOF OF EQUATION (30)

$$
\begin{aligned}
E_{Tx}(l,d) &= E_{Tx}(l) + E_{Tx-amp}(l,d) \\
&= \begin{cases} lE_{elecTx} + l\epsilon_{fs}d^2 & \text{if } d < d_0, \\ lE_{elecTx} + l\epsilon_{mp}d^4 & \text{if } d \geq d_0, \end{cases} \\
E_{Rx}(l) &= E_{Rx-elec}(l) \\
&= lE_{elecRx} \\
E_{CH} &= lE_{elecRx}(\frac{N}{k} - 1) + lE_{DA}\frac{N}{k} \\
&\quad + lE_{elecTx} + l\epsilon_{mp}d_{toBS}^4 \\
E_{non-CH} &= lE_{elecTx} + l\epsilon_{fs}d_{toCH}^2
\end{aligned}
$$

$$E_{non-CH} = lE_{elecTx} + l\epsilon_{fs}\frac{1}{2\pi}\frac{M^2}{k}$$

$$E_{cluster} = E_{CH} + (\frac{N}{k} - 1)E_{non-CH}$$

$$
\begin{aligned}
E_{total} &= k(E_{CH} + (\frac{N}{k} - 1)E_{non-CH} \\
&= k(lE_{elecRx}(\frac{N}{k} - 1) \\
&\quad + lE_{DA}\frac{N}{k} + lE_{elecTx} + l\epsilon_{mp}d_{toBS}^4 \\
&\quad + (\frac{N}{k} - 1)(lE_{elecTx} + l\epsilon_{fs}\frac{1}{2\pi}\frac{M^2}{k})) \\
&= l(NE_{elecRx} - kE_{elecRx} + NE_{DA} + kE_{elecTx} \\
&\quad + k\epsilon_{mp}d_{toBS}^4 + NE_{elecTx} + N\epsilon_{fs}\frac{1}{2\pi}\frac{M^2}{k} \\
&\quad - kE_{elecTx} - l\epsilon_{fs}\frac{1}{2\pi}M^2)
\end{aligned}
$$

Taking its derivative with respect to k and equating it with 0 we get

$$k_{new} = \sqrt{\frac{N}{2\pi}}\sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}}\frac{M}{\sqrt{(d_{toBS}^4 - \frac{E_{elecRx}}{\epsilon_{mp}})}} \tag{31}$$

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