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# ECOSENSE: An Energy Consumption Protocol for Wireless Sensor Networks

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**Abstract**

This paper 'ECOSENSE' proposes a medium access protocol derived for wireless sensor networks. Energy is a precious resource for wireless sensor networks, as sensor nodes are powered by small batteries. Various approaches have been proposed so far, to increase the life of wireless sensor networks. With the goal of developing a practical, efficient energy consumption protocol for wireless sensor networks, we introduced a threshold policy for the nodes in the entire network, where the sensors are distributed activated, whenever they are required. We calculated the life period of sensors and using priority levels and threshold values, we prolong the lifespan of sensor nodes. Scheduling is done according to the remaining life period of sensor nodes. We compare our algorithm with the existing S-MAC protocol and found considerably better due to its reconfigurable activation policy.


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*Keywords:* TDMA, Energy consumption, S-MAC protocol, Reconfigurable architecture, Sensor activation and Threshold policy;

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## 1. INTRODUCTION

Sensor devices can be deployed in large numbers in different environments for data gathering purposes about a wide variety of applications. Sensor devices are cheap and as well as unreliable. They are limited by battery energy. Medium Access Control (MAC) is an important technique that enables the operation of wireless sensor network [15]. Our aim is to design a good MAC protocol which overcomes the existing focus problems such as Collision, over hearing, Control Packet Overhead and idle listening. These problems can be overcome through proper sleeping schedules, periodic exchange of SYNC packets, RTS/CTS packet exchanges and message passing.
The greatest current challenge in wireless sensor networks consists in building a completely adaptive network without fixed infrastructures and with the smallest energy resources [1, 16, 17, 18]. Applications built upon such networks are various: from telemetry to medical follow-up and from intrusion detection to infrastructure maintenance. Nevertheless, their design requires a large effort to guarantee quasi unlimited lifespan as far as energy is concerned. In this work, we used Markov chain based model for estimating the power consumption of a wireless sensor network using CSMA/CA access protocol and suggesting a reconfiguration activation policy to reduce power consumption in distributed Wireless sensor networks. We know the sources of energy wastes and the ways to reduce the energy waste through the existing protocols. We want to devise ECOSENSE, a new sensor network protocol for energy conservation to lead the life of sensor nodes.

The remainder of the paper is scheduled as follows. Section II defines the issues in S-Mac. Section III describes our approach of ECOSENSE. Section IV describes the threshold activation policy and Section V describes network lifetime and sample outputs

**Nomenclature**

| | |
|---|---|
| ECOSENSE | Energy Consumption Protocol for Wireless Sensor Networks |
| S-MAC | Sensor- Medium Access Control |
| $AP_{1, 2, 3}$ | Access Point |
| $S_{1, 2, 3\ldots15}$ | Sensors |
| RTS | Ready To Send |
| CTS | Clear To Send |
| TDMA | Time Division Multiple Access |
| TRAMA | TRaffic Adaptive Medium Access |
| TDM | Time Division Multiplexing antenna |
| MAC | Medium Access Control |

## 2. Issues in S-MAC

Three major energy wastage events occurring at a conventional MAC layer have been identified:

- Collision results in energy wastage due to retransmissions of collided packets.
- Overhearing occurs when a node listens to transmissions not intended for it, needlessly wasting power.
- Idle listening occurs when nodes listen in the hope of receiving any possible data, also wasting energy.

Since the power consumed by nodes in idle, receive and transmit states are on the same order of magnitude, the power wastage caused by overhearing and idle listening is no less serious than that of collisions. The main idea of S-MAC [9] is to put nodes to sleep from time to time to reduce energy wastage caused by the above events. A node goes to sleep periodically if it is not engaged in transmission or reception, to reduce idle listening. It also goes to sleep if its neighbours are involved in communication, of which it is not a party, to reduce collision and overhearing in figure 1 [9]

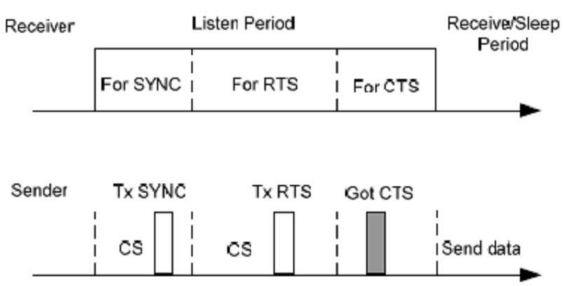

Fig 1. Node Transmission Cycle

A cycle in S-MAC consists of a listen and a sleep state. A node normally follows predetermined schedules to wake up or go to sleep with the following exceptions:

- A node goes to sleep if any of its neighbors are communicating, and the node is not a party.
- A node wakes up at the end of its neighbor's transmission if it needs to relay the packet.

Schedules are periodically exchanged by broadcasting SYNC packets among neighbouring nodes to induce synchronized listen behaviour as much as possible and thus to reduce latency caused by sleeping. Synchronized neighbours form a *virtual cluster*, but synchronization can only be achieved to a certain extent in an ad hoc environment. Lack of complete synchronization introduces sleep delay which results in increased packet latency.

An important feature of S-MAC is the concept of message-passing where long messages are divided into frames and sent in a burst. With this technique, one may achieve energy savings by minimizing communication overhead at the expense of unfairness in medium access. Periodic sleep may result in high latency especially for multi-hop routing algorithms, since all immediate nodes have their own sleep schedules. The latency caused by periodic sleeping is called sleep delay. Adaptive listening technique is proposed to improve the sleep delay, and thus the overall latency. In that technique, the node who overhears its neighbor's transmissions wakes up for a short time at the end of the transmission. Hence, if the node is the next-hop node, its neighbor could pass data immediately. The end of the transmissions is known by the duration field of RTS/CTS packets.

The energy waste caused by idle listening is reduced by sleep schedules. In addition to its implementation implicitly, time synchronization overhead may be prevented with sleep schedule announcements. Broadcast data packets do not use RTS/CTS which increases collision probability. Adaptive listening incurs overhearing or idle listening if the packet is not destined to the listening node. Sleep and listen periods are predefined and constant, which decreases the efficiency of the algorithm under variable traffic load. In-network processing is critical to sensor network lifetime. Since sensor networks are committed to one or a few applications, application-specific code can be distributed through the network and activated when necessary or distributed on-demand. Techniques such as data aggregation can reduce traffic, while collaborative signal processing can reduce traffic and improve sensing quality. In-network processing implies that data will be processed as whole messages at a time in store-and forward fashion, so packet or fragment-level interleaving from multiple sources only increases overall latency [7]. Finally, we expect that applications will have long idle periods and can tolerate some latency. In sensor networks, the application such as surveillance or monitoring will be vigilant for long periods of time, but largely inactive until something is detected. For such applications, network lifetime is critical. These classes of applications can often also tolerate some additional latency. For example, the speed of the sensed object places a bound on how rapidly the network must detect an object

## 3. **PROPOSED APPROACH**

We want to introduce a new threshold policy which will considerably reduce power and increase the lifespan of wireless sensor networks. Access Point maintaining 5 sensor nodes is shown in the figure 2. Here the transmitted power from Access Point to all sensor nodes will be equal, but receiving power is different.

**Number of nodes = Number of nodes the cell can accommodate α volume of cell.**

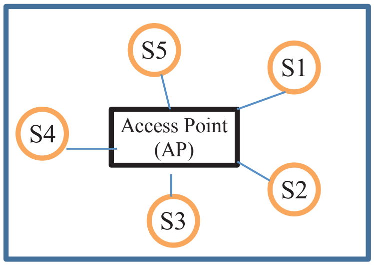


Fig 2. An Access Point and Associated Sensor Nodes

Consider an area with 15 sensors and 3 Access Points, Shown in figure 3, where each Access Point is connecting 5 sensors. Here the maintenance of sensors with Access Points will be discussed whenever topology change occurs.

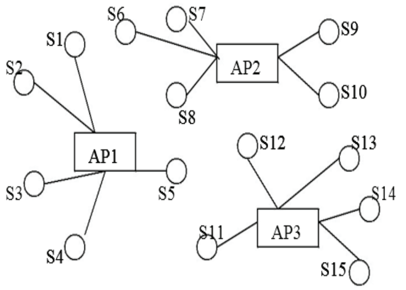


Fig 3. Initial position of sensors and Access Point

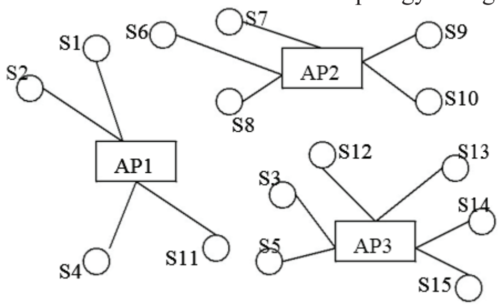


Fig 4. Position of sensors when topology change occurs

Sensor nodes may move from one Access Point to another Access Point whenever topology change occurs. By the movement of sensor nodes, the distance between source and sink may be decreased. Suppose sensor nodes s3 and s5 moved into the area of Access Point AP3 from AP1, and s11 moved to AP1. Then the distance between s1 and s11 is less compared to the initial position. Here the hop distance between s1 and s11 is 1 and the cost is 3,as in figure 4.

After changing the positions of sensors the hop distance is decreased to 1 and the cost is based on hop distance.

Since the entire network is shrinked, the nodes come closer and according to the size of the network, the following network parameters will be modified:

- Transmission Power needed is less
- Number of intermediate nodes will decrease
- Inter node distance is less
- Energy usage for transmission and reception -is less

### *3.1. Schema of ECOSENSE*

This is an Energy Efficient and Delay Aware MAC protocol. The main objective of ECOSENSE is:

- Energy efficiency
- Latency reduction

Energy efficiency will occur by shrinking the network of nodes very closer using reconfigurable policy. Latency aware will be achieved using load balancing with duty cycle. Sensor networks have two characteristics. First, the nodes periodically generate data for transfer to a distinguished node called the ‘Access point’. Second, the nodes are power and energy limited but access points are not operated through minimal power and using timer mechanisms to on and off the sensors based on their operating needs. For these type of networks, ECOSENSE protocol is proposed. This protocol uses low-powered access point to synchronize the nodes and to schedule their transmissions and receptions in a TDM manner. Access Point will gather topology information and announces the transmission schedule to the other nodes. The scheduling algorithm will minimize the delay considerably. S-MAC operates on duty cycle and

TRAMA protocol operates on load balancing. Our ECOSENCE protocol overcomes the delay by combining the features of load balancing and duty cycle. It also overcomes the space requirements through a reconfigurable architecture which adapts itself, in terms of software adaptation whenever topology change occurs. By that the intermediate node distance will be less or the number of intermediate nodes is less. So energy usage is less and efficient. The location based ECOSENSE performs better as an energy efficient protocol. RS codes and BCH codes are used for normalization.

Energy efficiency has been widely recognized as a key issue. It incorporates lot of challenges in wireless sensor networks. Many sensor platforms now allow their many components such as CPU, radio, and the sensor to work in many operating modes. There is lot of reasons why the lifetime of the sensor nodes have not been increased beyond a certain level.

They are

- Specialized sensors can be energy consuming. (from 60 mW to 375 mW )
- Even with common CPU and radio sensors loose energy, if they are not well managed.
- Idle energy consumption is also considerable.

In networks where ``interesting" events happen infrequently, an effective way of saving power is to turn nodes off when they are not needed. A sensor network is completely asleep during the long lulls in activity. When something does happen, only a limited zone of the network that is close to the event is kept in its fully active state. The active zone (See figure 5) should be centered at the current location of a target phenomenon that is being tracked; the zone should move through the network along with the target. Nodes that are not within sensing range of the event are outside of the zone, and therefore do not waste energy on data acquisition or housekeeping tasks such as maintaining time synchronization. Optimally, the zone should move such that a phenomenon of interest is always kept inside of the zone. If the zone is circular, with its radius proportional to the speed of the object is known as the ``Frisbee" model [8].

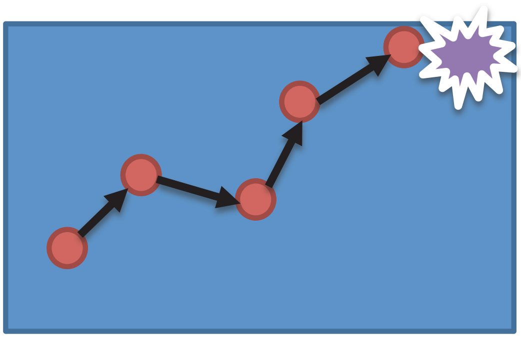

Fig 5: Example of an Active Zone

To implement an energy efficient MAC [1] we require:

- A low-power operating mode with wakeup: Access Point must always be vigilant; others must have a way of saving power such that they can be awakened by an external stimulus; and
- Sensors must use localized algorithms so that nodes can autonomously reconfigure the topology for energy reduction.

To obtain energy efficiency [1] in wireless sensor networks the communication factors are dealt below

*3.1.1. Energy Efficiency*

1. Minimized transmitted radio frequency power is the key.
2. To need this, the receiver has required Signal-to-Noise ratio below which can’t operate reliably.
3. Minimum Eo/No, where

   Eo – Required minimum energy per bit at the receiver

No - Noise power spectral density

4. $\frac{S}{N} = \frac{RE_b}{N_0}$

$= \frac{\eta E_b}{N_0}$

where R - Information rate or throughput in bps, B - Signal bandwidth, η - Ratio of information rate to bandwidth = spectral efficiency

5. Signal noise N – expressed as proportional to thermal noise and the signal bandwidth B, as

**N = mKTB**

where m – Noise proportionality constant, K – Boltzmen constant, T – Absolute temperature in K For Ideal receiver,

**RNF = 0dB = proportionally constant m = 1**

where RNF is Receiver Noise Figure

6. Received signal power $S_{RX}$ = S at a distance d km the transmitting source can be expressed in free space using the Friis transmission formula, Assume Omni directional antenna and no interference or obstacles.

$$S_{RX} = \left(\frac{1}{4\pi d^2}\right)\left(\frac{\lambda^2}{4\pi}\right)P_{TX}$$

Where λ = Transmitted wavelength = c/f $P_{TX}$ = Transmitted power

*3.1.2. SIGNAL STRENGTH and PATH LOSS COMPONENTS*

1. Assume the distance between sensors is 1 meter.(which places both corresponding antennas between the receiver and transmitter in far-field region)
2. $P_L$ – is the path loss, which is the loss in signal power at a distance d due to attenuation of the field strength.
3. $P_L(d) = P_L(d_0) + 10n\ log_{10}\left(\frac{d}{d_0}\right)$ where n = 2
4. This equation is generalized to include other values of n, which better fit the measured attenuation of environments and which are more cluttered or confined in the free space assumption
   n = Mean path loss component (n=2 for free space) do= reference distance = 1m
   d= transmitter-receiver separation (m) and the reference path loss at do is
   λ = The wavelength of the corresponding carrier frequency.
   $$P_L(d_0) = 20log_{10}\left(\frac{4\pi d_0}{\lambda}\right)$$
5. Minimum transmitted power without interference,
   $$P_{TX} = \left(\frac{S}{N}\right)N\left(\frac{4\pi d}{\lambda}\right)^2$$
   $$P_{TX} = \eta\left(\frac{Eb}{N_0}\right)mKTB\left(\frac{4\pi d}{\lambda}\right)^2$$
   $P_{TX}$ = η (Eb/ No) mKTB $(4\pi d/ \lambda)^2$
6. operation at higher frequency required higher transmit power.
7. Many transmission environments include significant obstacles and interference and have reduced Line-Of-Sight components.
8. Signal path loss or attenuation in these environments can be significantly greater than that in free space.

$$P_l(d) = \left(\frac{S_{RX}(d)}{P_{TX}}\right) = \left(\frac{4\pi d}{\lambda}\right)^2$$

$P_L$ is a path loss , which is the loss in signal power at a distance d, due to attenuation of field strength.

9. Minimizing transmitted power is considered to be the most critical parameter for a low power Wireless Sensor Network, whose battery life time is dependent on power consumption.
10. In a low power Wireless Sensor Network scenario transmitting with as much power as possible, up to regulatory limits, is not derivable.
11. Rather transmitting with as little power as possible, so as to extend sensor battery life, while maintaining a minimum required Signal-to-Noise ratio.
12. Deep-space satellite scenario, a low power Wireless Sensor Network is far more power constrained than bandwidth constrained.
13. To achieve power efficiency, we have to sacrifice spectral efficiency.

## 4. THRESHOLD ACTIVATION POLICY

A Threshold activation policy [2] for sensor node with parameter m is characterized.

1. A ready sensor s is activated, if the number of active sensors does not exceed m, after s is activated.
2. Otherwise, s is kept in the ready state.
3. A Threshold policy with parameter m tries to maintain the number of active sensors as close to m as possible.

Prefer queuing model for prioritization

4. The number of active sensors can never exceed m, and there can't be any ready sensors in the system, when the number of active sensors is less than m.
5. An active sensor report data on a regular basis or the date reporting is so infrequent that most of the energy expenditure occurs in sensing and processing.
6. Active sensors with all get discharged at the sense rate. Therefore, the system is better modelled with correlated discharge times.

Independent and Correlated recharge times:

- If the sensors are located close to one another, the recharge processes at different sensors are expected to the highly correlated.
- Otherwise, if the sensors are not closely located, then the system may be better modelled with independent recharge times.

### *4.1. Ecosense The scheduling algorithm*

1. At each Access Point note the interference from the neighbouring cells.
2. Recall that the Access Points assigned the same threshold to transmit their coordination packet does not have any interfering transmission at the sensor nodes.
3. The Access Points assigned to different threshold levels corresponds to the heterogeneous network.
4. The access point schedules the slots according to the network information and broadcast this information to sensor nodes and neighbouring Access Points.
5. Neighbouring Access Points should choose the next threshold level which is not a frequency slot of interferences.
6. The Access Points corresponding to each threshold level consider the schedules of the sensor nodes and allot slots accordingly.

Let the maximum number of sensor nodes used in connecting the linear network corresponding to each Access Point be n. If the heterogeneous network of an Access Point uses less number of threshold levels then all nodes except possibly common nodes inside the network sleep during the remaining slots. Since the network connected to an Access Point may have to wait for the scheduling of the common nodes if the rest of the nodes at the same level interfere with these nodes. The maximum number of the extra slots included for the neighbouring Access Points is the total number of packets that must be forwarded by these common nodes times the number of threshold levels.

Let us call the number of these packets x. Then the maximum duration for the total schedule length for an AP is $\alpha(|V|+x-1)$. Since the value of x only depends on the neighbouring Access Points

## 5. NETWORK LIFETIME

5.1. *Duty cycle Adaptation*:

Generally, the node with less energy should sleep more in order to balance the energy level of each node. To calculate the duty cycle [10], take both the remaining energy level and the remaining lifetime.

Let $T_{conf}$ and $T_{elap}$ denote the pre-configured network lifetime and elapsed time, respectively. Then, the ratio of $T_{elap}$ to $T_{conf}$ represents the ideal energy consumption rate, because if a node consumes the energy in that rate the node will die exactly at the end of the required lifetime. However, the traffic load is different among nodes and varies over time. So, fixing the same energy consumption rate for each node is not possible. Therefore, we choose to adjust the duty cycles of sensor nodes dynamically, which can make a sensor node consume its energy approximately at the ideal consumption rate.

*5.2. Synchronization*

In addition to the fields in the original SYNC message, we need two more fields:

- the timestamp of transmission time
- next starting time of the minimum duty cycle schedule

The timestamp of SYNC transmission time is used to correct clock skews among the nodes. The next starting time of the minimum duty cycle schedule is used to synchronize the starting time of each node's super frame. When a node changes its duty cycle, it starts a new super frame in the beginning of the next super frame of the minimum duty cycle. Without super frame synchronization [10], two nodes may not communicate with each other because if the starting times of the two schedules are different, they cannot receive the SYNC messages from each other. If the synchronizers of two nodes are equal, they will awake simultaneously at least once during the period of the minimum duty cycle.

*5.3. Calculating the Life Period of Sensor Nodes*

1. Find out the age of sensor nodes.
2. Assign priority levels and Threshold levels for sensor nodes.
3. Whenever sensor nodes using its energy, calculate the energy usage by using the formula

   **$E= \alpha.E_0 + (1-\alpha).Es$ Where E= Energy Usage**

   $\alpha$= Duty cycle of operation

   $E_0$= Energy usage in active operation Es= Energy usage in standby mode
4. Apply the load balancing and scheduling algorithms.
5. Based on the load prioritize the sensor nodes.
6. If the Priority level is greater than the Threshold level, choose the sensor to activate.
7. Otherwise, choose the priority of the next sensor.
8. Calculate the activation energy and repeat the process from step3.

Short range radio propagation is quite good for small distances about 3m. Packets are occasionally received about twice the distance.

Any point event E can be detected if and only if there is a sensor that lies with in the circle of radius r of the event. The probability that there are m sensors that can detect as arbitrary point event is

*P (m detecting sensors) =[ (λπr2)me -λπr2] / m!*

The average portion of time that the sensor spends in sleep state is denoted by p. that is the duty cycle is 1-p. P alternatively is also the long term percentage of sensors that are in sleep state in the network, called the sleep sensor ratio.

### 5.4. *ECOSENSE The Output Mechanism*

1. Based on the initial position of sensors, access point will be placed.
2. Access Points have to share the topology so that equal number of node allotment can be done per each Access Point.
3. When dynamically node started roaming, the topology changes.
4. All nodes which are connected to Access Point are initialized to make data transfer among themselves. (Sensor senses the information, if any event occurs. In case, any other node request the same information, the sensor must be ready to send the information based on the load balancing in minimum cost path)
5. Calculate the duty cycle.
6. Calculate the load balancing.
7. Maintain the location information of the intermediate nodes.
8. Routing table information.
9. Find out the shortest distance between source and destination using minimum cost path algorithm with minimum interference.

Then

- Energy savings during active period
- Energy savings during sleep period
- Energy savings through optimal scheduling and load balancing technique

When more than one node want to communicate with the same destination at the same slot, collision will occur. To avoid this we have assigned priority levels for the sensors based on the load.

### *5.5. Identify The Load*

The load of a sensor will be identified by counting the number of incoming packets and outgoing packets. Also depends on the time that the sensor will be active. Since the sending energy is greater than the receiving energy, only the number of outgoing packets is taken into consideration. For that a queuing model is proposed here. A counter will be maintained at each node to count the number of packets. The nodes which has less load will be given highest priority, See figure 6 .

If the priority level is greater than threshold level, the sensor will be activated.

Threshold levels are:

0 Passive state
1 Ready state
2 Active state

Priority levels are: 1 and 2

| Threshold level | Priority level | Status |
|---|---|---|
| 0 | 1 | Active |
| 1 | 2 | Active |
| 2 | 1 or 2 | Remains in same state |

Fig 6. Threshold and priority level combination values

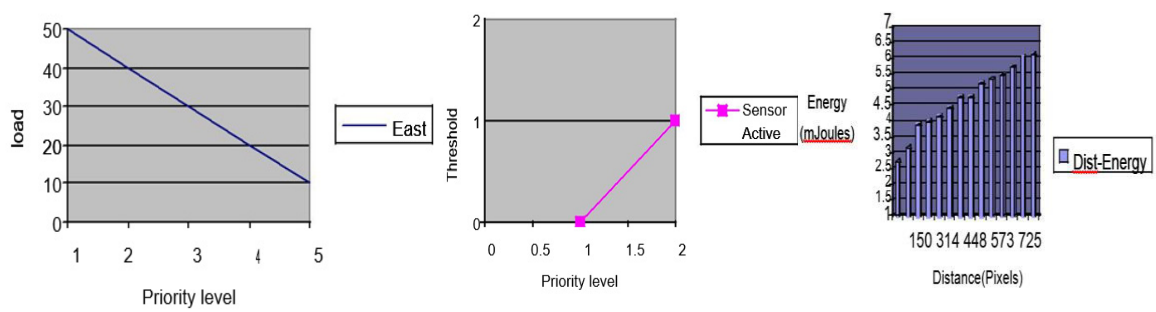


Fig 7.a) Graph between Load and Priority levels b) Graph between Threshold and priority level combination c) Performance curve

for Energy vs Distance

Table 1.a) from Source node s1 to s12 destination node packet transfer values and b) from Source node s12 to destination node s1 packet transfer values

| SOURCE | DESTINATION | DISTANCE | ENERGY |
|---|---|---|---|
| S1(150,70) | S12(900,70) | 750 | 6.12 |
| S1(150,70) | S12(850,260) | 725.32 | 6.02 |
| S1(150,70) | S12(600,540) | 650.69 | 5.70 |
| S1(150,70) | S12(750,70) | 600 | 5.47 |
| S1(150,70) | S12(650,350) | 573.06 | 5.35 |
| S1(150,70) | S12(400,540) | 532.35 | 5.16 |
| S1(150,70) | S12(600,70) | 450 | 4.74 |
| S1(150,70) | S12(500,350) | 448.21 | 4.73 |
| S1(150,70) | S12(650,260) | 442.83 | 4.43 |
| S1(150,70) | S12(350,350) | 344.09 | 4.14 |
| S1(150,70) | S12(400,260) | 314 | 3.96 |
| S1(150,70) | S12(450,70) | 300 | 3.87 |
| S1(150,70) | S12(200,260) | 196.46 | 3.13 |
| S1(150,70) | S12(300,70) | 150 | 2.74 |

| SOURCE | DESTINATION | DISTANCE | ENERGY |
|---|---|---|---|
| S12(500,350) | S1(400,260) | 134.53 | 2.59 |
| S12(500,350) | S1(350,350) | 150 | 2.74 |
| S12(500,350) | S1(650,350) | 150 | 2.74 |
| S12(500,350) | S1(650,260) | 174.92 | 2.95 |
| S12(500,350) | S1(400,540) | 214.70 | 3.27 |
| S12(500,350) | S1(600,540) | 214.70 | 3.27 |
| S12(500,350) | S1(450,70) | 284.42 | 3.77 |
| S12(500,350) | S1(600,70) | 297.32 | 3.85 |
| S12(500,350) | S1(200,260) | 313.20 | 3.95 |
| S12(500,350) | S1(300,70) | 344.09 | 4.14 |
| S12(500,350) | S1(850,260) | 361.38 | 4.25 |
| S12(500,350) | S1(750,70) | 375.36 | 4.33 |
| S12(500,350) | S1(150,70) | 448.21 | 4.73 |
| S12(500,350) | S1(900,70) | 486.26 | 4.94 |

Table1 a) contains measured values of energy and distance, this values are taken from packet transfer between the source node s1 and destination node s12. b) contains measured values of energy and distance, this values are taken from packet transfer between the source node s12 and destination node s1. In the both transmission energy usage measurement procedure given below.

## 6. CONCLUSION

The Ecosense protocol is implemented on two factors which were Energy consumption and Latency reduction. Energy consumption was achieved by location aware space reduction in dynamic movement of wireless sensors nodes. Latency reduction was achieved by proper load balancing and minimizing active duty cycle through threshold activation policy and implementing this through scheduling algorithms. Efficiency can be improved by properly combining both the factors in an optimized way.

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