New Priority MAC Protocol for Wireless Body Area Networks

Nourchène Bradai
LETI-ENIS: National School of Engineers, SFAX University, Route Soukra Km 4,3038 Sfax, Tunisia
norchene.bradai@gmail.com

Lamia Chaari Fourati
LETI-ENIS: National School of Engineers, SFAX University, Route Soukra Km 4,3038 Sfax, Tunisia
lamia.chaari@tunet.tn

Saadi Boudjit
L2TI – Institut Galilée – University of Paris 13, 99 Av J-Baptiste Clément 93430 Villetaneuse, France
boudjit@univ-paris13.fr

Lotfi Kamoun
LETI-ENIS: National School of Engineers, SFAX University, Route Soukra Km 4,3038 Sfax, Tunisia
Lotfi.kamoun@enis.rnu.

ABSTRACT
The rapid advancements in wireless communication technologies and micro-electronics systems have fostered the development of small and intelligent micro-components that incorporate sensing devices and wireless communications into a single miniature circuit that are wearable or implementable inside the human body for the purpose of medical and healthcare applications. These components when deployed are mainly known as WBANs for Wireless Body Area Networks. One of the main issues in such networks is the medium access techniques mainly for those data which could be urgent. The design of a medium access control protocol for a WBAN is a challenge due to the characteristics of wireless channel, the diversity of traffic, access latency and the need for minimization of energy consumption. Based on the integrated super frame structure of IEEE 802.15.4 and IEEE 802.15.6, an hybrid medium access control protocol named Priority MAC (PMAC) is proposed in this paper. In PMAC protocol, data channels are separated from control channels and the priority is given to the life critical traffic (emergency traffic). Furthermore, a sleep mode is used in order to save energy of the wearable wireless sensors and hence increase their lifetime.

Keywords
Wireless Body Area Networks; MAC Protocols, Healthcare.

Categories and Subject Descriptors
C.2.1 [**Network Architecture and Design**]: Wireless Communication
J.3 [**Life and Medical Sciences**]: Health, Medical Information Systems.

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1. INTRODUCTION
At the end of 2007 IEEE sets up a working group 802.15.6 to standardize WBAN schemes [1]. This standard operates in and around the human body (but not limited to humans). It can use existing ISM bands (2.4 GHZ) as well as frequency bands approved by national medical and/or regulatory authorities which are Medical Implant Communication System (MICS) and Wireless Medical Telemetry System (WMTS), as well as the Ultra-Wideband (UWB) frequency. The IEEE 802.15.6 appears to focus on the functioning at relatively low frequencies, less than one megahertz, and short-range use. Wireless body area networks (WBANs) provide a solution for short range, wireless communication in the vicinity of, or inside human body and play a key role in the future of e-Health. These networks are composed of wireless sensors, possibly actuators, which are wearable or implementable inside the human body, relay nodes and gateway or sink node for forwarding human's physiological parameters and forward them to the medical center in an efficient and reliable way. Many challenges and requirements [2] [3] should be considered in WBAN systems and architectures [4]. These include the restricted energy consumption, the wide variability of data rates, the need for reliability and quality of service, ease-of-use by medical professionals, interoperability, interference, security and system devices. MAC protocol is a non-trivial task in wireless body area networks (WBANs); sensing the importance of medium access control in WBANs and the availability of a significant body of literature on this topic are the main motivations that encourage the study and examination of MAC protocols. The remainder of this paper is organized as follows: Section II recapitulates the newest researches related to WBAN MAC protocols and architectures. Section III, describes the IEEE 802.15.4 and the IEEE 802.15.6 MAC protocols and highlights their limitations. Section IV, presents the proposed Priority MAC protocol and Section V concludes the paper.

2. RELATED WORK
In the last few years, many works related to WBANs access mechanisms have been proposed. The MAC proposals are classified into three categories: those based on IEEE 802.15.4, those proposed for integration in IEEE 802.15.6 and those based on IEEE 802.15.6. These MAC proposals with their descriptions and their quality of service support are presented in Table 1.

Table.1 Recent WBAN MAC proposals

Access Mechanisms		MAC Proposals	Description	QOS Support
Based on 802.15.4	Hybrid	VMAC [5]	An hybrid access mechanism called Virtual MAC (VMAC) presenting an asymmetric architecture.	Adaptability to changing conditions such as heterogeneous traffic, reliable data communication, performance in terms of QoS, providing statistical bandwidth guarantees and adaptive resource scheduling.
		PNP-MAC [6]	Preemptive slot allocation and non-preemptive transmission MAC presents a high reliability, low latency for periodic and continuous data, flexible configuration according to the demands from sensor	Can flexibly handle many applications with various requirements through fast and flexible super frame adjustments.
	CSMA/CA	DQBAN [7]	Distributed Queuing Body Area Network is an enhancement to 802.15.4. It utilizes two queues, Collision Resolution Queue (CRQ) for serving access requests and Data Transmission Queue (DTQ) for serving data packets.	Satisfy energy-efficient and stringent QoS demands for healthcare scenarios. A cross-layer fuzzy-rule based scheduler is introduced which permits to a body sensor, though not occupying the first position in DTQ, to transmit its data in the next frame.
	TDMA	U-MAC [8]	Urgency-based MAC is a protocol based on the IEEE 802.15.4a standard targeted for medical applications. In U-MAC protocol, critical nodes packet transmissions are prioritized over non-critical through non-critical nodes packet retransmission cut-off.	Provide Quality of Service (QoS) support through differentiating nodal access to the medium in WBANs
		Hybrid unified MAC (HUA) [9]	Hybrid Unified-slot Access protocol is based on the integrated superframe structure of IEEE 802.15.4. The slotted ALOHA is employed in the contention access period (CAP) to request the slot allocation	Satisfies QoS by transmitting data packets in the CFP and CAP. It is only used for command and best-effort data packets.
Proposed for integration in IEEE 802.15.6	Hybrid	IMEC [10]	IMEC Narrowband MAC protocol supports star, cluster tree, and P2P topologies and presents a Slotted Aloha and TDMA based concept.	Presents a dual duty cycling, flexibility and power efficient, enhanced slotted Aloha with QoS and a wakeup.
	CSMA/CA	YNU MAC [11]	YNU MAC uses SIFS, DIFS and backoff in contention window and it is a cluster based topology protocol. It presents a good channel utilization and high data throughput.	YNU MAC doesn't provide Quality of Service (QoS) support.
	TDMA	NICT MAC [12]	NICT MAC presents a star topology and it can operate in a beacon or non-beacon mode. It is scalable for the reason of using Group BAN superframe and Mini slots in Contention Access Period (CAP). The number of GTS in super frame is configurable.	In order to sustain QoS, NICTA MAC supports the superframe structure to provide guaranteed channel access for data traffic especially the most important life-critical and real time traffic.
		WiseMAC [13]	WiseMAC is an RF-FDMA based concept developed by CSEM (Swiss Center for Electronics and Microtechnology) in the use with optical sensor networks WiseNET. Its topology can support both star and mesh topologies and the No. of devices is scalable (traffic limited e.g. 6 to 256).	WiseMAC don't provide Quality of Service (QoS) support.
based on IEEE 802.15.6		MEB MAC [14]	Medical Emergency Body MAC protocol inserts listening windows dynamically within the contention free periods. The listening window insertion occurrence is based on the minimum delay tolerance. MEB MAC protocol utilizes idle slots to insert additional listening window opportunities for emergency traffic.	To balance contradicting requirements of energy efficiency and Quality of Service, MEB MAC reduces channel access delay for emergency traffic particularly for long superframe durations.

3. DESCRIPTION AND LIMITATIONS OF IEEE 802.15.4 AND IEEE 802.15.6

3.1 IEEE802.15.4

IEEE 802.15.4 [15] is a communication protocol designed for wireless networks from the family of LR WPAN (Low Rate Wireless Personal Area Network) because of their low paid and low-speed devices. It defines both PHY and MAC layers. There are two modes of operation of the MAC layer depending on the topology used and the need for guaranteed bandwidth, namely: non-beacon mode and beacon mode. In the non-beacon mode, the coordinator is the default state waiting for data. The device that wants to send data checks if the channel is free. If so, then it sends. If not, it waits a random period defined in the standard. When the coordinator has data to transmit to a device, it waits until the devices request the data. The coordinator then sends an acknowledgment of reception of the request. If data are pending, the coordinator transmits the data using the same principles of CSMA/CA. If there is no data waiting, the coordinator sends a data frame empty. The non-beacon mode is typically used for sensors that slept most of the time. When an event happens, the sensors wake-up and instantly send a frame alert. In this type of operation, the coordinator does not provide any explicit synchronization of the devices, no GTS can be reserved and only random access is adopted for medium distribution because of the absence of super frame and slot synchronization.This solution has.the advantage of optimizing the battery life of sensors and uses the channel only when it is necessary to transmit. In the beacon-enabled mode, a network operates periodically by sending a beacon in order to synchronize the devices with the coordinator. In an IEEE 802.15.4 network, all devices (including the coordinator) work independently. By consequence to communicate on the network, they must know when to wake up to transmit. To do this, they need to synchronize the clock over the coordinator. When a beacon arrived, all devices are notified of the super frame duration (period of activity of the coordinator) and when they can transmit data. In this mode, the coordinator has an active period and a period of hibernation to save energy. . The super frame is the period of activity of coordinator which is 16 time slots. It is divided into two parts: The first part is CAP (Contention Access Period) which is similar to the mode beaconless where any device can transmit randomly, but within the time slot that means transmission cannot start in the middle of a slot and the second is the CFP (Contention Free Period) used for guarantying access to the channel to a device for a specific number of slots, called GTS. All devices wishing to communicate during the CAP are placed in competition with others devices using the mechanism of CSMA/CA. Transmission is limited by the size of the CAP, if the device could not transmit during the CAP, it must wait for the next super frame to access the channel. Similarly, if the number of slots necessary for transmission of data is more important than the number of slots remaining in the CAP, then the device will send in the next super frame. All transactions must be completed before the next beacon. The coordinator may allocate up to seven GTS. A GTS may occupy more than one slot. Nevertheless, a sufficient portion of the CAP should be reserved for predicting the arrival of new devices in the network which is defined in the IEEE 802.15.4. The IEEE 802.15.4 defines three available models of transfer: transfer to the coordinator, transfer to a node and transfer point to point.

An illustration of the super frame structure is shown in fig.1 where aBaseSuperframeDuration is the number of symbols forming a super frame. The value of SO (super frame order) must satisfy to the condition 0<SO<BO<14, BO is the beacon order.

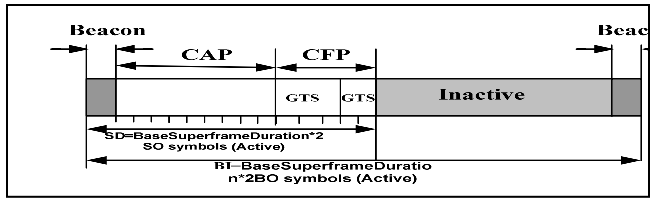

Figure 1. The super frame in beacon mode.

3.2 Limitations of IEEE 802.15.4

IEEE 802.15.4 has been examined as a candidate for body area networks but it presents some limitations such as:

- Power consumption
- Deployment and adaptability to changing the size, as the networks may include many nodes, used protocols must be capable of managing change in number of node dynamically and this doesn't figure in the IEEE 802.15.4. These nodes must be programmable, their programs must be changed during operation when new jobs become. A fixed programming does not meet the needs of a scalable body area network.
- Flexibility to changes in the network isn't taking into account in the IEEE 802.15.4[16]. In fact it's not adaptive to channel quality variation and multiple applications, not optimized for heterogeneous devices also there is no guarantee for life-critical transmissions.
- Idle listening is the biggest problem in IEEE 802.15.4 because of his waste of energy. The node does not know when the information is coming so it still listening to channel every moment, it must keep his radio in receive mode at all times.
- Fairness is the ability of different users or nodes to share the channel fairly. It is an important parameter in networks, because each user wants an equal opportunity to send or receive data for their own applications. However, in WBANs, all nodes cooperate for a single common task. A node can have considerably more data to send to the other nodes. Rather than treating each node in the same way.

3.3 IEEE 802.15.6

IEEE 802.15.6 [1] is a standard for Body Area Networks, which operate in and around the human body (but not limited to humans). It appears to focus on functioning at relatively low frequencies, less than one megahertz, and short-range use, low cost, reliable wireless communication, QoS and especially an ultra low power. A Wireless Body Area Networks is made up of nodes implanted in human bodies and on-body intra-nodes that continuously monitor patient information for diagnosis and prescription. All nodes process and communicate vital signs. Before their memory fills, sensor nodes keep information and issue them to the Personal Digital Assistant PDA or hub as it is declared in the standard. Every BAN has one hub and a range of nodes between 0 and 64. This standard specifies a medium access with different access modes and their access phases, which are beacon mode with beacon period super frame boundaries, non-beacon mode with super frame boundaries, and non-beacon mode without super frame boundaries. In this work, we consider that the hub operates in the Beacon mode with beacon period super frame boundaries. In this case, the hub transmits a beacon frame in each beacon period, except in inactive super frame, it has sensed to provide time referenced allocation and should divide the beacon access mode in access phases supported in beacon mode as it is shown in Fig.2. The super frame structure of IEEE 802.15.6 is constructed of nine access phases, which are beacon, Exclusive Access Phase 1 (EAP1), Random Access Phase 1 (RAP1), Managed Access phase (MAP), Exclusive Access Phase 2 (EAP 2), Random Access Phase 2 (RAP 2), Another Managed Access phase (MAP), and a Contention Access Phase (CAP).

- *Beacon:* Beacons initialize a super frame, they are sent in the first slot of each super frame. Their functions are to identify the coordinator, facilitates network management, power management, and clock, devices synchronization.
- *EAP1 and EAP2:* This access phases are used for an emergency traffics where failure of delivery in a certain delay, may affect the health of a person and his life so that they present the highest priority.
- *RAP1, RAP2 and CAP:* These kinds of access are dedicated for normal traffic where the data traffic is in their normal conditions without the critical time and events upon request.
- *Managed access phases (MAP):* This access phase is used to arrange scheduled uplink, downlink, and bilink allocation intervals. It can provide unscheduled bilink allocation intervals and also improvise type-I, but not type-II, immediate polled allocation intervals as well as posted allocation intervals starting in this MAP.
- *Beacon 2:* Beacon two frame is dedicated for indicating the begin and the end of the CAP phase, grouping acknowledgment, coexistence information and fast reservation or adaptation.

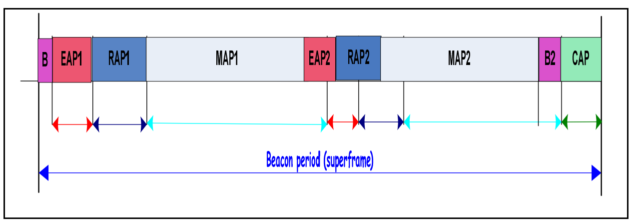

Figure 2. Access phases of a super frame in beacon mode.

3.4 Complexity and limitations of IEEE 802.15.6

IEEE 802.15.6 offers a very complicated MAC layer supporting different PHYs. The WBAN networks have very sophisticated heterogeneous traffics. WBAN traffic is categorized into on demand, normal and Emergency traffic. The coordinator or doctor, launch traffic on Demand to acquire information, mostly used for diagnostic recommendations, this is further divided into continuous (in case of surgical events) and discontinuous (when timely disclosure is required). Normal traffic is the data traffic in normal condition without the critical time and events upon request. This includes health monitoring of a patient and treatment of several diseases such as gastro-intestinal, neurological disorders, cancer detection, rehabilitation of disability, and heart disease. The nodes initiate the emergency traffic when they exceed a predefined threshold. This kind of traffic that is produced on a regular basis is very unpredictable. In the MAC frame format of the IEEE 802.15.6, the emergency traffics access to the channel in a contention based access mechanisms (CSMA/CA or Slotted Aloha) or we know that it may cause collusion between packets and that can affect the health of a person and his life because they present the highest priority. Beside of all previous wireless communication standards, a new protocol MAC for body area network is required to be proposed because they are not satisfying the reliable low-power transmission and don't take into consideration the emergency traffic that may need high priority and QoS and have to be served first. In the following, we define and specify a new Priority MAC (PMAC) protocol allowing the integration of QoS modules over the coordinator and sensors nodes MAC. The main objective of PMAC is to overcome the limitations of other protocols such as reducing control packet overhead, packet collisions ratio, switching times and idle listening duration.

4. PRIORITY MAC PROTOCOL

4.1 Description of the Protocol

In the Priority MAC protocol, the network is controlled by the coordinator, which regularly transmits beacons for device synchronization and association control. The coordinator should choose the boundaries of super frames which are indicated by the beacon, and hence the allocation slots therein. The coordinator shall communicate such boundaries by transmitting beacons at the beginning of the super frames, containing their transmit time relative to the start time of the current super frame. Besides that, the coordinator schedules uplink allocation intervals, downlink allocation intervals and reports into DL and UL subfields the resource allocation information of the downlink and uplink sub frames. The PMAC protocol is based on hybrid MAC frame structure which contains two subfields namely downlink sub frame and uplink sub frame. The adaptively and the flexibly uplink and downlink configuration facilitate the sleep mode design and improve the efficiency of this mode which is explained further. The downlink sub frame begins with a frame dedicated for synchronization and equalization. The start preamble is followed by two frames used for control. One is for downlink named DL and the other for uplink named UL. The DL specifies when the Physical layer occurs within the DL sub frame which can be either unicast data for a specific node or broadcast data for all the nodes in the network. However, the UL contains an information element per node, which includes the transmission opportunities for each node. The uplink sub frame is subdivided into two subfields. The first is a TDMA portion, which can be used by one or more nodes in order to transmit information to the coordinator. TDMA is divided into timeslots reserved for emergency medical traffic (TSRE) and timeslots reserved for normal traffic (TSRN). The second is a contention-based allocations (CAP) based on CSMA/CA. CAP, in turn, is subdivided into Control channel UCE used for uplink control of emergency medical traffic and Control channel UCN used for uplink control of normal traffic. On one hand, during the CAP period, nodes with emergency traffic contend for transmission in the UCE and UCN. On the other hand, nodes with normal traffic contend for transmission only in the UCN. The super frame structure of the priority MAC is shown in Fig.3. To improve the performance of PMAC, we introduce in our protocol two new inter-fames space. One is called EIFS (Emergency IFS) and the other is NIFS (Normal IFS). Each node (sensor) maintains a so-called Contention Window (CW), which is used to determine the number of slot times a sensor has to wait before transmission. An emergency node has to wait EIFS with EIFS < NIFS before transmitting its packet in the UCE channels; whereas, nodes with normal traffic have to wait NIFS before transmitting their data into the UCN channels.

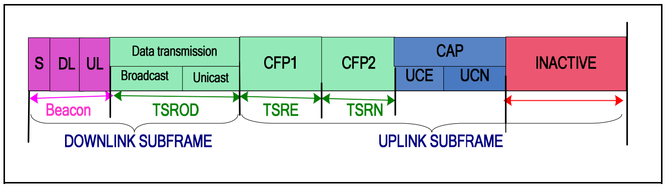

Figure 3. The super frame structure of PMAC.

To conclude, the emergency traffics are served at first either in the TSRE or in the UCE subfields after waiting EIFS. An illustration of the device transmission is shown in fig.5. The PMAC also uses flexible and efficient bandwidth allocation schemes. In fact the bandwidth allocated in TSRE and TSRN can be changed in each MAC frame to meet the requirements of nodes. As though, the allocation of bandwidth is determined at the beginning of the MAC frame, nodes with no bandwidth allocation have to go in sleep mode in order to meet the dynamic requirements of BANs specially the decreasing of energy consumption.

4.2 Sleep mode

Sleep mode is a solution to overcome the problem of idle listening, as it's explained before, the node have to stay awake to receive data. However, because there is a major part of wasted energy, in the sleep mode, the sensor turns itself off when there is no data coming. Sleep mode should perform a minimization of power consumption, the use of the coordinator air interface resources and a proper tradeoff between flexibility and energy efficiency. Since there are nodes in WBAN systems, which have a very low duty cycle, and there is no packet sent to these nodes from the coordinator, it's a waste of energy when beacons are sent to these sensors in each super frame. In PMAC, nodes are frequently in a sleep state whether in beacon, downlink, and uplink. The basic idea behind a synchronous MAC is to let the sensors sleep periodically, and to have them somehow aware of each other's sleeping schedules. In order to work efficiently, a very basic requirement is to have sensors tightly coupled or synchronized to each other. In this mode, a sleep request is sent to the coordinator by node in the CAP super frame in order to request for entering in sleep mode in a predefined duration. In order to know about the good reception of SLP-REQ frame, the coordinator should send an ACK (acknowledgement) to the sensor. The sleep mode parameters (start frame, number of frames and sleep duration) are sent also in the CAP period, depending on the nature of traffic .i.e. emergency traffics in UCE and normal traffics in UCN, by the sensor to the coordinator at the beginning of a sleep mode process. After that, the coordinator sends a SLP-RP informing the sensor node of the response of its request. A node go into sleep state in a maximum time T max sleep and when it ends, the node wakes-up and listen if there is a traffic for it from the coordinator. If not it returns to his sleep state for (T max sleep /2) and the procedure continues. The sleep state should not exceed T max because the more T max is bigger the more energy will be saved. Fig. explains the sleep mode. The node wakes up even before terminating T max sleep because of an event report sending by the sensor node at the UCE period in the CAP because of a time critical event. The coordinator sends ACK to inform the node of a good reception of the event after that the node can return to his sleep state, so that the sleep mode has to support the time critical event.

5. CONCLUSION

Wireless body area network (WBAN) brings out a new set of requirements and specifications, which are important to consider when developing a WBAN MAC protocol. In this paper, a hybrid MAC protocol, named Priority MAC, is described. This protocol gives priority to life critical traffics (emergency traffics). Moreover, a sleep mode is integrated to guarantee the minimum consumption of energy. In our future work, we aim to implement the new protocol using a network simulator such as OMNET++ in order to compare its performances with other proposed MAC protocols in literature for WBAN networks.

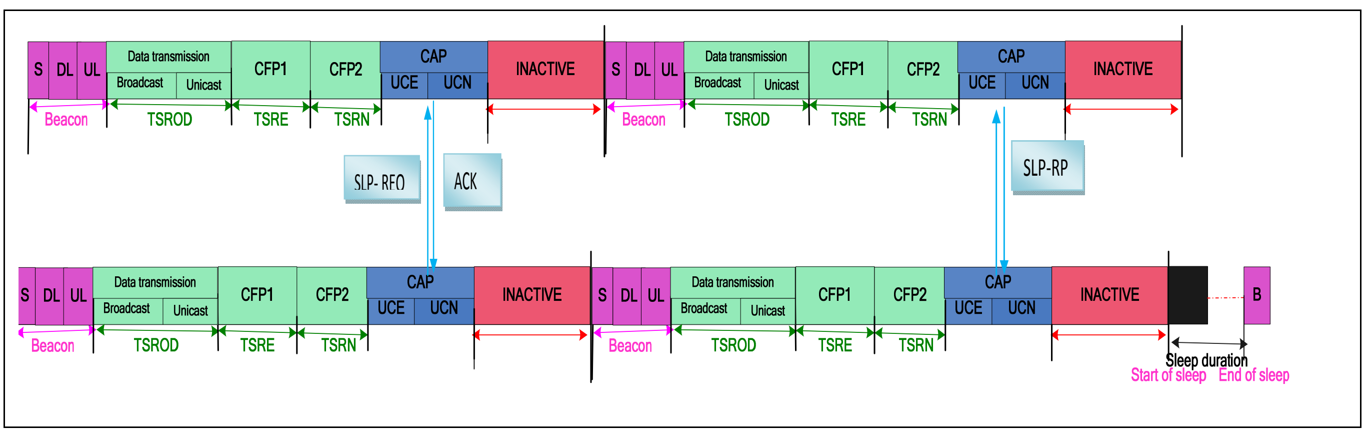

Figure 4. Sleep mode in PMAC protocol

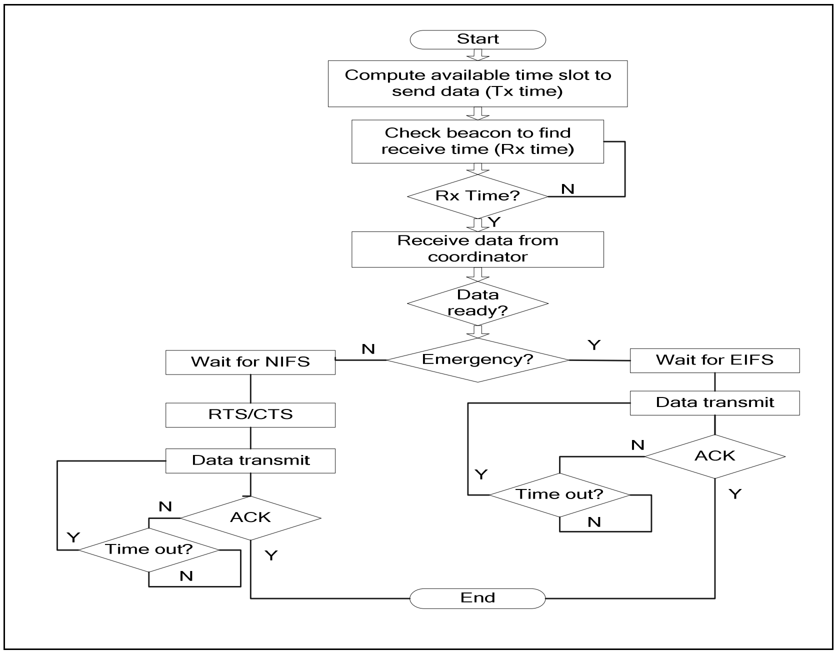

Figure 5. The Flow chart of device transmission

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