# CTRL – IoT

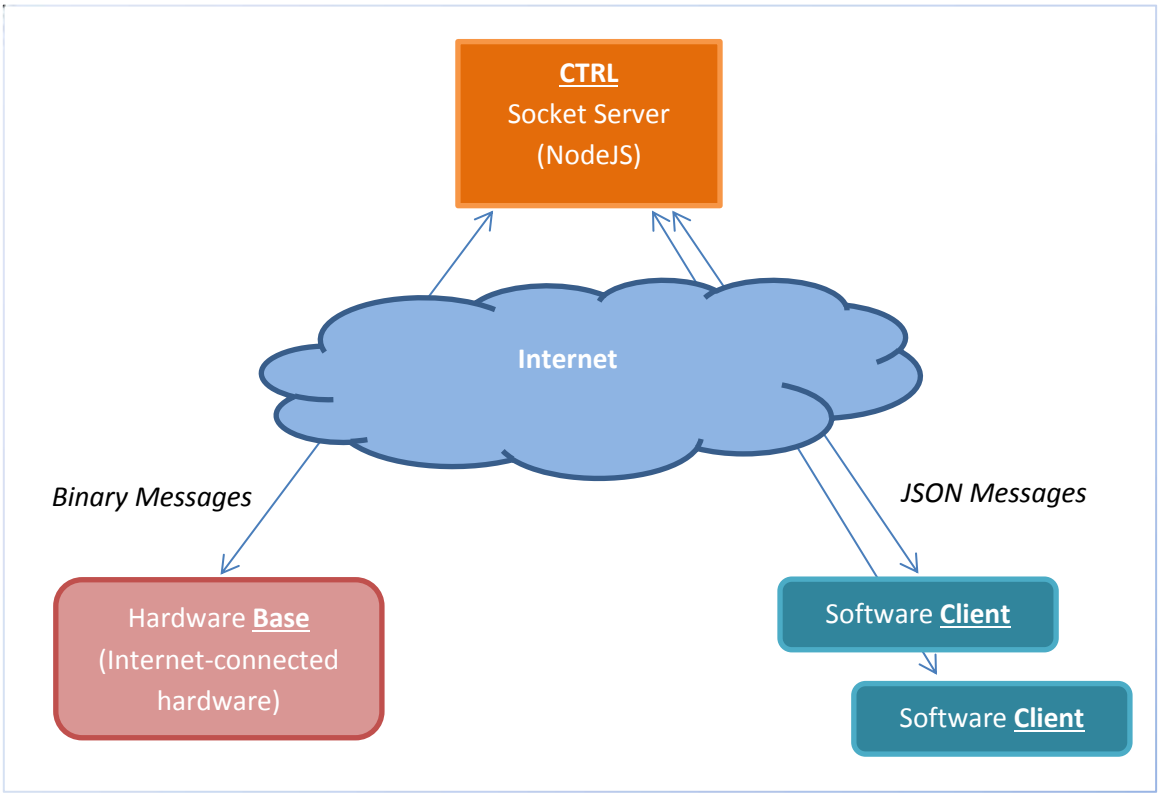
## Contents

## Introduction

The idea is to connect the Base(s) and Clients to Server and exchange messages between Base and all associated Clients currently connected to Server. All associated but unconnected Clients will receive messages from Base(s) once they connect to Server. There can be multiple Clients associated to one Base, and multiple Bases can be controlled by the same client. This is different from the previous version in which number of Clients could control just one Base.

System consists of these parts:

1. Base Station (**Base**) – Internet-connected hardware
2. Software Client (**Client**) – Internet-connected software: Web app, Android app…
3. Socket Server (**Server**) – Server written in NodeJS that accepts connections from many Bases and Clients (some might know it as *the Cloud*)




*Basic idea (shows just one Base with multiple Clients for **that** Base)*

Client can send a message that will be delivered **to all** or **just one targeted** Base (which it owns) but Bases send messages to **all** associated Clients, meaning that Base can't target a particular Client for message delivery.

## Message Exchange Protocol

Important aspect of message forwarding is to ensure that messages which are forwarded through Server **are delivered** to their destination **in order** they were sent out from the sender. Even though TCP sockets are used for communication, there is no “out of the box” mechanism to ensure that sending party knows that message went through and was delivered to Server. TCP will generate a *timeout* in case connection breaks but until that happens sender doesn’t know what has been delivered to Server and what hasn’t.

Message Exchange Protocol features:

- Ensures message delivery by using message queues
- Handles acknowledgements of received messages
- Makes sure that message re-transmissions are ignored but acknowledged back
- Supports notification-type messages which are not acknowledged back and not re-transmitted in case of failure of delivery
- Supports system-type messages which are not forwarded to other party (from Base -> Client and vice versa) which are used for system-related operations (for example: Base can privately communicate with Server and ask for current Timestamp for its internal RTC)
- Supports “Back-off“ acknowledgements with exponential delay increments to inform the sender to delay sending further messages (implemented only for Binary Messages for communication between Server<->Base)

Server talks to Clients by using JSON Messages and to Bases by using Binary Messages. Talking to Base uses Binary Messages because Bases are usually small micro-controller solutions which do not have plenty resources to parse JSON, so Server is happy to bridge these two types of messages together.

Each type of message contains a **Header**, **TXsender** and **data** sections. **Header** section contains important bits about the message itself (whether it is an acknowledgement, a system-type message, or a notification-type message and so on). **TXsender** is used for synchronization between sender and a receiver and is used to check whether received message is a re-transmission, new message, or if sender and receiver are out of sync. Payload in “**data**” section is binary data in case of Binary Messages and for JSON Messages it is in hexadecimal ASCII format!

Format of JSON and Binary Message is naturally different but meaning of sections and fields are the same.

## JSON Messages

This message type is a string of JSON with three sections: **header**, **TXsender** and **data**. Optional fourth section is **baseid** which is used when sending message to just one targeted Base. Each message is terminated by a New-Line character (\n) so it is important to never introduce this character in message itself except at the very end where it actually ends. Section "data" is encoded in hexadecimal ASCII format and should always contain even number of hexadecimal characters.

Example of JSON Message:

```
{
    „header": {
        „sync": false,
        „ack": false,
        „processed": false,
        „out_of_sync": false,
        „notification": false,
        „system_message": false,
        „backoff": false
    },
    „baseid": ["01234567890123456789012345678901"],
    „TXsender": 5081,
    „data": „68656c6c6f20776f726c6421"
}
```

### *Header – section*

| Property | Value | Description |
|---|---|---|
| **sync** | true/false | Tells the receiver of this message to sync to „0". Used only in authentication procedure when socket connection is first (re)created. |
| **ack** | true/false | Means that this message is an acknowledgment of previous message with the same TXsender value provided. |
| **processed** | true/false | Tells whether the receiving side processed this command. (It is not processed only if it was a re-transmission). This bit is used only if this message is an ACK. |
| **out_of_sync** | true/false | Tells that receiver is out of sync with the transmitter of the message with this TXsender. The sender of message should try re-sending all unacknowledged messages from its queue, and if failed to re-sync after *n* attempts should flush entire TX queue. This bit is used only if this message is an ACK. |

| | | |
|---|---|---|
| **notification** | true/false | Low priority messages that don't get ACKs back, and no re-transmissions in case of failure. Also TXsender field is not checked for sync (it is ignored and can be omitted from the message). |
| **system_message** | true/false | Tells to receiving side that this message is a private message between connected party and the server (not forwarded to/from either Base or Client). |
| **backoff** | true/false | Tells the receiver that this TXsender message is not received, and to delay sending further messages.<br>*Currently not implemented in Client<->Server communication because we assume that both Server and Client have enough storage space and processing power.*<br>This bit is used only if this message is an ACK. |

*Note:* In case any property is missing from Header section it is considered to be **false**.

### *BaseID – section*

This is an array of BaseID tokens of Bases that will receive this message. Targeted Bases must be owned (associated to) by the Client in order to forward the message successfully.
In case "baseid" section is omitted from JSON Message or an empty array is provided, the message will be forwarded to every Base associated by the sending Client!
*Note:* "baseid" parameter can (and should) be omitted in Special System Messages for communication between Client and Server.

### *TXsender – section*

This is the sequence ID of the transmitter. Its value increments from 1 to 2^32 (unsigned integer) and can only be reset to 1 during authentication procedure. This means that each connection can transfer 2^32 messages until it rolls over to 1.

### *Data – section*

This is the actual payload and is encoded in hexadecimal ASCII format. There is no actual limitation to the length of this data but Base can accept only first 65535 bytes (a bit less than that, which will be described in Binary Messages topic, and later on might be extended to more by using MQTT length-coding method).

## Binary Messages

This message type is a binary data stream which consists out of four objects: **Length**, **Header**, **TXsender** and **data**. There is no "termination character" after each message (binary data stream) but there is a **length** section which tells how many bytes follow for that particular message.

Example of Binary Message:

`0011000000001B668656c6c6f20776f726c6421`

Sections highlighted in example are:

- `0011` = **Length** section
- `00` = **Header** section
- `000001B6` = **TXsender** section
- `68656c6c6f20776f726c6421` = Section **data**

### *Length – section*

This section is always two bytes long and defines length of the message which follows. These two bytes are **not included** into the actual message length (in the example above we can see that entire binary data stream is actually 19 bytes long, but the **Length** section says 17 bytes).

*Note: Better idea would be to implement dynamic length instead of fixed 2-bytes for length. See MQTT protocol definition for this solution. This could be done in future version. http://public.dhe.ibm.com/software/dw/webservices/ws-mqtt/mqtt-v3r1.html#fixed-header*

### *Header – section*

This section is 1 byte long and contains flags which are important for the transmitted message.

| Flag (property) | Bit location | Description |
|---|---|---|
| **sync** | 0000000**1** | *Same as in JSON Messages* |
| **ack** | 000000**1**0 | *Same as in JSON Messages* |
| **processed** | 00000**1**00 | *Same as in JSON Messages* |
| **out_of_sync** | 0000**1**000 | *Same as in JSON Messages* |
| **notification** | 000**1**0000 | *Same as in JSON Messages* |
| **system_message** | 00**1**00000 | *Same as in JSON Messages* |
| **backoff** | 0**1**000000 | *Same as in JSON Messages* |
| *reserved* | **1**0000000 | |

### *TXsender – section*

This is the sequence ID of the transmitter. Its value increments from 1 to 2^32 (unsigned integer) and can only be reset to 1 during authentication procedure. This means that each connection can transfer 2^32 messages until it rolls over to 1.

### *Data – section*

This is the actual payload data and is a raw binary stream. In current implementation the limitation to the length of this data is 65535-sizeof(Header)-sizeof(TXsender).

## Authenticating the Socket Connection

After the socket connection is established from either Base or Client towards the Server, it must be authenticated. In case it doesn't get authenticated within a timeout, Server will close the connection. Bases authenticate by using their **baseid** and Clients authenticate by **auth_token**. Each unsuccessful authentication attempt is logged on Server and can be viewed. There is also a protection against brute-force attacks for both Base and Client accounts. Server checks for failed authentication attempts within past 5 minutes (configurable) for IP address which is trying to authenticate and in case of 5 failed authentication attempts (also configurable) it refuses the authentication attempt completely.

### Base Authentication Procedure

After Base establishes the socket connection to Server, it must send the authentication request message. Example of authentication request message (in hexadecimal format):

**0015HH00000000BABABABABABABABABABABABABABABA**

Explanation of sections:

- 0015 = length of message, always 0x15 (21 decimal)
- HH = **Header** section (please see *Synchronization Mechanism* for importance of Header section bits during authentication procedure)
- 00000000 = **TXsender** section (not important during authentication procedure)
- BABABABABABABABABABABABABABABA = **data** section, 16 bytes of your Base's **baseid**

After Server receives and processes the received authentication request message, it will reply with an authentication reply message. Example of authentication reply message (in hexadecimal format):

**0006HH00000000RR**

Explanation of sections:

- 0006 = length of message, always 0x06 (6 decimal)
- HH = **Header** section, **notification** bit is always set, and **system_message** bit is always set. (please see *Synchronization Mechanism* for importance of other Header section bits during authentication procedure)
- 00000000 = **TXsender** section (not important during authentication procedure)
- RR = **data** section, 1 byte of authentication result. Possible values that will be sent by the server are: 0x00 (AUTH **OK**) and 0x01 (AUTH **ERROR**).

### Client Authentication Procedure

After Client establishes the socket connection to Server, it must send the authentication request message. Example of authentication request message:

```
{
    „header": {
        „sync": (please see Synchronization Mechanism topic),
        „ack": ignored,
        „processed": ignored,
        „out_of_sync": ignored,
        „notification": ignored,
```

```
            „system_message“: ignored,
            „backoff“: ignored
        },
        „TXsender“: ignored,
        „data“: {
                „auth_token“: „my-secret-auth-token“
        }
    }
```

After Server receives and processes the received authentication request message, it will reply with an authentication reply message. Example of authentication reply message:

```
    {
        „header“: {
            „sync“: (please see Synchronization Mechanism topic),
            „ack“: false,
            „processed“: false,
            „out_of_sync“: false,
            „notification“: true,
            „system_message“: true,
            „backoff“: false
        },
        „TXsender“: 0,
        „data“: {
                „type“: “authentication_response”,
                „result“: 0,
                „description“: „Logged in.“
        }
    }
```

Section **data** contains object with three properties: **type**, **result** and **description**. Property **result** can have three values:

- 0 = Logged in.
- 1 = Wrong auth_token.
- 2 = Too many failed authentication requests.

Property **type** is a string containing word “**authentication_response**”.

Upon successful authentication of the Client, Server will send a Special System Message to inform the Client about the connection status of his associated Base. Please see *Special System Messages* topic for this.

## Synchronization Mechanism (Sequence Synchronization)

In order to implement re-transmissions and acknowledgements and to distinguish re-transmissions from new messages, a sequence number is introduced into the protocol. This sequence number is called TXsender, starts from 1 and increments by the sending party after each transmitted message. Maximum value it can get to is 2^32 (unsigned integer). In practice this sequence number will hardly ever reach its maximum value (and potentially rollover) because socket connection will probably break before it happens. After the socket connection breaks and re-connects, authentication procedure will take place where this sequence number gets a chance to reset (re-sync) to 1. In case it does get to its maximum value, socket connection must be restarted and re-synchronization will take place during authentication handshake. This sequence number has a capacity to send one message per second for 136 years until it rolls over, so this limitation is not to be worried about.

Each transmitting party has its own TXsender sequence number and is responsible for incrementing it and restarting to 1. Sequence numbers are not blindly restarted on each authentication handshake, but are restarted only if there are no pending messages on the sending party.

Socket connections are always originated by Base and Client towards the Server, so the handshaking procedure is as follows (example: Base is connecting to Server and authenticating…):

```
BASE OPENED A SOCKET CONNECTION TO SERVER:
   1. Base prepares an authentication message to send to Server
   2. Base checks to see if it has some pending messages to send to Server
   3. If it has pending messages in queue:
         a. Base doesn't set SYNC bit in Header and doesn't reset its internal
            TXsender value to 1 but continues from whatever value it had earlier
   4. If it doesn't have pending messages in queue:
         a. Base sets SYNC bit in Header, and resets its internal TXsender to 1
   5. Base now sends the authentication message to Server and waits for the reply
   6. ...
   7. Server prepares an authentication reply message to send to Base
   8. Server accepts the message and if authenticated it checks to see whether it
      must re-sync its copy of Base's sequence number to 0
         a. If SYNC bit is set in authentication request message:
               i. Server resets its copy of Base's TXsender to 0
         b. If SYNC bit is not set in authentication request message:
               i. Server doesn't alter its copy of Base's TXsender
   9. Server now checks to see if it has some pending messages to send to Base
   10. If it has pending messages in queue:
         a. Server doesn't set SYNC bit in Header of the reply message and doesn't
            reset its internal TXsender value to 1 but continues from whatever
            value it had earlier
   11. If it doesn't have pending messages in queue:
         a. Base sets SYNC bit in Header, and resets its internal TXsender to 1
   12. Server now sends the authentication reply message to Server and in case it
       had pending messages queue it will also start sending those pending messages
       to Base
   13. Base naturally receives this authentication reply message and if it also had
       some pending messages in queue it will start sending them to Server
   14. ...
```

*Pseudo-code*

If during communication either party receives an acknowledgement with out-of-sync bit set, that party should flush its pending messages queue and restart the socket connection that will re-synchronize sequence numbers.

For example: in case the Server receives out-of-sync acknowledgement, it should flush the queue and simply close the socket connection. The party to which Server was communicating will re-establish

the connection and continue with the authentication handshake which will re-synchronize the sequence number.
In case Base or Client receives the out-of-sync acknowledgement, it should flush the queue and restart the socket connection followed by the authentication and re-sync procedure as mentioned before.

## Special System Messages

This section describes special system messages which could be sent by Server (to Base and/or Client) at any given time on active socket connection.

### Special System Messages sent from Server -> Client

#### *Base Connection Status*

A connected Client can receive a system message from the Server when Base connects or disconnects from its socket. This message is also of type **notification** and is not re-transmitted and doesn't have to be acknowledged by the Client.

Example of this system message notification:

```
{
    „header": {
        „sync": false,
        „ack": false,
        „processed": false,
        „out_of_sync": false,
        „notification": true,
        „system_message": true,
        „backoff": false
    },
    „TXsender": 0,
    „data": {
            „type": "base_connection_status",
            „connected": true,
            „baseid": „babababababababababababababababa"
    }
}
```

Section **data** contains three properties: **type**, **connected** and **baseid**.

Property **type** will have word: "base_connection_status", property **connected** can have a Boolean value of true or false.

Since this is a message of type **notification**, the **TXsender** is ignored and will always have value: 0.

### Special System Messages sent from Client -> Server

#### *Pull unacknowledged messages*

Client can send a message to server that will force it to re-send all unacknowledged messages from its **txserver2client** queue. It should also be of type: **notification** but it is not obligatory.

Content of this message is (entire message example):

```
{
    „header": {
        „sync": false,
        „ack": false,
        „processed": false,
        „out_of_sync": false,
        „notification": true,
        „system_message": true,
        „backoff": false
```

```
        },
        „TXsender“: 0,
        „data“: {
                „type“: “pull_unacked”,
        }
    }
```

That’s it. After Server receives this system message it will start re-sending all unacknowledged items from its queue and hopefully Client will now receive them and acknowledge.

### Special System Messages sent from Server -> Base

There are currently no implemented special system messages which are sent to Base by the Server.

### Special System Messages sent from Base -> Server

#### *Pull unacknowledged messages*

Base can send a message to server that will force it to re-send all unacknowledged messages from its **txserver2base** queue. It should also be of type: **notification** but it is not obligatory.

Content of this message is (without protocol header sections, only payload **data** section):

```
01
```

That’s it. After Server receives this system message it will start re-sending all unacknowledged items from its queue and hopefully Base will now receive them and acknowledge.

#### *Enable Keep-Alive on current socket connection*

In case Base’s network hardware replies to Keep-Alive messages, this option can be enabled by sending the appropriate system message.

Content of this message is (without protocol header sections, only payload **data** section):

```
02
```

If Base’s network hardware supports Keep-Alive messages, it is strongly recommended to enable this option since it helps connected Clients know when Base’s socket connection drops almost immediately.

#### *Disable Keep-Alive on current socket connection*

In case Base’s network hardware replies to Keep-Alive messages, this option can be enabled by sending the appropriate system message.

Content of this message is (without protocol header sections, only payload **data** section):

```
03
```

**Note: Keep-Alive is disabled by default for each new socket connection.**

## Document Change Log

| Date | Changed By | Summary |
|---|---|---|
| **2014-09-08** | Trax, trax@elektronika.ba | Initial document write |
| **2014-09-09** | Trax, trax@elektronika.ba | Still writing initial document... |
| **2014-09-19** | Trax, trax@elektronika.ba | Changed the way OUT-OF-SYNC situation is handled. Added Special System Message to turn on/off KEEP_ALIVE on server side. |
| **2014-09-28** | Trax, trax@elektronika.ba | Changing system to support many Bases to many Clients instead just one Base per many Clients. |
| **2014-09-29** | Trax, trax@elektronika.ba | Changed the way Clients login, instead of using username/password there is now **auth_token** parameter for Client authorization. This token is generated by the PHP admin web site. |
| **2014-10-01** | Trax, trax@elektronika.ba | Changed baseid type in JSON messages to array, so that server can accept a group of BaseID's |
| | | |