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SIGFOX System Description
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Abstract

   This document presents an overview of the network architecture and
   system characteristics of a typical SIGFOX Low Power Wide Area
   Network (LPWAN), which is in line with the terminology and
   specifications defined by ETSI. It is intended to be used as
   background information by the IETF LPWAN group when defining system
   requirements of different LPWAN technologies that are suitable to
   support common IP services.

Status of This Memo

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1. Introduction

This document presents an overview of the network architecture and
system characteristics of a typical SIGFOX LPWAN, which is in line
with the terminology and specifications defined by ETSI [etsi_unb].
It is intended to be used as background information by the IETF LPWAN
group when defining system requirements of different LPWANs that are
suitable to support common IP services.

LPWAN technologies are a subset of IoT systems which specifically
enable long range data transport (e.g. distances up to 50 km in open
field), are capable to communicate with underground equipment, and
require minimal power consumption. Low throughput transmissions
combined with advanced signal processing techniques provide highly
effective protection against interference. LPWAN technologies can
also cooperate with cellular networks to address use cases where
redundancy, complementary or alternative connectivity is needed.

Because of these characteristics, LPWAN systems are particularly well
adapted for low throughput IoT traffic. SIGFOX LPWAN autonomous
battery-operated devices send only a few bytes per day, week or month
in an asynchronous manner and without the needed for central
coordination, which allows them to remain on a single battery for up
to 10-15 years.

2. Terminology

The following terms are used throughout this document:

   Base Station (BS) - A Base Station is a radio hub, relaying
   messages between DEVs and the SC.

   Device Application (DA) - An application running on the DEV or EP.

   Device (DEV) - A Device (aka end-point) is a leaf node of a LPWAN
   that communicates application data between the local device
   application and the network application.

   End Point (EP) - An End Point (aka device) is a leaf node of a
   LPWAN that communicates application data between the local device
   application and the network application.

   Low-Power Wide-Area Network (LPWAN) - A system comprising several
   BSs and millions/billions of DEVs, characterized by the extreme
   low-power consumption, long-range of transmission, and typically
   connected in a star network topology.

   Network Application (NA) - An application running in the network
   and communicating with the device(s).

   Registration Authority (RA) - The Registration Authority is a
   central entity that contains all allocated and authorized Device
   IDs.

   Service Center (SC) - The SIGFOX network has a single service
   centre. The SC performs the following functions:

   * DEVs and BSs management

   * DEV authentication

   * Application data packets forwarding

   * Cooperative reception support

3. System Architecture

   Figure 1 depicts the different elements of the system architecture:

```
              +---+
              |DEV| *                      +------+
              +---+   *                    |  RA  |
                    *                       +------+
              +---+       *                     |
              |DEV| * * *    *                  |
              +---+       *   +----+             |
                       * | BS | \  +--------+
              +---+       *   +----+  \ |        |
        DA -----|DEV| * * *                 |   SC   |----- NA
              +---+         *             / |        |
                       * +----+ /  +--------+
              +---+       *  | BS |/
              |DEV| * * *   * +----+
              +---+          *
                          *
              +---+      *
              |DEV| * *
              +---+
```
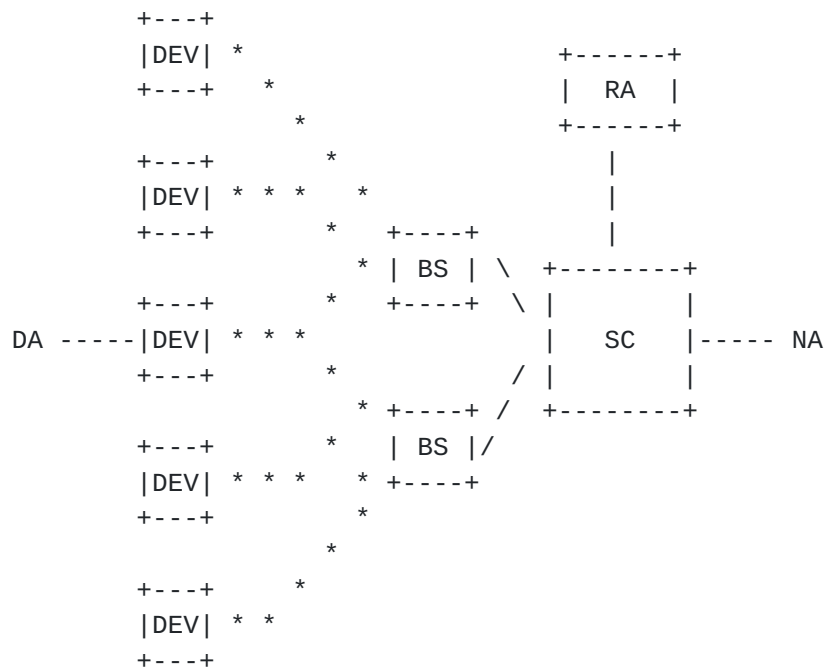
Figure 1: SIGFOX network architecture

SIGFOX has a "one-contract one-network" model allowing devices to
connect in any country, without any need or notion of either roaming
or handover.

The architecture consists of a single cloud-based core network, which
allows global connectivity with minimal impact on the end device and
radio access network. The core network elements are the Service
Center (SC) and the Registration Authority (RA). The SC is in charge
of the data connectivity between the Base Stations (BSs) and the
Internet, as well as the control and management of the BSs and
Devices. The RA is in charge of the Device network access
authorization.

The radio access network is comprised of several BSs connected
directly to the SC. Each BS performs complex L1/L2 functions,
leaving some L2 and L3 functionalities to the SC.

The Devices (DEVs) or End Points (EPs) are the objects that
communicate application data between local device applications (DAs)
and network applications (NAs).

Devices can be static or nomadic, as they associate with the SC and
they do not attach to any specific BS. Hence, they can communicate

with the SC through one or multiple BSs without needing to signal for
handover or roaming.

Due to constraints in the complexity of the Device, it is assumed
that Devices host only one or very few device applications, which
most of the time communicate each to a single network application at
a time.

4. Radio Spectrum

The coverage of the cell depends on the link budget and on the type
of deployment (urban, rural, etc.). The radio interface is compliant
with the following regulations:

   Spectrum allocation in the USA [fcc_ref],

   Spectrum allocation in Europe [etsi_ref],

   Spectrum allocation in Japan [arib_ref].

At present, the SIGFOX radio interface is also compliant with the
local regulations of the following countries: Australia, Brazil,
Canada, Kenya, Lebanon, Mauritius, Mexico, New Zealand, Oman, Peru,
Singapore, South Africa, South Korea, and Thailand.

5. Radio Protocol

The radio interface is based on Ultra Narrow Band (UNB)
communications, which allow an increased transmission range by
spending a limited amount of energy at the device. Moreover, UNB
allows a large number of devices to coexist in a given cell without
significantly increasing the spectrum interference.

Since the radio protocol is connection-less and optimized for uplink
communications, the capacity of a SIGFOX base station depends on the
number of messages generated by devices, and not on the actual number
of devices. Likewise, the battery life of devices depends on the
number of messages generated by the device. Depending on the use
case, devices can vary from sending less than one message per device
per day, to dozens of messages per device per day.

Both uplink and downlink are supported, although the system is
optimized for uplink communications. Due to spectrum optimizations,
different uplink and downlink frames and time synchronization methods
are needed.

5.1. Uplink

5.1.1. Uplink Physical Layer

The main radio characteristics of the UNB uplink transmission are:

o Occupied bandwidth: 100 Hz / 600 Hz (depending on the region)

o Uplink baud rate: 100 baud / 600 baud (depending on the region)

o Modulation scheme: DBPSK

o Uplink transmission power: compliant with local regulation

o Link budget: 155 dB (or better)

o Central frequency accuracy: not relevant, provided there is no
   significant frequency drift within an uplink packet transmission

For example, in Europe the UNB uplink frequency band is limited to
868.00 to 868.60 MHz, with a maximum output power of 25 mW and a
maximum mean transmission time of 1%.

5.1.2. Uplink MAC Layer

The format of the uplink frame is the following:

```
+--------+--------+--------+-----------------+-------------+-----+
|Preamble| Frame  | Dev ID |     Payload     |Msg Auth Code| FCS |
|        | Sync   |        |                 |             |     |
+--------+--------+--------+-----------------+-------------+-----+
```


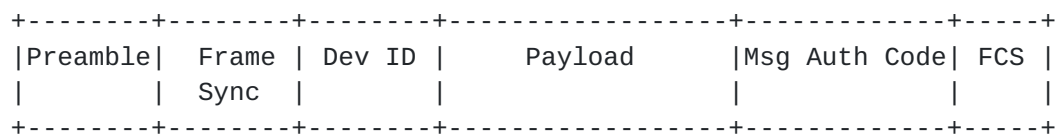   Figure 2: Uplink Frame Format

The uplink frame is composed of the following fields:

o Preamble: 19 bits

o Frame sync and header: 29 bits

o Device ID: 32 bits

o Payload: 0-96 bits

o Authentication: 16-40 bits

o Frame check sequence: 16 bits (CRC)

5.2. Downlink

5.2.1. Downlink Physical Layer

The main radio characteristics of the UNB downlink transmission are:

o Occupied bandwidth: 1.5 kHz

o Downlink baud rate: 600 baud

o Modulation scheme: GFSK

o Downlink transmission power: 500 mW / 4W (depending on the region)

o Link budget: 153 dB (or better)

o Central frequency accuracy: Centre frequency of downlink
   transmission are set by the network according to the corresponding
   uplink transmission

For example, in Europe the UNB downlink frequency band is limited to
869.40 to 869.65 MHz, with a maximum output power of 500 mW with 10%
duty cycle.

5.2.2. Downlink MAC Layer

The format of the downlink frame is the following:

```
+------------+-----+---------+-----------------+------------+-----+
|  Preamble  |Frame|   ECC   |     Payload     |Msg Auth Code| FCS |
|            |Sync |         |                 |            |     |
+------------+-----+---------+-----------------+------------+-----+
```
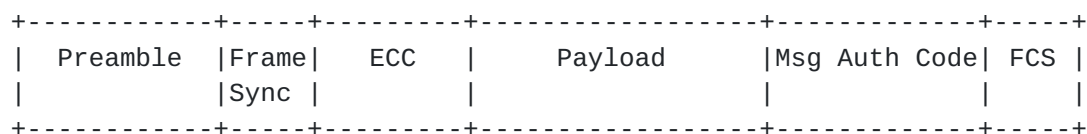
Figure 3: Downlink Frame Format

The downlink frame is composed of the following fields:

o Preamble: 91 bits

o Frame sync and header: 13 bits

o Error Correcting Code (ECC): 32 bits

o Payload: 0-64 bits

o Authentication: 16 bits

o Frame check sequence: 8 bits (CRC)

[5.3](). Synchronization between Uplink and Downlink

The radio interface is optimized for uplink transmissions, which are
asynchronous. Downlink communications are achieved by devices
querying the network for available data.

A device willing to receive downlink messages opens a fixed window
for reception after sending an uplink transmission. The delay and
duration of this window have fixed values. The network transmits the
downlink message for a given device during the reception window, and
the network also selects the base station (BS) for transmitting the
corresponding downlink message.

Uplink and downlink transmissions are unbalanced due to the
regulatory constraints on the ISM bands. Under the strictest
regulations, the system can allow a maximum of 140 uplink messages
and 4 downlink messages per device. These restrictions can be
slightly relaxed depending on system conditions and the specific
regulatory domain of operation.

[6](). Network Deployment

As of today, SIGFOX's network has been fully deployed in 12
countries, with ongoing deployments on 26 other countries, giving in
total a geography of 2 million square kilometers, containing 512
million people. The one-contract one-network model allows devices to
connect in any country, without any notion of roaming or handover.

The vast majority of the current applications are sensor-based,
requiring solely uplink communications, followed by actuator-based
applications, which make use of bidirectional (i.e. uplink and
downlink) communications.

Similar to other LPWAN technologies, the sectors that currently
benefit from the low-cost, low-maintenance and long battery life are
agricultural and environment, public sector (smart cities, education,
security, etc.), industry, utilities, retail, home and lifestyle,
health and automotive.

7. IANA Considerations

    N/A.

8. Security Considerations

    Due to the nature of low-complexity devices, it is assumed that
    Devices host only one or very few device applications, which most of
    the time communicate each to a single network application at a time.

    The radio protocol provides mechanisms to authenticate and ensure
    integrity of the message. This is achieved by using a unique device
    ID and a message authentication code, which allow ensuring that the
    message has been generated and sent by the device with the ID claimed
    in the message.

    Security keys are independent for each device. These keys are
    associated with the device ID and they are pre-provisioned.
    Application data can be encrypted at the application level or not,
    depending on the criticality of the use case, allowing hence to
    balance cost and effort vs. risk.

9. Acknowledgments

    The authors would like to thank Olivier Peyrusse for the useful
    inputs and discussions about ETSI.

10. Informative References

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             MHz to 1 000 MHz frequency range with power levels ranging
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    [etsi_unb]
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             Range Devices (SRD); Technical characteristics for Ultra
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             1 GHz", February 2017.

   [fcc_ref]   "FCC CFR 47 Part 15.247 Telecommunication Radio Frequency
               Devices - Operation within the bands 902-928 MHz,
               2400-2483.5 MHz, and 5725-5850 MHz.", June 2016.

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