Whitepaper

MXC SMART MACHINE BIDDING

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Contents

1 MXC Vision

The MXC Foundation is a Berlin-based non-profit organization. MXC has provided the open source Machine Xchange Protocol (MXProtocol) to connect Low Power Wide Area Network (LPWAN) technology with the blockchain as an infrastructure for Internet of Things (IoT). MXC automates machine-to-machine (M2M) transactions and provides a device data economy. MXC has introduced a blockchain based token called the Machine Xchange Coin (MXC). Using MXC tokens, devices [1] should pay for the uplink[2]/downlink[3] of LPWAN gateway resources. MXC token is also used for trading data collected by devices and sensors in the MXC (inter-chain) data market place.

The MXC LPWAN server consists of the primary components of the MXProtocol; including smart machine bidding (SMB), event storage, M2M wallet, inter-chain data market, and anti-collision coordinator. Figure 1 displays the MXC LPWAN structure, data flow in the MXC network, and the main components of the MXProtocol. More information on the MXC Foundation, and the MXProtocol are provided in the MXC technical white paper; available on the MXC official website[4]. In this white paper, the smart machine bidding component of MXProtocol is discussed in detail.

2 MXC Smart Machine Bidding (SMB)

In MXC LPWAN, gateways provide the downlink/uplink resources for LPWAN devices and their corresponding servers; e.g. a mobile phone application which controls a smart lock or receives data from a temperature sensor (hereafter referred to as clients). MXC Smart Machine Bidding (SMB) runs on the MXC cloud and is responsible for:

1. Assigning downlink resources of gateways to device downlink requests. Since multiple clients are requesting downlinks, and multiple gateways may be available, a decision must be made to assign each downlink request to a downlink resource (gateway). This decision is made by the SMB.

[1] In IoT networks, devices are also known as nodes or sensors
[2] Signal transmission from device to gateway
[3] Signal transmission from gateway to device
[4] http://www.mxc.org

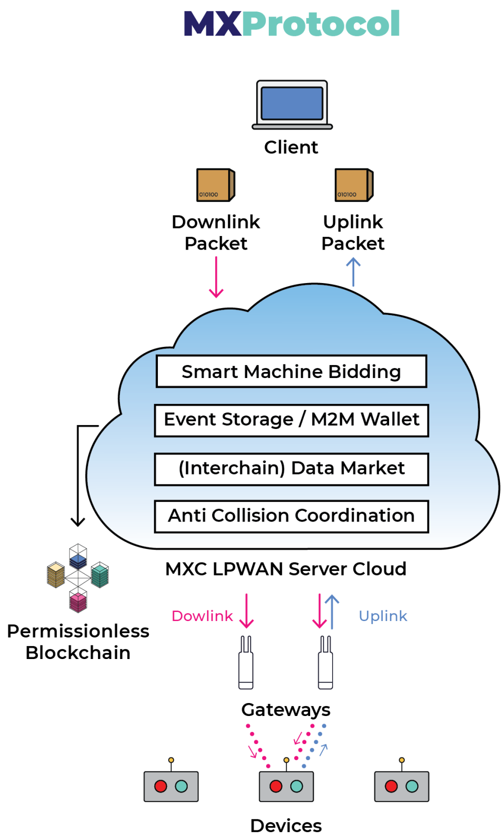


Figure 1: MXProtocol, MXC LPWAN structure and its data flow

2. Determine pricing policies for using LPWAN resources.

The SMB manages the aforementioned responsibilities by providing an LPWAN resource auction market. Each gateway owner can offer the downlink resources through different bidding strategies. Likewise, device owners can define their bidding strategies, and the price they are willing to pay for the LPWAN resources. The SMB has the following advantages:

- **Improvement of network services and cost reduction**
  Competition between gateways will lead to cost-effective and high-quality device data network.

- **Network expansion**
  Companies or individuals are more likely to install gateways in areas of high downlink/uplink demand to profit from sharing network resources. This will lead to the expansion of LPWAN.

- **Flexible pricing for data prioritization**
  SMB, and the provided network resources auction market, will allow devices to use network resources based on their requirements. Low priority data may be sent with some delay (and a lower bid), whereas high priority data with a higher bid will be sent promptly.

In summary, SMB provides an ecosystem through which gateway owners, device owners, client owners and data customers[5] can profit. A primary component of the MXProtocol is MXC data driven automated services. This component provides services for device/gateway owners and optimizes the procedures based on data driven algorithms and machine learning methods. SMB also provides a fair pricing solution based on the time on air of each packet and ADR[6].

In the following chapters, SMB strategies and procedures will be discussed. After that data driven SMB and its ADR services are explained. At last, uplink payments and user interfaces of the SMB are discussed.

3 MXC Smart Machine Bidding Strategies

Various bidding strategies are provided by the MXC smart machine bidding solution. SMB strategies can be divided into two categories: subscription, and single bidding strategy. Data driven automated SMB is also used to optimize and improve services provided by bidding strategies. Each gateway owner can provide different types of subscriptions and single bidding strategies. The provided

[5] Individuals or companies who purchase data through the MXC inter-chain data market
[6] Adaptive Data Rate

bidding strategies from the gateways can be selected by device owners based on their own use case scenarios and preferences (e.g. data priority, data transmission pattern, and budget). Device owners can select an appropriate subscription or use single bidding for each of their packets to get access to the downlink resources of MXC LPWAN. If a person is both gateway and device owner, she can provide a special subscription for herself; in this case she does not need to pay for downlink resources.

To provide a better understanding on the SMB procedure, in this chapter bidding and corresponding pricing policies are discussed based on packets. Later in chapter 6, details of SMB strategies and procedures based on time on air will be discussed. In the following sections, downlink resource management by SMB is discussed. Uplink resource management and its corresponding pricing policies are discussed later in chapter 7.

3.1 Provided Machine Bidding Strategies

A gateway owner can provide different strategies and pricing policies for downlink resource management; these are:

- **Subscription** [7]

  A device owner can subscribe to a subscription offered by a gateway, an organization (which provides multiple gateways), or a network (which contains multiple organizations) to use the downlink resources of MXC LPWAN. A subscription can be limited to a certain period of time (e.g. one month), on downlink volume (e.g. 100 MB), or a region (e.g. Berlin). Generally speaking, a SMB subscription is similar to flat services offered by internet service providers or mobile telecommunications companies. Mainly it is more reasonable for the device owners who use the network resources frequently to use subscriptions (rather than single bidding). It can be more cost efficient, and subscribers often have access to higher quality network resources.

- **Single Bidding Strategy**

  Single bidding strategy needs a payment for each downlink packet transmission separately. Here are the the possible single bidding strategies offered by gateways:

[7] Subscription is named quantitative purchase in MXC technical white paper

  - **Fixed price**

    If a gateway offers the fixed price strategy, the downlink resources of the gateway are offered at a fixed price. For this strategy, *fix_bid* value is defined by the gateway owner. Any device requesting the downlink resource of this gateway, should pay *fix_bid* amount of MXC tokens for each packet transmission.

  - **Auction**

    The auction strategy simulates an open market, where a packet transmission should be considered as a trade between gateway owners and device owners. The balance between supply and demand will ensure affordable network rates for device owners. In order to achieve that, each gateway provides *min_bid* value representing the minimum price offered by the gateway to use the downlink resource for packet transmission. If the demand for downlinks is relatively low, *min_bid* value in MXC tokens will be paid by the device owner for the downlink. Otherwise, if the number of requests are relatively high, a live auction will take place, and the downlink resource will be sold to the highest bidder. The auction is an automated process, triggered each time multiple devices are requesting a same downlink resource. To regulate the amount paid per downlink, device owners can define the *max_bid* that they are willing to pay (at max) per downlink. SMB will determine the final price paid per downlink. This decision is based on the provided bidding parameters, as discussed in chapter 4.

- **MXC Automated Smart Machine Bidding**

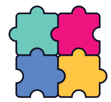
  This category will be introduced with data driven algorithms based on machine learning methods providing (or suggesting) near-optimum bidding strategies for device owners. This will be further discussed in chapter 5.

3.2 Multiple Strategies

It is possible for a gateway to provide both subscription and one single bidding strategy (either fixed price or auction) simultaneously. A gateway can not provide fixed price and auction strategy together[8]. It is possible, if one gateway provides subscription and auction strategies, and another gateway provides subscription and fixed price strategies in the same network. By providing various

[8]Since the price which the device should pay can not be both *fix_bid* and *min_bid*

bidding strategies, gateway owners offer more flexibility to device owners for using downlink/uplink resources. The MXC data driven automated SMB can provide automated bidding suggestions for device owners to participate in the bidding.



3.3 Multiple Priority Handling

A device can have multiple types of downlink packets with different priorities. The device owner is willing to pay more MXC tokens to transmit high priority packet over a stable and prompt LPWAN connection. For low priority packets, the device owner might prefer to wait (during network traffic time when gateways are busy), in order to pay less for using LPWAN resources.

For example, a device receives two types of downlink packets from its client. The first type are controlling commands. The second type are reporting requests. Reporting requests are used to tell the device to send its gathered data to the client. In many use cases (like a smart lock), the controlling commands (commands to lock or unlock the door remotely) are more important than reporting requests. SMB allows device owners to define priority groups for the downlink packets of a single device. For each priority group, the device owner provides corresponding bidding parameters. This configuration works both for subscriptions and single bidding strategies (auction, and fixed price). In section 4.1 it will be further discuss how multiple priorities are handled in MXProtocol.

4 MXC Smart Machine Bidding Procedure

In this chapter, the SMB procedure is discussed. At first SMB related parameters and definitions are provided. After that, the SMB procedure is presented; which is illustrated in figure 2. An example scenario on the SMB is also provided in figure 3.

4.1 Controlling Parameters

For each downlink request, in order to use single bidding (auction or fixed bidding strategies), the following controlling parameters should be defined. Note that both the device owner (via the device owner panel) and the client, are able to define these parameters.

- **max_bid**: the maximum bidding price defined by the device owner shows the upper payment threshold of the device (in MXC tokens) for the downlink request.
- **max_delay**: this parameter defines, under certain circumstances, the maximum acceptable delay (in seconds) for the packet to be sent. If *max_delay* is reached, the packet will not be sent and the cloud will notify the client about the rejection of the downlink request.
- **accepted_delay**: the tolerable delay defined by the client (or device owner) to indicate the time period a packet is willing to wait for the lowest possible price. Lowest possible bidding price is the current lowest bid of available gateways for the device. *accepted_delay* should be defined considering the listening time of class A and B of LoRaWAN devices.

As discussed in section 3.3, priority groups contain above parameters can be defined for the downlink packets. Two options are available to define the priorities of each packet and the corresponding controlling parameters, as below:

1. Set by the device owner; priority groups and related controlling parameters can be defined by the user in the device control panel (more details about the panel can be found in chapter 8). Each downlink packet should contain an additional field determining the priority group of the packet.
2. Set by the client; controlling parameters can be defined by the client as additional fields for each packet.

Note that the additional fields (controlling parameters) in the downlink packet, are not included in the payload. Therefore they will put no extra load on the LPWAN. These fields are defined in MXProtocol. It should be mentioned that the MXProtocol is LoRaWAN compatible.

As mentioned in section 3.1, gateway owners define bidding strategies and corresponding parameters; including list of subscriptions and subscribed devices, *min_bid* for auction, and *fix_bid* for the fixed price strategy. This information will be used in addition to the aforementioned SMB controlling parameters for the SMB procedure.

4.2 Flow Controller

Downlink requests will be managed by the *flow controller*; the system responsible for passing the downlink requests to the gateways considering bidding strategies, downlink requests, signal strengths, and etc. It is also able to stop feeding a gateway when it is busy sending other packets and check if a gateway was able to transmit a downlink packet. Indeed *flow controller* is managing the SMB procedure, as discussed in the following section.

4.3 Main Procedure of Smart Machine Bidding

The smart machine bidding main procedure will take place in the MXC cloud (servers running MXProtocol). If a device has a subscription with a gateway, the subscription will be used to allocate the LPWAN downlink; otherwise the single bidding strategy will be used. Device owners may also use the single bidding strategy as a backup plan if the gateway to which the device is subscribed is unavailable. The main procedure of SMB works as below:

- Downlink requests will be added to the *flow controller*

- Gateway filtering: The *flow controller* filters some of the available gateways for each downlink request. Gateway filtering will be done using the following conditions:
  - RSSI [9]: Received signal strength should be more than a defined threshold
  - The gateway should be able to provide services required by the device (e.g GPS-free localization)
  - The device owners can define conditions on the gateways (e.g. MTBF [10], ranking, rating, gateway popularity, etc) [11]
- Downlink packet will be forwarded to a gateway by *downlink passing procedure* (to be discussed in section 4.3.1)
- The gateway will be asked whether it was able to send the packet. If the gateway was unable to send it, *max_delay* of the packet will be checked. At this point, two actions may occur:
  - *max_delay* has been reached ⇒ Notify the client that the packet was not sent
  - *max_delay* has not been reached ⇒ Add the packet to *flow controller*

Flowchart of the SMB main procedure is represented in figure 2.

4.3.1 Downlink Passing Procedure

When the downlink packets are received by the *flow controller*, the *downlink passing procedure* is responsible for deciding which gateway will be assigned to each downlink request. The following conditions will be checked to make this decision:

- The *downlink passing procedure* follows subscriptions first. A device that is subscribed to a gateway has relatively higher priority when it comes to use downlink resource of that gateway comparing to other devices that use single bidding strategies (auction and fixed price).

[9] Received Signal Strength Indicator
[10] Mean Time Between Failure
[11] Gateway ranking, rating and popularity will be provided by MXC automated data driven services discussed in chapter 5

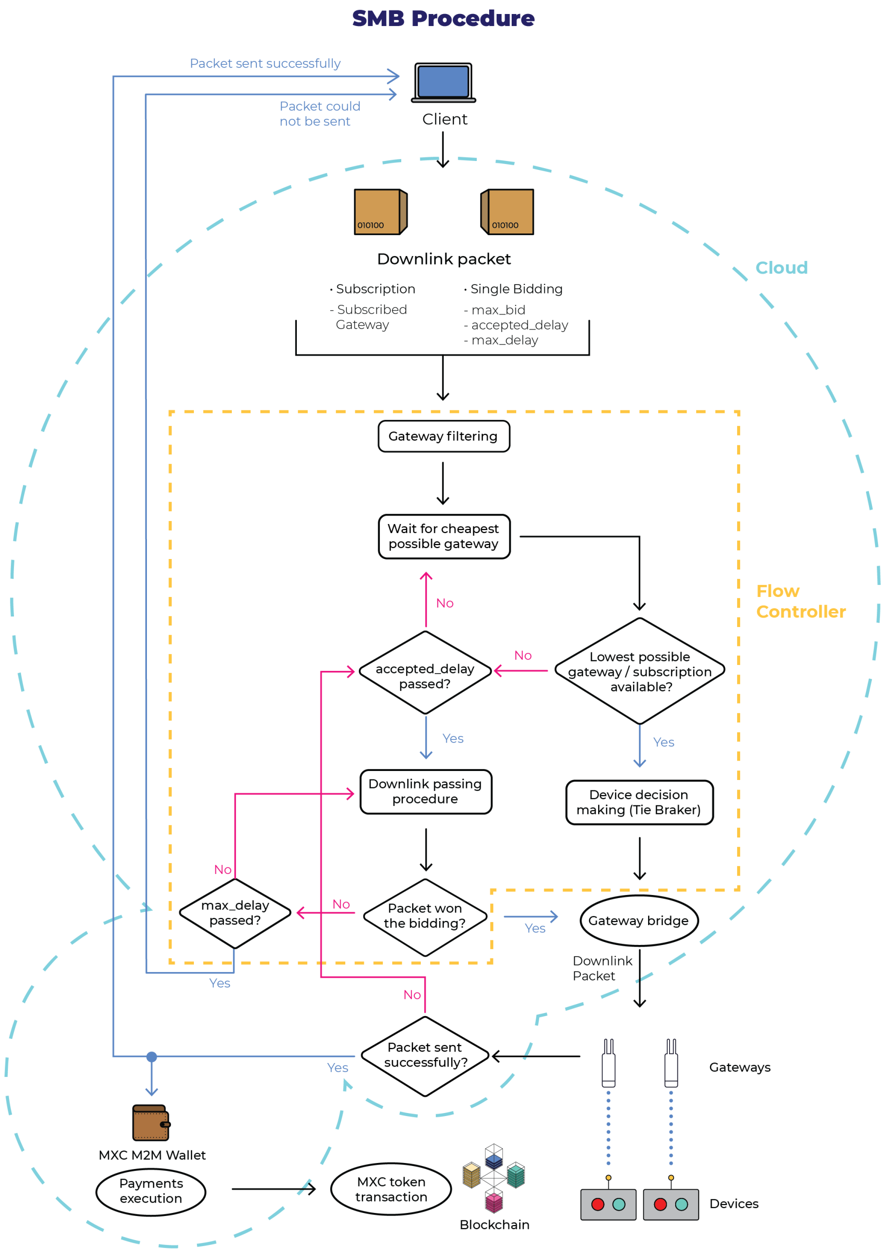


Figure 2: MXC Smart Machine Bidding (SMB) procedure

- The downlink packet will wait (until *accepted_delay* is reached) for the lowest possible *min_bid* price. If a gateway with a cheaper *min_bid* is currently busy and it is able to transmit the downlink packet later, the request will wait in the queue of the *flow controller* for the cheaper downlink resource. When the *accepted_delay* is reached, the downlink request will be passed to the *downlink passing procedure* where bidding among different packets take place.

- Downlink request can only be sent during the *max_delay*. If the *max_delay* is reached, the downlink request will not be sent and the client (whom the downlink request is from) will be notified about the failure to send the packet.

These conditions will determine which of the following scenarios will happen:

1. Single available gateway, single request:

   The downlink packet request will be transmitted if the *min_bid* offered by the gateway owner is less than or equal to the *max_bid* offered by the device owner. Payment for this transmission will be equal to the *min_bid* value.

2. Multiple available gateways, single request:

   The cheapest available gateway (if gateway *min_bid* $\leqslant$ device *max_bid*) will be used. If multiple gateways offered the same *min_bid* price, *device decision making* procedure [12] will be used to select between those gateways.

3. Single available gateway, multiple requests:

   The downlink request with the greatest *max_bid* is the bidding winner and will be passed to the available gateway (if gateway *min_bid* $\leqslant$ downlink request *max_bid*). The price that the bidding winner will pay for the transaction is equal to the second greatest *max_bid* price. If the second greatest *max_bid* is less than the *min_bid* of the gateway, the *min_bid* will be considered as the price. Consider the example below:

[12] will be discussed in 4.3.2

Table 1: Single available gateway, multiple requests example

Bid A	Bid B	Bid C	Gateway min_bid	Bidding winner	Payment
4	8	12	4	C	8
4	8	12	9	C	9
4	8	12	14	-	-

In the above table, three devices A, B, and C have set *max_bid* values equal to 4, 8, and 12 MXC. When the *min_bid* value offered by the gateway is 4, device C is the bidding winner and pays 8 MXC to the gateway. When *min_bid* is 9, device C should pay 9 MXC to use the downlink resource. If *min_bid* value offered by the gateway is 14, none of the devices will be the bidding winner as *min_bid* value offered by the gateway is greater than all of the *max_bid* values defined by the devices.

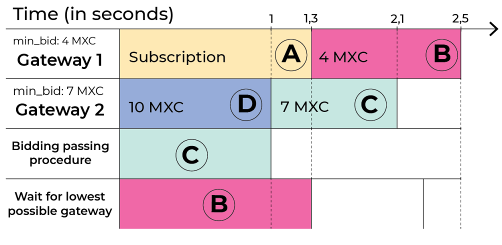
In *single available gateway, multiple requests* scenario, when multiple downlink requests have the same greatest *max_bid* values, the winning bid is chosen on a *first come first serve* basis. Note that, a gateway will become available after it finishes the last transmission it was responsible for. Both the downlink request packets and the availability of gateways comes one by one (not in a batch). The SMB procedure performs promptly in the cloud; therefore *multiple available gateways, multiple requests* scenario will not take place. In rare special cases, first come first serve converts this scenario to either *multiple gateways, single request* or *single gateway multiple requests*.

4.3.2 Device Decision Making

When multiple gateways with the same *min_bid* price are available, device will choose which gateway to use. The device decision is made using the following conditions:

- Predefined gateway(s) by the device (e.g. subscription)
- Gateway with higher RSSI and SNR[13] of the received uplink packet
- Gateway which receives the uplink packet first

[13] Signal to Noise Ratio



Bidding → Parameters / Device ↓	Subscription	max_bid	accepted_delay	max_delay
A	Gateway 1			
B	No	20	6	10
C	No	10	0	8
D	No	12	0	3
E	No	8	1	1

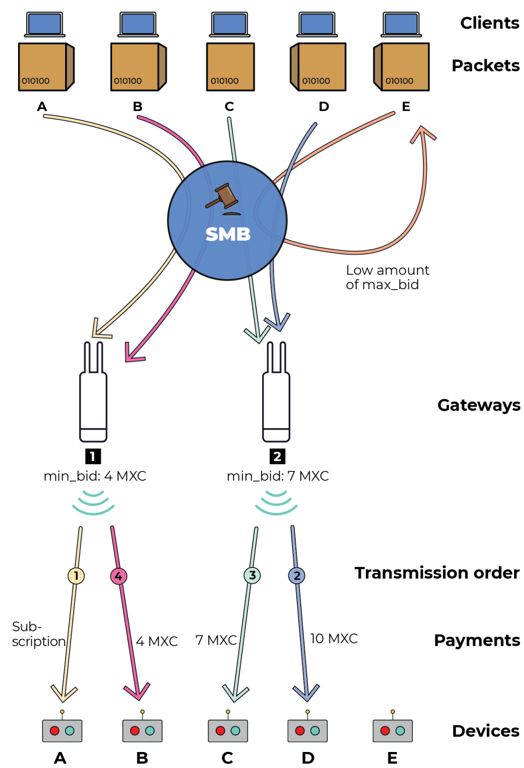


Figure 3: SMB procedure example. In this scenario five clients (A, B, C, D, and E) have downlink requests to be transmitted to their corresponding devices by the MXC LPWAN using available gateways 1, and 2. Bidding details of the downlink requests are given in the upper right table. The upper left table demonstrates situations of the packets, gateways and the flow controller during the passing of time. The lower figure is an illustration of the events of the scenario.

5 Data Driven Smart Machine Bidding Services

In order to make the MXC LPWAN for IoT devices more efficient and cost effective, data driven services (based on AI[14] methods) will be employed. Based on the user defined bidding strategies and parameters, and the flow of the data on the network, data analysis and machine learning methods will be used to provide automated bidding procedures, recommendations, scheduling, and fault / fraud detection. In the following sections, these services are discussed in detail. Figure 4 provides an abstract on data driven AI services of the SMB.

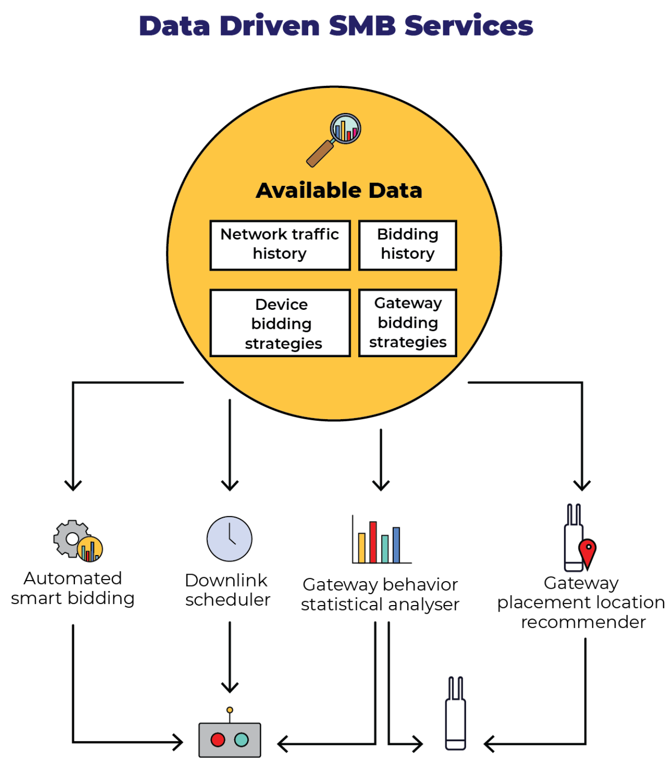


Figure 4: MXC Smart Machine Bidding Data Driven Services

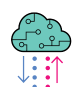
Note that the flow of data on the MXC LPWAN is end to end encrypted; meaning both the security of data and the data ownership are totally respected

[14] Artificial Intelligence

and guaranteed by the MXProtocol. The flow of anonymous data on the MXC LPWAN is used to provide the data driven algorithms. Since the MXProtocol is open source and the source code will be available to the community, no interference can affect the data and the user privacy issues of the MXProtocol. Additionally, two levels of encryption, one for application payload and LoRaWAN MAC commands (NwSKey), and the other one for the end to end encryption of application payload (AppSkey) are used in the LoRaWAN protocol and are bound in the MXProtocol[15].

5.1 Automated Smart Machine Bidding

Based on the downlink/uplink data flow on the MXC LPWAN, the MXC cloud can provide data driven automated SMB and corresponding recommendations for devices (and device owners) as outlined below:



5.1.1 Subscription Recommendations

Based on the device data flow history and the available subscriptions (provided by the gateways), the SMB recommends subscriptions to best meet the need of the device owners. Hybrid recommendation methods[16] based on elements such as bidding history, similarity of packet transmission patterns, and defined bidding parameters by the users, will be used to provide the most appropriate subscription recommendations.

5.1.2 Automated Bidding Parameter Determination

If the device is using single bidding strategies (auction or fixed price), *max_bid* parameter should be provided by the device owner or the corresponding client. *accepted_delay* and *max_delay* parameters are related to the application and priority of the data which is known by the device owner/client. *accepted_delay* and *max_delay* are set based on the requirements of the device and its data priority.

[15] More details can be found in the LoRaWAN security white paper provided by LoRa Alliance

[16] Combination of collaborative filtering and content-based filtering

On the other hand, *max_bid* parameter should be provided by the device owner (or client) to balance the priority of the uplink/downlink packets and the corresponding data transmission cost. Alternatively, *max_bid* (or multiple *max_bid* values based on multiple priority groups) can be automatically provided for the device owner to achieve this balance. SMB data driven algorithms can automatically determine *max_bid* based on the priority of the data, aggregate payment limit (for all of the transmissions) set by the device owner, and the downlink resource usage history of the device(s).

5.2 Downlink Scheduler

In some applications, devices with low priority data are not restricted to transmit the downlink data at fixed time slots, and the downlink transmission time can be flexible. If appropriate transmission time slots get prepared for these low priority data, the device owner should pay less amount of MXC tokens for LPWAN resource usage and also LPWAN traffic will be handled; so downlink scheduler can optimize both cost and the quality of the services of the LPWAN.

Downlink scheduler service of the SMB can provide appropriate time slots (cheap and safe) for the low priority data of the devices. Note that SMB downlink scheduler works with respect to listening time of the device. Time series analysis based on traffic history, bidding history, and data priorities will be used to provide the MXC downlink scheduler service.

5.3 Gateway Behavior Statistical Analyser

It is possible that a gateway accepts a downlink request, however it does not transmit it properly. This might happen either when the gateway is damaged, or when the gateway is attempting fraud to gain more money.

It should be noted that it is possible that a few downlink requests (transmitted by a normal gateway) will not be delivered to the devices. As an example, consider a sensor on a bike. Based on the movement of the bike, in some places the downlink packet might not be delivered to the bike sensor as it is out of range of the gateways.

An intelligent service is needed to provide dedicated analysis on gateway behavior based on statistical methods. This can be done by pattern analysis of sent packets (e.g. join requests) by devices to the gateway. The correlation of the gateway's behavior with other gateways which were used to transmit recent packets to the same device can also be used for gateway behavior statistical analysis.

Based on the statistical analysis of gateway behavior, rating (and ranking) will be assigned to the gateways. This information can be used by device owners to define restrictions on the gateways they want to use. Based on the detected faulty gateways, machine learning methods will be used to detect patterns of a faulty gateway's behavior in order to detect other faulty gateways.

Let's discuss possibility of detecting a faulty gateway; it is achievable based on the last n transmitted downlink packets of the gateway, and the history of the packet transmissions in the MXC LPWAN. Consider the following definitions:

- G_1: Normal gateway (considering the downlink transmission pattern)
- G_2: Faulty gateway (considering the downlink transmission pattern)
- X: x_1, x_2, ..., x_n (last n downlink packets transmitted by a single gateway)
- $p\ (G_1 \mid X)$: probability of observing a normal gateway considering X
- $p\ (G_2 \mid X)$: probability of observing a faulty gateway considering X

Lets define $s(X)$, as status of a gateway based on its last n transmitted downlink packets X as below:

$$\begin{aligned}
s(X) &= \frac{p(G_1|X)}{p(G_2|X)} \\
&= \frac{p(X|G_1)p(G_1)}{p(X|G_2)p(G_2)} && (\textit{based on Bayes' theorem}) \\
&= \frac{p(x_1, x_2, ..., x_n|G_1)p(G_1)}{p(x_1, x_2, ..., x_n|G_2)p(G_2)} \\
&= \Pi_{i=1}^{n} \frac{p(x_i|G_1)}{p(x_i|G_2)} \times \frac{p(G_1)}{p(G_2)} && (\textit{i.i.d. data})
\end{aligned}$$

Distribution of X is considered i.i.d.[17] to simplify the model. It is possible to consider more complex models for gateway behavior analysis by considering X as a sequence with non-independent elements. Note that to provide more complex models, sufficient amount of train data (for hyper parameter optimization and probability density estimation) and powerful computational resources are needed.

$p(G_1)$ is the ratio of the normal gateways to all of the gateways in the MXC LPWAN. This value can be estimated based on the real data flow on the LPWAN and number of gateways detected as faulty (e.g. based on experimental data, statistical analysis, or provided data by gateway manufacturers). Lets call this estimation λ. By the definitions of $p(G_1)$ and $p(G_2)$ we have:

$$\lambda := p(G_1)$$

$$p(G_1) + p(G_2) = 1 \Rightarrow p(G_2) = 1 - \lambda$$

$$s(X) = \Pi_{i=1}^{n} \frac{p(x_i|G_1)}{p(x_i|G_2)} \times \frac{\lambda}{1-\lambda}$$

$p\ (x_i \mid G_1)$ is be calculated using distribution of transmitted packets by normal gateways (G_1). A feature vector should be defined for x. The time of receive of the next uplink packet from the receiver device of the downlink packet, and the time of receiving the next join request from the same device are two features of x; other features can also be defined. Probability density functions (PDF) of G_1 and G_2 are estimated over feature space of x using non parametric probability density estimation methods such as KDE[18]. Lets call PDF of G_1 over feature space of variable x as $f_1(x)$ and PDF of G_2 over x as $f_2(x)$. These PDFs are estimated using flow of data on the MXC LPWAN (either experimentally or statistically). Estimations on $f_1(x)$ and $f_2(x)$ can get improved over the time as more data flow through the MXC LPWAN. So, calculation of $s(X)$ continues as below:

[17] Independent and Identically Distributed
[18] Kernel Density Estimation

$$
\begin{aligned}
s(X) &= \Pi_{i=1}^{n} \frac{p(x_i|G_1)}{p(x_i|G_2)} \times \frac{\lambda}{1-\lambda} \\
&= \Pi_{i=1}^{n} \frac{f_1(x_i)}{f_2(x_i)} \times \frac{\lambda}{1-\lambda} \\
&= exp(ln(\Pi_{i=1}^{n} \frac{f_1(x_i)}{f_2(x_i)} \times \frac{\lambda}{1-\lambda})) \\
&= exp(\Sigma_{i=1}^{n} ln(\frac{f_1(x_i)}{f_2(x_i)}) + ln(\frac{\lambda}{1-\lambda}))
\end{aligned}
$$

By the above equation, *s(X)* can be calculated for each gateway based on its last *n* transmitted downlink packets (X). Based on definition of *s(X)*, by follow conditions status of a gateway can be determined automatically:

- *s(X)* $\geq$ *1* $\Rightarrow$ Gateway is detected as normal
- *s(X)* $<$ *1* $\Rightarrow$ Gateway is detected as faulty

When faulty gateways are detected by *s(X)*, multiple actions can be taken. Behavior of the faulty gateway can be observed more dedicatedly to detect the problem. It is also possible that the gateway owner be notified to repair the gateway or relocate it. In special cases, the gateway can be removed from MXC LPWAN to improve LPWAN quality and reduce number of lost packets.

5.4 Gateway Placement Location Recommender

Some gateway owners want to add new gateways to the MXC network. The gateway owners need to know where they should put their gateways to gain more money (it will also improve the service quality of the MXC LPWAN). The locations with higher packet transmission density need more gateways. Based on the history of data transmission flow, bidding history, and geographical location of gateways and devices, data driven services of MXC can detect near-optimal places for new gateway placements. Gateway placement location recommender system will be useful both for gateway owners and optimization of the service quality of MXC LPWAN (which will be useful for devices).

In figure 5, an example on gateway placement location recommendation is provided. The area is covered by four gateways. Determined *min_bid* prices (in MXC tokens) can be seen in the figure. Two locations (shown by bold pink dot) are suggested to provide new gateways. Note that in this figure details about pricing by ADR which is discussed in chapter 6 are not considered to provide a better understanding on the main idea of the gateway placement location recommender.

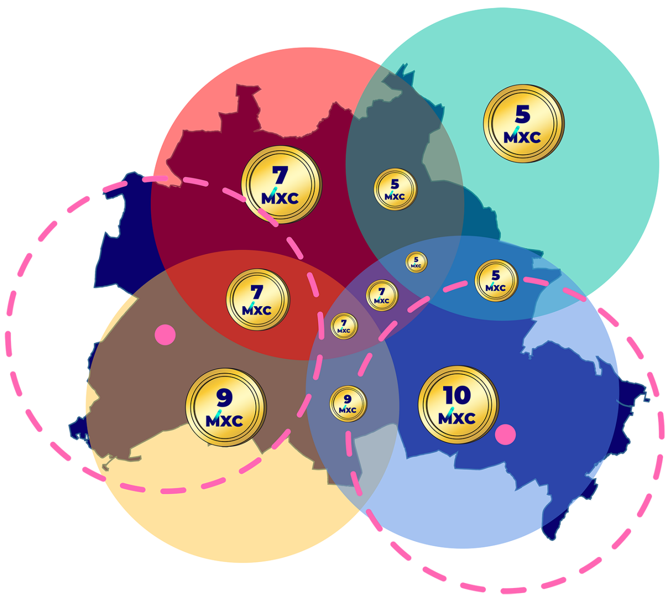


Figure 5: Gateway placement location recommender. Four gateways are available with shown *min_bid* prices. New location suggestions are shown by bold pink dots and dashed lines.

6 Smart Machine Bidding ADR

In the previous chapters, in order to provide a better understanding, SMB strategies and pricing policies were discussed based on the bidding on each individual packet. Now, the exact details regarding bidding payments of the SMB based on Time on Air (ToA) of the packet shall be discussed:

6.1 Time on Air

The required transmission time for a packet sent from a gateway is called *time on air*[19]. Time on air is not a fixed value for all of the packets, and subsequently has many variables, depending on various factors and parameters. In SMB procedure, provided bidding values from gateways and devices are compared based on the *time on air* of each packet. Indeed, the *time on air* of a packet can be considered as the main load of a packet (downlink/uplink request) on the LPWAN. When we consider *time on air* for SMB pricing policies, fair pricing will be provided, which allow users (and also developed applications and firmwares) to use the LPWAN resources in an optimum way. All of these mechanisms result in an overall improvement in the quality of the MXC LPWAN services. Two main factors can influence *time on air* value of a downlink packet transmission:

- **Packet Size**

  The transmission time of a packet has a direct correlation with the size of the packet (smaller packets, shorter *time on air*). For example, controlling packets (e.g. join request) are often small and therefore take less time to send. In regards to pricing policies based on *time on air*, payment for the small packets is subsequently less than packets with considerable payload size.

- **Spreading Factor (SF)**

  Spreading factors are used to determine the data transmission rate in correspondence with the transfer range (distance between the gateway and the device). As the SF increases, the data transmission rate will drop, time on air will increase, and the signal is able to cover a wider range.

In general, *time on air* vary for different packets. Gateways can provide subscriptions based on *time on air*, downlink volume or even unlimited downlink resource usage. Each Gateway provides the *min_bid* of single bidding strategies for a unit of time on air. Devices will bid based on a packet (or the packet size,

[19]Also known as airtime

based on their choice). SMB allows for the individual calculation of *time on air* of each packet. The real value of *max_bid* parameter of each packet on a gateway downlink resource and the competition to use a downlink resource, refers to two factors. First, the bidding prices (*max_bid* and *min_bid*), and second the *time on air*. The ratio of *max_bid* per *time on air* is the bidding decision making criteria; this ratio is named *bid_merit*, highlighted in the following example:

Table 2: Bidding Merit Explanation

downlink request	**max_bid** MXC	**time on air** second	**bid_merit** MXC/second
A	4	1	$4/1 = 4$
B	9	3	$9/3 = 3$

As shown in table 2, packet *A*, and *B* are competing to use a downlink resource with shown *max_bid* and *time on air* parameters. Procedure to select the bidding winner is based on the *bid_merit*. As in the example above, although *max_bid* of packet *B* is greater than *max_bid* of packet *A*, and *B* is willing to pay more MXC tokens for the downlink transmission, the bidding winner is *A*, since it has a greater value of *bid_merit*.

6.2 SMB Spread Factor Based Bidding

MXProtocol is also LoRaWAN protocol compatible and uses SF7 to SF12 [20]. SF7 provides the shortest time on air while SF12 provides the longest. Each unit increment in the spreading factor, doubles the *time on air* of a packet transmission. e.g. transmission rate of SF10 is two times of SF11's. Vice versa, *time on air* of SF11 for a packet is two times of SF10s for the same packet.

If a gateway needs to use a higher value of SF to transmit a packet, *time on air* of that packet will increase and therefore, *min_bid* should also increase. In other words, *min_bid* of each gateway with different SFs should be different. To define prices for each SF, the gateway owner defines *min_bid* prices for SF12; *min_bid* of the same gateway, for other spreading factors, are automatically calculated by:

[20] Based one the region it may vary

$$min\_bid(g,i) \ = min\_bid(g,12) \times 2^{(i-12)} \tag{1}$$

when *min_bid (g,i)* is *min_bid* price provided by gateway *g* for SF#i (e.g. if *i* is equal to 10, *min_bid* of gateway *g* on SF10 is considered). Based on *min_bid (g,i)*, SMB procedure will calculate the respective bids and determines the bid winner.

6.3 Smart Machine Bidding ADR

The Adaptive Data Rate (ADR) of the LoRaWAN protocol is responsible for adaptation of spreading factors(SF) of the devices to achieve the fastest data rate taking the transmission range into consideration. Based on the SMB procedure, and in order to provide minimal payments in the network, MXProtocol ADR is different from LoRaWAN ADR. The following is a simplified version of the MXProtocol ADR.

The downlink packet should be sent by a specific SF based on the used SF for transmission of the last uplink packet from the same device. When a downlink packet is sent, the MXProtocol ADR will provide the best SF for the device to send the next uplink/downlink packets. The main idea behind the MXProtocol ADR is that the lowest possible price for the current downlink packet of a device (if it was possible to modify SF for this packet) with a high probability, is also the best price for the next packet of the same device. The MXProtocol ADR works as stated below:

The lowest bidding price for a device (*optimum_bid(d)*) considering *min_bid* (provided by the currently in range gateways) and the least possible SF of the gateway (which covers the device) is calculated by:

$$optimum\_bid(d) := \min_{g=1:G} 2^{(optimum\_SF(g,d)-12)} \times min\_bid(g) \tag{2}$$

when *optimum_SF(g,d)* is the lowest possible SF of gateway *g* and is able to transfer packets to/from device *d*. The best gateway (with high probability) that can be used for the next packets sent by device *d* is called the *optimum_gateway(d)*. It must be noted that it is possible that another gateway rather than *optimum_gateway(d)*, will be used for the current downlink packet of device *d*, as the SF may not be specifically tuned for the current packet; MXProtocol ADR, however will manage it for the next packet.

$$optimum\_gateway(d) := \arg\min_{g=1:G} 2^{(optimum\_SF(g,d)-12)} \times min\_bid(g) \qquad (3)$$

When *optimum_gateway(g)* is the cheapest gateway in range and is able to transfer packets with device *d*. The best SF for transmitting the next packet of device *d* is called *next_SF(d)* and is calculated as below:

$$next\_SF(d) := optimum\_SF(optimum\_gateway(d), d) \qquad (4)$$

next_SF(d) will be passed to the device that will be used for the next uplink/downlink request. If a device has a subscription with a gateway, the most sufficient SF for that gateway (which can be calculated by LoRaWAN protocol ADR) will be passed to that device.

7 Uplink Payments

MXC tokens will be used to pay for the utilized LPWAN resources. The payments calculated by MXProtocol will be executed on MXC M2M wallets owned by the device and gateway owners. Aggregation of a group of multiple transactions of a single user will be placed onto the blockchain. All payments related to the downlink resources are based on the SMB as discussed previously. Payments for the uplink resources, are calculated as follows.

There is a fundamental difference between a downlink and an uplink packet in the LPWAN. A downlink packet is passed to a gateway by a cloud (e.g. MXC cloud) and the downlink transmitter gateway will receive the payment for the transmission of that packet. On the other hand, the uplink packets are received by multiple gateways (all gateways which are in range of the device and can detect it will receive the uplink packet). Therefore, uplink payments can not simply be allocated to a single gateway. An uplink pricing policy is needed to avoid misuse of LPWAN uplink resources by some devices. That is why the SMB has uplink payment solution that addresses this issue. Based on the SMB uplink payment solution, device *d* has freely allowed the uplink volume of:

$$allowed\_uplink(d) := \alpha \times allowed\_downlink(d) \tag{5}$$

In the equation above, α is a constant value, and *allowed_downlink(d)* is the downlink volume allocated by device *d* (based on *time on air*). The *allowed_downlink(d)* is considered in both subscription, and single bidding strategies.

If the device needs more uplink resources than the previously mentioned amount, the device will then pay for the extra uplink usage. The payment amount for a unit of extra uplink is calculated by:

$$extra\_uplink\_price := \beta \times avg\_downlink\_price \tag{6}$$

β is a constant value. *avg_downlink_price* is the average of downlink payment (for a unit of the *time on air*) in the network, area, or the whole MXC based networks. Payments received by extra uplink will be used indirectly to pay MXC LPWAN (super node) owners and the rest will turn to deflation in the network. Constant values α, β and the selection of which *avg_downlink_price* (network, area, etc) to use, will be determined through community voting. More details in this regard will be provided in further MXC announcements.

8 User Interfaces

Device and gateway owners are able to provide their bidding strategies and related parameters in the MXC dashboard (user panels). The provided values are then stored and used in the MXC cloud in order to carry out the smart machine bidding calculations. Device and gateway owners will be able to monitor what has happened to each of their packets as well as the bidding process of their packets; this will be visible via reports and logs which will be made available to eligible users. Gateway and device users will then be able to change their bidding strategies and related parameters based on these reports.

8.1 Dynamic Bidding API

Incorporating smart machine bidding (SMB), APIs will be readily available to user and gateway owners in order to provide dynamic bidding (dynamic pricing). Using these APIs, the users can dynamically change their individual parameters and bidding strategies. This feature allows the SMB to act as a real auction market resulting in more affordable market prices and an increased quality network service. For example: a gateway owner can write their own software [21] based on SMB APIs which will allow changes to the gateway's *min_bid* price dynamically according to network traffic and requests.

8.2 Device User Panel

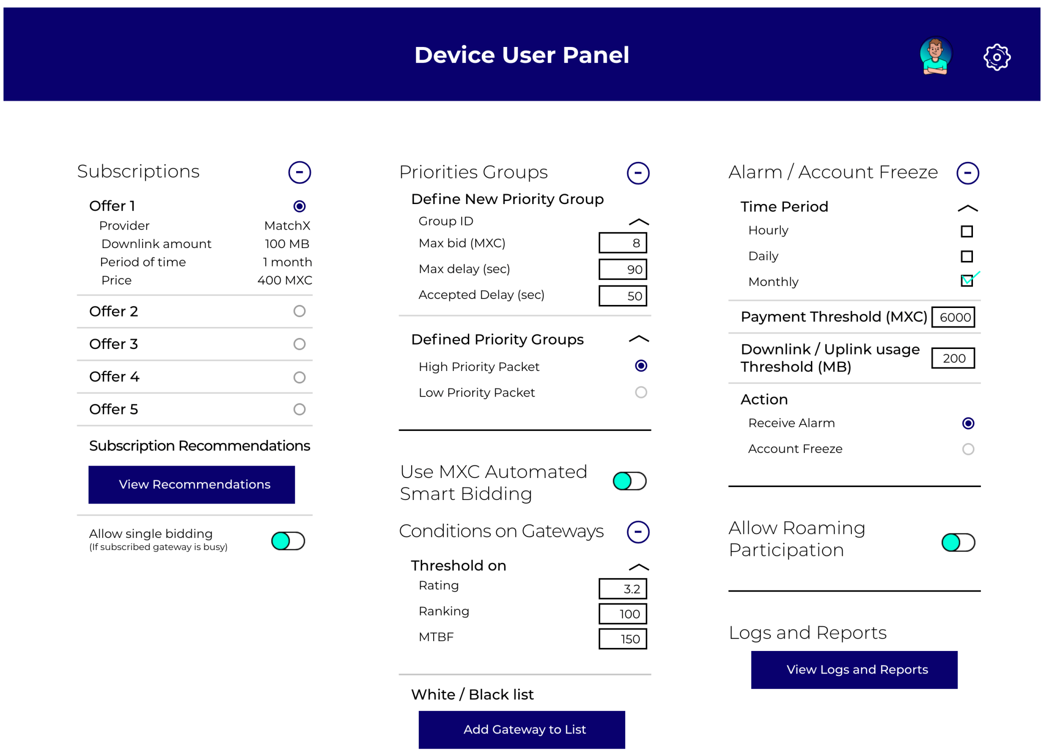


Figure 6: Device user panel

[21] Alternatively, the software can be provided by third parties

As shown in figure 6, the device user panel provides the ability to select a variety of options; including subscriptions, define priority groups (and corresponding parameters), enable MXC automated SMB, define conditions on the gateways, place a threshold on payments, and view logs and reports.

8.3 Gateway User Panel

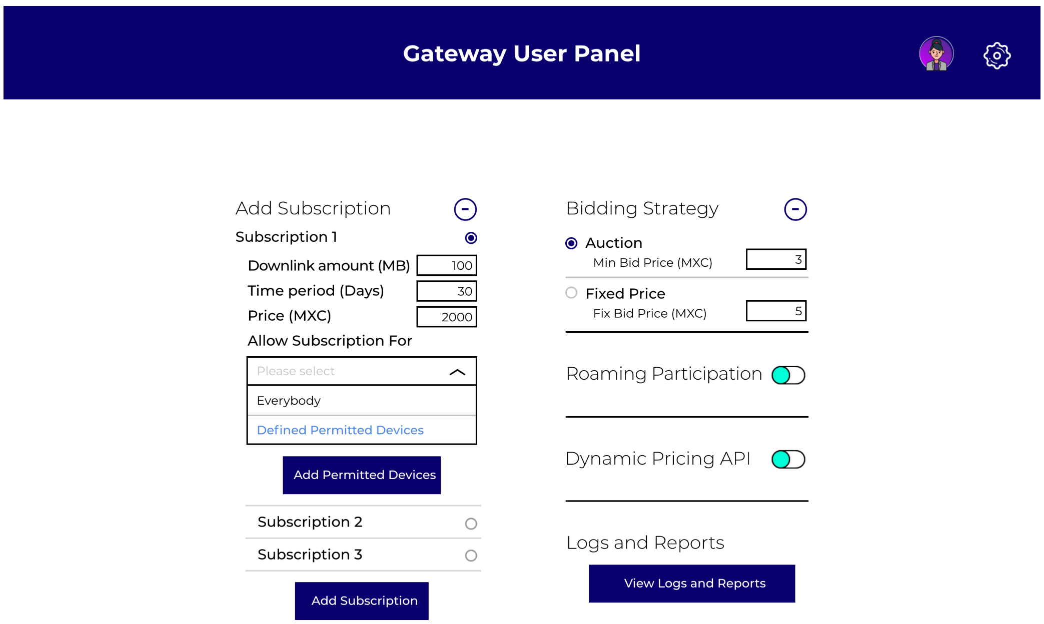


Figure 7: Gateway user panel

The gateway user panel is shown in figure 7. The gateway owner can add subscriptions, define permitted devices, provide bidding strategies, enable/disable dynamic pricing API, and view logs and reports.

9 Reference

- Machine Xchange Protocol. Premium Network Infrastructure, Infinite Data Stream. White paper. MXC Foundation, 2018
- Powering the decentralised global IoT data network. Economical white paper. MXC Foundation 2018
- Full end–to–end encryption for IoT application providers. White paper. LoRaWAN TM security. By gemalto, actility and semtech, 2017
- Literature Review: Machine learning techniques applied to financial market prediction, Henrique Et al., Expert Systems with Applications, 2019
- Setting smarter search bids inside automated bidding with AdWords. White paper. Google TM, 2018
- LoRaWAN range, part 1: The most important factors for a good LoRaWAN signal range. https://smartmakers.io/, 2018
- Basics of Algorithmic Trading: Concepts and Examples. Shobhit Seth. https://www.investopedia.com, 2019
- Spreading factor (SF), time on air and (adaptive) data rate. Lennart Nordin. https://zakelijkforum.kpn.com/
- LoRaWAN TM 101 A Technical Introduction, LoRa Alliance