EML-MAC: A SIMPLIFIED TIME SLOT SYNCHRONIZATION ALGORITHM FOR WIRELESS SENSOR NETWORKS

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EML-MAC: A SIMPLIFIED TIME SLOT SYNCHRONIZATION ALGORITHM FOR WIRELESS SENSOR NETWORKS

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LIST OF ABBREVIATIONS

Ack	Acknowledge
AMTA	Adaptive Multi-Timeslot Allocation
BM	Beacon Message
CM	Control Message
CR	Communication Request
CS	Carrier Sense
CSMA/CD	Carrier Sense Multiple Access with Collusion Detection
CTS	Clear-To-Send
DM	Data Message
eL-MAC	enhanced Lightweight Medium Access Control
E-MAC	Eyes Medium Access Control
GTS	Global Time Synchronization
L-MAC	Lightweight Medium Access Control
MAC	Medium Access Control
ML-MAC	Mobile Lightweight Medium Access Control
NP-hard	Non-deterministic Polynomial-time hard
PL	Physical Layer
RTS	Request-To-Send
Rx	Reception
SB-MAC	Slotted Beaconless Medium Access Control
S-MAC	Simple Medium Access Control
STS	Slotted Time Synchronization

TC	Traffic Control
TDMA	Time Division Multiple Access
TSS	Time Slot Synchronization
Tx	Transmit
WSN	Wireless Sensor Network

EML-MAC: SUATU ALGORITMA PENYELARASAN SLOT MASA YANG DIPERMUDAHKAN UNTUK RANGKAIAN PENDERIA TANPA WAYAR

ABSTRAK

Rangkaian Penderia Tanpa Wayar (WSN) merupakan satu teknologi yang pesat berkembang, yang banyak digunakan untuk pelbagai aplikasi seperti ramalan cuaca, pemantauan persekitaran, penjejakan sasaran dan aplikasi ketenteraan. Memandangkan nod WSN banyak digunakan di luar, ianya banyak bergantung pada bekalan bateri dalaman. Kekangan ini memaksa para penyelidik mencari beberapa cara untuk mengurangkan pengunaan tenaga oleh nod-nod ini. Objektif tesis ini ialah untuk memperbaiki keefisienan tenaga bagi nod-nod rangkaian penderia tanpa wayar dan melanjutkan jangka hayat bateri dengan mengubah suai algoritma penyelarasan slot masa. Tesis ini mencadangkan protokol Kawalan Capaian Medium Ringan Bergerak yang Dipertingkatkan (EML-MAC), yang mempunyai algoritma penugasan slot teragih yang lebih mantap dan menyeluruh. Ciri ini mampu menangani masalah penugasan slot pendua, yang wujud dalam protokol MAC sebelum ini. Lagipun, protokol ini mampu berfungsi tanpa memerlukan nod-nod khas, yakni koordinator, sink atau get laluan untuk memulakan atau menguruskan proses penugasan slot. Menurut kaputusan-keputusan simulasi yang diperoleh dalam tesis ini, EML-MAC mampu mengurangkan pengunaan tenaga sebanyak 20% jika dibandingkan dengan protokol L-MAC. Tambahan lagi, purata masa yang diperlukan untuk menyelaraskan 17 nod yang berada dalam satu kawasan adalah lebih kurang 2 saat. Daya pemprosesan data juga bertambah sebanyak 1.2 % berbanding dengan L-MAC.

EML-MAC: A SIMPLIFIED TIME SLOT SYNCHRONIZATION ALGORITHM FOR WIRELESS SENSOR NETWORKS

ABSTRACT

Wireless Sensor Network (WSN), is a fast growing technology, which is widely used for different applications, namely weather forecast, environmental monitoring, target tracking and military applications. Since WSN nodes are mainly used for outdoor applications they mainly rely on their internal battery supply. This limitation forces the researches to come up with ways to reduce the energy consumption of these nodes. The objective of this thesis is to improve the energy efficiency of the wireless sensor network nodes and extend the battery life time by modifying the existing time slot synchronization algorithms. This thesis proposes the Enhanced Mobile Lightweight Medium Access Control (EML-MAC) protocol, which has a more solid and comprehensive distributed slot assignment algorithm. This feature addresses the problem of duplicate slot assignment, which was seen in previous MAC protocols. Moreover, this protocol is able to work without the need of special nodes, namely coordinator, sink or gateway to start or manage the slot assignment process. According to the simulation results obtained in this thesis, EML-MAC reduces the energy consumption by 26% compared to L-MAC protocol. Furthermore, the average time needed to synchronize 17 nodes located in one area is around 2 seconds. Finally, the data throughput increased by 1.2 % compared to L-MAC.

CHAPTER 1

INTRODUCTION

1.1 Introduction to Time Slot Assignment

This thesis investigates ways of improving the energy efficiency of the Wireless Sensor Network (WSN) nodes by improving the time slot synchronization algorithm of the Medium Access Control (MAC) layer. It will also be covering different existing MAC protocols, which are using different methods of synchronization, especially time slot assignment. Getting inspired by these methods, an innovative distributed time slots assignment algorithm would be introduced. This new algorithm, assigns time slots among the WSN nodes in the network, which would result in having the lowest energy consumption compared to other existing TDMA based MAC protocols.

This chapter will briefly look at the background of WSNs. Then present the problem statement of this thesis. Followed by that, there will be reasons about the significance of this thesis and why it is important to increase the energy efficiency of the MAC layer. The scope of this thesis would then be specified. Next, the theoretical framework would be presented, explaining the different variables in this problem and how feasible is the approach to the solution. Following that, the contributions of this thesis will be highlighted. Finally, this chapter will be ended by summarizing the organization of the following chapters.

1.2 Background

Nowadays, the hardware and software technologies have matured and reached to a stage which enables developers to combine several sensors, a single microprocessor, and a short range wireless transceiver on a single board which is no bigger than a coin, and could easily operate using a small coin battery like the ones used in watches, for more than a year. These small low-cost devices are known as wireless sensors network nodes. Since these nodes are usually used in outdoor applications, for instance, environmental monitoring, target tracking, border surveillance, weather forecast, industrial process monitoring, medical, robotic, and military applications (Chiras *et al.* 2008; Demikol *et al.* 2006; Wilson 2006), it might not be possible to locate and change the batteries of all these devices, therefore usually it is preferred to employ new nodes to replace the old ones.

1.3 Problem Statement

In the past few years, it has become a fact that computation activities of the WSN node do not consume much power in comparison with other activities (Muneeb *et al.* 2006), for example the transmission and reception of radio signals. It has been proven by previous researchers that the major power consumption of wireless sensor network nodes are related to their radio transceiver's activities, which attracts the attention of researchers to state the problem of improving the energy consumption of these devices by reducing the active time of their radio transceiver. In other words, what are the methods or ways to increase the life span of the WSN nodes?

In order to solve the above mentioned problem, firstly, it is important to clearly understand and know how WSN nodes work. Secondly, it is also important to identify which parts of the operating system and the activities of the nodes could be changed or improved to reduce the energy consumption and increase the overall efficiency of the nodes.

Every node needs the network stack in order to communicate with other nodes. Figure 1.1 illustrates a simple WSN stack. Starting from the bottom up, the first layer is the Physical Layer, which is responsible for frequency selection, frequency generation, and signal detection. The bandwidth is specified in this layer and there would be different modulation schemes to choose from. After this layer, is the data link layer or MAC layer, which is responsible for data frame detection, medium access, and error control. This layer tries to form an interface between the physical layer and the upper layers. Furthermore, connections like point to point and point to multipoint is implemented in this layer. Note that, this is where, all the researchers are trying to cut down energy consumption and, where this thesis is going to focus more, by investigating and using different types of MAC protocols, for example, S-MAC, A-MAC, L-MAC, eL-MAC, ML-MAC, SB-MAC, etc. Finally, there is the network and application layer, which focus more on routing and the application aspects of the program, respectively.

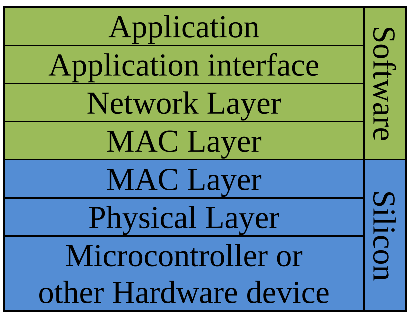

Figure 1.1: A simple WSN node stack.

1.3.1 What are the important issues of designing MAC protocols?

The first and foremost important issue is the medium that the WSN nodes use for their communication purposes. The MAC protocol stands for Medium Access Control, which clearly specifies that, in this layer all the issues related to how nodes access and use the wireless medium is declared. Since the battery life of the device is limited in WSN nodes, while designing the MAC scheme, it is necessary to optimize the performance and at the same time increase the life time of the device.

The second issue that is in direct concern while designing the MAC layer, is the application which the WSN node is going to be used for. The general idea in this thesis is to design a general and optimized MAC protocol that could be used for any application. The existing MAC protocols for WSNs, possess several deficiencies. For instance: the need for a centralized node to establish and maintain a constant connection between the end user nodes and the coordinator node.

Finally, an optimal MAC protocol should have a schema for minimizing or totally omitting collision of packets. For solving this problem, there are many existing methods which deal with the synchronization issues. When dealing with synchronization issues the topology of the network, the maximum density of the nodes in a certain area, distributed or centralized synchronization, etc., play important roles in the MAC protocol design. The main idea of this thesis is to design a MAC protocol, which could be used for all general applications, however, at the same time try to optimize the energy usage.

1.4 Objectives

The objectives of this thesis are to study and improve the energy efficiency of the wireless sensor network nodes by modifying the existing Time Slot Synchronization Algorithms to gain the following advantages:

- Find a more solid and comprehensive distributed slot assignment algorithm which addresses the problem of duplicate slot assignment.
- Generalize the existing wireless sensor MAC protocols to be able to work without the need of special nodes, namely coordinator, sink or gateway to start or manage the slot assignment process.
- Reduce the energy consumption using an enhanced distributed time slot assignment algorithm.

The proposed modifications in the synchronization algorithms would be simulated, tested and compared with existing algorithms using a simulation program specially developed for this purpose.

1.5 Significance

As mentioned in Section 1.2, one of the major problems facing WSN nodes is their limited power supply. These devices are designed to be deployed in the most deserted, remote areas and in some cases in dangerous environments. Accordingly, it is not possible to change these nodes power source every time their battery runs out. Hence, scientists have tried to come up with other ways to extent the nodes life time, one of which, is by assigning time slots to reduce collisions. The other, is to decrease the duty cycle of the transceiver usage. Finally, but not least, drop down the number of switches between each transceiver state needed for handshaking and sending data to other nodes.

The above mentioned problems are the motivation behind this thesis. The aim is to develop a more efficient way for slot assignment, which reduces the number of collisions. The proposed method will not only reduce the duty cycle of the transceiver, it will also improve the handshaking process to limit the number of times needed to switch between transceiver states.

1.6 Scope

The scope of this research is as follows:

- All the materials used and investigated in this thesis are limited to the standard and published protocols or algorithms that have in fact been implemented or simulated.
- The main concern of this thesis is limited to the energy efficiency of the proposed method and improving it, compared with existing methods.

1.7 Theoretical Framework

The focus of this thesis is to design an improved MAC layer for WSN nodes, which are assumed to have an Ad-Hoc topology. In this thesis, *energy consumption* and *throughput* are considered to be competing goals for WSN's MAC layer. Moreover, *time* is closely related to *energy consumption*. Energy consumption in WSN nodes has direct relationship with the usage time of the transceiver. In other words, the more time, nodes use to transmit, receive or switch between the transceiver states, the more energy is consumed. Apart from that, throughput is another independent variable that is used to evaluate the privileges between different MAC protocols. A MAC protocol that has a much higher data throughput is considered to be preferable. Figure 1.2 gives a better view of the relationships between dependent and independent variables.

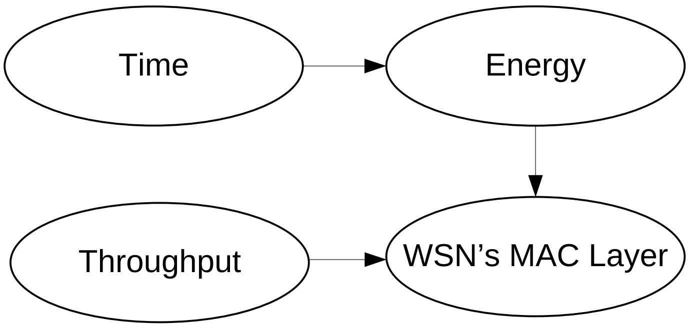

Figure 1.2: Variable relationship.

According to the problem statement in Section 1.3 and objectives in Section 1.4, the proposed distributed time slot assignment algorithm will improve the energy efficiency and the data throughput, therefore improving the WSN's MAC layer. To scrutinize, by enhancing the time synchronization, the usage time of the transceiver is optimized and the number of times needed to switch between transceiver states is minimized, resulting in lower energy consumption, in other words, better WSN MAC protocol.

Nevertheless, by introducing a better slotted time synchronization protocol with less collision, and assigning each node its own time slot, the overall data throughput of the MAC layer is increased resulting in an even better MAC protocol.

1.8 Contributions

This thesis will propose a new MAC protocol algorithm, which improves the existing Time Slot Synchronization algorithm of ML-MAC protocol and omit the need for special nodes, like coordinator, sink or gateway.

This new TDMA based MAC protocol not only will improve the energy efficiency of the WSN nodes, it also will reduce and in some cases completely prevents the possibility of packet collision. Furthermore, this protocol would be simulated based on parameters found in real WSN nodes.

1.9 Thesis Organization

This research is organized into six chapters. Chapter 1 has briefly outlined the background of WSN, problem statements, motivation, objectives, research scope, contribution, the proposed method and the research methodology. Chapter 2 covers the different types of time slot synchronization. It also provides a summary of related MAC protocols, namely S-MAC, E-MAC, L-MAC, eL-MAC, A-MAC, ML-MAC and compare their advantages and disadvantages between them. Chapter 3 explains the proposed EML-MAC protocol used in this research. Chapter 4 provides an over view of the simulation architecture and how the EML-MAC is tested with this simulation. Chapter 5 presents the simulation results and the evaluation of these results. Finally, Chapter 6 discusses the conclusions of this research and recommendation for future works.

CHAPTER 2

LITERATURE SURVEY

2.1 Introduction

This chapter will summarize time synchronization and list the main features of different types of time synchronization methods. Furthermore, it will compare global time synchronization with slotted time synchronization. In addition, it will present a selected number of existing medium access control protocols namely, S-MAC, E-MAC, L-MAC, eL-MAC, A-MAC and ML-MAC. Each protocol would be briefly explained and the advantages and disadvantages of each method would be highlighted. The selected MAC protocols are arranged in a way that the least energy saving algorithm would be mentioned first and the most optimal method for saving energy at the end.

2.2 Time Synchronization

In WSNs, each node is equipped with its own internal clock. To enable the power saving for the WSN nodes, it is crucial for the nodes to be synced with each other in order for them to sleep and wake up at the same time and communicate with each other without having any collision. The mechanisms that ensure these internal clocks are properly synchronized with each other are better known as time synchronization algorithms. Time synchronization has been used for many years now and they are used for several different applications.

The following are factors that affect the time synchronization schemes:

1. Communication Overhead

   One of the trade offs of using synchronized schemes is the extra communication overhead that it is added to the actual message. These extra communications overhead are used to synchronize the neighboring nodes. Before deciding to use synchronization techniques it is necessary to calculate whether it is worth adding extra synchronization overhead to or not.

2. Available bandwidth

   The most important advantage of using time synchronization schemes is increasing the bandwidth utilization. Synchronized nodes have a better chance of using the available bandwidth than other techniques; since a time slot is assigned to them, there would not be any collision.

3. Accuracy requirements

   In every synchronization scheme, there are required level of accuracy, which nodes need to posses in order to remain synchronized. These requirements are affected by the time drift of the internal clock or by the frequency of calibration of the time offset.

4. Scalability issues

   One of the other limitations of time synchronization is the scalability issues. Many of the existing time synchronization techniques used for WSN nodes limit the density of the network topology.

Normally, to simplify the problem, the number of time slots is fixed and this makes the protocol, application dependent.

5. Infrastructure requirements

In some synchronization techniques, special infrastructures are required, namely in some schemes the transceiver is required to support multiple channels. Normally, WSN nodes are assumed to have a one channel transceiver to reduce the complexity, cost and increase the battery life time.

Table 2.1 summarizes the features of different types of time synchronization. See (Elson and Estrin 2001), (Römer *et al.* 2005), (Sivrikaya and Yener 2004), (Jeremy *et al.* 2002), (Ganeriwal *et al.* 2003) and (Stojmenović 2005) for more detailed information.

Table 2.1: Different types of synchronization modules.

Time Synchronization Type	**Features**
Internal Time Synchronization	• Master-Client • Client-Client
External Time Synchronization	• External Standard Time Synchronization
Continuous Time Synchronization	• Higher Communication over head • Higher Power Consumption
On Demand Time Synchronization	• Time Synchronization is performed when client requests • Energy Saving Network
All Nodes Time Synchronization	• All nodes are synchronized on every occurrence of Time Synchronization
Subset of Nodes Time Synchronization	• Usually a subset of nodes which are observing the event are synchronized
Rate Synchronization	• Clock rate is synchronized with server
Offset Synchronization	• Time offset is calculated with the server and the time instance is modified

2.2.1 Global time synchronization VS. Slotted time synchronization

In Global Time Synchronization (GTS) there is usually one main clock source, which all the other resources in the network are synced with that. In contrast, Slotted Time Synchronization (STS), nodes rely on its own internal clock source to get synchronized with other neighboring nodes.

One of the main problems of GTS is getting all the nodes to be synced with one time source. For example, if the global time source sends a broadcast message or beacon indicating that one unit of time has passed, there is no guaranty that all nodes receive that message at the same time because of several variables, namely the distance. There are several techniques proposed that solve these problems.

Likewise, STS's main problem is to divide time into slots in a distributed manner. Since the idea is to have no central control system, the nodes have to negotiate among themselves for a time slot. One of the advantages of STS is being independent from having certain resources, which makes is suitable for WSN nodes. Whereas, in GTS there are many constrains. For instance, in the topology, different classification of nodes and bandwidth.

In conclusion, STS conserves more energy by sending less beacon packets. Since, WSN nodes are mostly designed different topology structures like Mesh, Star, etc... STS provides more flexibility.

2.3 Sensor-MAC or S-MAC Protocol

Wei Ye mentions three major improvements in this protocol compared to other existing protocols at that time. The first improvement was adding a SLEEP state. By doing this he managed to increase the battery life, solving the *idle-listening problem*. Furthermore, by introducing virtual-clusters he managed to simplify the sleep schedule synchronization process. Every node would automatically schedule to wake up for their neighboring node's active period. Finally, he tried to reduce the battery usage by turning the radio transceiver off while the sent packet is not addressed to it (Ye *et al*. 2002).

This protocol is categorized as a CSMA/CD-based protocol (Carrier Sense Multiple Access with Collision Detection) and although it solves the *over-hearing* or *hidden-terminal problem* by adding Request-To-Send (RTS), Clear-To-Send (CTS) and Acknowledge (Ack) packets for collision avoidance, it still has the problem of *collision* since its media access is contention-based.

2.4 EYES-MAC or E-MAC Protocol

The main idea of this protocol was to use different protocols in the MAC and routing layer to produce a new cross-layer protocol that is energy-efficient. Some of the advantages of (Van Hoesel *et al*. 2004b)'s works are as follows:

1. To be able to work independent from a control center, in a dynamic network topology.
2. To spontaneously establish an ad-hoc network independently.
3. To adapt to device failure and degradation.

4. To tolerate the movement of mobile nodes.
5. To rapidly respond to changes in task and network requirements.
6. To supporter wireless environment, mobility and changes of network density.

This protocol is categorized as a TDMA-based MAC protocol. In addition to that all nodes will automatically synchronize themselves. This is done by periodically listening and sending a control message. In this broadcast message not only control message is sent, it also sometimes *piggybacks* different types of information. The term piggybacking is used since if nodes have extra information to send for their neighbors they append them to this compulsory transmission. This will improve the throughput and energy consumption. The control message is used for creating an optimum independent set of nodes and to establish and maintain efficient routes in a dynamic topology.

(Van Hoesel *et al*. 2004b) assumed that nodes could have three states, Active, Passive and Dormant. In the *Active mode* nodes would be in their full capacity and would be able to transmit and forward packets, whereas in *Passive mode* nodes will conserve their energy and only rely on active nodes to pass them their packets.

(Van Hoesel and Havinga 2004b) mention in its paper that one of the main energy saving ways, that this protocol presents, is done by the passive nodes. Inspired by the mesh-like backbone mechanism and without the need to create a connection in the network these nodes conserve their energy to maintain a schedule and rely on active nodes.

The *Dormant mode* is similar to sleeping mode in the S-MAC protocol where the node will turn its transceiver off and is not able to transmit or receive any packets. The other important assumption for designing this protocol was that although the network topology is changing and nodes are mobile and moving, this change is very limited (Van Hoesel *et al*. 2004b).

One of the problems of assigning different roles for nodes was pointed out by (Van Hoesel and Havinga 2004b). Their results showed that in dynamic network topology the energy consumption of this protocol is much lower that the static network topology. This was because the roles of active and passive nodes did not change in static networks.

To avoid all the problems of collision, over-hearing, idea-listening and virtual clusters, this protocol divides the time into Slots. The main idea was to assign a time slot for every node so each node would be allowed to transmit in its own time slot. This would for sure solve all the previously mentioned problems of the S-MAC protocol. However, assigning slots between nodes and maintaining this schedule presents new problems of its own.

The first problem introduced by this method was the limited number of time slots in a Super Frame (several time slots form a super frame). It is not possible to assign all the nodes with different time slots. So (Van Hoesel *et al*. 2004b) allowed the reuse of time slots as long as they did not overlap each other.

In the EYES-MAC protocol time slots were further divided into Communication Request (CR), Traffic Control (TC) and Data section. The idea of having CR was originally inspired by the RTS in S-MAC protocol. In this section any neighboring node that want to send a request to the time slot owner will randomly pick a time within the sort time of CR section and send its request. Nodes that do not have requests will remain in low power mode. The CR section is not Collision free just as the RTS section in S-MAC.

The TC message will be always broadcast by the slot owner and all the one hope neighbors will try to receive, since it contains synchronization, control information and information on which nodes are addressed to receive the Data section. So if a node's request is not approved in the TC section, that node could go to sleep. In this protocol, a passive node will not own a slot and will communicate only by sending requests to the active nodes around it. Figure 2.1 illustrates the subdivisions of a super frame in the E-MAC protocol along with the subdivisions of a single slot in the super frame (Van Hoesel *et al*. 2004b).

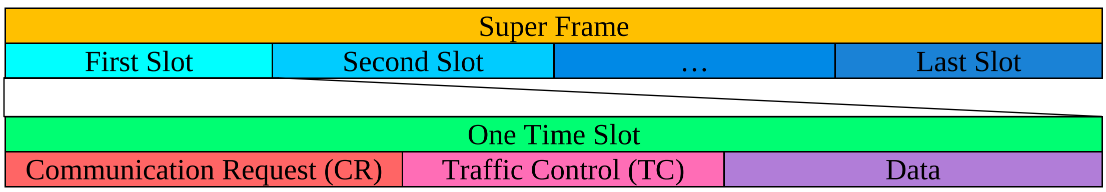

Figure 2.1: The subdivisions of a Super Frame in E-MAC protocol.

Figure 2.2 shows how neighboring nodes around the slot owner try to send their requests. In this figure, one could see that Neighbors 1, 3, 4 and 6 have tried to send their requests. However, since in the CR section nodes will only perform a simple Carrier Sense (CS) action before sending their request, there is a possibility of collision for node 4 and 6. As it is clearly shown, this collision does not affect the rest of the process and the slot owner will choose node 3 and will announce which request has been accepted at the TC section. It is also clear that all nodes except the dormant node are required to listen to the Traffic Control message.

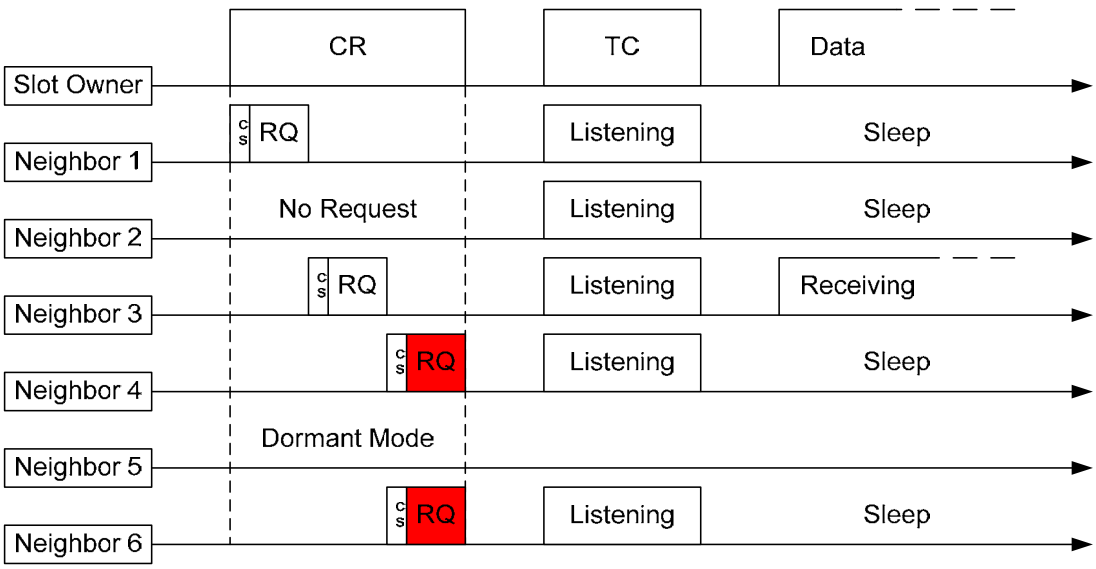

Figure 2.2: Sending request to the slot owner in E-MAC protocol.

Choosing a time slot is another problem that faced (Van Hoesel *et al*. 2004b); they needed a method which used the local information to choose a time slot not used by any of its one hope neighbors. They did that by using the occupied slot table in the TC message. The idea was to use logic OR operation on all the neighboring occupied slot tables to find out a free time slot. To avoid choosing similar slots, nodes would randomly choose their slot between the free slots. This too is not a collision free method but it is the simplest way.

(Van Hoesel *et al*. 2004b) says "Active nodes transmit a small table in the TC message that contains those time slots the node considers to be occupied by itself and its one-hop neighbor nodes" and continues with "To reduce the chance that two nodes start controlling the same time slot, nodes pick a random time slot from those not yet controlled".

Figure 2.3 illustrates another example of (Van Hoesel *et al*. 2004b)'s slot assignment process. In this figure, there are a few interesting details that is important, in the slot assignment process. Firstly, every node will announce which slot is assign to them. This is shown by the number of each node and also with the blue slot. Secondly, when a node announces its occupied slots, what it is interpreted by the others is which are the free slots that they could choose from.

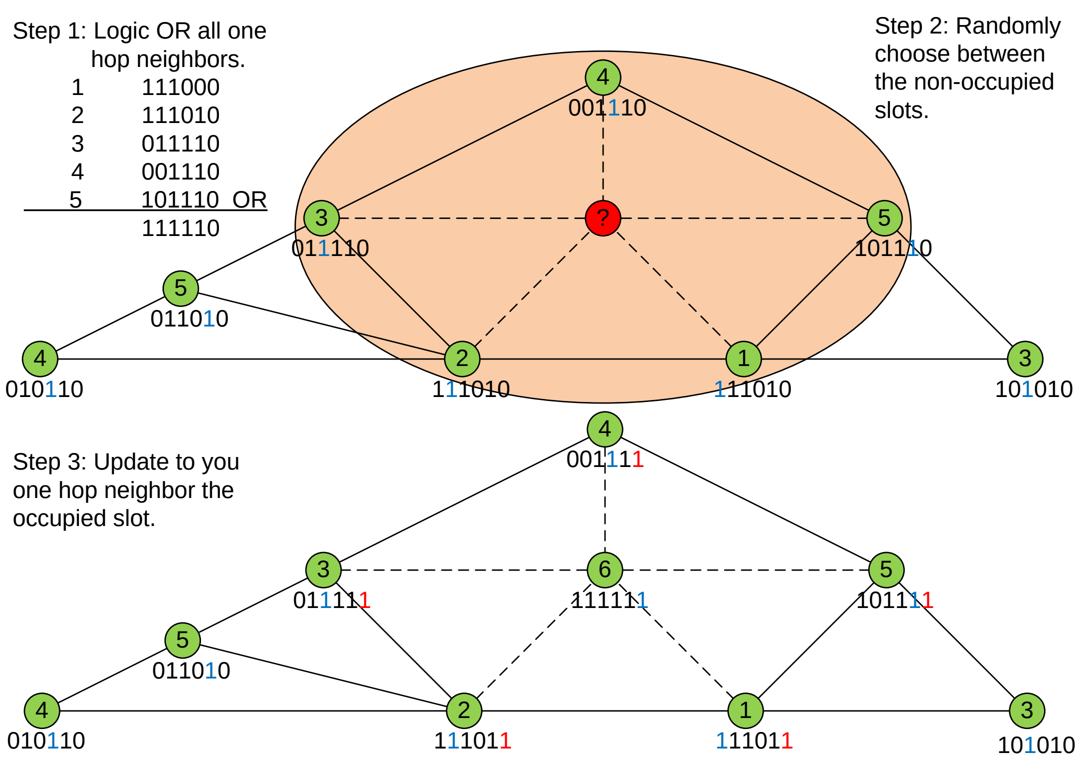

Figure 2.3: The slot assignment process in E-MAC protocol.

One of the main problems facing this protocol is the finite slots assignment. If the densities of nodes are more than the number of slots, this protocol is not able to cover or cope with this problem. There are other dynamic protocols that the slot length could be changed, namely ML-MAC protocol. Nevertheless, there must be a limit on how long the slot length could get since increasing the length of the slot will increase the length of the TC packets and larger packet size will result in less battery life.

2.5 Lightweight-MAC or L-MAC Protocol

The main idea behind designing this protocol was to maximize the life time by minimizing the overhead of the Physical Layer (PL). The idea was to minimize the number of times needed for the transceiver to switch between receive and transmit mode. This also decreased the complexity of the implementation. Furthermore, to support multi-hop communication in energy constrained environment. Moreover, self configuration and distributed synchronization were other goals of this protocol.

The main assumptions of this protocol were similar to the E-MAC. This protocol also wanted to solve the idle listening, hidden terminal and a single channel transition. Interestingly (Van Hoesel *et al*. 2004a) adds another limitation by having no hierarchical organization in the network. This last assumption contrasts with Van's work with the E-MAC, since E-MAC had active, passive and dormant modes for nodes and with that hierarchical approach he made the slot assignment much simpler.

L-MAC is a TDMA-based MAC protocol that uses the distributed algorithm of (Nieberg *et al*. 2004) for its time slot assignment. One of the other differences of this protocol compared to E-MAC is that, time slots are divided in to two sections instead of three, namely Control Message (CM) and Data Message (DM). This is better illustrated in Figure 2.4. In this picture one could see that the CM is compulsory to be sent.

However, the DM is dynamic and depends on the slot owner whether it needs to send any data to other nodes and how big the data is. L-MAC's CM as mentioned in the previous paragraph is compulsory and the message length is 12 bytes. Table 2.2 shows a summary of the CM packet structure. More details on what each field is used for, could be found in reference (Van Hoesel and Havinga 2004a).

Table 2.2: Contents of the L-MAC control message (Van Hoesel and Havinga 2004a).

Control Message Description	Size (bytes)
Identification	2
Current Slot Number	1
Occupied Slots	4
Distance to Gateway	1
Collision in Slot	1
Destination ID	2
Data Size (bytes)	1
Total	12

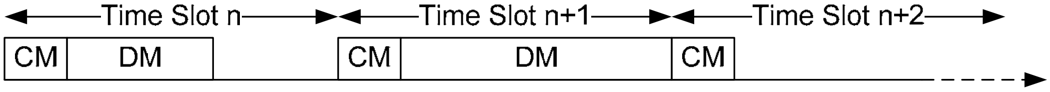

Figure 2.4: An Example of time slot contents in L-MAC protocol (Van Hoesel and Havinga 2005).

One of the interesting things about L-MAC and E-MAC is that, they need some sort of sink or gateway to start the synchronization. All the nodes will keep on listening until they hear the gateways CM packet or for the E-MAC the TC packet.

Since there is a possibility of two or more nodes picking the same time slot in the network setup period or when the topology of the network is very dynamic, one of the one hop neighbors will announce the collision and both nodes will randomly choose another time slot after a Back Off time depending on their ID number.

This efficient collision resolution mechanism stops repetition of more collision. The limited number of time slots still exists in this protocol (Van Hoesel and Havinga 2004a). “The number of time slots to use in the network depends heavily on *local maximum* network connectivity (Van Hoesel and Havinga 2005)”.

Figure 2.5 is a much detailed and improved version compared to (Van Hoesel and Havinga 2005)’s distributed time slot selection algorithm.

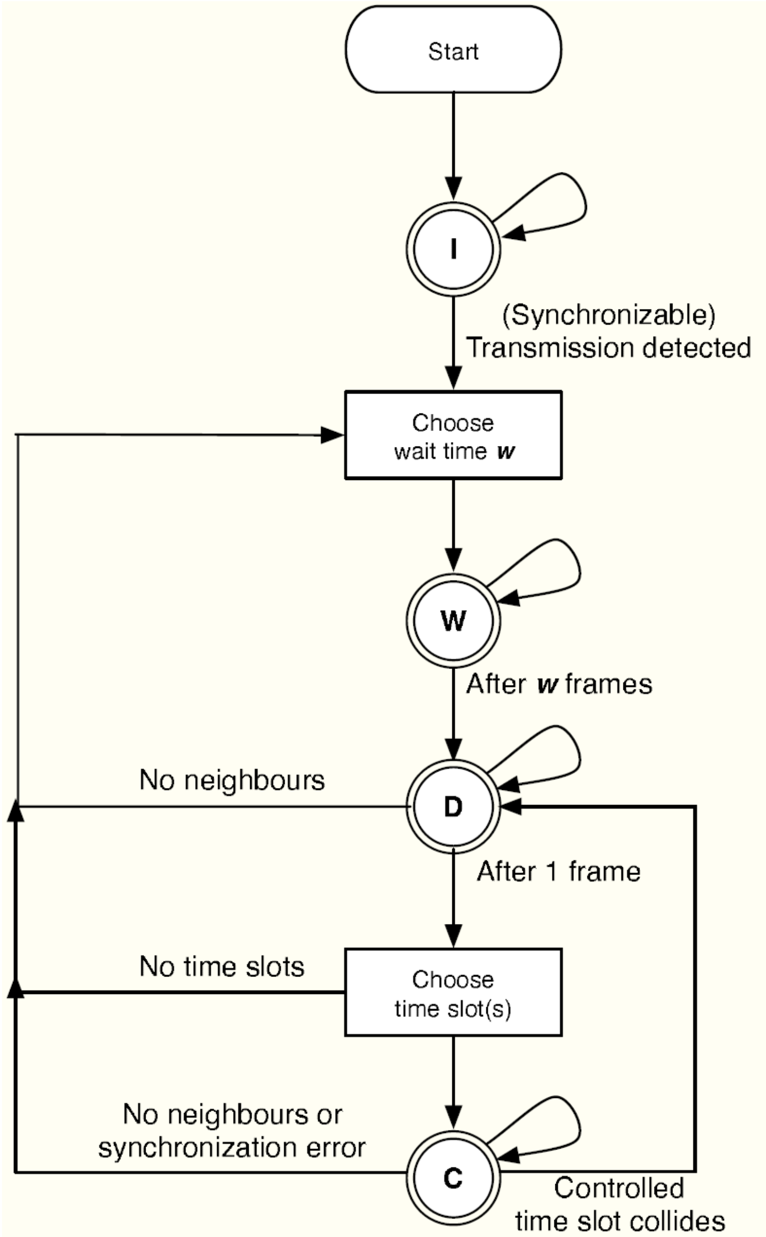

Figure 2.5: L-MAC's Distributed Time Slot Selection Flow Chart (Fehnker *et al*. 2007).

The main advantages of this protocol that differentiate it from the E-MAC are (Van Hoesel and Havinga 2004a):

- ID dependent back off time.
- No need to wait between transmitting the CM and DM (if any).
- No need for handshaking therefore less transceiver state switches.

It is clear that L-MAC is not able to eliminate all collisions. Therefore, (Fehnker *et al*. 2007) tries to iteratively improve the L-MAC protocol, by reducing the number of network topology formations that suffer from this kind of problem. (Fehnker *et al*. 2007) looks at the collision problem that is caused when two or more nodes fall in an infinite collision loop. This problem occurs if there is no third node to report the collision or is unable to send a collision free packet. What is interesting about (Fehnker *et al*. 2007)'s work is pointing out all the ambiguous informal protocol description, which helps to find and improve the L-MAC rules.

Following are the rules that (Fehnker *et al*. 2007) added to the existing L-MAC protocol:

- If a node does not hear anything after a certain period, it automatically understands that it is either isolated from the other nodes or it is participating in a collision. In this case it must restart and choose another slot.
- If a node hears the same collision twice in a row it will conclude that it is also participating in a collision. Consequently, it restarts and chooses another slot.
- The listening period before selecting a time slot was increased to two super frames.
- The time between every information update was decreased.
- The initialization of nodes starts form the gateway.

In different experiments (Fehnker *et al*. 2007) found that collision gets resolved by its own when the connectivity is higher. In this case, instead of considering very large network topologies for the test bed, it is better to consider finding solutions for all possible situations for a small number of nodes.

2.6 An enhanced Lightweight-MAC or eL-MAC Protocol

As the name shows, eL-MAC is an enhancement to the original L-MAC protocol. One of the main differences in this protocol is the ability to adapt the different application requirement. This is possible by allowing the *Duty Cycle* to be configured by the user. Duty cycle is a percentage of active time over a single time slot.

Furthermore, similar to L-MAC, this protocol also has two message types in every time slot, namely Beacon and Data Message. Beacon Message (BM), which is illustrated in Table 2.3, is similar to the CM in the L-MAC, only BM is only 10 bytes long, which is two bytes shorter and contains information about the current time slot. More details on BM and what each field is used for could be found in (Rashid *et al*. 2008).

Table 2.3: The Beacon Message field structure (Rashid *et al*. 2008).

Description Size	(bytes)
Time slot	1
Level	1
Occupied Slots	4
Destination Node	2
Transmit Delay	2
Total	10