A Slotted Random Access algorithm for efficient transmission in White area: case of artisanal fishing in West Africa

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Abstract. LORA technology is increasingly used for white zone communications. The access to the channel for the different nodes of the network is managed in various ways. We propose an algorithm based on a controlled sliding backoff for communication in a maritime environment: the case of Senegal. Indeed, fishing activities in Senegal are carried out in an offshore environment, without network coverage and therefore without means of communication in case of danger. We define different communication phases according to the type of information to be transmitted, and analyze the network behavior thanks to mathematical equations. Simulations are used to set parameters and determine the duration of each communication phase.

Keywords: Ad hoc Network · Artisanal fishing · Communication · Localization · LoRa

1 Introduction

The access of several devices to a shared bandwidth is always controlled to avoid or minimize possible collisions. An access control algorithm is used to enable different devices to use a resource simultaneously. These algorithms can be divided into two groups:

- The first group concerns the algorithms that operate in a predetermined way such as time division multiple access (TDMA), frequency division multiple access (FDMA), code division multiple access (CDMA), orthogonal frequency division multiple access (OFDMA) or single carrier frequency division multiple access (SC-FDMA). Each device knows exactly how to access the resource without any possible collision. These techniques are often used in radio access network (RAN) of mobile telecommunications systems like Long Term Evolution (LTE) or 5G for example.

- The second group concerns the random access based algorithms. When traffic or the number of devices is low, users can randomly access the entire bandwidth and transmit data at any time. However, in case of high traffic or high device density, collisions become important. In this case, several algorithms can be used to optimize the success rate, such as ALOHA, slotted ALOHA or carrier sense multiple access (CSMA).

In our work, we are interested in artisanal fishing in the west african coasts, especially in Senegal. The artisanal fishers have to go far from the coast, sometimes even beyond 20km, to find fish because of the effects of climate change. As a result, artisanal fishing is carried out in white spot areas where no operator has deployed its mobile and/or internet network. Fishers have no means of communication or alert in case of distress (MAYDAY). The social and human conditions are difficult, including safety problems (nearly 100 deaths per year). Our goal is to set up a very long range "ad hoc" network to interconnect embedded devices on fishers canoes, based on LoRa technology. It is important to note that conventional centralized marine positioning systems (VMS or AIS) are not used for financial reasons. Indeed, the purchasing power of fishers does not allow them to buy this type of system. Since there is no network infrastructure at sea, we focus on random access techniques.

Different types of information are sent by fishermen, and transmissions must meet a certain quality of service. The access technique used in Lora networks is Aloha, but it is subject to interference with a success rate of 18.4% [7]. This is insufficient to ensure safety at sea. In this paper, we propose an algorithm based on slotted aloha, but which differs from it in certain functional aspects. This is a controlled sliding backoff algorithm, adapted to our study context, to enable the sharing of information between canoes at sea with a high success rate. The objective is to size the duration of the different transmission phases according to the number of users and the required success rate.

The rest of the paper is organized as follows : Section 2 describes the related works on random channel access techniques, section 3 analyzes the communication system, in section 4 the performance analysis of slotted ALOHA algorithm is made, section 5 deals with the proposed algorithm, section 6 discusses the obtained results and section 7 concludes our work.

2 Related work

In this section, we review some random channel access techniques. LoRa is a technology using the chirp spread spectrum (CSS) modulation. It is more and more used in the deployment of ad hoc communication systems in white areas [1][2][5][9][10] [11]. In a Lora network, access to the transmission channel must be managed. LoRaWAN is a MAC layer standard which coordinates the medium and adopts pure Aloha [1]. Aloha is a medium access control (MAC) protocol for transmission of data via a shared network channel. In pure aloha, each station transmits when data is available without checking whether the channel is free or not. Thus, collisions can occur and the data frame can be lost. In Pure Aloha, maximum efficiency is 18.4% [7]. Many techniques such as slotted Aloha, CSMA or other random access solutions are exploited as an alternative to Pure Aloha [7].

Slotted aloha does not allow the transmission of data whenever the station wants to send it. In slotted Aloha, the shared channel is divided into fixed time intervals called slots. Thus, if a station wants to send a frame in a shared channel, the frame can only be sent at the beginning of the slot, and only one frame is allowed to be sent to each slot. If the station has failed to send the data, it has to wait until the next slot. The maximum success rate in slotted aloha networks is 37% [8].

The purpose of CSMA is to check the state of the medium before transmission. If it is busy, the transmitter waits until it is idle before starting to transmit. This effectively minimizes the risk of collision and allows more efficient use of the medium. This variant of CSMA is also known as persistent CSMA. Another variant of CSMA is non-persistent CSMA. The main difference between persistent CSMA and non-persistent CSMA is that a non-persistent CSMA node does not continuously listen to the channel to determine when it becomes free. When a non-persistent CSMA terminal detects that the transmission channel is busy, it waits a random amount of time before detecting the channel again. This improves channel utilization compared with persistent CSMA. The maximum success rate in CSMA persistent is 52.9% and for CSMA non-persitent it is 81.5% [8].

Aloha and Slotted Aloha techniques have low transmission success rates and do not provide the level of security required for offshore fishing. For CSMA techniques, the time taken to listen to the medium before sending could be problematic if it is long and if there are many nodes. We will take advantage of the slotted aloha technique , and adapt it to our context through our Mac Access algorithm.

The communication system is discussed in the section 2.

3 Communication System and Goals

3.1 The different components of the system

In order to allow communication in maritime area, we propose a communication system illustrated in Fig. 1.

- A communication device, named mobile relay, is embedded in each pirogue (canoe). The mobile relay has two communication interfaces. A WLAN (Wireless Local Area Network) interface that enables interconnection with the fishermen's smartphones and a LPWAN (Low Power Wide Area Network) interface for long range communications with other canoes and/or base stations on the mainland.
- A mobile application developed as part of this work is installed on the fishers' smartphones. This application enables to retrieve the time, the location of the canoe and the alerts sent in case of distress. Indeed, the mobile interface

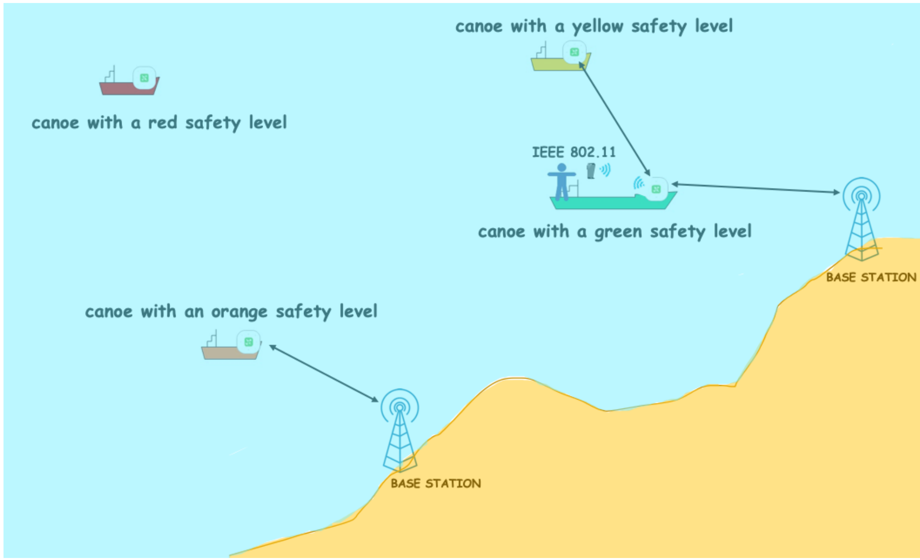

Fig. 1. Communication system

enables to send a distress message by turning on the “MAYDAY” button. The application also enables to visualize on a map the positions received from other canoes, the level of security (we will come back to this in the following) and the messages from the base stations.

- Base stations with two communication interfaces are deployed on mainland. The LPWAN (Low Power Wide Area Network) interface enables long range communications with canoe. The base station are also connected to internet (3G and/or 4G). On the one hand, in the sea-land direction, the base stations can receive the information sent by the canoe. This information will be transferred via internet to the servers of the Senegalese national navy. The navy can have a map of the canoe at sea but also alerts in case of “MAYDAY” with the position of the concerned canoe. On the other hand, information about weather warnings from the Senegalese National Agency for Civil Aviation and Meteorology (ANACIM) can reach the canoe via the land-sea link.

3.2 The different safely levels

Fig. 1 depicts the different situation of connectivity according to our cases studies. This is an "ad hoc" network where the nodes are transceivers. Therefore, a canoe can be in four different states called safety level:

- A canoe is on **green safely level** when its embedded relay mobile is both connected to at least another canoe and a base station.

– A canoe is on **yellow safely level** when its embedded relay mobile is only connected to at least another canoe.
– A canoe is on **orange safely level** when its embedded relay mobile is only connected to a base station.
– A canoe is on **red safely level** when its embedded relay mobile can't establish any connection.

3.3 The different communication phases

To ensure proper operation of our communication system, access to the long-range communication link must be controlled. We use LoRa technology as a mean of communication between mobile relays and between mobile relay and base station. Indeed, LoRa radio technology is used in the deployment of ad hoc communication systems, in disaster areas [9][10], white areas [5][6][11][2] and agricultural environment [13] to have very large and robust coverage. Coverage tests carried out in rural white areas achieved a range of 16 Km [5][2]. In the context of a maritime area, on the other hand, the tests carried out in Senegal and Finland made it possible to reach a range of more than 20 Km [6][11]. We have previously worked on an algorithm for location updates in deep-sea communications[14].

In addition to the access control problem, it is mandatory to define a communication strategy according to the type of information but also the appropriate time of their transmissions. The communication strategy we propose is shown in the Fig. 2.

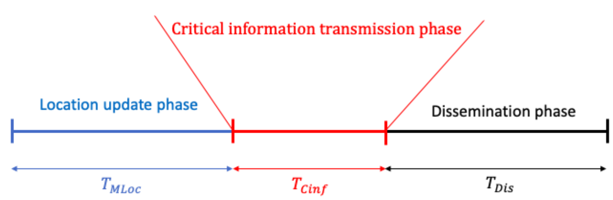

Fig. 2. The different communication phases

We propose three different phases of communication that are repeated periodically over time. It is important to note that the synchronization between the different mobile relays is possible via the time recovered from the smartphones.

The cycle begins with the location phase. Each mobile relay must update its location before sending it through its LoRa interface. During this phase, the base stations must also send their beacon to indicate their presence. At the end of this phase, each mobile relay or base station has a map of its neighbors. The safety levels are then visible on the smartphones' interfaces according to what the relay has received or not.

After that, the critical information transmission phase will begin. During that phase, information about weather warnings have to be sent by the different base stations. As previously explained, fishermen can turn on the “MAYDAY” button at any time. However, a mobile relay receiving a “MAYDAY” from the smartphones of its local network (WLAN) must wait for the arrival of this phase to broadcast the alert.

The last phase is called dissemination phase. During this phase, any mobile relay that received an alert message during the previous phase must broadcast it.

The access control to the long-range communication link during these phases and the probability of non-collision (success rate) are studied in the following sections.

4 Performance analysis of slotted ALOHA algorithm

In this section, we mathematically analyze the behavior of a network using the slotted ALOHA access technique. To do this, we are interested in the ratio between the traffic successfully transmitted $A_{Success}$ (without collision) and the total traffic A_{Total} (all transmission attempts of all devices). These two traffic are defined by the following equation 1 and 2.

$$A_{Total} = \lambda_{Total} * \tau_{slot} \ , \tag{1}$$

where λ_{Total} is the frequency of transmission and τ_{slot} is the time slot duration.

$$A_{Success} = \lambda_{Success} * \tau_{slot} \ , \tag{2}$$

where $\lambda_{Success}$ is the frequency of transmission.

Denoting the probability of non-collision by $P_{Success}$, $A_{Success}$ can be written as:

$$A_{Success} = P_{Success} * A_{Total}. \tag{3}$$

In random access context, each device transmits with probability p independently of the other devices on the shared bandwidth. In that context, the commonly used model is the discrete time Poisson process [19]. Thus, the probability that k devices generate a frame during the same time slot is given by the Poisson distribution formula:

$$P(k) = \frac{(\lambda_{Total} * \tau_{slot})^k * e^{-\lambda_{Total} * \tau_{slot}}}{k!} \tag{4}$$

When a device generates a frame, it is now possible to determinate the probability of non-collision $P_{Success}$ which is the probability that no other device generates a frame during the same time slot:

$$P_{Success} = P(0) = \frac{(A_{Total})^0 * e^{-A_{Total}}}{0!} = e^{-A_{Total}} \tag{5}$$

4.1 Discussion

On the one hand, the use of slotted ALOHA as an access control technique is coherent in our study context, since all the device can be synchronized thanks to the clock available in the fishermen's smartphone (see section 3.1).

On the other hand, in the considered communication system , the information that each device have to send is available at the beginning of each of the three communication phases (see section 3.3). The data to be sent by each device during each communication phase is not important. Devices only send respectively location, "MAYDAY" and weather warnings during phases 1,2 and 3. One frame per device is largely sufficient per communication phase.

Based on this last remark, the frequency of transmission per device for each communication phase can be set to 1. Then, instead of the commonly considered discrete time Poisson process, we can propose a specific model.

5 Mac Access Algorithm

5.1 Random access by drawing slots in a sliding time window

The principle of our algorithm is shown in Figure 3. The idea is to divide the time into several time slots of fixed size, each slot corresponding to a number. As shown in the diagram, we have for example 2 transmission phases of 7 and 6 time slots. The principle is to allow each node to choose a number between 1 and the number of slots at random, and send to the corresponding slot number.

Each node sends once per transmission phase.

When 2 nodes choose the same number, they send to the same slot and a collision occurs (as in slot 4 of phase 1, device 2 and 4 collide).

Phase duration is not fixed and varies according to the number of users accessing the network. If the number of users increases, the number of time slots increases. If the number of users decreases, the number of time slots also decreases. Hence the name: Random access by drawing slots in a sliding time window.

We first deal with the case of the first phase of communication. We will then extend it to the other phases by analogy.

- The first step is to divide T_{MLoc} (Location phase duration) into $N_{slot} = \frac{T_{MLoc}}{\tau_{slot}}$ time slot. N_{slot} is the number of time slot. Note that the time slot duration τ_{slot} must be set to a value that allows to send a full frame.
- At the second step, each device randomly chooses a value between 1 and N_{slot}. This backoff strategy is used to avoid collisions.
- At the last step, each device transmit its frame during the chosen time slot number.

We will then determine the duration of each communication phase : T_{MLoc} (the location phase duration), T_{Cinf} (the critical information transmission phase duration) and T_{Dis} (the dissemination phase duration).

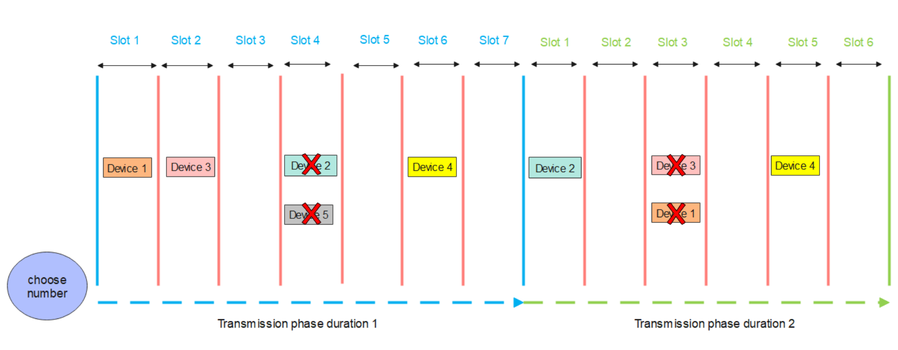

Fig. 3. Mac Access SAFE

5.2 Performance analysis

Since each device randomly selects a time slot, the probability that the *i-th* device selects the *j-th* time slot is:

$$P_i(j) = \frac{1}{N_{slot}} \text{ , } 1 \leq j \leq N_{slot} \tag{6}$$

Then, the probability of non-collision (success rate) denoted by $P_{Success}$ becomes:

$$P_{Success} = \sum_{j=1}^{N_{slot}} P_i(j)[1 - P_i(j)]^{N-1} = (1 - \frac{1}{N_{slot}})^{N-1}, \tag{7}$$

where N is the number of device that have to send a frame.

By analogy, the equation 7 is the same for all three phases of communication. However, the parameters N and N_{slot} will vary from one phase to another. We consider the following notations:

- N^1, N^2 and N^3 as the number of device that have to send a frame for respectively the communication phase 1,2 and 3.
- N^1_{slot}, N^2_{slot} and N^3_{slot} as the number of time slot in respectively the communication phase 1,2 and 3.

6 Evaluation

We carry out a series of simulations in order to analyze the performance of the proposed random access technique, in terms of probability of non-collision (success rate), under low, medium and high load conditions. We have to determine the optimal value of N^1_{slot}, N^2_{slot} and N^3_{slot}.

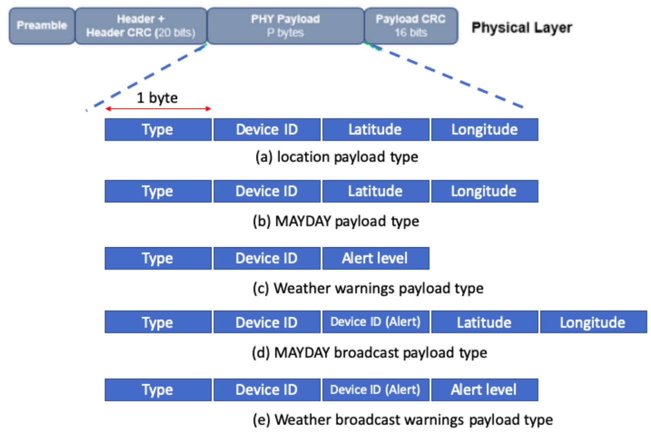

Fig. 4. The five different types of payloads

6.1 Simulation settings

LoRa interface configuration There are several transmission modes in LoRa technology and each mode is a combination of three parameters: bandwidth (BW), coding rate (CR) and spreading factor (SF). In the simulations, we consider the same parameters that we used in our radio coverage tests at sea [6] which were: $BW = 125\ KHz$, $CR = 4/5$ and $SF = 12$. This LoRa mode, called Mode 1, allows to reach the maximum range with a sensitivity of $-134dBm$. However, the time to transmit a packet, called time-on-air, is the longest. In Senegal, we use LoRa devices operating on the ISM EU868 band. The maximum payload size, in this context, for the Mode 1 is 51 bytes [20]. As explained in section 4.1, the data to be sent by each device during each communication phase is not important in terms of size. We propose, in our context, five types of payloads (see Fig. 4), however we can divide them into 3 groups:

- the location type payload which have to be used in the communication phase 1. Four bytes are enough (1 for the type, 1 for the device ID, 1 for the latitude and the last one for the longitude).
- the "MAYDAY" and weather warnings types which have to be used in the critical information transmission phase 2. Four bytes are enough for the "MAYDAY" (1 for the type, 1 for the device ID,Data types used in the dissemination phase 3 by mobile relay to broadcast the received "MAYDAY" and weather warnings during the phase 2. 1 for the latitude and the last one for the longitude) and three for the weather warnings(1 for the type, 1 for the base station ID and the last one for the alert level).
- Broadcast types used in the dissemination phase 3 by mobile relay to broadcast the received "MAYDAY" and weather warnings during the phase 2. Five bytes are enough to broadcast a "MAYDAY" (1 for the type, 1 for the device ID, 1 for ID of the alerting device, 1 for the latitude and the last one for the

longitude) and four for the weather warnings(1 for the type, 1 for the device ID, 1 for base station ID and the last one for the alert level).

Therefore, only five bytes are enough to handle all the type of information to be sent.

As previously fixed, only 5 bytes preamble are enough. The corresponding time-on-air value is 1318.9 ms [20]. Based on this, we fix the time slot to $\tau_{slot} = 1.5\ s$.

6.2 Simulation results

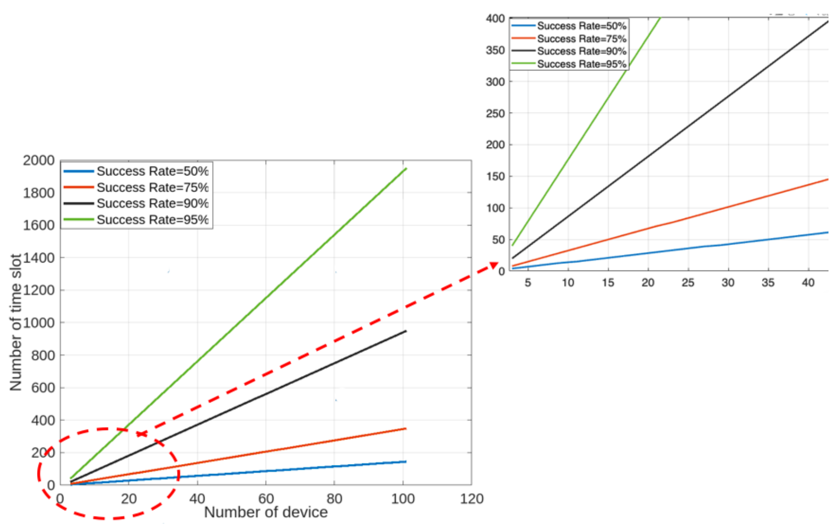

Fig. 5. The number of time slot as a function of devices number for predefined probability of non-collision (success rate)

The Fig. 5 shows the number of time slots required for different non-collision probabilities (Success rate) and different numbers of device. We based on equation 7. The idea is to fix a transmission success rate according to the concerned phase, then choose the number of devices that can be supported and deduce the number of time slots required. We use Matlab platform for the simulation.

The first observation is that, no matter the number of considered device we can have, the higher the fixed success rate, the higher the number of time slots required is. Remember that the duration of each of the three communication phases, we are trying to size, is linked to the number of slots required.($T_{MLoc} = \tau_{slot} * N^1_{slot}$, $T_{Cinf} = \tau_{slot} * N^2_{slot}$ and $T_{Dis} = \tau_{slot} * N^3_{slot}$).

Sizing of the critical information transmission phase duration

- On the one hand, only the base stations that broadcast weather warnings and the canoes in distress ("MAYDAY") have to transmit during that phase. The number of devices that have to randomly access the shared bandwidth is very small.
- On the other hand, the information transmitted during this phase is of great importance. thus, the success rate have to be set at a very high threshold.

Therefore, we propose to set the success rate equal to 95% and to also consider that the maximum number of canoes in distress does not exceed 10. The required number of slots is equal to 200 and then $T_{Cinf} = \tau_{slot} * N^2_{slot} = 1.5 * 200 = 5mn$

Sizing of the dissemination phase duration During phase 3, the equipment that received alerts in phase 2 are the ones that transmit. They disseminate the same information to spread alerts. In this case, we don't need a very high success rate since a single frame sent successfully is enough to reach the canoes over a radius of several kilometers.

We consider a success rate of 50% and a phase duration of $2mn$ and $30s$ which represent 100 time slot. We can have up to 70 devices disseminating alerts with 50% success rate.

Sizing of the location phase duration This phase allows to update the previously (section 3.2) defined security levels. Up to 100 devices will be able to share their location with a success rate of 50% if we consider a phase duration of $3mn$ and $45s$ (150 time slot).

7 Conclusion

Safety at sea has become a real concern for Senegalese fishers over the past two decades. Artisanal fishing is carried out on the deep sea in the absence of communication networks. Fishers have no means of sharing location, alerts or information in case of danger. For financial reasons, they can't afford conventional centralized marine positioning systems.

We have therefore proposed an ad hoc communication system based on lora technology. It is necessary to manage access to the transmission channel for the various nodes in the network. Aloha, the access technique used in lora networks, does not allow efficient use of the channel. We proposed a controlled sliding backoff algorithm to size the transmission phases and achieve a high success rate. The results show that the network is adaptive. In fact, depending on parameters such as the number of users, the target success rate and the number of time slots, we obtain different duration of the transmission phases. Our solution is intended for delay-tolerant networks and can be an important support for security issues in maritime areas, especially in Senegal.

In a future work we plan to implement a version of this model in our mobile relays in order to have empirical tests.

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