Performance Evaluation of Proposed SEHEE-MAC for wireless Sensor Network in Habitat Monitoring

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Abstract—Environmental sensor networks have been a topic of significant research in recent years. Sensor network enables researchers to do continuous long term, autonomous sensing of many different aspects of environmental systems. They must be so energy efficient that they can remain in same situation with little human interaction and be maintenance-free for years together. Habitat monitoring, with its focus on dynamic interactions within and between a variety of scales is an ideal application of sensor network. Many protocols have been proposed for WSNs and have focused on extending the lifetime of sensor networks, WSNs powered by ambient energy harvesting are more useful and economical in the long-term because ambient energy may be harvested from the environment at all times. To improve the life time of WSN this work evaluate the performance of new proposed scheme-Solar Energy Harvesting Energy Efficient MAC (**SEHEE-MAC**). The SEHEE-MAC protocol controls the activities of Radio by using slotted preamble technique and obtains significant energy savings by allowing nodes to sleep for extended periods of time. The results are compared with ZigBee and Preamble protocols for solar harvesting sensor networks.

Index Terms—Habitat, MAC, Slotted Preamble, Solar, WSN

1 INTRODUCTION

Wireless adhoc network is a generic term grouping different networks, which are self organizing, meaning that there is neither a centralized administration nor a fixed network infrastructure, and communication links are wireless. Sensor network enables researchers to do continuous long term, autonomous sensing of many different aspects of environmental systems. Today, densely deployed sensor networks are being scaled to the size of the organisms under study, sampling phenomena at frequencies the organisms encounter, and isolated in patterns that capture the full range of environmental exposures to provide the fine-grain information needed for accurate modeling and prediction.

They must be unobtrusive yet durable under a range of environmental stresses, including damage caused by the organisms themselves. They must be so energy efficient that they can remain in same situation with little human interaction and be maintenance-free for years together. Several qualitative differences from traditional instrumentation make sensor networks attractive for habitat and environmental monitoring. [36] Increased power efficiency gives applications more flexibility in resolving fundamental design tradeoffs, e.g. between sampling rates and battery lifetimes. Low-power radios with well-designed protocol stacks allow generalized communications among network nodes, rather than simple point-to-point telemetry.

Habitat monitoring, with its focus on dynamic interactions within and between a variety of scales is an ideal application of sensor network because answering fundamental bio-complexity research questions on animal interaction on land-scapes that are changing in response to normal as well as anthropogenic requires large amount of diverse data, collected and correlated across large temporal and spatial scale.

Much of the research on sensor networks have focused on extending the lifetime of sensor networks which are assumed to rely on finite energy sources like batteries for power. In contrast, wireless sensor networks (WSNs) powered by ambient energy harvesting are more useful and economical in the long-term as they can operate for very long periods of time until hardware failure because ambient energy may be harvested from the environment at all times. However, as the rate of charging is usually much lower than the rate of energy consumption for the sensor nodes, proposed MAC (SEHEE-MAC) nodes can only be awake for a short period of time before it needs to shut down in order to recharge. Moreover, the time taken to charge up the sensor is not constant due to environmental factors. This work addresses this fact by proposing power controlling algorithm.

2 RELATED WORK

In the literature, many protocols have been proposed for WSNs. Most of them aim to achieve low energy consumption in transmitting packets between nodes. These protocols also have the goals of low delay and minimum packet loss.

In [1], Ye *et al.* proposed S-MAC for WSN. S-MAC uses a few novel techniques to reduce energy consumption and support self-configuration. First, nodes form *virtual clusters* based on common sleep schedules to reduce control overhead and ena-

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ble traffic adaptive wake-up. Second, S-MAC uses in-channel signaling to avoid overhearing unnecessary traffic. Finally, S-MAC applies *message passing* to reduce contention latency.

Ye *et al.* [2] introduced SCP-MAC, which uses *Scheduled Channel Polling* (SCP) to achieve more energy savings than other protocols that use coordinated transmissions and listen periods. The contributions of SCP-MAC are the ultra low duty cycles it achieves and its capability to adapt to variable traffic loads. Dam *et al.* [3] proposed T-MAC, a contention based MAC protocol for WSNs.

Lu *et al.* [4] proposed DMAC, a protocol whose objective is to achieve very low latency. Mainwaring *et al.* [5] provided an in-depth study of applying WSNs to real-world habitat monitoring. A set of system design requirements are developed that cover the hardware design of the nodes, the design of the sensor network, and the capabilities for remote data access and management.

The SEA-MAC [6], focused on reducing energy consumption in environmental monitoring applications. Compared to SMAC [1], SEA-MAC reduces the *duty cycle* (DC) of nodes, and thus lowers drastically idle listening. Miguel A. Erazo *et al*,[7] propose a new MAC protocol to achieve even lower energy consumption for periodic monitoring applications. This protocol takes advantage of the fact that the traffic pattern is periodic to achieve low energy consumption levels. This approach focuses on reducing packet delay and collisions. Zebra Net [8] uses PDA-level device with 802.11b wireless network. Great Duck Island [9] uses Berkeley mote, and watch ducks without disturbing them at low cost.

3 MAC Requirements of Habitat Monitoring

Habitat and environmental monitoring represent a class of sensor network applications with enormous potential benefits for scientific communities and society as whole. Such applications share a common structure, where field of sensors are tasked to take periodic reading and report the result and derived values to a central repository.

For Habitat monitoring following are the major requirements. [10]

1. Energy efficiency: The sensor nodes should not need refreshing of batteries for at least 6 months.

2. Remote querying and reconfigurability: It should be possible to query the data in several formats and to reconfigure the monitoring parameters via the Internet.

3. Ease of deployment: The user should be able to deploy the system without any need of special design.

4. Reliability: The provided data should be real-time and faithful. The system should be available 99% of the time and should recover from a crash quickly.

A very important parameter for Habitat monitoring is energy efficiency; it is prime task to design an energy efficient MAC protocol so as to enhance the life of network from few months to several years. A MAC protocol regulates access to the medium, to ensure that no two nodes are interfering with each other.

Habitat-monitoring applications consist of several software components implementing core system services. Because they require ways to specify and deliver data of interest, they need a routing and tasking service, current applications achieve this goal via duty cycling, or changing the amount of time the subsystem is active during any given period, at several levels. The percentage of time each node is awake is known as the node's duty cycle, and a variety of approaches are available for achieving low duty cycle operation. The research is going on to design energy efficient MAC protocols based on either schedule based technique or contention based technique, so as to prolong the life of network.

4 SEHEE-MAC Overview

In many real-time deployments we don't have enough accessibility of the sensors to change the batteries. Some studies have proposed very good solutions for effective utilization of the life of battery powered sensor nodes. The main challenge is life of the battery. The solutions to enlarge the life of the node is done by decreasing the power wasted by decreasing the duty cycle of the node and keep the node more in power saving mode and only be active when there is sensing is needed to be done.

Some proposals suggests changing the MAC protocol such that the by decreasing the overhead of packet, effectively decreasing packet size decreasing the possibility of energy consumption. These proposals have elongated the life of the node but still there is trade-off of between the accuracy of the data and the life of the node. One of the solutions to this problem is we need to gather the energy from the ambient resources and store it the rechargeable batteries and use them for the operations of the application.

Wireless sensor networks (WSNs) powered by ambient energy harvesting are more useful and economical because ambient energy may be harvested from the environment at all times. However, as the rate of charging is usually much lower than the rate of energy consumption for the sensor nodes, this work propose **Solar Energy Harvesting Energy Efficient MAC(SEHEE- MAC)** in which nodes can only be awake for a short period of time before it needs to shut down in order to recharge.

After studying all different models we have chosen solar energy as our interest for collection of energy. In fact, wireless sensor nodes, being mostly planned for outdoor long time operations, the solar one is generally the most effective in outdoor applications for the high power density provided and exploitable through solar cells. Using energy harvesting to supplement batteries does not eliminate the problem of having to replace the batteries when they run out. Combining low-power electronics, energy harvesting devices, and super capacitors, it is possible to implement WSNs that rely solely on energy harvesting to operate, i.e. WSN-HEAP. [12]

Since the rate of energy harvesting (≈1mW) is significantly lower than the rate of energy consumption (typically of the order of tens of mW), the harvested energy is continually stored in a rechargeable battery. To improve the life of network with efficient operation, together with the energy harvesting technique, in this proposed **SEHEE MAC,** instead of conventional preamble technique which may be used in many MAC protocol, for sleep-wake-up scheduling, slotted preamble technique is used.

5 ASSUMPTIONS FOR EXPERIMENT DESIGN

Following are the assumptions for designing.

- Selection of monitoring parameters: light, temperature, pressure, humidity
- Topology: We assume star topology and single hop transmission. Each patch has a sink node. Sink node collects all data and has an uplink connection for Internet connectivity. Every node must be in range of the sink node.
- Size of network: In total 100 nodes are used in single-hop network.
- Energy harvesting source: For the application under study we will be using solar energy harvester,
- Selection of Sensor nodes: In our deployment, we are proposing Telos, the latest wireless sensor device, designed and developed in the University of California, Berkeley, [11] Telos is an ultra-low power wireless sensor module for research and experimentation

Design of solar panel: For proposed work Telos node is selected for Habitat monitoring the panel size for this node is,
Solar panel size for Telos node (in^2) is 2.58 x 1.26

Sampling Frequency: Depending on sensing parameters and sensor, sampling frequency various from 2 Hz to 2 KHz.

6 SEHEE MAC DESIGN

A slotted Preamble technique:

To improve the life of network with efficient operation, together with the energy harvesting technique, in this we have proposed SEHEE MAC, instead of conventional preamble technique for sleep-wake-up scheduling, slotted preamble technique is used.

The MAC protocol is designed to run on top of the 802.15.4 PHYSICAL layer **SEHEE-MAC** -MAC reduces the power consumption by switching the mode of operation of node as per the status of energy level at regular intervals. To send a packet, initially, node would go into the carrier sensing state to determine whether the channel is free. If the channel is free a node broadcasts a train of tiny preamble packets. The tiny preamble packet train is long enough to allow all nearby devices to be switched on at least once. After receiving a tiny preamble packet, a node turns on its radio in preparation of receiving a full packet. As an optimization for unicast packets; the tiny preamble packets include the address of the receiver of the full packet. When receiving a tiny preamble, a target receiver (sink) immediately sends a short acknowledgment packet. The sender can then immediately send its full packet. Other nodes that happen to overhear the tiny preamble packets can turn off their radios until the full packet has been transmitted. The flow chart shown in Figure: 1 elaborate the working of proposed MAC.

The definition and default values of parameters used for computation are listed in table (I)

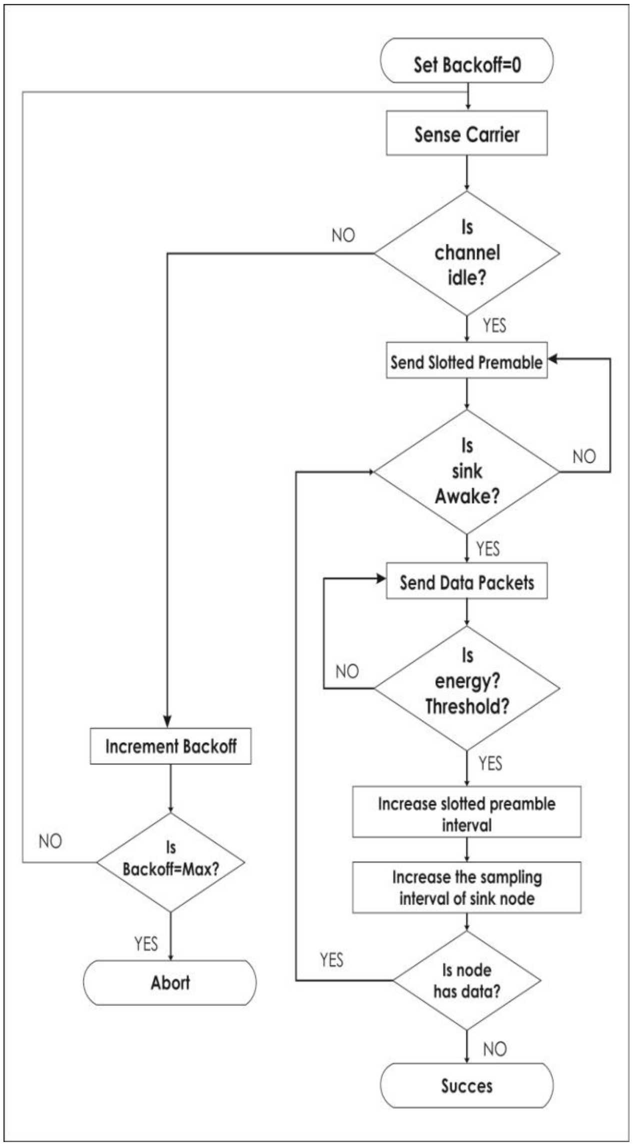

FIG. 1. FLOW CHART FOR SEHEE-MAC

7 ANALYTICAL COMPUTATION DETAILS

This analysis focuses on energy required for sending packets with variable traffic, and variable node density considering only battery power as well as battery power together with solar power. This analysis also focuses on finding life of node required for transmitting packets with and without solar energy.

Let P_{Tx}, P_{Rx} and P_{sleep} be the power required to transmit, receive, and sleep respectively. T_t, T_{data}, T_{ack} , T_{sp}, T_{ta} , P_c and k denote the duration of setup, the sender's data (packet body) , acknowledgement listen, mini preamble period, turnaround time, an average power generated from solar and number of tiny-slots transmission periods t_s and T_{sleep} be the wake-up and sleep period of receiver. $P_{tr\text{-}sleep}$, $P_{\mu c\text{-}sleep}$, and P_{other} are power consumption of the RF transceiver, microcontroller and other components in sleep mode.

$$P_{sleep}=P_{tr\text{-}sleep}+P_{\mu c\text{-}sleep}+ P_{other}. \quad (1)$$

The two sets of computations performed one for constant node density and variable traffic and other with constant traffic and variable node density.

For set one node density = 10, Traffic $\lambda = 10^{-5}$ to 1 packets/sec and for set two constant traffic

$\lambda = 10^{-2}$ and node density N = 1 to 100.

Both the sets of computations are computed for powering the node with only battery and battery plus solar.

A) The expected energy to transmit data packet and number of days i.e. life of node without solar energy and with variable traffic:

If P_{TX} is power required for radio in transmit mode, T_{ta}, T_{data}, T_{ack} and T_{CAP} are time required to switch transceiver mode, data and acknowledgement transmission and contention access period, T_t, T_{sp}, P_{RX} are set up time, slotted preamble time and power required in receiving data ,then sending energy is given by

$$Es = P_{Tx} \times (T_{CAP} + T_t + T_{data} + T_{ta} + K \times T_{SP}) + P_{RX} \times (T_{ta} + T_{ack}) \quad (2)$$

If we assume arrival rate of data as λ then the energy consumption per packet is

$$E_{SP} = E_S \times \lambda \times N \quad (3)$$

If a 3V battery with 1000 mAh is assumed, the battery lifetime and hence life of node in number of days is,

$$Ds_1 = Conversion\ facor\ for\ days\ (Battery)\ /Es \quad (4)$$

B) The energy to transmit data packet and life of node with solar energy and with variable traffic:

With reference to figure 2, let E_b be battery energy, P_c be power during charging and E_t total energy.

With the availability of solar power requirement of battery power will be less. With this concept energy required for node to send a packet is,

$$Es = P_{Tx} \times (T_{CAP} + T_t + T_{data} + T_{ta} + K \times T_{MP}) + P_{RX} \quad (5)$$

Energy consumption of the devices per packet for poisons arrival rate λ with solar and battery power is,

$$E_{SP} = E_{SP} \times \lambda \times N \quad (6)$$

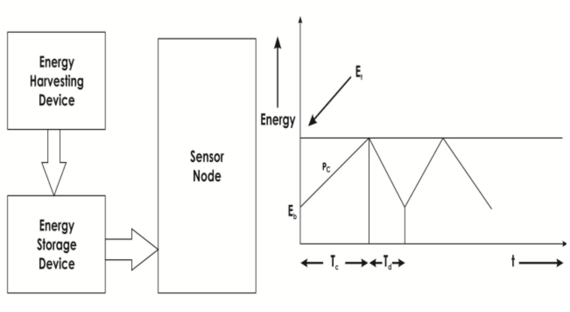

FIG. 2. COMPONENTS AND ENERGY MODEL

If a 3V battery with 1000 mAh is assumed, the battery lifetime and hence life of node in number of days with solar energy is,

$$Ds_1 = Conversion\ facor\ (Battery + Solar)\ /Es$$

8 PERFORMANCE OF SEHEE-MAC

The performance of proposed MAC is carried out for habitat monitoring using Telos node. Figure: 3 and Figure 4 shows transmission energy required in case of SEHEE-MAC with battery and node supplemented by solar panel and life of node respectively.

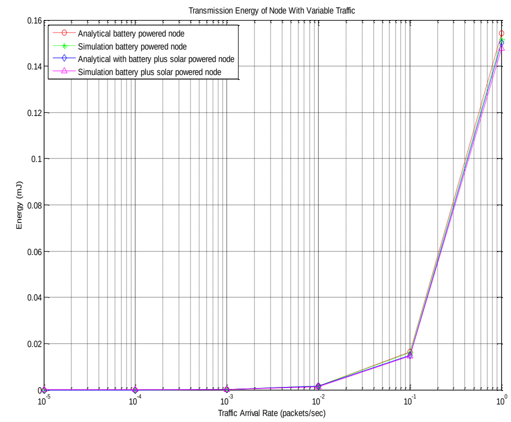

FIG. 3. EVALUATION OF SEHEE-MAC SIMULATION AND ANALYTICAL MODE.

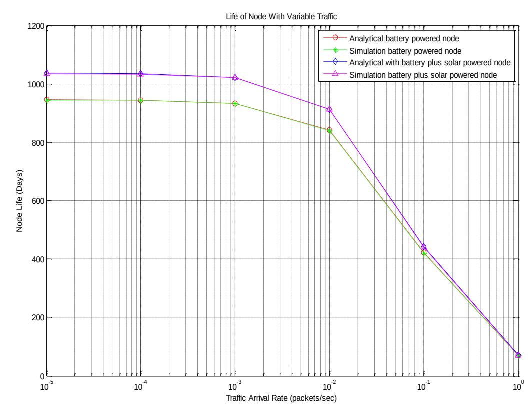

FIG. 4. LIFE OF NODE WITH VARIABLE TRAFFIC.

To verify the performance of proposed MAC, we have conducted the experiment by varying the number of nodes.

9 COMPARISON WITH EXISTING PROTOCOLS

To defend the applicability of the proposed SEHEE-MAC, we have weighed the performance against most suitable and popular medium access control algorithms such as ZigBee and preamble MAC.

Fig: 5 shows the comparison of energy required for transmission of packet by the node at different arrival rate. It is observed that the proposed MAC needs least amount of energy for transmission which is less by 1440 times than ZigBee and 2060 times than preamble MAC. This saving is achieved by design of SEHEE-MAC based on slotted Preamble wake-up technique

Fig: 6 demonstrates the comparison of proposed MAC with ZigBee and preamble MAC for life of node with variable traffic. From the figure we observe that for very low traffic preamble MAC is better than ZigBee, but for moderate to heavy traffic ZigBee is better than preamble MAC. Whereas, the proposed SEHEE-MAC out performs both the ZigBee and preamble MAC by 60% and 70%.

The performance is checked for all these three MACs when the node is supplemented by the solar energy. It is observed that solar energy will give 8.7 % increase in life at low traffic, for a traffic of 10^{-2} the 8. % improvement in node life and even at high traffic condition the (10^{-1}) it is 4.7 %. For the traffic of 1 packet per second the life is almost equal to ZigBee, but it out performs the preamble.

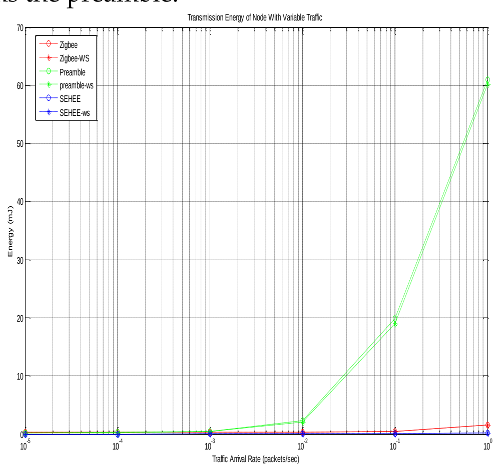

FIG. 5. COMPARISON OF ENERGY REQUIRED FOR TRANSMISSION WITH VARIABLE TRAFFIC.

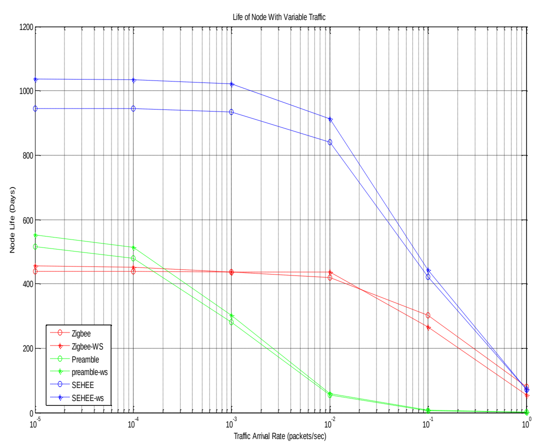

FIG. 6. LIFE OF NODE FOR VARIABLE TRAFFIC

Figure : 7 shows the transmission energy requirements for three MACs in comparison. It is observed that for variable node density the energy requirement of proposed MAC is the least and is less by 514 times in comparison with preamble MAC and 180 times in comparison with ZigBee MAC.

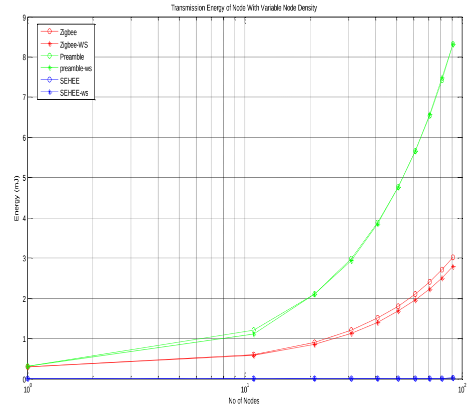

FIG. 7. COMPARISON OF TRANSMISSION ENERGY FOR NODE DENSITY.

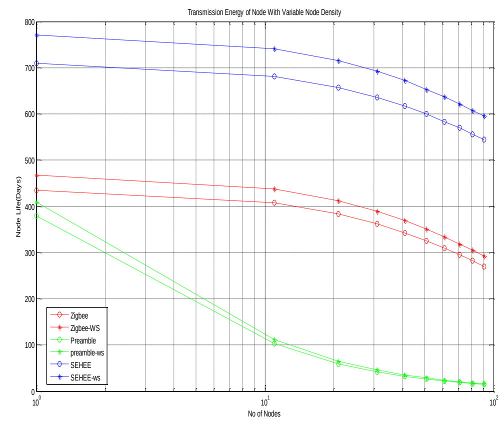

FIG. 8. COMPARISON OF PROPOSED MAC FOR VARIABLE DENSITY VERSUS LIFE OF NODE.

Figure 8 shows the comparison ZigBee, preamble MAC and proposed MAC for variable density against life of node in days. For variable node density ZigBee is better than preamble MAC at traffic of 10^{-2} packets per second. The proposed SEHEE-MAC surpasses both the MACs in consideration. Further the test was conducted to check the performance with solar panel supplementing the battery. It is found that there is rise in life of node by 303 days as compared to ZigBee for a node density of 50.

10 CONCLUDING REMARKS

This research develops a new energy-efficient MAC protocol to extend network lifetime and monitoring capabilities. In later part of this work, energy harvesting opportunities have also been exploited to further extend the life of network. This is done by powering the node with solar power harvesting devices. Designed for energy efficiency, SEHEE-MAC dramatically improves the network lifetime and energy consumption per node.

It is clearly observed from the above graphs that the proposed SEHEE MAC protocol possesses a substantial edge over the other two protocols in terms of energy consumption and life time of a node and the network.

TABLE 1
PARAMETERS OF THE SEHEE MAC FOR HABITAT MONITORING

Parameter	Description	Value
P_{TX}	power consumption of Radio in Tx mode	58mw
T_t	setup time of rf from sleep to awake	1.1ms
P_{sleep}	Power consumption in sleep mode	30µw
P_{RX}	power consumption of Radio in Rx mode	65mw
T_{data}	Time required for data packet	1.856ms
T_{ack}	Time for acknowledgement	0.288ms
T_{ta}	turn around time from TX-RX OR RX-TX	2.2ms
Data_Rata	Data rate	250kbps
$B_{capacity}$	Capacity of the battery	1000 mAh
Pc	Charging rate	
T_{sample}	Time for sampling the channel	2.08ms
Tc	Charging time of capacitor	
T_{SP}	Time of sotte préambule	100ms

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