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Scientific Research and Essays

Full Length Research Paper

A new gateway node for wireless sensor network applications

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Wireless sensor network based applications have gained a significant importance in recent years. However, it creates problems when sending the detected data over distant stations even though establishment of sensor networks by means of ZigBee communication modules as the communication range of these modules are limited. For this reason, in this study, design of a gateway node which can be used in the sensor network applications was developed. The gateway node developed consists of a CC2530 ZigBee Module, an MSP430G2553 ultra low power microcontroller and a SIM900 GSM/GPRS module. As a result of this node, the sudden changes can be sent as data packets (SMS), also, the data can easily be monitored on web based and mobile platforms. It is anticipated that the study will be useful for the researchers conducting sensor network applications.

Key words: Wireless sensor networks, ZigBee, sensor node, gateway node.

INTRODUCTION

The wireless networks using sensors for monitoring physical or environmental conditions in diversified locations such as temperature, humidity, light, pressure, pollution, soil constituents, noise level, vibration and object movements in a cooperative way and containing devices working independently from each other are called “wireless sensor networks” (Akyildiz et al., 2002).

As for the nodes that are used in wireless sensor networks and that have the capabilities of calculation, perceptual data collection and communication with the other connected sensors in the network are called sensor nodes (Chong and Kumar, 2003).

Sensor nodes fundamentally consist of the main constituents of a microcontroller, a transceiver, an external memory, a power source and a sensor (Gupta et al., 2013). The field of use of Wireless Sensor Networks increases each passing day. The Wireless Sensor Networks can be used in military applications containing guarding of battle grounds, monitoring of enemy movements, exploring of the land, tracking of military and personnel vehicles, monitoring of friendly forces and speeds and locations of the targets; in environmental applications containing forecasting of weather and air pollution, tracking of natural disasters such as flood, earthquake and forest fires, monitoring of agricultural activities and monitoring of animal farms; in medical

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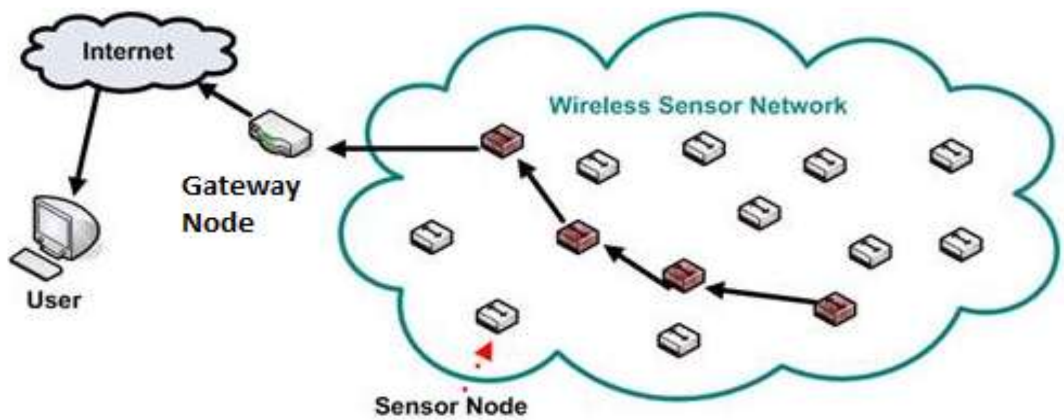

Figure 1. Wireless Sensor Network.

applications containing locating doctors in a hospital, monitoring of conditions of patients, guarding of the elderly and monitoring of various medical parameters; in commercial applications containing monitoring and locating vehicles, monitoring of power lines, tracking of young children by their parents, lighting control, control of traffic lights and fire systems; and in home automation applications containing smart home environments and building security systems (Carlos et al., 2007).

But, existing sensor nodes like TelosB, MicaZ, Mica2 etc, have no gateway node for sending information to distant stations. These nodes senses data and can send data only in a PC which is connected to a USB cable and to each other. For example, if you have a wireless sensor network in your farm, you can monitor obtained datas with these nodes only in same farm. If you are in the home, this place is far from your farm, you cannot monitor the values. Therefore, these nodes cannot be used in many applications which require you to send your data to distant stations.

In this study, a gateway node was developed for ZigBee networks. Through the gateway node developed, the data detected from the sensor nodes in the medium can be sent to the distant stations with the help of GSM/GPRS technologies.

This rest of the paper is organized as follows. The general structure of the sensor networks is given in the 2nd part. In part 3, the related works are explained. While the hardware design of the sensor node developed is presented in part 4, the software design of the sensor node is presented in part 5. Testing and results are presented in part 6. The conclusions of the study are given in part 7.

OVERALL STRUCTURE OF WIRELESS SENSOR NETWORK SYSTEM

Wireless Sensor Networks consist of small-sized sensor nodes installed on the environment. These nodes carry, by collaborating in a physical ground, what they learn from the physical world to the virtual world platform (Mayank, 2005). This is shown in Figure 1.

The data obtained from the physical environment by various sensors in sensor networks are wirelessly transferred onto their target data processing network by means of a collaboration method called from ear to ear. The gateway to the data processing network is called a gateway node. This node is a special node which is able to communication with the sensor nodes as well as with the communication network. The node is considered to be a static node with no energy issues and with a high calculation capability.

As for the sensor nodes, they are general units with limited energy and calculation capabilities that communicate through radio technology. These units are automatically placed and installed with a purpose to detect and monitor some conditions and phenomena in the detecting zone. The numbers can be from hundreds to thousands depending on the application. On Wireless Sensor Networks, the wireless communication between the sensor nodes in the environment is generally carried out via a ZigBee Module.

ZigBee (ZigBee Alliance, 2005) is a technology based on 802.15.4 standard that has been developed for Personal Area Networks consuming low power which is suitable for high level communication protocols. ZigBee is suitable for short ranged applications requiring low data transfer rates. ZigBee standard was designed for M2M applications and provides simple, secured communication means with low failure rate for M2M applications. As the data packet sizes, power consumption and complexity of technologies such as Wi-Fi and Bluetooth are too large, they are more prone to failures as compared to ZigBee networks. There are 3 tasks of devices in ZigBee networks.

1. Gateway: There is only one in a given network. It is responsible for the arrangement of the network structure of the network. Gateway needs to be started first in

ZigBee networks. It is the node in which memory, RAM and processing capacity features are the most advanced.
2. Router: It is responsible for relaying messages that have been sent to it to the other nodes (gateway or end devices) in the network. It does not process the data; it is just used as a router and for extending the range.
3. End device: It is installed on the sensors in the network and its task is to transfer the measurements it makes to the router or the gateway nodes.

As is known, the range of the sensor nodes in the ZigBee networks is limited. Thus, there is a limited communication range in ZigBee sensor networks. In the existing sensor nodes (TelosB, Mica2, MicaZ, etc.), the gateway node is formed by means of connecting it to a personal computer in the laboratory or the classroom and the applications are carried out this way. Therefore, the existing nodes are not usable in the applications containing hundreds of sensors distributed in the environment.

In this study, all issues were overcome and a new gateway node was developed for Wireless Sensor Networks.

RELATED WORKS

There are limited numbers of studies on gateway nodes that can be used for Wireless Sensor Networks. And most of the studies conducted consist of designs only. Yepeng et al. (2013) designed a gateway for the communication between ZigBee networks and the Internet in Smart Home technologies. They used an S3C2440 microprocessor, a JN5148 ZigBee module and a VT6656 as a WiFi Module. They converted the ZigBee Protocol data into WiFi protocol data. This way a gateway that can be used in a smart home technology was formed. Despite the fact that the node developed is used in smart homes, it cannot be used in different terrains where there would be no WiFi communication and other applications of the sensor networks. Thus, the scope of the study is limited.

Zhixiang and Jinxiang (2002) designed a gateway based on S3C2410 processor. They designed a new data sending protocol and degraded the differences between the ZigBee and the TCP/IP protocol; also, they designed a data sending management module. But the study conducted remained a theory. It was not put into implementation.

Zennaro et al. (2008) designed a new gateway node. They developed a prototype using development cards. Steenkamp et al. (2009) however, designed a gateway node on TinyOS using AT91RM9200 ARM development cards. The disadvantages of this study are that they use development cards. Wang et al. (2014) designed a gateway node using ZigBee and GPRS technologies. They used ARM S3C2440 as a processor. Song et al. (2008) designed a gateway node based on PXA270 processor using Linux. Wang et al. (2009) designed a ZigBee technology based gateway node using web services. The node designed is for home or building automation applications. Sunitha et al. (2013) designed a ZigBee WiFi gateway node based on ARM7 LPC2148, ARM9 S3C2440 and embedded WiFi module. He et al. (2009) designed a ZigBee and GPRS technology based gateway node. They used S3C2410 processor. Manukonda and Nakkala (2009) designed a gateway node based on STM32W108 radio chip and embedded WiFi. All these studies consist of designs only.

However, in this study, a gateway node having a GSM and GPRS infrastructure which can be used with the existing sensor nodes was developed.

HARDWARE DESIGN

The gateway node is intended for reaching out to the sensor nodes available in the medium through distant stations and to control them. In the design of the sensor node CC2530 ZigBee module and MSP430G2553 processor was used. RXD, TXD and GND connections are established between the sensor node and the SIM900 GSM/GPRS node and the gateway node is thus obtained. The circuit diagram of the sensor node and SIM900 GSM/GPRS node is given in Figures 2 and 3.

The GSM/GPRS module is connected to the UART pin of the microcontroller through the pin J2. Thus, the communication of the GSM/GPRS module with the sensor node through serial communication protocol UART at 9600 baud speed will be established. The gateway node possesses all the features the sensor node possess. In addition to the codes of the sensor node codes for communicating with the GSM/GPRS module is added and sending of the data over the distant stations can be established.

The gateway node consists of four units: the power unit, transceiver, processing unit and GSM/GPRS Modem.

Power unit

The gateway node was designed in a way to be fed through a 12V/1A Adaptor. The feeding unit contains transformers for 4.2 V max. 2A GSM voltage and 3.3 V 100 mA RF unit voltage needed for 12 V entrance voltage. LM2576 Series, SIMPLE SWITCHER 3A Step-Down voltage regulator was used for 12 – 4.3 V transformer. Working with a 52 kHz Internal Fixed Frequency oscillator high level voltage regulation was obtained. LM1117-3.3 800 mA Low-Dropout Linear Regulator numbered LM1 was used for 4.2 – 3.3 V transformer. The feeding of the medium node connected is obtained through J3 terminal.

Transceiver

RF unit was designed in IEEE 802.15.4 standard used for personal domain networks using small low-power digital radio to support the typical networks such as wireless star topology and tree topology and the general mesh networks. Data security was aimed to be established by customising with high level communication protocols. The 3.3 V supply voltage is provided by LM1117-3.3 800 mA Low-Dropout Linear Regulator numbered LM1. In the RF unit of the gateway node IEEE 802.15.4 CC2530 ZigBee module was used. The working frequency is 2.4 GHz. The data transmission rate varies between 20 and 900 kilobit/second. The active running is 28 mA in RX mode, 68 mA in TX mode and varies between 1 and 200 μA in Sleep Mode. It completes its transition from sleep mode to active mode in just 30 ms. The task of the RF unit is to transmit

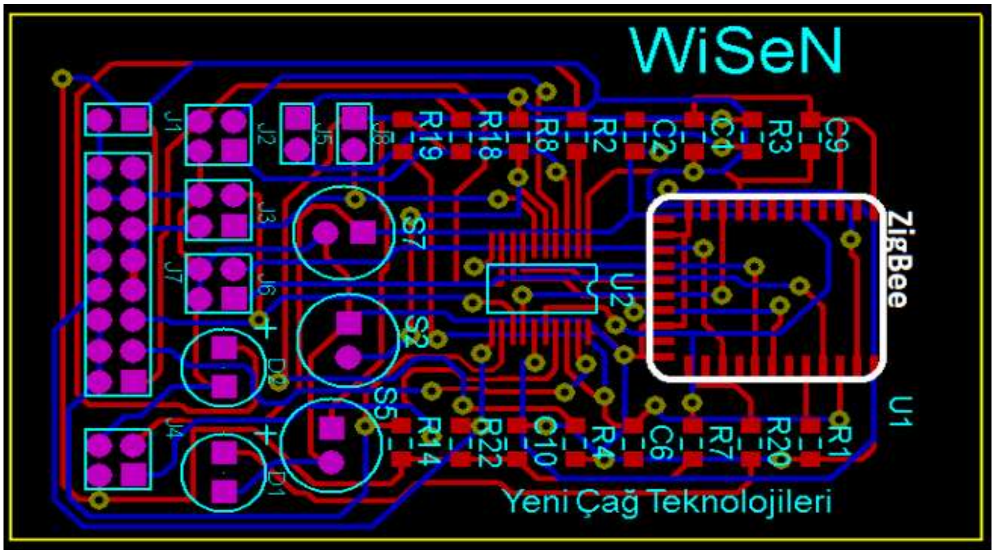

Figure 2. Sensor node.

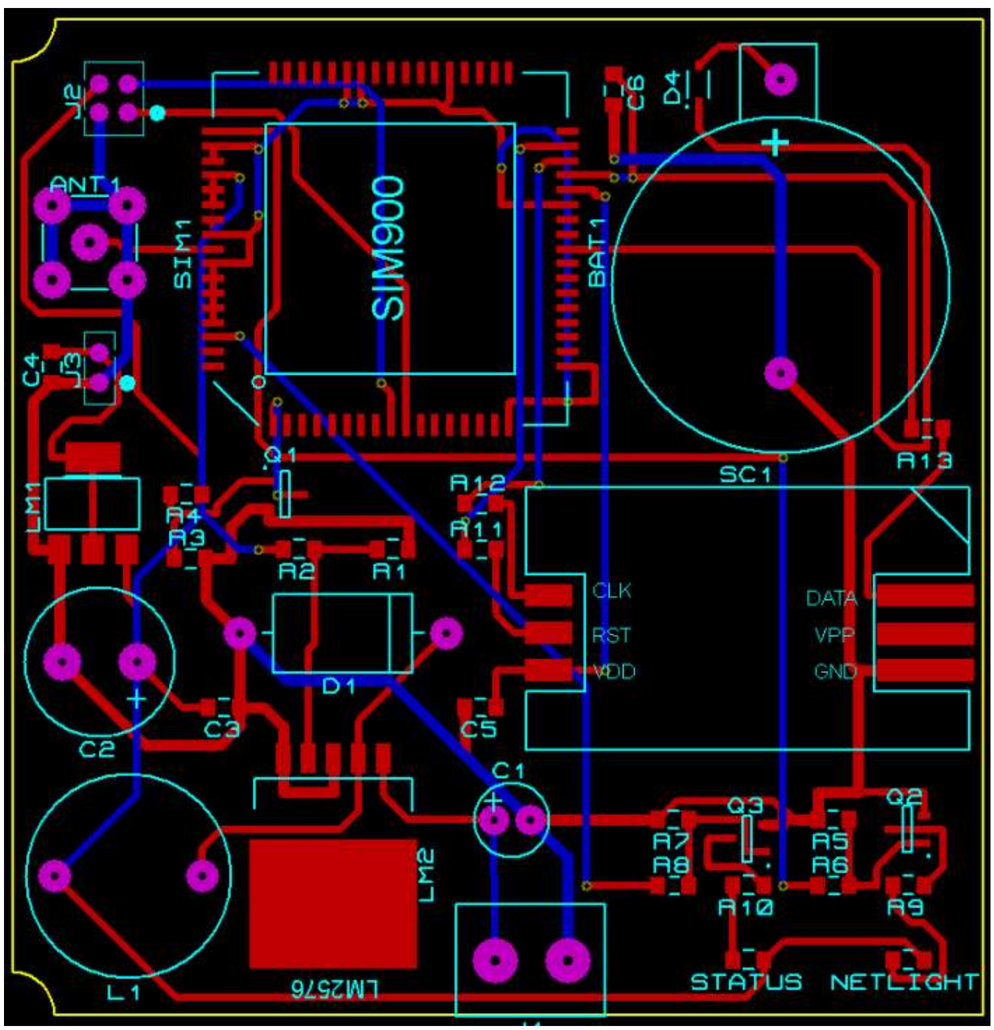

Figure 3. SIM900 GSM/GPRS node.

the data it collects from the sensor nodes in the environment over the network structure through the Serial UART module to the GSM/GPRS unit at a speed of 9600 baud from the J2 connector.

Processing unit

As it is known, the microcontrollers are micro-computers containing a microprocessor, a data and program memory, digital (Logical) inputs and outputs (I/O), analogue entries and other peripherals that add more power and functionality such as timers, counters, switches, analogue-to-digital converters put together on a single silicon chip. On the node, the MSP430G2553 model of the Texas Instruments company was used. The 3.3 V supply voltage is provided by LM1117-3.3 800 mA Low-Dropout Linear Regulator numbered LM1 on the circuit. Its task is to provide the coordinated working between the RF unit and the GSM/GPRS unit and to provide the transfer outside the sensor data it receives from the RF unit by means of the GSM/GPRS modem.

GSM/GPRS modem

SIM900 GSM/GPRS module of SIMCom Company in Quad-Band 850, 900, 1800, 1900 MHz frequency at 1 W 1800/1900 MHz power was used. There is one SIM card connection. The supply voltage of Max. 2A, in the range of 3,4 V to 4,5V is provided by the SIMPLE LM2576 series SWITCHER 3A Step-Down Voltage regulator as nominal 4.2 V 3A. Its task however, is to collect the data accumulated in the network structure in the central server via mobile data transfer over the Internet, in other words, it is the door of the sensor networks opening outwards.

Operation

Out of the 12 V, 1 A, 12 W input voltage 4 V SIM900 supply voltage is formed by SIMPLE SWITCHER 3A Step-Down Voltage Regulator. And gateway node voltage is formed by LM1117-3.3 800 mA Low-Dropout Linear Regulator. Through J1 terminal voltage is sent to the gateway node, and through J2 terminal serial data transfer is carried out at a speed of 9600 baud and the GSM and GPRS functions are conducted by means of AT commands. The on/off signal sent is strengthened over R4, R3 and Q1 by the MSP-PWRKEY pin and applied on the SIM900 Power Key input. CR2032 was used for the battery and the 1N4148 as well as the SIM900 memory. As for the StatusLED; the signal for turning on LED sent from the SIM900 is strengthened by the members R8, R7 and Q3 and the Status LED is turned on with the R10 current-limiting resistor. For NetLightLED, the signal for turning on the LED sent from the SIM900 is strengthened by the members R6, R5 and Q2 and the NetLight LED is turned on with the R9 current-limiting resistor. The SIM card of the relevant GSM operator is inserted into the SIM card slot connected into the circuit in order to establish communication in 800-900 and 1800-1900 MHz network frequencies. The circuit diagram of the SIM900 GSM/GPRS node is given in Figure 4. The gateway node designed can be used with other sensor nodes by means of connecting relevant ends into the SIM900 GSM/GPRS module.

SOFTWARE DESIGN

The software was developed in Code Composer Studio provided freely by the Texas Instrument company. The data coming from the sensor nodes in the environment arrive at the CC2530 ZigBee module available in the gateway node. The data arrived is processed by the MSP430 processor and sent to the GSM/GPRS module. The MSP430 being used as a microcontroller communicates with the CC2530 ZigBee module being used as a transceiver over SPI line. It communicates with the GSM/GPRS module over the UART line. There are 2 conditions on the data coming to this GSM/GPRS module:

1. For standard applications where there is no threshold value, the data is directly saved on the database.
2. For critical application where there is a threshold value however, the data is saved on the data base as well as transactions such as sending a message/making a call to the registered numbers are performed. These situations are described in Figure 5.

PostgreSQL was used as the database. The data that come to the database however, can be transiently monitored and tracked over the web or mobile based application in real time. This was described in Figure 6. Data limitation on the general protocol run on ZigBee networks is shown in Table 1.

Due to the fact that the gateway node developed is programmable, this packet structure can be customised. The network table created by the network addresses assigned to the devices in the ZigBee network is given in the Figure 7.

By means of carrying out Channel and Address adjustments on the gateway node designed, the gateway node can even be used together with different sensor nodes.

TESTING AND RESULTS

In order to evaluate the performance of the gateway node, two tests were run:

1. CPU usage.
2. Power consumption.

Results are given below.

1. The CPU usage was very small in all conditions. Approximately, it was 1%.
2. Power supply ratings of the gateway node depend on factors like configuration and load on the node.

The gateway with a 12V power supply and measured current consumption in 6 scenarios were powered:

1. Gateway Node is POWER DOWN mode
2. Gateway Node is SLEEP mode
3. Gateway Node is IDLE mode
4. Gateway Node is TALK mode
5. Gateway Node is DATA mode, GPRS (3 Rx, 2Tx)
6. Gateway Node is DATA mode, GPRS (4 Rx, 1 Tx)

Average supply currents are given in Figure 8. Figure 8 indicates that the average supply current is as follows:

Scenario 1 – 0.03 mA, Scenario 2 – 1.5 mA, Scenario 3 – 200 mA, Scenario 4 – 235 mA, Scenario 5 – 435 mA, Scenario 6 – 266 mA. Therefore, this gateway node can be used in wireless sensor network applications.

CONCLUSIONS

The study is on a development made on a gateway node

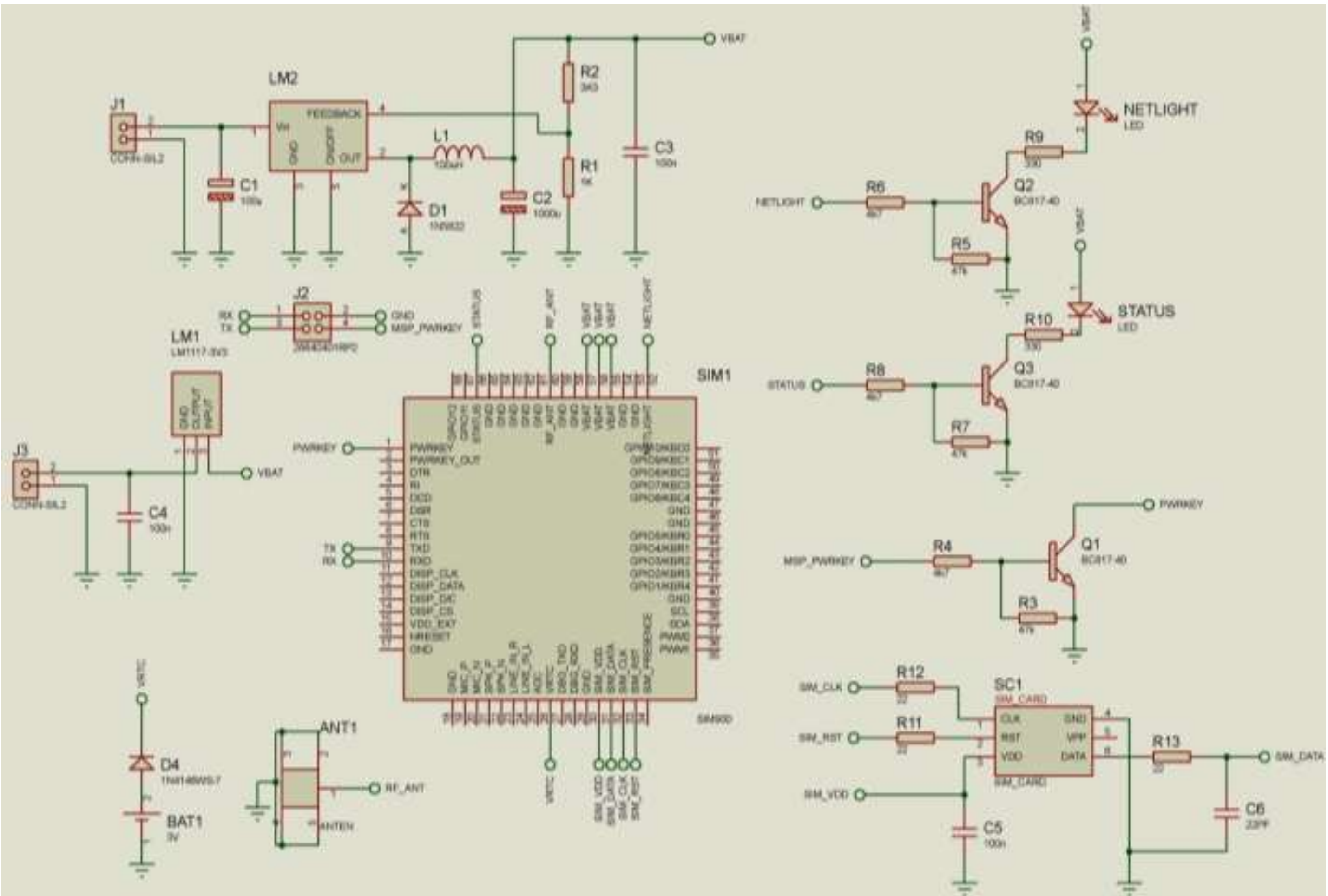

Figure 4. The circuit diagram of the SIM900 GSM/GPRS node.

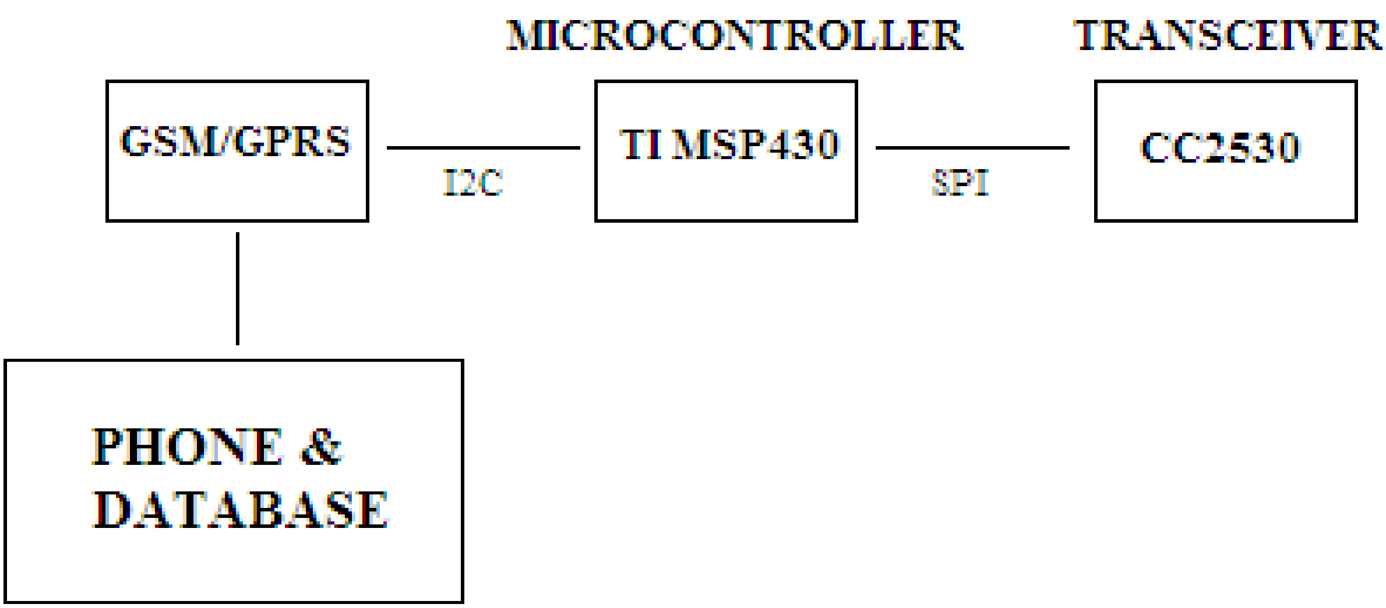

Figure 5. Structure of the Gateway Node developed.

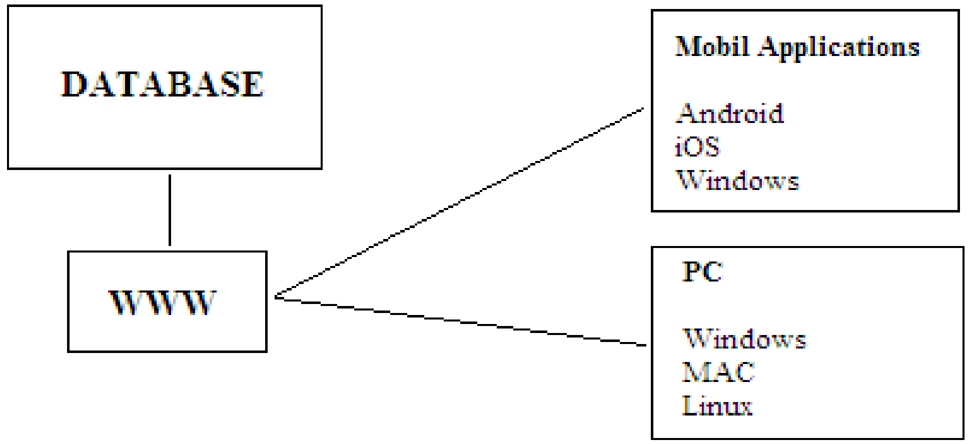

Figure 6. Database transactions.

Table 1. Data limitation of the general protocol run on ZigBee networks.

Octets: 2	**1**	**0/2**	**0/2/8**	**0/2**	**0/2/8**	**Variable**	**2**
Frame control	Sequence number	Destination PAN ID	Destination Address	Source PAN ID	Source Address	Frame Payload	FCS
		Addressing fields					
MHR						MAC Payload	MFR

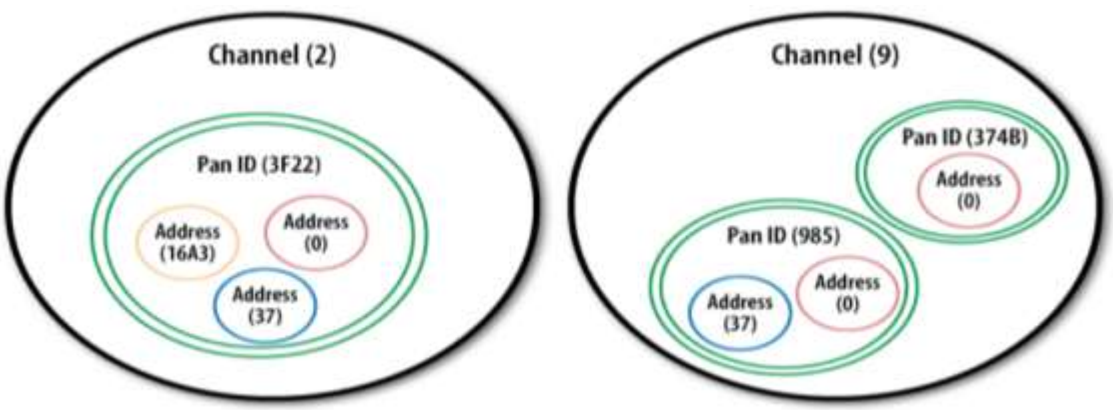

Figure 7. Channel, PAN ID, Address.

needed for the realisation of many wireless sensor network applications. By means of the new age gateway node prepared and designed for the purpose of developing a new and a user-friendly alternative, the detected data can be sent over the distant stations and can be monitored transiently. On the existing sensor nodes:

1. The software support is as much as given by the companies.
2. There is no alternative for gateway node. The node is connected to a PC and used as a gateway node in the laboratories or classrooms.

On the gateway node developed however:

1. Data can be received from any wireless module.
2. The gateway node can directly communicate with the mobile phones as well as with the database.
3. The data can be traced over the web or mobile platforms in real time.
4. Software support can be provided fast and easily.

Since the gateway node is programmable, any desired

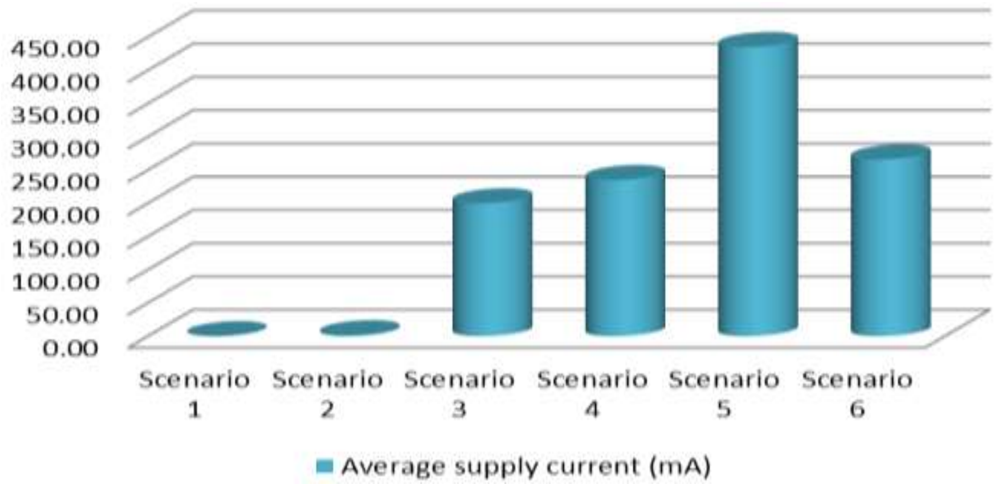

Figure 8. Average supply currents.

network structure can be established. This way, unnecessary power losses and program complications can be eliminated and new algorithms and techniques can be developed in terms of speed. Also, as a result of the gateway nodes being programmable:

1. An environment in which researches can be made in Wireless Sensor Networks was established
2. It was ensured that the theoretical knowledge applied in the Wireless Sensor Networks was reduced to a level that can be used in the daily life.

Thus, with the gateway node which is the subject for this study, a gateway node can be used in the areas requiring wireless sensor networks to be used such as smart home systems, building security systems, vehicle tracking systems, monitoring of power transmission lines, control of illumination systems, fire tracking systems, monitoring of patients, monitoring of medical parameters, earlier prediction of natural disasters, monitoring of agricultural activities, guarding of battle grounds and locating mobile targets. However, there is no such comprehensive and trouble-free solution in the known condition of the technique.

With the production of gateway node, rational, cheap, easy-to-use sensor nodes have been put into practise for people conducting researches in Wireless Sensor Networks and for Wireless Sensor Network applications in the field of application.

Conflict of Interests

The author has not declared any conflict of interests.

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Full Length Research Paper

Lessons withdrawn from the diversity of inland valleys cultivation at a regional scale: A case study of Mono and Couffo departments in south Benin

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In a context of greater climate variability and increasing population pressure, inland valleys are considered as high potential agricultural area. This agricultural potential has been subject to multiple initiatives for characterization which were generally based on the physical characteristics. However, support strategies based on such inventories often fail to fit with the promoters' expectations. One of the reasons is that approaches used to classify inland valleys do not generally take into account socio-economic factors. This study aims to characterize the diversity of inland valleys in the departments of Mono and Couffo based on a joint consideration of biophysical, agronomic and socio-economic characteristics and to prioritize the factors affecting their agricultural use. Data were collected on 158 inland valleys and were related to biophysical characteristics, uses, management and economic productivity. Six types of inland valleys differentiated by the production systems, economic productivities and socioeconomic characteristics were identified. The production system based on rainfed rice and off-season vegetable with application of chemical fertilizer generated the highest economic productivity. Strengthening farmers' technical abilities was important for a better capitalization on inland valleys. These results support the importance to combine several approaches in the classification of inland valleys and to fully understand the factors affecting their valorization by rural populations.

Key words: Diversification, inland valleys, intensification, performance, typology, uses.

INTRODUCTION

The rapidly growing population in Sub-Saharan Africa (SSA) necessitates an increase in food production. Inland

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Table 1. Values (mean and standard error) of surface soil characteristics (0-20 cm) of the dominant soil types of the study area.

Sites	pH	OC (%)	N (%)	P (ppm)	K (%)
Lixisol	0.90±0.21	0.07±0.01	10.40±3.36	1.87±0.81	6.51±0.24
Gleysol	0.94±0.15	0.07±0.01	15.90±12.34	0.24±0.05	6.72±0.20

Source: Igué et al. (2013).

valleys offer extensive potential for agricultural production (Faure, 2005). Inland valleys can be defined as waterlogged areas where the water of small catchments converges (Andriesse and Fresco, 1991). The flooding character of this area, the relative difficulty to manually till the soils often dominated by clay and weed pressure have been for long time the major obstacles to their cultivation (Windmeijer et al., 2002). However, in a context of greater climate variability and increasing pressure on uplands, the privileged hydrological conditions of inland valleys make them a great agricultural potential area for flood-tolerant crops such as rice and for off-season production (Giertz et al., 2012). Thus, the agricultural potential of inland valleys has been subjected since the 1980s to many initiatives for inventory and characterization (Legoupil et al., 2000).

Approaches used to classify inland valleys were generally based on the conditions of the physical environment: climate, morphology, pedology and hydrology (Windmeijer and Andriesse, 1993). This physical knowledge of inland valleys was the basis for public policies to support their agricultural use with hydraulic structures, especially in the Sudanese region (Ahmadi, 1998). The results obtained by the development projects in inland valleys, however, rarely reached the expectations and objectives of the promoters. The causes of this mixed assessment included the lack of control on the water regimes of inland valleys due to their complexity and the negligence of socio-economic factors (Ahmadi, 1998; Onyeweaku et al. 2010; Umeh and Chukwu, 2013). Thus, a better knowledge of the physical and socioeconomic components of inland valleys appeared to be necessary to guide interventions for their agricultural use.

At a regional scale, with the objective to diagnose agricultural constraints and potentials, it has rarely been applied characterization approaches combining biophysical, socio-economic and agronomic dimensions. This study is specifically designed to test this integrated approach by using multi-factor analysis, an original method that differs from the other integrated analysis, such as those of Sakané et al. (2011). The specific objectives of this study were (i) to characterize the diversity of inland valleys of the departments of Mono and Couffo in southern Benin by establishing a typology based on a combined consideration of biophysical, agronomic and socio-economic factors; (ii) to identify and prioritize the factors affecting the agricultural use of inland valleys.

MATERIALS AND METHODS

Study area

The departments of Mono and Couffo are located in southern Benin between 1°15' E and 2°10' E and 6°15' N and 7°30 N. The climate of the study area is sub-equatorial with two rainy seasons alternating with two dry seasons. Annual precipitation fluctuates between 800 and 1000 mm. Air temperature slightly varies within the season. The mean annual air temperature is around 27°C. The dominant types of soil are Lixisols and Gleysols (Table 1) (Youssouf and Lawani, 2000). The main economic activities are agriculture, fishing, breeding, transformation of agricultural products, handicrafts and trade. The crops mostly cultivated are maize, rice, tomato, pepper, okra, leafy vegetables, cowpeas, groundnuts and cassava (Dossou et al., 2006; Ogouwalé, 2006; Amoussou, 2010).

Data collection and processing

Data collection was done in two steps: identification of inland valleys and their mapping (limits of the area subject to flooding, coordinates of the center) with the Global Positioning System receiver and administration of questionnaires to the users of inland valleys. Visits in inland valleys were made by investigators to assess the biophysical characteristics. Soil texture and fertility were evaluated according to farmers' knowledge and perception. Soil texture was assessed by feeling the weight and rubbing soil between fingers. Soil fertility was assessed based on observable plant and soil related characteristics namely; soil colour, crop yield, soil water holding/retention capacity, stoniness, difficulty to work soil, type and abundance of indicator weeds, colour of leaves and deficiency symptoms observed on crops, crop growth rate and presence and abundance of soil macro-fauna (Table 2). The flood heights in the different parts of the inland valleys were evaluated with a graduated vertical stick. Focus groups were conducted to harmonize the answers of the interviewees on soil texture, fertility and hydrological characteristics of the inland valleys. In total, 158 inland valleys were identified from a comprehensive inventory (Figure 1). The typology of inland valleys was based on multivariate analysis. This is an integrated approach that allows understanding the interactions between land uses, socio-economic and biophysical characteristics of the environment (Sakane et al., 2011). Data processing consisted of the realization of multiple factor analysis and hierarchical cluster analysis with R software.

Multiple factor analysis

Multiple factor analysis (MFA) is a multi-factorial table method.

Table 2. Indicators of soil fertility.

Indicator	Fertile soils	Infertile soils
Crop performance		
Crop growth rate	Fast/high growth rate	Stunted and slow plant growth
Crop yield	Consistently high yields	Low yields
Colour of leaves of growing crops	Large green leaves	Small/ stunted yellowish leaves
Soil characteristics		
Soil colour	Dark colour	White/pale/light
Moisture holding capacity	High	Low
Soil workability	Easy to work	Difficult to work
Stoniness of soil	Few stones and pebbles present	Numerous stones and pebbles present
Biological characteristics		
Presence of worm casts	Numerous wet worm casts	Few worm casts
Presence of soil macro-fauna	Earthworms, beetles and millipedes present	Few
Presence of indicator weeds	*Chromolaena odorata* with large green leaves	- *Chromolaena odorata* with small yellow leaves - Grassy weeds

Beyond the theoretical approaches (Escofier and Pagès, 1984), few applications were made in agriculture. One of these applications was conducted on livestock farms by Alary et al. (2002). The advantage of this method is its ability to combine a global analysis using various types of data and a partial analysis focusing on each group of data. The MFA allows highlighting the relationships between variables grouped into themes by searching for common factors of differentiation of statistical units. In this study, the statistical unit was the inland valley. The data set was divided into a series of tables; each table corresponded to a group of variables that described a component of the inland valley.

The themes used in this study covered the following components:

i) the "biophysical" component informed about the physical characteristics (area, soil texture, fertility) and hydrological characteristics (beginning, duration, height of flooding and drainage) of inland valley;
ii) the "agricultural" component was divided into two sub-themes (a) the production system according to the combination of crops practiced and the levels of inputs used, (b) the agricultural performance in terms of economic productivities (gross product per hectare) and cropping intensity;
iii) the component "economical environment" described market access and facilities of the town or village and the presence of support structures for agricultural development.

The analysis focused on four themes bringing together sixteen variables. The variables were broken into forty-six modalities based on the distribution of the values of each variable in order to obtain balanced frequencies (Table 3).

Hierarchical ascendant classification (HAC)

Hierarchical ascendant classification was conducted to subdivide the 158 inland valleys into classes; each class consisting of relatively homogeneous inland valleys.

RESULTS

Factors structuring the diversity of inland valleys agricultural uses

For each theme, the key factors that differentiated the sample of inland valleys were identified (Figure 2). Two major groups of inland valleys were identified. At the positive side of the axis 2, there was a first group of inland valleys whose farmers benefited from the technical support of projects and used chemical fertilizers. The farmers of this group of inland valleys had a production system based on off-season vegetable with high economic productivity. During the rainy season, some of these inland valleys were cultivated with maize with high productivity (dial: axis 1 negative, axis 2 positive). Others, meanwhile, were cultivated during the rainy season in vegetable with low productivity (Dial: axis 1 positive, axis 2 positive). The cropping intensity of this group of inland valleys was medium to high. At the negative side of the axis 2, there was a second group of inland valleys cultivated mainly during the rainy season with rice with a moderate productivity (dial: axis 1 negative, axis 2 negative). Therefore, technical support of projects, use of chemical fertilizers, production system and economic productivity were the major factors structuring the diversity of inland valley agricultural uses.

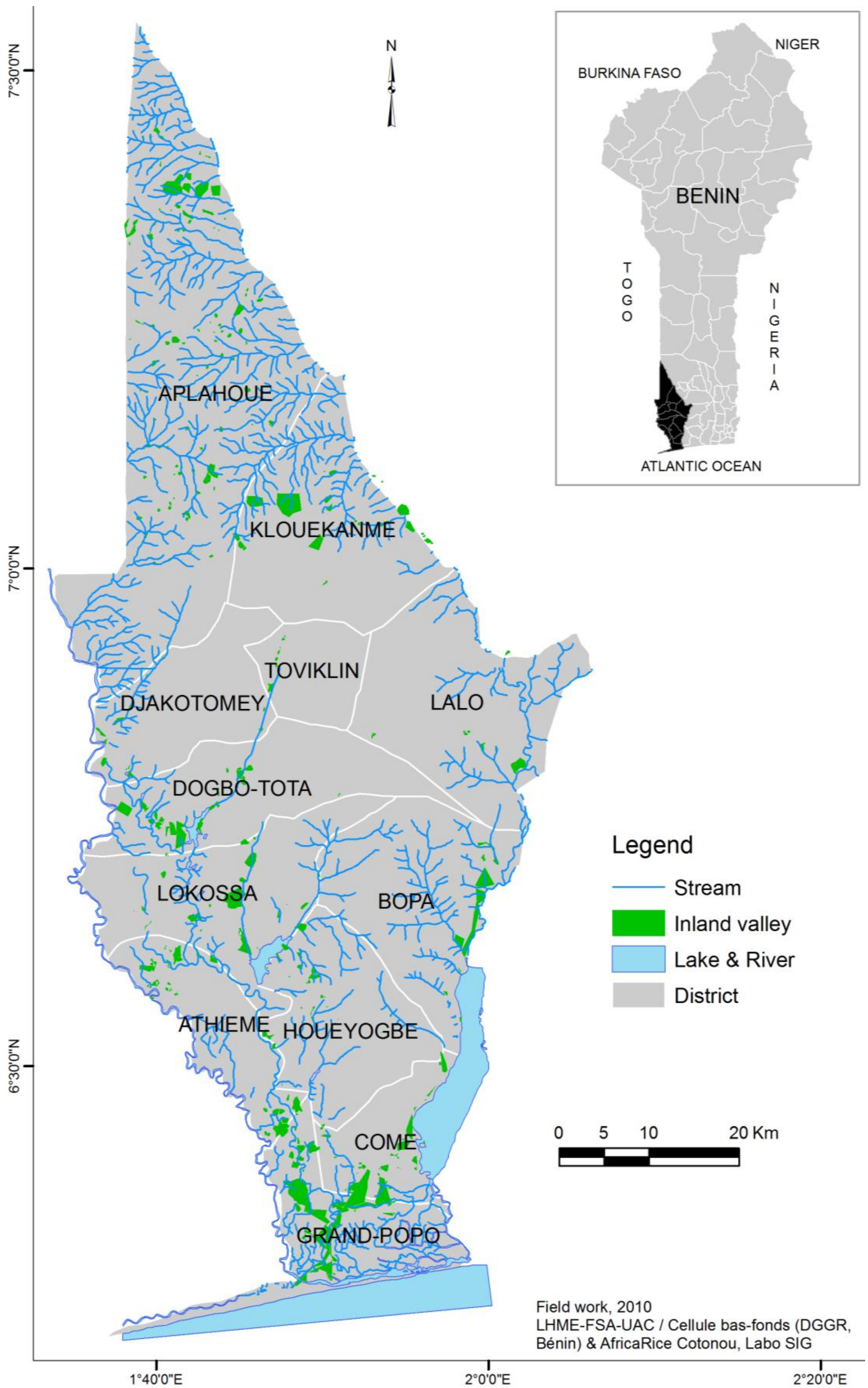

Figure 1. Location of the Mono and Couffo departments and the inventoried inland valleys.

Table 3. Themes and selected variables.

Themes	Variables
Physical and hydrological environment	Area of inland valley, beginning of flooding, duration of flooding, height of flooding, soil fertility
Agricultural performance	Gross income in rainy season, gross income in dry season, cropping intensity
Production system	Cropping system in rainy season, cropping system in dry season, use of chemical fertilizer
Socioeconomic environment	Distance inland valley to village, store in the village, rice miller in the village or in the district of the village, support to inland valley farmers and accessibility to village

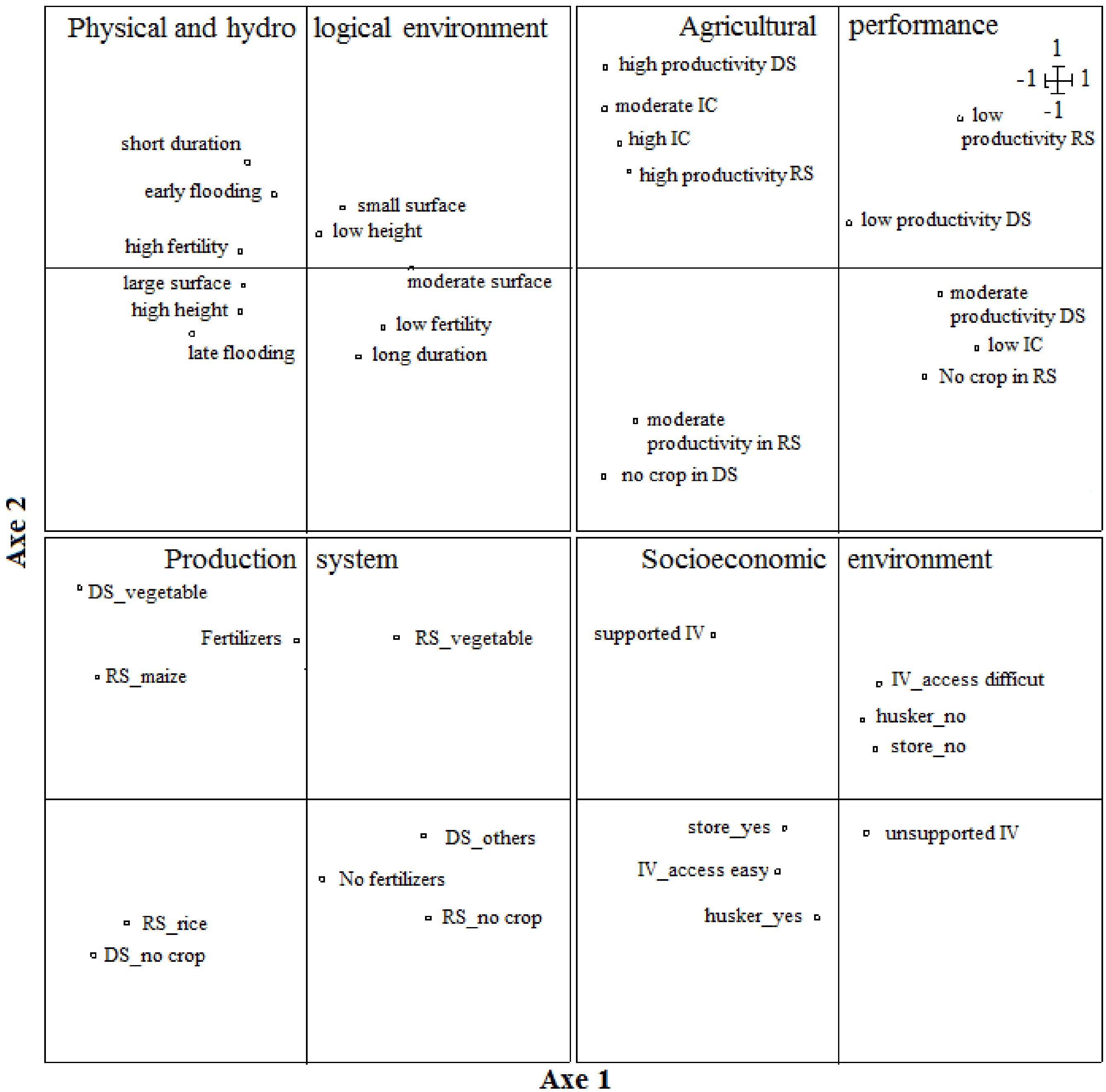

Figure 2. Projection of the modalities of each theme on the factorial plan 1 x 2. IC: cropping intensity; IV: inland valley; RS: rainy season; DS: dry season.

Table 4. Characteristics of types of inland valleys.

Characteristics	Inland valleys cultivated both in rainy season and dry season			Inland valleys cultivated only in rainy season		
	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
Weights (%)	12	23	9	11	19	26
Crop in rainy season	Maize	Maize	Maize	Rice	Maize	Maize
Crop in dry season	Tomato, pepper	Tomato, pepper, maize	Maize/okra	no crop	no crop	no crop
Gross income in rainy season (FCFA/ha)	> 600000	100000-300000	> 300000	> 900000	> 400000	< 100000
Gross income in dry season (FCFA/ha)	> 600000	> 400000	< 100000	0	0	0
Soil fertility	Very good	Bad	Good	Bad	Good	Bad
Use of fertilizers	Yes	Yes	Yes	Yes	No	Yes
Technical support	Yes	No	Yes	Yes	No	No
Water control	Bad	Bad	Bad	Medium	Bad	Bad

Classification of inland valleys

The analysis of the dendrogram revealed a first level of classification of inland valleys into two groups mainly differentiated by the agricultural use (presence or absence of off season crop). In order to gain in consistency, we represented the diversity of the inland valleys by a partition into six types. Table 4 presented the characteristics of the different types of inland valleys.

Group 1: Inland valleys cultivated during rainy and dry seasons

Type 1 - Inland valleys cultivated with maize during the rainy season and with tomato and pepper during the dry season: This type comprised 12% of the inland valleys of the study area; that is 19 inland valleys. It represented the type of inland valleys cultivated on their fringes with maize during the rainy season and in their center with tomato and pepper during the dry season with high economic productivity (greater than 600,000 FCFA/ha). These inland valleys were fertile. The producers used chemical fertilizers to maintain a high level of production. About 70% of the producers of this inland valleys group benefited from NGOs and projects supports.

Type 2 - Inland valleys cultivated with maize during the rainy season and with tomato, pepper associated with maize during the dry season, without technical support: This type comprised 23% of the inland valleys of the study area; that is 36 inland valleys. It represented the type of inland valleys cultivated on their fringes with maize during the rainy season and in their center with tomato and pepper associated with maize during the dry season. During the rainy season, maize cultivation generated a relatively moderate gross income (100,000 to 300,000 FCFA/ha). During the dry season, tomato and pepper associated with maize generated a relatively high gross income (over 400,000 FCFA/ha). The producers did not benefit from technical support. They usually used chemical fertilizers to produce on their inland valleys largely dominated by poor soils.

Type 3 - Inland valleys cultivated with maize during the rainy season and with maize associated to okra during the dry season: This type included 9% of the inland valleys of the study area; that is 15 inland valleys. It represented the type of inland valleys cultivated on their fringes with maize during the rainy season and in their center with maize associated with okra during the dry season. During the rainy season, maize cultivation generated a relatively high gross income (over 300,000 FCFA/ha). During the dry season, maize associated with okra generated a relatively low gross income (less than 100,000 FCFA/ha). The producers generally benefited from NGOs and projects support. They used chemical fertilizers to produce on their inland valleys with good soil fertility.

Group 2: Inland valleys cultivated only during the rainy season

Type 4 - Inland valleys cultivated only during the rainy season with rice: This type comprised 11% of the inland valleys of the study area; that is 17 inland valleys. It represented the type of inland valleys cultivated only during the rainy season in rice with high economic productivity (greater than 900,000 FCFA/ha). The producers benefited from NGOs and projects support. They used chemical fertilizers to have a good production on their inland valleys dominated by poor soil fertility.

Type 5 - Inland valleys cultivated only during the rainy season in maize with relatively high economic productivity: This type comprised 19% of the inland valleys of the study area; that is 30 inland valleys. It represented the type of inland valleys cultivated only during the rainy season on their fringes with maize with a relatively high economic productivity (greater than

Table 5. Gross margin of the main crops of inland valleys (campaign 2009-2010).

Period	Crop	Frequency (158 IV)	Yields (T/ha)	Production value (FCFA/kg)	Gross product/ha (K FCFA/ha)
RS	Rice	37	3.2 (1 – 5)	225 (150 – 350)	500 (100 – 1500)
	Maize	86	1.4 (0.3 – 3)	170 (125 – 275)	322 (30 – 800)
	Tomato	64	2.7 (1.2-7)	115 (100-240)	375 (12-800)
	Pepper	61	0.5 (0.1-1.2)	137 (100-400)	100 (20-270)
DS	Tomato	24	2.9 (0.7 – 9)	335 (250 – 350)	1006 (100 – 3000)
	Pepper	25	4.2 (0.12 – 10)	460 (250 – 500)	1017 (30 – 3500)
	Okra	18	1.11 (0.9 – 2)	260 (200 – 350)	606 (105 – 1600)
	Maize	4	2.15 (0.8-4)	140 (100-350)	490 (250-600)

IV: Inland valley; RS: rainy season; DS: dry season; K FCFA: 1000 FCFA; () = class of value in 95% threshold.

300,000 FCFA/ha). The producers did not benefit from NGOs and projects support. They did not use chemical fertilizers despite the low soil fertility of their inland valleys.

Type 6 - Inland valleys cultivated only during the rainy season with maize or vegetable with a relatively low economic productivity: This type comprised 26% of the inland valleys of the study area; that is 41 inland valleys. It represented the type of inland valleys mainly cultivated during the rainy season on their fringes with maize or vegetable with a relatively low economic productivity. The producers did not benefit from NGOs and projects support. They used chemical fertilizers to produce on their inland valleys with relatively poor fertility.

Factors affecting the economic productivity of inland valleys

The analysis of the gross income per unit land in the inland valleys (Table 5) showed that tomato and pepper, the major crops of off-season were distinguished by a very high gross income. The relative importance of off-season crops was therefore important in the economic productivity of inland valleys. The types of inland valleys with large presence of off-season crops (Types 1 and 2) had the highest gross income. During the rainy season, rice production generated the highest gross income. This contributed to explain the relatively high gross income in the rainy season of producers of inland valleys of type 4. Therefore, the cropping system based on rainfed rice and off-season vegetable production would be the most profitable and should be integrated in the recommendation scheme for inland valleys farmers.

DISCUSSION

Technical support by the development institutions (projects and NGOs) to the agricultural valorization of inland valleys was a determining factor in the improvement of the gross income both in wet and dry seasons. These institutions follow, support and advise farmers and facilitate access to agricultural inputs; thereby improving farmers' technical abilities and contributing to an increase in production. Meanwhile, inland valleys whose farmers did not benefit from institutional support had a relatively lower productivity. The same observation was made by Gruber et al. (2009) and Giertz et al. (2012) about the inland valleys of central and northern Benin and by Nwaru and Iheke (2010) about the inland valleys of Abia State in Nigeria. Those authors attributed the low valorization of the agricultural potential of inland valleys to the low technical abilities of farmers and emphasized on the importance to strengthen farmers' technical abilities.

The physical environment was not an important factor in the differentiation of the inland valleys in the study area. This could be attributed to the fact that all the inventoried inland valleys presented similar soil characteristics. Contrary to our results, Karimou et al. (2005) found significant differences in the soil characteristics of inland valleys in the department of Mainé-Soroa, Niger. Furthermore, the inland valleys in the study area were not different from hydrological point of view. They were flooded from June for a period of 3 to 6 months. Their hydrological functioning was determined by the characteristics of rainfall (intensity and frequency) and the regime (flood, recession) of the Mono and Couffo rivers (Amoussou, 2010).

In the rainy season, maize was the main crop in 89% of the inventoried inland valleys and was grown on the fringes of inland valleys. Rice was the main crop in 11% of inland valleys and was grown in the center (bottom) of inland valleys. The main crop chosen by a producer during the rainy season was correlated with his ability to control the water regime in the inland valley during this season (Table 4). The inland valleys on which rice was the major crop during the rainy season were those on which the producers have a functional drainage system to prevent prolonged inundation that often disrupts planting, germination and favors weeds proliferation (Rodenburg and Johnson, 2009). In order to capitalize on their inland valleys, most producers in the study area grow maize on the fringes (well drained areas). This shift of maize from uplands to inland valleys was observed by Ogouwalé (2006) in South and Central Benin. This shift was interpreted as an endogenous adaptation strategy to climate change by producers specifically as response to the erratic character of rainfall during the rainy season (Ogouwale, 2006).

Less than 50% of the inland valleys of the study area were cropped during the dry season (Table 4), despite the relatively high gross income from the production of off-season vegetable (Table 5). The main constraint to farming in the dry season was the lack of water to irrigate crops. Therefore, support to producers in the development of irrigation infrastructures in the dry season and drainage infrastructures in the rainy season are crucial for the diversification (rainfed rice and off-season vegetable) in inland valleys, which further determined the economic productivity (Table 5). Similar suggestions were made by Saidou and Kossou (2009) and by Totin et al. (2012) for the agricultural development of inland valleys.

Conclusion

This study allowed understanding the diversity of inland valleys and the factors affecting their economic productivity in the departments of Mono and Couffo. Six types of inland valleys were identified based on the production system, socio-economic environment and economic productivity. The production system based on rainfed rice and off-season vegetable production with an application of chemical fertilizer generated the highest economic productivity and should be integrated in the recommendation scheme for inland valleys farmers. Furthermore, the results highlighted the importance to strengthen farmers' technical abilities for a better capitalization on inland valleys. These results support the importance of combining several approaches in the classification of inland valleys and fully understand the factors affecting their valorization by rural populations.

Conflict of Interests

The authors have not declared any conflict of interests.

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