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# CMPE312 Spring2021 Term Project task “Wireless sensor networks simulator development” explanations

## Overview of the system: energy consumption perspective

Wireless sensor network (WSN) is illustrated by Fig. 1. It has a number of sensors arranged in clusters (3, in Fig. 1), each cluster having a cluster head (CH) and cluster members (CM) show by filled and empty circles respectively. Sensors are responsible for collecting (sensing) data and sending them to the base station (BS). Communicating of the data to the BS is done according to low-energy adaptive clustering hierarchy (LEACH) protocol [1]-[3]. In LEACH protocol, clusters are created dynamically, and data are transmitted from CMs to BS via respective CHs.



Fig. 1. WSN [1]

Two snapshots of WSN cluster configurations are shown in Fig. 2. 

Fig. 2. Two cluster configurations [2].

Cluster configurations are defined periodically. Time diagram of WSN working is shown in Fig. 3.



Fig. 3. Time diagram of WSN working [2]

WSN work is a sequence of rounds, each round having set-up and steady-state phases. In the set-up phase, clusters are formed (CMs and CHs, time-division multiple access (TDMA) schedules defining for each CM and CH time of data exchange, and time of CH-BS exchange are defined).

Steady-state phase is a sequence frames inside which CH-CM and CH-BS data exchanges are made. One round detaıled tıme dıagram ıs shown ın Fıg. 4.



Fig. 4. One round detailed time diagram [1].

## System parameters and energy consumption formulas

System simulation parameters used in [1] are given in Fig. 5.



Fig. 5. System parameters used in [1].

Parameters from Fig. 5 (excepting the last two, $t\_{max}$ and $σ$ used in Algorithm 1 in [1] for distributed cluster formation) are used in energy consumption model given in Fig. 6.



Fig. 6. Energy consumption model [1].

Thus CH energy consumptıon for one frame (see Fig. 4) ıs gıven by

|  |  |
| --- | --- |
| $E\_{CH}=\left(n-1\right)bE\_{elec}+nbE\_{da}+bE\_{elec}+bε\_{mp}d^{4}$*,* | () |

where $\left(n-1\right)bE\_{elec}$ energy is consumed to get data from CMs, $nbE\_{da}$ is consumed for aggregation of the data obtained of CMs, and $bE\_{elec}+bε\_{mp}d^{4}$ energy is consumed for transmitting the aggregated data to BS, since it is assumed that distance from CH to BS is greater than $d\_{0}$.. A CM for transmission of its data in a frame consumes

|  |  |
| --- | --- |
| $E\_{CM}=bE\_{elec}+bε\_{FS}d^{2}$*,* | () |

since it is assumed that distance from CM to CH is less than $d\_{0}$. If the cluster reformation interval, $T\_{crf}$ is one week, reporting interval, $T\_{rep}$ is one hour, as specified in Fig. 5, then the number of frames in the steady state period of one round (see Fig. 4) is

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| --- | --- |
| $Frames=floor(\frac{T\_{crf}-T\_{cf}}{T\_{rep}})$*,* | () |

where $T\_{cf}$ is the time for cluster formation. Cluster formation follows LEACH protocol discussed in detail in Section 3, and $T\_{cf}$ is estimated in (5), (6) as 0.32 sec that compared to $T\_{crf}=7$ days and $T\_{rep}=1$ hour, can be neglected in (3) for parameters used in Figs. 5, 10. Knowing the number of frames in a round, energy consumption of each CH and CM can be calculated:

|  |  |
| --- | --- |
| $$ECHR=Frames∙E\_{CH}, ECMR=Frames∙E\_{CM}$$ | (4) |

Radio energy dissipation model is given pictorially in Fig. 7



Fig. 7. Radio energy dissipation model [2]

In [2], energy model is described similarly as shown in Fig. 8:





Fig. 8. Energy consumption model [2].

System parameters used in [2] are shown in Fig. 9:



Fig. 9. Experiment setup on energy [2]

Other system parameters used in are given in Fig. 10:



a)



b)

Fig. 10. System parameters on a) the number of nodes, area, transmission rates, and packets used in [2]; b) nodes, area used in [1].

Radio characteristics used in [3] are given in Fig. 11:



Fig. 11. Radio characteristics used in [3]

## LEACH protocol detailed description

LEACH protocol details are given in Fig. 12











Fig. 12. Details of LEACH protocol [3]

Pictorially LEACH protocol is described in Fig. 13



Fig. 13. Flowchart of LEACH

The optimal number of clusters is estimated in Fig. 14, where WSN area is assumed $M×M$ sized, M in meters.



Fig. 14. Optimal cluster number estimate from [2]

Observed in simulations [2] energy dissipation dependence on the number of clusters is given in Fig. 15



Fig. 15. Observed energy dissipation as a function of the clusters number [2]

Hence, it was decided in [2] as shown in Fig. 16:



Fig. 16. Defining number of clusters for experiments [2]

Time cluster formation, $T\_{cf}$, according to LEACH protocol, neglecting computation time related with threshold comparison, can be estimated as

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| --- | --- |
| $T\_{cf}=\frac{2Nb}{rate}$*,* | () |

where $rate$ is the bit rate of data transfer, $N$ is the total number of nodes in the WSN. It accounts for the time of CH announcements and join-request messages transfer (see Fig. 13) assuming that each message is of $b$ bits. In Fig. 10, $rate=1Mb/s$, the number of bits in a packet of 200 bytes (as in Fig. 5), is $b=200∙8=1600 bit$, and with $N=100$ (as in Fig. 10),

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| --- | --- |
| $T\_{cf}=\frac{2Nb}{rate}=\frac{2∙100∙1600}{10^{6}}=0.32$ sec. | (6) |

## 4. Simulation principles

### 4.1. Simulation of parallel activities by a sequential process

To simulate N sensors behavior according to LEACH algorithm with the aim of defining dependence of the number of alive/dead nodes on time, it is necessary tracking battery charge dropping with time as data are transferred. Transfer of data is necessary for clusters set-up (exchange of CH announcements and join-request messages, see Fig. 13) and steady state (regular sensed data transfer, see Figs. 3, 4). For example, N=3, and the nodes need exchanging two messages, m1 and m2, i.e. each node sends its instance of m1, receives m1 from all the nodes, then similarly, each node sends and receives m2. It can be modeled by the following state diagram shown in Fig. 17:

M2 received sent

M1 received sent

M1 sent sent

M2 sent sent

Fig. 17. State chart diagram of two-message sending-receiving by each node

We assume that all three nodes do actions shown in Fig. 17 in parallel. It can be simulated by a sequential process similar to how a sequential processor, CPU, handles pseudo-parallel processes running in conventional multi-tasking operating systems such as Windows or Linux: using time sharing. In our case, it is as shown in Fig. 18:

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Physical Time quanta | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Node1 | M1 send |  |  | M1 receive |  |  | M2 send |  |  | M2 receive |  |  |
| Node2 |  | M1 send |  |  | M1 receive |  |  | M2 send |  |  | M2 receive |  |
| Node3 |  |  | M1 send |  |  | M1 receive |  |  | M2 send |  |  | M2 receive |
| Simulation time | 1 | 2 | 3 | 4 |

Fig. 18. Time sharing between three nodes with 12 physical and 4 simulation time units spent

### 4.2. Simulation of random events

In LEACH, choice of a CH is made randomly as shown in Fig. 12, 5.1 Advertisement phase, formula for

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| --- | --- |
| $T\left(n\right)=\left\{\begin{array}{c}\frac{P}{1-P∙\left(r mod\frac{1}{P}\right)}, if n\in G\\0, otherwise\end{array}\right.$ . | (7) |

In (7), $P$ is the desired percentage of CHs. For the number of clusters used in [2] (see Figs. 15, 16), $k=5$, and the total number of sensor nodes, $N=100$ (see Fig. 10), they are used in equation (11) in [2], the desired percentage $P=\frac{k}{N}=\frac{5}{100}=0.05$, as specified in Fig. 12, 5.1 Advertisement phase. For example if $r=225$ and $n\in G$, then $T\left(n\right)=\frac{0.05}{1-0.05∙\left(225 mod\frac{1}{0.05}\right)}=\frac{0.05}{1-0.05∙\left(225 mod 20\right)}=\frac{0.05}{1-0.05∙5}=\frac{0.05}{1-0.25}=\frac{0.05}{0.75}=0.67$

To make decision to be a CH, a node generates randomly a number from $[0,1]$ using pseudo-random number generator (PRNG), and if it is less than $T(n)$, it becomes a CH for the current round, and, not, otherwise.

### 4.3. Simulation of sensor networks from the energy consumption perspective

Each node at the beginning has full battery with energy specified by initial node energy parameter in Fig. 5. In each round, the nodes consume energy defined by (4) for CH and CM, $ECHR$ and $ECMR$, respectively. Thus, in every round, energy of each node decreases by $ECHR$ or $ECMR$. A node dies if its energy drops to zero.

## What is to be done?

The aim of the project is to develop a software product allowing a registered user to specify system parameters (see Figs. 9-11), conduct simulations, and output their results in numerical and graphical forms. Settings and results for a registered user can be saved, and retrieved later. For a guest user, limited simulations facilities are provided (e.g., limited number of nodes, clusters, rounds, etc.; limited area; absence of permanent data keeping). Allocation of resources for keeping data, and responding requests of the users is responsibility of a system administrator.

## References

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