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## **Abstract**

Inserire abstract. I margini nell'abstract sono stati ridotti di un centimetro. In caso non si volesse questa riduzione rimuovere *changemargin*.



# Glossary

**GSM** Acronym for "Global System for Mobile Communications", it's a 2nd generation mobile communication standard, see [3] for more information.

**LTE** Acronym for "Long Term Evolution", it's a 4th generation mobile communication standard, see [4] for more information.

**FTP** Acronym for "File Transfer Protocol", built on top of TCP, see [5] for more information.

**VHF** Acronym for "Very High Frequency", it refers to the radio frequency band between 30 and 300 MHz.

**PHY** Stands for physical layer protocol specification.



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# **Chapter 1**

## **Introduction**

Place introduction here



# Chapter 2

## Bacco protocol

The goal of this chapter is to give a description of the *Bacco* protocol and to discuss the implementation choices that were made in order to deploy it. This is achieved using a top-down ordering for the level of detail, meaning that the overview of the network is presented before its specifics.

### 2.1 Overview

The network is built upon 3 fundamental categories of devices:

- **SENDER NODE** - collects data and sends it to the gateway using LoRa
- **REPEATER NODE** - listens to the incoming LoRa messages from Senders and sends them to a Gateway <sup>1</sup>
- **GATEWAY NODE** - collects data coming from the sender nodes and sends it to the web server using the FTP protocol over a mobile network such as GSM or LTE.. This node has also the role of coordinating and synchronizing Sender nodes. It can be optionally configured to perform pre-processing operations (e.g. filtering, smoothing, interpolation ...) on the incoming data
- **WEB SERVER** - receives data coming from the gateways through FTP, elaborates it and makes it available through a self-hosted web application

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<sup>1</sup>The use of Repeaters where physical obstacles compromise the integrity of the signals is of very high relevance in agricultural contexts, since natural barriers such as hills can easily block VHF radio signals.

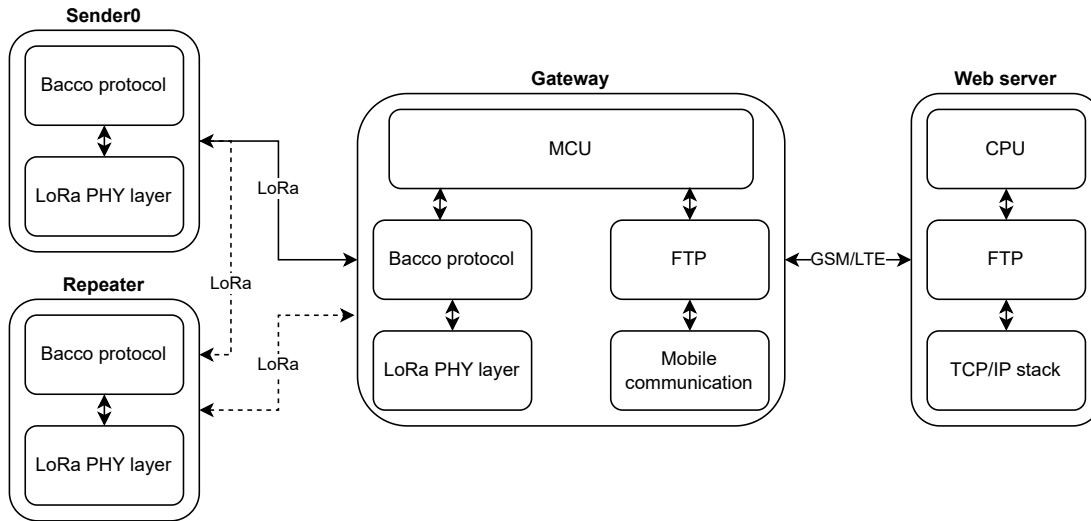


Figure 2.1: Schematic representation of the protocols involved

## 2.2 Topology

The network has a star-of-stars topology, in which the zeroth level is occupied by the Web server, the first level by the Gateways and Repeaters, and the second level contains the Senders. Figure 2.2 shows the type of devices that are involved and their communication schema.

The structure is equivalent to a tree, hence we can define a hierarchy of nodes. The root node is the central web server and its children nodes are the Gateways. All sender nodes are children of either a Gateway or a Repeater and have to children, so they correspond to the leaves of the tree.

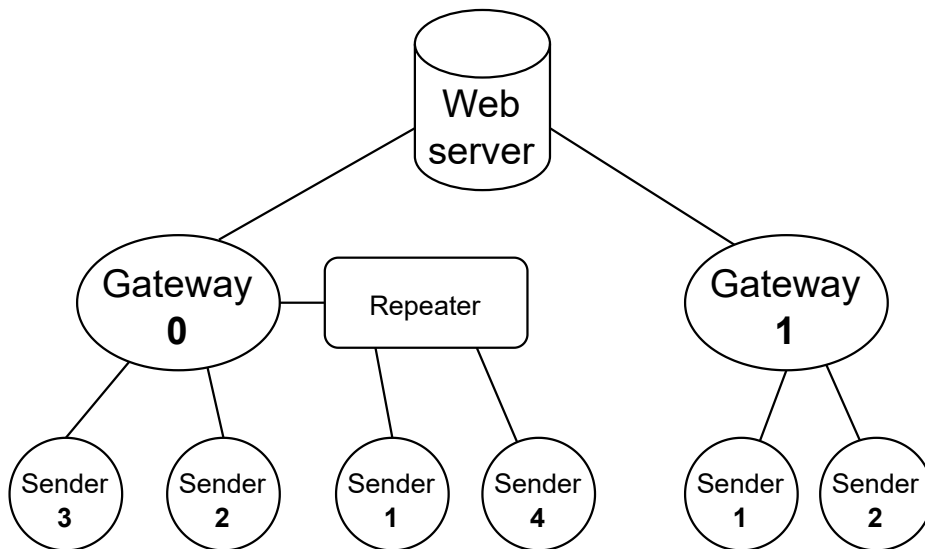


Figure 2.2: Network topology

## 2.3 Addressing

The addressing scheme follows from the hierarchical structure of the network.

A first description of the addressing algorithm is given in the case where there's a fixed number of nodes connected to the network. Later the procedure will be extended in order to achieve the addition or removal of nodes from the network. Note that since repeaters do not modify the repeated message (see [DESCRIZIONE DEI RIPETITORI] for a detailed description), they are transparent to the other nodes and thus they will be treated as straight edges by the addressing algorithm. Note also that since there is only one central Web Server, it is redundant to assign it an identifier.

### 2.3.1 Static addressing

In order to uniquely identify each node in a static network represented as a tree, we can apply the following procedure:

- May  $T$  be a tree and may  $r$  be its root node
- May  $\{T_i\}$  be a forest of subtrees with cardinality of  $I$ , where  $T_i$  is a subtree rooted in the child node  $i$  of  $r$ , and  $I$  is equal to the degree of  $r$
- For each root node  $i$ , assign it an identifier that is unique among the other  $i$ s. In particular the integers contained in the interval  $[1, I]$  will be used to represent each node
- For each  $T_i$  apply the same procedure from the first step in a recursive way
- After applying this algorithm to every possible subtree down to the leaves, each node will have a unique identifier among its sibling nodes
- Now, to get a unique identifier among all the network for every node, we can concatenate the identifiers generated by the algorithm for each ancestors of the node, starting from the root and traversing the tree from parent to child

Each Gateway is manually given a static and unique identifier based on its physical location in the range  $[0, 65535]$ . The maximum number of Sender nodes connected to a single Gateway is limited to  $256^2$ .

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<sup>2</sup>This choice is influenced by the current Italian regulations[CITAZIONE PARAGRAFO REGOLAME  
[2] on duty cycle for the 868MHz band and the fact that most agricultural contexts do not require a huge amount of sensors

## 2.4 Distribution of transmission activity

The LoRa PHY protocol does not cover the matter of sharing the communication link between multiple connected devices, thus it is necessary to define a method for doing so, in order to minimize interference and achieve a reliable exchange of information. Many techniques can be applied in the domain of both time and frequency.

The Bacco protocol distributes the activity on the channel over time using slots reserved for each Sender, using a concept that was first introduced by the AlohaNet[1] protocol.

## 2.5 State machine description

In order to achieve dynamic addressing,

### 2.5.1 Dynamic addressing

Dynamic addressing is achieved through the

Addressing of Sender nodes can be managed dynamically by the corresponding Gateway in order to seamlessly integrate new sensors into the network.

## 2.6 Interference mitigation techniques

- CAD - IQ inversion

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