AN3972
Application note

Home web console for ZigBee® smartplugs

Introduction

This document describes how to use the STM3210C-EVAL, based on the STM32F107VC microcontroller, as a web console to monitor and control a ZigBee® network of smartplugs. The application can be used as a reference for the development of a ZigBee - TCP/IP Networks Bridge and is an example on how, in a smartgrid scenario, the services offered by a ZigBee HAN can be exported to the Internet by an Ethernet/Internet gateway.

The STM32F107VC coordinates the ZigBee network through an SPZB260-PRO module included in an adapter connected by the expansion connectors of the STM3210C-EVAL; the ZigBee network is built using several STEVAL-IHP001V3s used to monitor and control several AC loads (lights, appliances, etc.) inside the HAN. The adapter also includes an M24LR64-R dual interface EEPROM to store the TCP/IP network configuration. In fact, in the microcontroller firmware, a web server is also implemented which allows to monitor the AC load power consumption measured by each smartplug and to control its status (ON/OFF).

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1 Document and library rules

This document uses the conventions described in the sections below.

1.1 Acronyms

Table 1 describes the acronyms used in this document.

Table 1. List of acronyms

Acronym	Meaning
APP	Application
API	Application programming interface
HAL	Hardware abstraction layer
RTOS	Real time operating system
HAN	Home area network
MCU	Microcontroller unit
SPI	Serial peripheral interface
OOP	Object oriented programming
EEPROM	Electrically erasable programmable read only memory
OS	Operating system
RTOS	Real time operating system
HA	Home automation
ZCL	ZigBee clusters library
SICS	Swedish institute of computer science
TCP	Transport communication protocol
IP	Internet protocol
HTTP	Hypertext transfer protocol
HTML	Hypertext markup language

2 Hardware kit

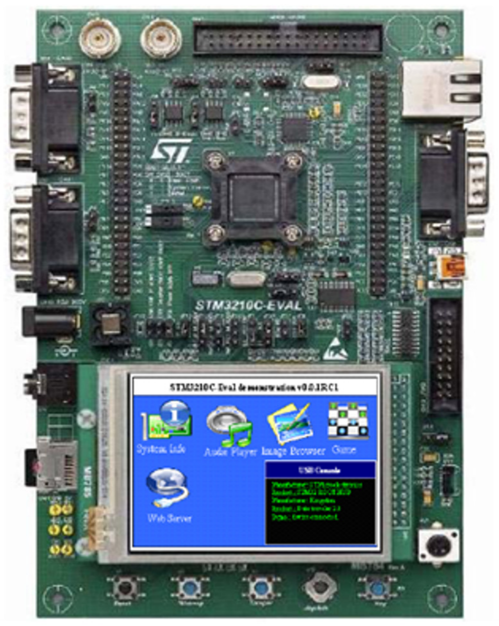
This section describes the hardware components necessary to set up the home web console demo kit:

- One STM3210C-EVAL board
- One SPZB260-PRO module adapter board for the STM3210C-EVAL
- Several ZigBee smartplug boards (STEVAL-IHP001V3).

2.1 STM3210C-EVAL demonstration board

The STM3210C-EVAL is a standard evaluation tool for the STM32F107xx microcontroller which includes an embedded Ethernet controller; this is the main feature necessary for the home web console. For further details about this board please refer to the UM0600 user manual.

Figure 1. STM3210C-EVAL demonstration board



The connectors CN8 and CN9, which include all the MCU pinouts, are used to connect the SPZB260-PRO adapter, so a specific configuration of the board is necessary to free some MCU I/O resources. The following is the board setup:

- To close jumper JP19
- To open jumper JP15
- To remove R79, R84 and R169.

Table 2 shows the pinout mapping of the connectors over the adapter.

Table 2. SPZB260-PRO adapter pin description

STM32 pin no.	Pin name	STM3210C-EVAL I/O assignment	Extension connector pin no.	ZigBee adapter I/O assignment
-	VDD	3.3 V	CN8-Pin 48	VCC_3V3
-	VSS	GND	CN9-Pin 50	GND
29	PA4	SPI1_NSS	CN9-Pin 41	ZIG_SS
30	PA5	SPI1_CLK	CN9-Pin 40	ZIG_SCLK
31	PA6	SPI1_MISO	CN9-Pin 38	ZIG_MISO
32	PA7	SPI1_MOSI	CN9-Pin 37	ZIG_MOSI
92	PB6	CAN2_TX/I2C1_SCK	CN8-Pin 36	I2C1_SCK
93	PB7	I2C1_SDA	CN8-Pin 37	I2C1_SDA
2	PE3	Trace_D0	CN8-Pin 42	ZIG_HOST_INT
3	PE4	Trace_D1	CN8-Pin 43	VCC-GPIO (for M24LR64-r)
4	PE5	Trace_D2	CN8-Pin 44	ZIG_WAKE
5	PE6	Trace_D3	CN8-Pin 47	ZIG_RSTB

2.2 SPZB260-PRO adapter

This board allows to add the ZigBee connectivity to the STM3210C-EVAL board; it includes the connectors for the SPZB260-PRO module and the M24LR64-R dual interface EEPROM. *Figure 2* shows the adapter layout.

Figure 2. SPZB260-PRO adapter layout

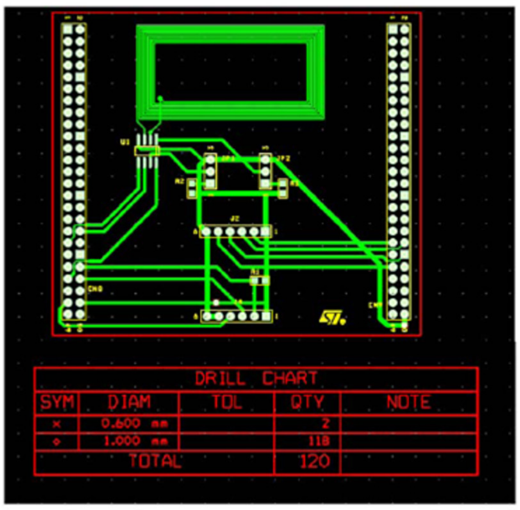
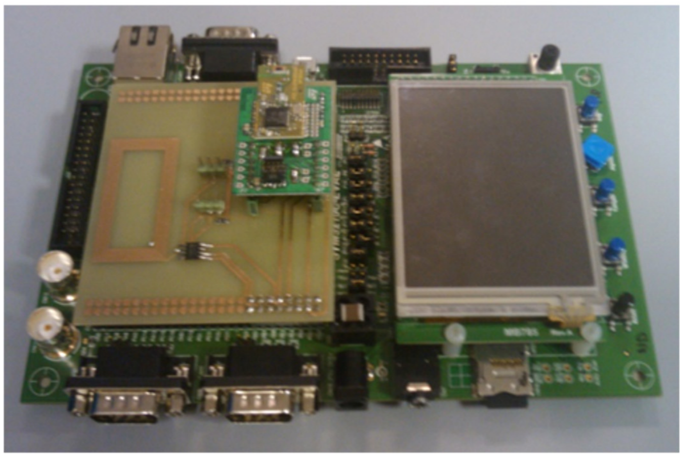


Figure 3 shows how to connect to the STM3210C-EVAL board.

Figure 3. How to connect SPZB260-PRO adapter to the STM3210C-EVAL



The SPZB260-PRO is a 2.4 GHz ZigBee module compliant with FCC regulations (FCC ID: S9NZB260A); for further information refer to the SPZB260-PRO datasheet. The M24LR64-R is an EEPROM with both I^2C interface and RF interface; this allows a “standard” memory access for an MCU using the I^2C and an access for a standard long range (ISO 15693/ISO 18000-3 mode 1) RFID reader. Using the RF interface, the memory can read/write even when it is not powered. In this application, the EEPROM stores, in the first three 32-bit memory locations, the TCP/IP network parameters:

- IP address
- Gateway IP address
- IP address mask.

The parameters are programmed by the RFID reader with the board switched off and at the power-on, during boot, the MCU reads the network parameters to configure the TCP/IP stack. The 64-Kbit memory is organized into 8192 x 8 bits accessing from the I^2C bus and into 2048 x 32 bits accessing from the RF interface. M24LR64-R is the slave of the I^2C communication with STM32; the two jumpers included on the board are used to set the slave address of the memory. For further information about M24LR64-R functionalities, refer to the M24LR64-R datasheet; for information related to application development, several application notes are available for downloading at www.st.com.

2.3 STEVAL-IHP001V3

The STEVAL-IHP001V3 ZigBee smartplug demonstration board employs the STM32F10x microcontroller, ZigBee SPZB260-PRO module, and STPM01 energy metering IC to implement a ZigBee meter node which allows the user to monitor and manage the energy consumption of a connected load.

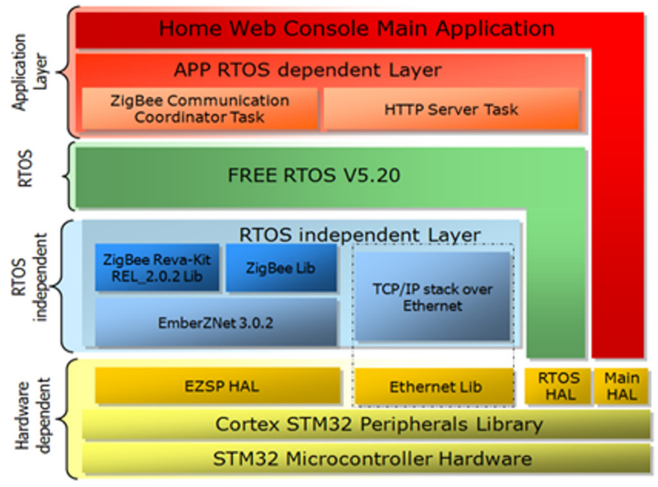
In a typical home system implementation, the board is plugged into an electrical wall socket, and supplies a home appliance or other generic electrical load. Current, power, energy and other information related to the electrical load connected to the smartplug board can be shown on an LCD displayed locally, or sent to a ZigBee data concentrator through a home/building ZigBee network.

While the STEVAL-IHP001V3 replaces the STEVAL-IHP001V2, the hardware for both the V2 and V3 versions of the smartplug demonstration boards are identical. The STEVAL-IHP001V3 differs from the V2 version only in terms of the ZigBee PRO stack update. More information is available for downloading at www.st.com.

3 Application firmware description

The firmware has been developed over the FreeRTOS operating system in order to simplify the integration of the different application parts. *Figure 4* shows the firmware architecture.

Figure 4. Firmware architecture



The firmware includes a common hardware dependent layer which mainly includes the STM32 standard library; over this layer the libraries and the application tasks are grouped in two sections: one for the ZigBee part and the other for the TCP/IP part. The FreeRTOS allows the correct execution of these tasks and their interaction.

3.1 ZigBee section

3.1.1 ZigBee libraries

The ZigBee libraries, which are independent from the OS, are part of the firmware package of the STEVAL-IHP001V3 board and are fully documented; please refer to www.st.com.

3.1.2 ZigBee application layer

The application is based on the same principle as the typical “sink - sensors” scenario supporting a “many-to-one” protocol, where there are several sensors (which in this case are the smartplugs) that periodically send data to a concentrator, which in this case is also the network coordinator, and is implemented by the STM3210C-EVAL.

The application layer is implemented by the task prvApplicationTask which is implemented inside the “main.c” file. It calls the function emberTick, which includes the functions for the ZigBee stack finite state machine evolution, and the function applicationTick, which implements the ZigBee section of the application layer.

The application maintains a list of the smartplugs joined to the HAN; a smartplug is removed from this list when it isn't heard from for a specified time and it is added when the concentrator receive a “select-sink” message from it; this message is managed in handleSensorSelectSink called by the callback function ezspIncomingMessageHandler. At the same time, the application periodically sends in broadcast the “Sink-Advertise” message to keep the network alive and a “many-to-one-route-request” to update the routing tables of all smartplugs in the network. The code sections that implement these functions are the following:

Joined smartplugs list maintenance

```
for (i=0; i<APPLICATION_ADDRESS_TABLE_SIZE; i++) {
      if (ticksSinceLastHeard[i] != 0xFFFF) {
        if (++ticksSinceLastHeard[i] >
            (MISS_PACKET_TOLERANCE * SEND_DATA_RATE)) {
          //Remove the lost SmartPlug from the Plugs collection MP
          CoordinatorType* pObjCoordinator = GetCoordinatorObj();
          if(pObjCoordinator){
            pObjSmartPlug = pObjCoordinator
>GetSmartPlug(pObjCoordinator,emberGetAddressTableRemoteNodeId(i));
            if ( pObjSmartPlug )
            {
              id = pObjSmartPlug->ID;
              pObjCoordinator-
>DelSmartPlug(pObjCoordinator,emberGetAddressTableRemoteNodeId(i));
              sprintf( msg, "Node %d Deleted", id );
              LCD_DisplayStringLineCol(Line8, 300, ( unsigned char * )msg );
              emberSetAddressTableRemoteNodeId(i, EMBER_TABLE_ENTRY_UNUSED_NODE_ID);
              emberSerialPrintf(APP_SERIAL,
                                  "EVENT: too long since last heard, ");
              emberSerialPrintf(APP_SERIAL,
                                 "deleting address table index %x, status %x\r\n", i,
status);
              ticksSinceLastHeard[i] = 0xFFFF;
            }
          }
        }
      }
    }
```

Network maintenance

```
if (timeBeforeSinkAdvertise == 2) {
        status = emberSendManyToOneRouteRequest(concentratorType,
                                               10); // radius
        emberSerialPrintf(APP_SERIAL,
                          "EVENT: sink send many-to-one route request,"
                          " status 0x%x\r\n", status);
      }
```

```
// do the sink advertise (multicast)
if (timeBeforeSinkAdvertise == 0) {
  emberSerialPrintf(APP_SERIAL,
      "EVENT: sink automatically advertising to find sensors\r\n");
  sinkAdvertise();
  timeBeforeSinkAdvertise = TIME_BEFORE_SINK_ADVERTISE;
}
```

Each smartplug object of the list includes all the information related to the power consumption measurement of each smartplug device installed in the building. These data are sent using a private ZigBee profile with a specific cluster ID (CLUST_GET_PLUG_DATA_ID = 0x1010) which is initialized into the function ZB_ClustersInitialization; the message related to this cluster is managed by the function OnGetPlugDataMsg that updates the data of the smartplug object included in the smartplug objects list.

The smartplug devices are compliant with both the “Home Automation” profile and the private profile implemented in the Home Web Console application running on the STM3210C-EVAL. On the smartplug, the ON/OFF command is implemented by the HA standard profile so the home web console uses a standard ZCL command for this command implemented by the function SendZclOnOffCmd.

3.2 TCP/IP section

3.2.1 TCP/IP stack

The web section of the application is based on the “lwIP” stack implemented by SICS. It is designed to reduce memory usage and code size in order to be used in embedded systems. For details related to this TCP/IP stack, refer to the lwIP manual available at www.sics.se. The TCP/IP task, which is implemented by the tcpip_thread function, is created by the function vStartEthernetTasks. The tcpip_thread task creates the task ethernetif_input that manages the messaging process with the Ethernet controller which is embedded in STM32.

3.2.2 TCP/IP application layer

The HTTP server services run on the task httpd; it mainly creates a TCP listener on port 80 and as soon as an incoming connection is received the server accepts it and parses the HTML request by the function ParseHTMLRequest; after the parsing procedure the connection is closed. The task is normally in sleep state and it is woken up by the incoming connection request from the client.

The HTML parser processes both GET and POST requests and expects to immediately get the data. The web page is made up of two static parts and two dynamic parts, so it is organized into four frames. The static parts and the “index” pages are stored in the embedded flash of the STM32; the dynamic parts are built at runtime on the basis of the smartplug data objects list maintained by the ZigBee application layer described in *Section 3.1.2*. The first dynamic part shows a table reporting the label, the measured voltage, current and power consumption for each smartplug in the HAN; the table is refreshed every 30 seconds. The second dynamic part shows a list of smartplugs (using the labels) according to the table allowing the selection of each smartplug and sends an ON or OFF command to it. The command is sent as a POST request to the web server. The page is formatted according to a styles file (.css) which is also stored in the embedded flash.

The network parameters (IP address, IP Gateway address, and IP address subnet mask) are stored in the DUAL-EEPROM included in the ZigBee module adapter and read at the startup by the MCU; if an EEPROM isn't recognized the default values are used. The parsing procedure is as follows:

HTML parsing procedure

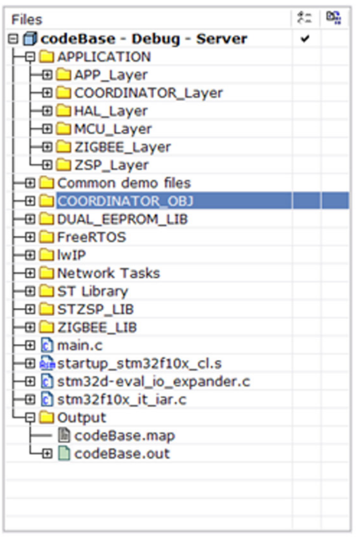
```
    if( pxRxBuffer != NULL )
    {
        // Where is the data?
        netbuf_data( pxRxBuffer, ( void * ) &pcRxString, &usLength );
        // Is this a GET?  We don't handle anything else.
        if( !strncmp( pcRxString, "GET ", 4 ) )
        {
              for(int i = 4; i < usLength; i++)
              {
                  if (pcRxString[i] == ' ' || pcRxString[i] == '\r' || pcRxString[i]
== '\n')
                  {
                    pcRxString[i] = 0;
                  }
              }
              // Is the page requested debug.html ?
              if ( !strncmp((char *)pcRxString + 4, "/top3.htm", 9) )
              {
                  ++sReqCount;
                  // Build the dynamic page
                  file.data = s_cDynamicPage;
                  PrepareFrame2(s_cDynamicPage,pxNetCon);
                  file.len = strlen(s_cDynamicPage);
                  --sReqCount;
              }
              else if ( !strncmp((char *)pcRxString + 4, "/top2.htm", 9) )
              {
                  // Build the dynamic page
                  file.data = s_cDynamicPage;
                  PrepareFrame1(s_cDynamicPage,pxNetCon);
                  file.len = strlen(s_cDynamicPage);
              }
```

```
                  else if ( !strncmp((char *)pcRxString + 4, "/conf.htm", 9) )
                  {
                      // Build the dynamic page
                      file.data = s_cDynamicPage;
                      PrepareFrameConf(s_cDynamicPage,pxNetCon);
                      file.len = strlen(s_cDynamicPage);
                  }
                 else
                  {
                      int nFileFound = 0;
                      if (*(char *)(pcRxString + 4) == '/' && *(char *)(pcRxString + 5)
== 0)
                      {
                          if ( sReqCount < 1 )
                            nFileFound = fs_open("/index.html", &file);
                          else
                            nFileFound = 0;
                      }
                      else
                      {
                          nFileFound =  fs_open((char *)pcRxString + 4, &file);
                      }
                      if (!nFileFound)
                      {
                          fs_open("/404.html", &file);
                      }
                  }
                  // Write out the HTTP OK header.
                  strcpy(txt, webHTTP_OK);
                  sprintf( txt + strlen(webHTTP_OK), webHTTP_Info, file.len );
                  // Write out the HTTP Info header.
                  netconn_write( pxNetCon, txt, (u16_t) strlen(txt), NETCONN_COPY );
                  // Write out the dynamically generated page.
                  WriteGeneratedPages(file,pxNetCon);
              }
              //Post Command Handler
              if( !strncmp( pcRxString, "POST ", 5 ) )
              {
                if ( !strncmp((char *)pcRxString + 5, "/top2.htm", 9) )
                {
                  //Detect Smart Plug Action
                  ActionDetect(pcRxString, usLength ); //SB
                  PrepareFrame1(s_cDynamicPage,pxNetCon);
                  file.data = s_cDynamicPage;
                  file.len = strlen(s_cDynamicPage);
                }
                else if ( !strncmp((char *)pcRxString + 5, "/conf.htm", 9) )
                {
                  //Detect Smart Plug Action
                  ActionDetectConf(pcRxString, usLength ); //SB
                  PrepareFrameConf(s_cDynamicPage,pxNetCon);
                  file.data = s_cDynamicPage;
                  file.len = strlen(s_cDynamicPage);
                }
                strcpy(txt, webHTTP_OK);
                sprintf( txt + strlen(webHTTP_OK), webHTTP_Info, file.len );
                // Write out the HTTP Info header.
                netconn_write( pxNetCon, txt, (u16_t) strlen(txt), NETCONN_COPY );
                WriteGeneratedPages(file,pxNetCon);
              }
             netbuf_delete( pxRxBuffer );
         }
```

3.3 Source code organization

The firmware has been developed using IAR v5.50.1 but it is portable with minimum effort to other development tools. The source code is organized following the folder tree shown in *Figure 5*.

Figure 5. Source code folder tree



```
Files
⊟ codeBase - Debug - Server                  ✔
├⊟ APPLICATION
│ ├⊞ APP_Layer
│ ├⊞ COORDINATOR_Layer
│ ├⊞ HAL_Layer
│ ├⊞ MCU_Layer
│ ├⊞ ZIGBEE_Layer
│ └⊞ ZSP_Layer
├⊞ Common demo files
├⊞ COORDINATOR_OBJ
├⊞ DUAL_EEPROM_LIB
├⊞ FreeRTOS
├⊞ lwIP
├⊞ Network Tasks
├⊞ ST Library
├⊞ STZSP_LIB
├⊞ ZIGBEE_LIB
├⊞ main.c
├⊞ startup_stm32f10x_cl.s
├⊞ stm32d-eval_io_expander.c
├⊞ stm32f10x_it_iar.c
└⊟ Output
  ├── codeBase.map
  └⊞ codeBase.out
```

The “STZSP_LIB” folder files include all the low level functions for interfacing the SPZB260-PRO module; the “ZIGBEE_LIB” and “COORDINATOR_OBJ” folders include the basic ZigBee libraries which implement the ZigBee data, the smartplug data and Coordinator data objects. The “APPLICATION” folder files include the interface to the ZigBee basic libraries and also the application layer source files.

The “DUAL_EEPROM_LIB” folder includes the library for the I^2C access of the M24LR64-R.

The “FreeRTOS” includes all source file of the OS from www.freertos.org. The source code reports the license agreement to use it.

The “lwIP” folder includes the source file of the TCP/IP stack from SICS. The source code reports the license agreement to use it.

The “Network Tasks” folder includes the source code of the tasks related to the TCP/IP stack execution and the HTTP web server task with the file system implementation as well.

The “ST Library” folder includes the STM32 MCU standard library source files.

The “main.c” files include the configuration functions, the OS startup function, and the ZigBee Section task prvApplicationTask.

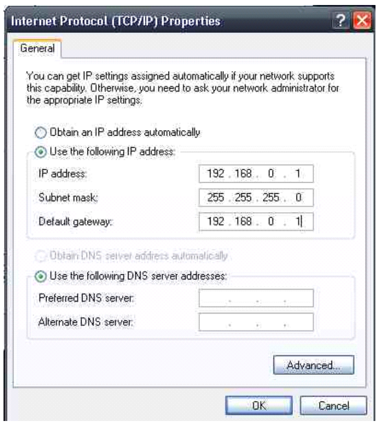
4 Demo setup

To set up the demo, one STM3210C-EVAL board (modified as described in *Section 2.1*) with a ZigBee adapter is necessary, a set of STEVAL-IHP001V3s, a PC with Ethernet connectivity, and an Ethernet switch (or hub) with standard Ethernet cable; if an Ethernet switch (or hub) is not available it is possible to use a crossed Ethernet cable. The adapter is not provided in the package but the Gerber files are available for downloading together with the firmware package. By using the browser of the PC it is possible to monitor and control each smartplug of the HAN simply writing the IP address of the board (shown in the board display) in the address bar. It is possible to do the same from any computer connected to the Internet configuring the PC as the Internet gateway, providing it has an Internet connection, of course, with a public IP address; unfortunately, not all Internet providers assign public IP by default.

Go step-by-step:

1. Turn on the STM3210C-EVAL board with daughterboard
2. Set the PC network with static IP address

Figure 6. PC TCP/IP properties configuration



Internet Protocol (TCP/IP) Properties

General

You can get IP settings assigned automatically if your network supports this capability. Otherwise, you need to ask your network administrator for the appropriate IP settings.

○ Obtain an IP address automatically
[✓ Use the following IP address:]

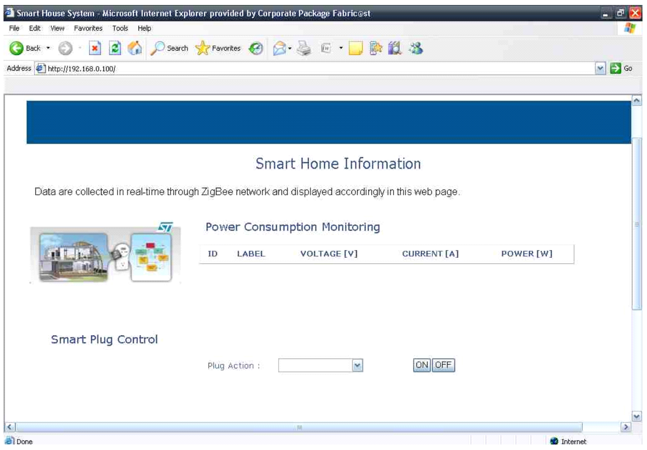
IP address:	192 . 168 . 0 . 1
Subnet mask:	255 . 255 . 255 . 0
Default gateway:	192 . 168 . 0 . 1

○ Obtain DNS server address automatically
[✓ Use the following DNS server addresses:]

Preferred DNS server:	. . .
Alternate DNS server:	. . .

3. Connect the Ethernet cross-cable from STM3210C-EVAL to PC
4. Open Internet Explorer on 192.168.0.100 (as shown in the LCD display)

Figure 7. Smart Home Information web page



Smart House System - Microsoft Internet Explorer provided by Corporate Package Fabric@st

Address http://192.168.0.100/

Smart Home Information

Data are collected in real-time through ZigBee network and displayed accordingly in this web page.

Power Consumption Monitoring

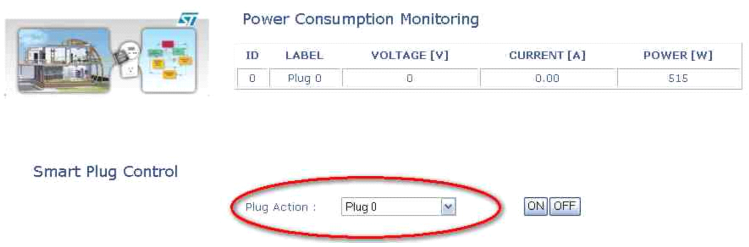
ID	LABEL	VOLTAGE [V]	CURRENT [A]	POWER [W]

Smart Plug Control

Plug Action :

5. Turn on one or more ZigBee smartplugs; make sure that the smartplug is linked to the coordinator (STM3210C-EVAL board with daughterboard), in this case the connection icon on the smartplug LCD should show the red light blinking; push the button on the upper right on the smartplug to link/unlink to the coordinator.
6. Refresh Internet Explorer

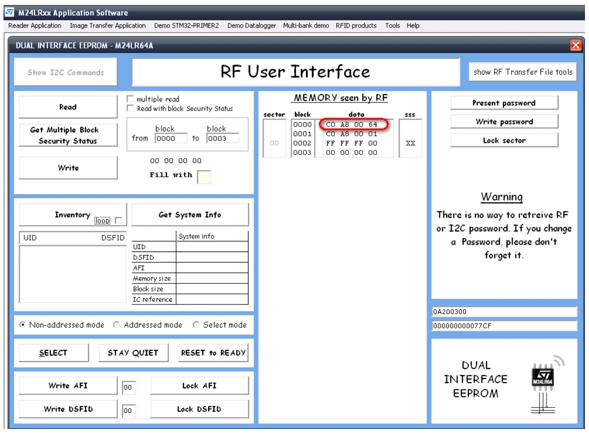
Figure 8. Smartplug list detail of Smart Home Information web page



ID	LABEL	VOLTAGE [V]	CURRENT [A]	POWER [W]
0	Plug 0	0	0.00	515

7. Now it is possible to control the remote ZigBee smartplug
8. To change the IP address, the user must power off the board and connect to it using the RF interface. For example, using STARTKIT M24LR64. In this case the user should read the block 0 of the EEPROM DUAL IFs, 4 bytes, reading the actual IP address.

Figure 9. RFID PC user interface



from block 0000 to block 0003

00 00 00 00

MEMORY seen by RF

sector	block	data	sss
00	0000	C0 A8 00 64	XX
	0001	C0 A8 00 01	
	0002	FF FF FF 00	
	0003	00 00 00 00	

UID	DSFID

	System info
UID	
DSFID	
AFI	
Memory size	
Block size	
IC reference	

Warning

There is no way to retreive RF or I2C password. If you change a Password, please don't forget it.

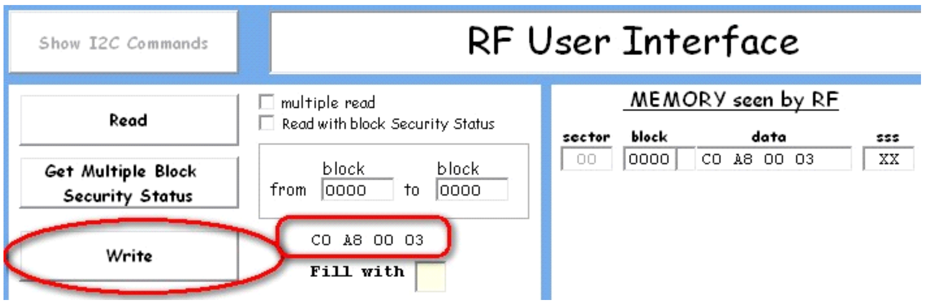
0A200300

000000000077CF

Write AFI 00 — Write DSFID 00

9. The user can easily change this value, putting the new IP address in HEX, for example, writing 192.168.0.3 --> C0h, A8,h 00h, 03h.

Figure 10. Writing details of RFID PC user interface


Show I2C Commands
RF User Interface
Read
Get Multiple Block Security Status
Write
multiple read
Read with block Security Status
Fill with

from block 0000 to block 0000

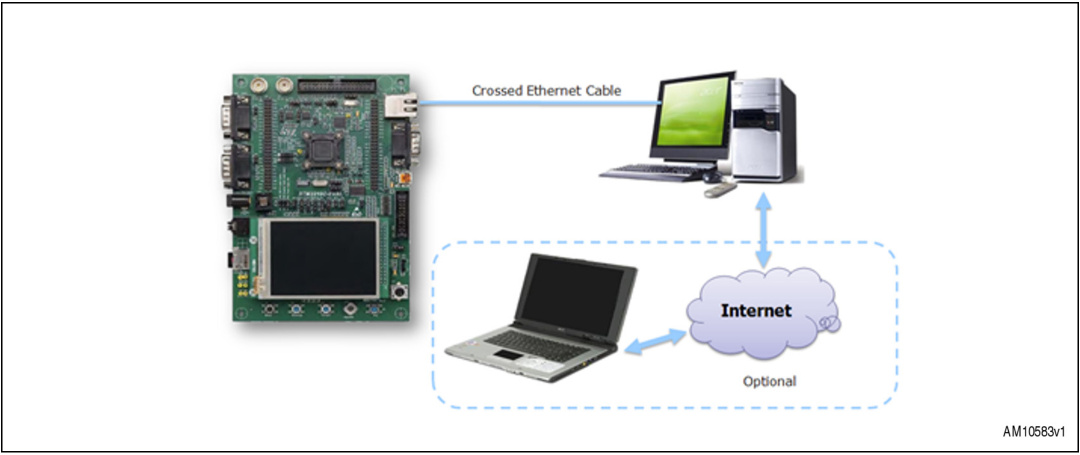
C0 A8 00 03

MEMORY seen by RF

sector	block	data	sss
00	0000	C0 A8 00 03	XX

If it is available, the simplest method to use the PC as gateway is to share the Internet connection and enable the web server service from the settings specifying the board IP address. If the PC is configured correctly it works as a gateway with IP address 192.168.0.1; the subnet mask of the LAN is set accordingly and if the board has, for example, an IP address like 192.168.0.xxx, the subnet mask is set to 255.255.255.0, so it is enough to configure the IP addresses set of the board accordingly; from a PC connected to the Internet write the public IP address of the PC in the address bar to reach the web server running on the STM3210C-EVAL board. *Figure 11* shows a typical demo setup.

Figure 11. Demo setup



4.1 HTTP server limitations

The system has been tested with several Internet browsers and some limitation has been found with the following browsers:

- Opera
- Mozilla
- Safari

The limitations are related mainly to the page formatting and, in the case of Safari, to the POST management as well.

Full compatibility is only achieved with Internet Explorer and Google Chrome.

4.2 Demo limitations

Only for demonstration purposes, the number of smartplugs that the STM3210C-EVAL can manage is limited to 5.

5 References

1. STM32F107VC datasheet
2. RM0008 reference manual
3. STM32F10xFWLib 3.1.2
4. FreeRTOS official website www.freertos.org
5. lwIP user manual
6. SICS website www.sics.se
7. UM0600 user manual
8. AN2993 application note

6 Revision history

Table 3. Document revision history

Date	Revision	Changes
11-Nov-2011	1	Initial release.