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ZIGBEE BASED SENSOR NETWORKS TELESURVEILLANCE SYSTEM

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During the past years in the industry of power plants the necessity for applications that supervise a wide range of parameters from one or more locations has appeared due to the constant growth in the number and diversity of parameters that need permanent monitoring, parameters that are critical for the decisional process in the endless search to avoid alarming states or reducing the outcome of potential incidents. One of the most important matters at power plants refers to monitoring the mechanical vibrations produced by turbo generators as well as to the vibrations induced by these units in the structure of the housing compounds.

Keywords: ZigBee, system, telesurveillance system, vibrations, monitoring

1. Introduction

In case of power plants, the parameters referring to the mechanical vibrations produced by turbo generators as well as to the vibrations induced by these units in the structure of the housing compounds are monitored by performing periodical measurements that are separated by various time intervals i.e., weeks or even months. In case of disaster or incident investigation, the result of this process is not as relevant as would be the one provided by an integrated system that can perform the same thing at configurable time intervals.

These observations reveal that the necessity for an integrated monitoring, processing and alarming system is obvious and such a system could prove to be very helpful in practice. A system of this kind has been presented and improved in the previous papers referring to ZigBee based Sensor Network Telesurveillance System (ZBSNTS) developed with the purpose to collect distant data with the help of an ad hoc sensorial network (SN) for preventing possible defects from appearing, and for minimizing the reaction and intervention time in case of their appearance [1].

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2. Structural and functional concepts

Conceptually and functionally, ZBSNTS is structured on three levels: one level for data acquisition, one level for storage and processing and one information-communicational level disseminated throughout the first two, which ensures the good cooperation of the first two levels and the functionality of the entire system (Fig. 1).

Thus, the first functional level, assisted by the third, is represented by an ad hoc SN which, in turn, is composed of two components: a set of primary data acquisition modules (PDAM) and a network coordination module (NCM). Each PDAM consists of a platform with a microcontroller, one sensor one ZigBee communication device and one Wi-Fi device. Functionally, NCM differs from the PDAM by the functions it provides and the lack of the sensor.

The second functional level, also assisted by the third, is represented by a set of specially designed software applications which provide data storage and processing and also the coordination of the whole system. This level is split in three parts: the local data server for telesurveillance (LDST), the central data server for telesurveillance (CDST) and the user interface (UI).

A series of problems have been solved at the information-communication level. The first one regards the data collecting mode from as many points as possible, and concentrating them in one single point for insertion in the system, having in mind the hardware limitations of the equipments that use cables and connectors, and the space of the location. The solution was the use of a SN which uses ZigBee equipments for network establishment, network coordination and for communication within the network. As [2] shows, using ZigBee devices for data transfer is not feasible and a mix solution that uses Wi-Fi devices for transferring big amounts of data was adopted. A second solved problem refers to offering a 24/7 availability of the system. Due to the importance of the data and the architecture of the system, the communication between components is essential and must have a permanent characteristic. Because of these reasons a mixed solution was adopted which apart the main communication method offers back-up communication solutions for maintaining the link between system components. Another, but not the last, solved problem is the minimization of the intervention time in case of emergency, no mater the functional state of the system. The implementation of software modules, at each system level, that analyze the data and send alarms through an SMS server was chosen as a solution.

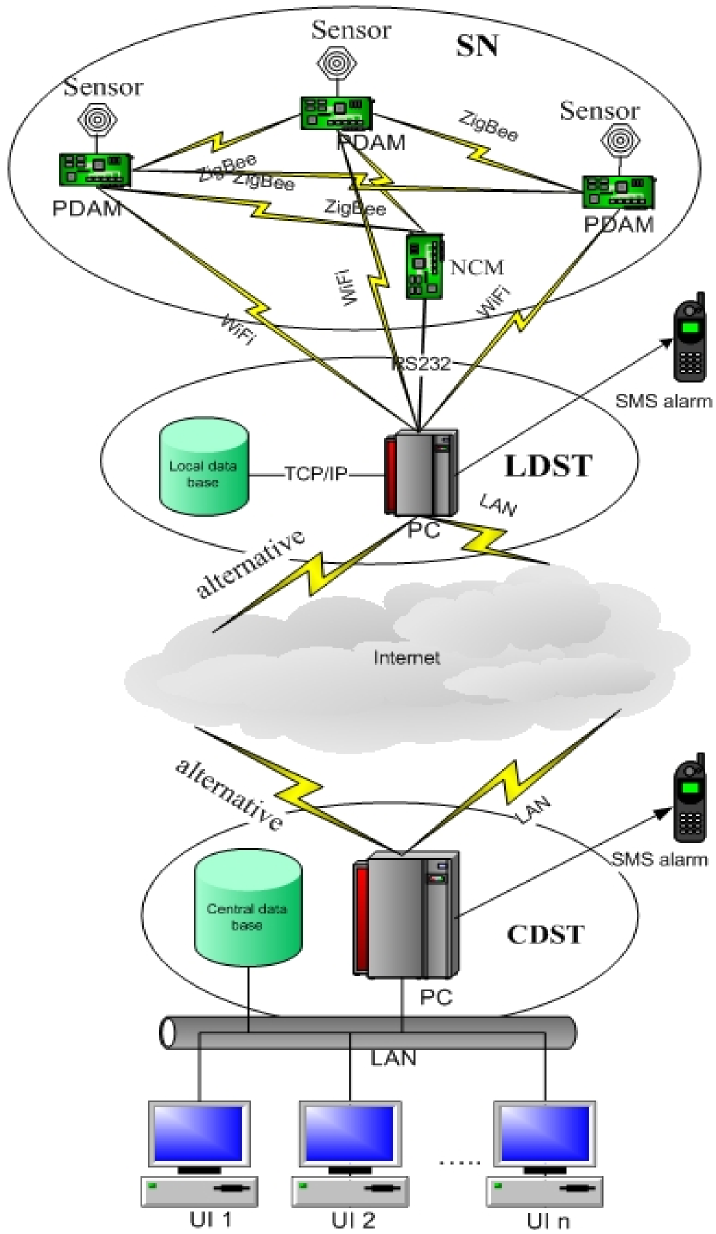

Fig. 1. Structural architecture of ZBSNTS

3. Sensorial network

On designing the system, the most present idea was that it has to be adaptable which in turn translates into flexibility. The place where this flexibility is most important is the sensor network, which represents the first level of the system responsible for collecting data from sensors and inserting these data into the system.

An Ad Hoc network is a collection of nodes that use wireless communications in order to form a temporary network without the help of an infrastructure or a centralized administration. An AdHoc network is also called an infrastructure-less network due to the fact that the composing nodes establish routes in a dynamic fashion in order to create their own network. Sensor networks are a special category of the AdHoc networks used in order to offer the needed infrastructure between sensors that are mounted in a certain location. Sensor nodes are small electronic equipments with the capability to measure certain parameters and transmit through the network to the monitoring equipment. Sensorial networks are fault tolerant because many sensors monitor the same event and because the cooperation and collaboration of the nodes, precise data can be obtained [3, 4].

ZigBee [5, 6] equipments are used for communication support inside the network, ensuring both the network formation and coordination in the absence of a fixed and previous infrastructure and the wireless communication inside the network. The ZigBee devices are used only for network coordination and control while for measured data transfer, Wi-Fi devices are used due to the decrease of the transmission rate in correlation with the increase of PDAMs number (Fig. 2).

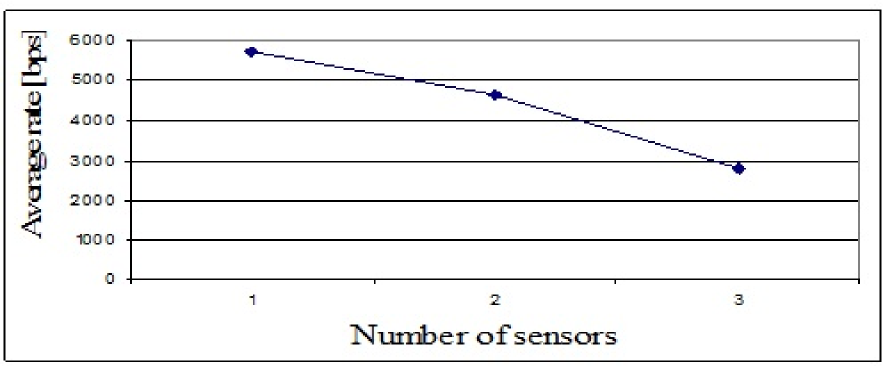

Fig. 2. Average transmission rate as a function of PDAMs number

3.1. PDAM’s architecture

PDAM’s are the main components of the SN which perform the first task of the system, namely data collecting. PDAM is an electronic module that incorporates all the necessary components for ensuring that data is collected by sensors, processed and then inserted into the system (Fig. 3).

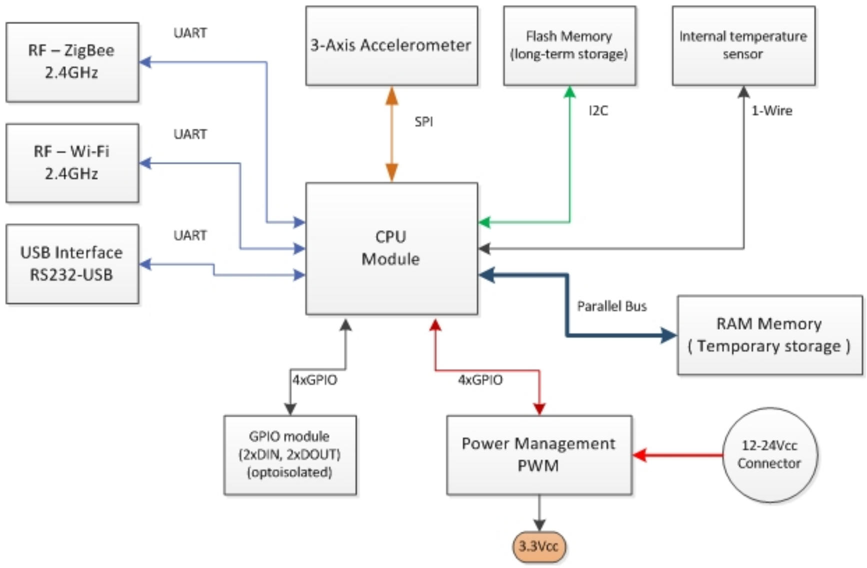

Fig. 3. PDAM's architecture

On designing the module, the main objectives were low power and wireless communications. Low power because a device that could run on batteries for a long period of time was desired, and wireless communication because it was a starting condition due to the necessity of a flexible system with devices that could be moved around without constraints.

The heart of PDAM is the central processing unit (CPU) module defined by all hardware components that process data based on the firmware algorithms. The CPU ensures the proper functioning of all the modules, takes the data from the sensor, processes the control commands received from the system and in the same time manages data storage, ZigBee and Wi-Fi modules in order to achieve maximum battery life. ATXMEGA128A [7] from Atmel was chosen for its capabilities such as 8kB internal RAM and 128kB internal program flash and other capabilities that are more than enough.

For the ZigBee device we used the Telegesis ETRX357 [8], a 2.4GHz ISM band transceiver based on the Ember single chip ZigBee/IEEE 802.15.4 solution. Telegesis ETRX357 is the third generation of advanced ZigBee modules from Telegesis and the first module family on the market to feature EM357 and EM351 - the latest ARM Cortex M-3 SOCs from Ember. The ETRX3 series are low-power ZigBee modules, integrating a 2.4GHz, IEEE 802.15.4 compliant transceiver with up to 192k of flash, 12k of RAM, and many advanced peripherals. In deep sleep mode, the power consumption is reduced to 800nA and even further to 400nA if the self wakeup feature is not enabled. All of the above features make the module a perfect fit for a low power long time battery life device.

For the communication needed to transfer the sensor data to LDST a second communication device of PDAM is used namely the Wi-Fi module that acquires data from the CPU and sends it to the server in short high speed transfers. For this module the Lanotronix MatchPort b/g [9] was used due to its characteristics. This module is a dedicated co-processor one that manages both wirelesses and network activity enabling the device's host microprocessor to function at maximum efficiency. Using a dual processor design (one for converting wired serial data into TCP/IP packets and providing web server capabilities, and the other an 802.11 b/g baseband and radio chipset) MatchPort b/g enables 802.11 wireless connectivity and web services on any device with a serial interface on its host microcontroller. The module is powered by a Lantronix DSTni™ x86 class processor SoC with 256 KB of on-chip SRAM, and also includes 2MB of Flash memory for web page storage and firmware.

The main component of PDAM regarding the task it has to carry out is the 3-axis accelerometer. For this component we selected the ADIS16227 3-axis accelerometer from Analog Devices due to the following important characteristics [10]: it is dedicated for vibration analysis and has wide bandwidth, comes in a small form package and provides digital communication with the CPU, it has auto calibration and it outputs data in time domain and FFT

The ADIS16227 is a complete vibration sensing system that combines wide bandwidth, tri-axial acceleration sensing with advanced time domain and frequency domain signal processing. Time domain signal processing includes a programmable decimation filter and selectable windowing function. Frequency domain processing includes a 512 point, real-valued FFT for each axis, along with FFT averaging witch reduces the noise floor variation for finer resolution. The 16-record FFT storage system offers users the ability to track changes over time and to capture FFTs with multiple decimation filter settings.

The components that participate to the completion of PDAM are subsequently presented in brief. The USB interface is used to manually configure the device when no RF communication is available. Flash memory is used to store data on user request or temporary if no communication is available. In order to use the Wi-Fi module as little as possible to reduce the consumption of power, data is stored in the external RAM over more consecutive measurements cycles. The internal temperature sensor will measure the PCB level temperature and periodically report to the CPU, that based on its configuration can decide to trigger a warning or alarm. The last component of PDAM is the power management module represented by a DC-DC convertor with the responsibility to convert the power input voltage (9-36Vcc) to 3.3Vcc used by all the internal components.

3.2. PDAM's functionality

The main purpose of PDAM is to collect data from sensors and insert it into the system and it was specifically programmed having in mind the low power consumption demand. The only component that is functioning all the time is the CPU that coordinates all the others. When there are no measurements to be made the accelerometer is powered off as well as the ZigBee and Wi-Fi modules. ZigBee is powered on only for transmitting and receiving configuration data and the Wi-Fi is powered on only for transmitting measured data.

Functionally PDAM is structured on two layers, hardware and software, each one with its own data flow.

The data flow at the hardware layer involves only two types of streams namely data and configuration. Measurements from sensors are passed to the processing unit witch in turn transfers it to the communication unit in order to be sent to the server. Configuration data coming from the server follows the same path in the other direction.

At the software layer there are several types of data streams due to the complexity of PDAM. On start up the ZigBee device is powered on in order to receive the PDAM configuration and subsequently it is turned of to reduce the power consumption. Data is being acquired depending on the sensor configuration and then either stored for later transmission or immediately sent to the server. During PDAM functioning, alarms can be generated either by the accelerometer, which is recording a value bigger than the threshold it was programmed for, or by the main finite state machine (FSM) which is recording an anomaly in the functioning of the system and in this case the alarm module is informed and specific information is sent to the server.

The Wi-Fi module is active only to transmit data to the server and is in off line mode the rest of the time to reduce power consumption as much as possible.

4. System servers and user interface

The second functional level of the system is represented by a set of custom software applications [11] running in different points of the system such as: the local data server for telesurveillance, the central data server for telesurveillance and not lastly the user interface.

The reason for choosing a two servers architecture is the desire for minimizing the loss of data, regardless the functional state of the system and offering the possibility to expand for monitoring more locations in the same time.

LDST is the part that provides the interface between the SN and the rest of the system, and also the initial data storage and processing. At this level, data processing is not so complex, due to the reduced computational power of the computer but is configurable, based on the computational power of the server the user being able to specify the data processing level.

CDST comes to complete the system's two server architecture and to ensure the access of the user interface to the system. At this level the final data storage and extended processing takes place.

Both servers are software programs developed as Windows services in C++ and taking the advantage of parallel processing with multiple threads that allows for better resource usage and faster response. By making use of Windows services the problem of SPF (Single Point of Failure) was solved. In such a case the servers can run on dedicated powerful machines while the user interfaces can run o many low power computers.

The part that completes ZBSNTS is the user interface that provides the functions for: configuring the system and the SN, managing the users and the wrights they have and for data processing in order to obtain the most useful information that are needed in the decisional process.

5. Communication techniques

Having in mind the general architecture of ZBSNTS, the communication is split into three components: the communication inside the sensor network both ZigBee [12] and Wi-Fi, the communication between the two servers of the system and the communication between the servers and the user interface. The first one is represented by the wireless communication that takes place inside the sensor network and it is provided by the ZigBee and Wi-Fi modules for the lower levels of the OSI stack. For the application level a proprietary protocol was developed that implies the message-ACK pattern with three time retransmission. As mentioned before the ZigBee devices are used only for network creation and coordination while for transferring big amounts of data the Wi-Fi devices are used.

The communication between the two servers has raised some problems generated by the will to offer a system that is available 24/7. For solving these problems a decision was made to split the communication in two. The main communication link is established by connecting to the internet through the LAN that the servers are connected to. In case of impossibility to establish a link in this way, a second solution, called the Backup solution, was implemented. This Backup solution, aimed to establish a connection between the two servers, makes use of: the user's private network if it exists, the services offered by a GSM operator, on the condition that the technical solution provides a fixed IP, or the transport support as offered by a service provider. Independently of the link establishment method, the communication is based on the TCP/IP protocol combined with a proprietary protocol for the application layer.

6. Data collection, data processing, alarming module

Conceptually and functional PDAM was designed in order to accommodate any demand regarding data collection from periodical to non-stop monitoring. Driven by the desire to obtain a reduced complexity for PDAM it was preferred a simple implementation from the offered facilities perspective so the device would have to complete only the basic tasks that is data collecting from the accelerometer and the PCB sensors monitoring. In making this decision the fact that the device is powered on batteries and a minimum intervention was desired also was considered. As a result PDAM's functions are reduced to data collecting based on two available modes and a minimum data processing for alarms detection.

There are two data collecting modes available namely periodical and continuous. The continuous mode implies permanent monitoring and immediate forwarding of results to the LDST. This mode is the easiest one with respect to data processing but is also the most power consuming mode since data is collected and sent to the LDST continuously which means that the Wi-Fi device is always active which in turn translates to great power consumption. To put it simple, in this mode, the module is instructed to collect data and send it directly to LDST.

The periodical data collection mode is the most complex one in terms of the operations that take place inside PDAM but is the one that ensures the longest life time for the battery. In brief this operation mode develops as follows:

- The operator sets the time intervals at witch periodical measurements are performed and their duration
- The operator sets the time interval when control measurements are performed. This implies a two buffer mechanism. This option gives the possibility to detect alarms even between the measurements interval and gives a perspective view of events providing information about the circumstances that triggered an event
- When the timer for control measurements expires the device wakes up and collects data for inspection. If a certain defined threshold is exceeded an alarm is generated and LDST is informed. Depending on how LDST was programmed he can take certain actions or he can wait for instructions
- When the timer for periodical measurements expires the device wakes up and collects data for the defined time period sends this data to LDST and goes back into sleep mode

A unique feature of the system is the possibility to program each PDAM individually so one module can collect data at a different time interval and for a different time period as any over PDAM in the network. Although each PDAM is configured individually a unitary behavior can be obtained for the entire network when all modules are configured identically offering the maximum possible flexibility.

Having in mind both the purpose of the system and its aiming to help the user in the decisional process by providing the most needed information, and preventing any future malfunctions, special attention was paid to the data processing problem.

Data processing inside ZBSNTS is implemented at every level, that means processing at the PDAM's level, at each server level, both local (Fig. 4) and central, and also at the UI level. The most complex data processing takes place at the user interface where the decisional process also takes place.

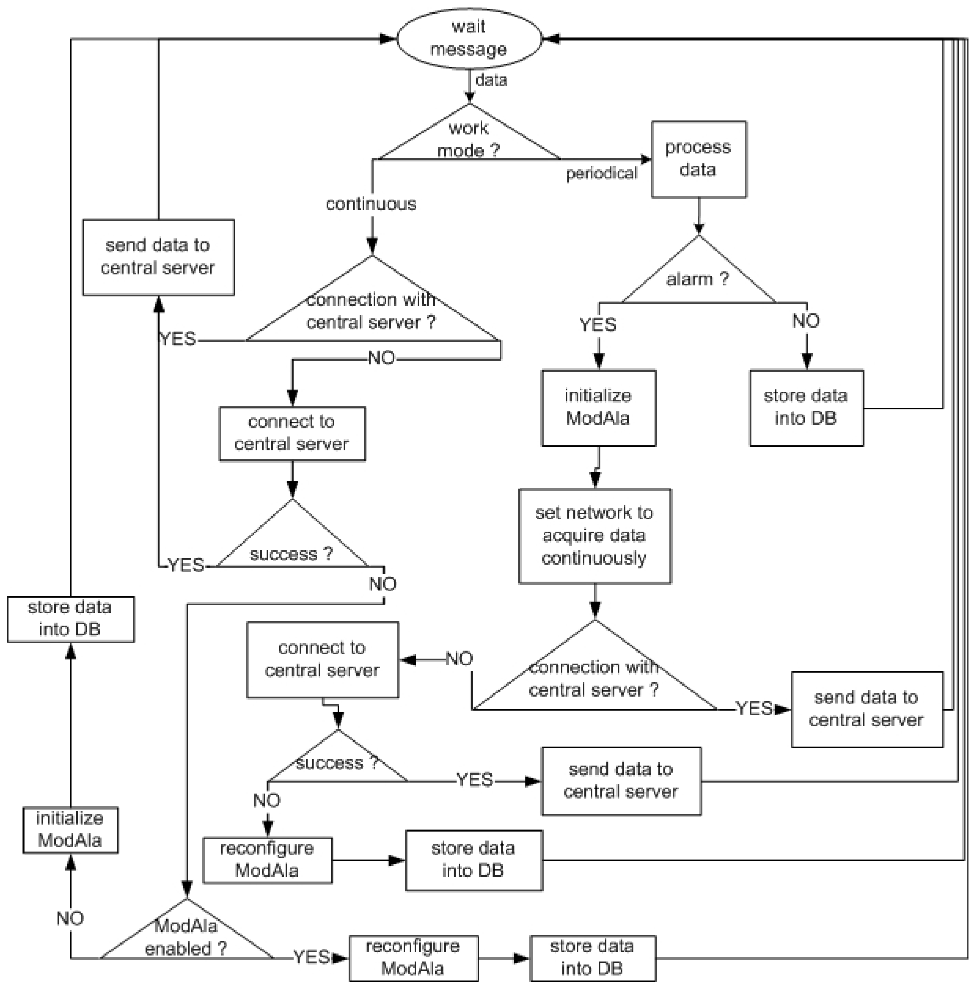

Fig. 4. Data processing at LDST level

It was opted for data processing both at the network and the two server's levels due to the necessity to minimize the reaction time in case of system defects or alarms generated by data processing. This necessity lead to the implementation of an alarming module (ModAla) disseminated throughout the whole system that, with the aid of an SMS server, sends alarms to predefined users informing them of the encountered problem. The way that the tandem data processing – alarming module works is as follows: inside the system criteria that generate alarms are defined. The criteria are represented by systems malfunctions and unexpected results of data processing. In case an alarm is generated, the alarm module is initialized in order for SMS messages to be sent. The messages are sent to specific users, depending on the alarm type, and consist of information about the problem encountered.

Dissemination of data processing and alarm module throughout each level of the system, ensures that the user is informed about the alarms no mater the functional state of the entire system.

7. Conclusions

The use of a sensors network, the possibility to configure the network in such a way as to obtain various behaviors and modes for acquiring data, processing data at each level of the system and the collaboration with the alarming module for obtaining a minimal response time in case of alarms, the use of multiple ways to provide communication between ZBSNTS components and last but not least using adequate modular software, make the presented ZBSNTS the perfect candidate for automating the actual monitoring process of the vibrations produced by the turbo generators at power plants.

R E F E R E N C E S

[1] *Tihon, V. Croitoru*, "ZigBee sensor networks telesurveillance", ISSCS 2011 (International symposium on signals, circuits and systems) IEEE proceedings, Iasi 2011, Romania, pp 225-228, IEEE catalogue number: CFP11816-PRT, ISBN: 978-1-4577-0201-3, Library of congress: 978-1-612484-943-0/11

[2] *I. Tihon, V. Bistea, V. Croitoru*, "Sensor network test bed for ZBSNTS", COMM 2012 (The 9-th International Conference) – Proceedings, Bucharest, 2012, pp. 213-216, IEEE Catalog nr. CFP1241J-PRT, ISBN 978-1-4673-2573-8

[3] *C. Siva Ram Murthy, B.S. Manoj*, "Ad Hoc Wireless Networks Architectures and Protocols", Prentince Hall PTR, ISBN 0-13-147023-X

[4] *S. Basagni, M. Conti, S. Giordano, I. Stojmenovic*, "Mobile Ad Hoc Networks", John Wiley & Sons inc., 2008, ISBN 0-471-37313-3

[5] *A. Elahi, A. Gschwender*, "ZigBee wireless sensor and control network", Prentice Hall, November 2009, ISBN-13: 978-0-13-713485-4, ISBN-10: 0-13-713485-1

[6] *S. Farahani*, “ZigBee wireless networks and transceivers”, Newness, ISBN: 978-0-7506-8393-7
[7] http://www.atmel.com/Images/doc8151.pdf, PDF document
[8] http://www.telegesis.com/downloads/general/TG-ETRX35x-LRS-PM-015-103.pdf, PDF doc
[9] http://www.lantronix.com/pdf/MatchPort-bg-Pro_IG.pdf, PDF document
[10] http://www.analog.com/static/imported-files/data_sheets/ADIS16227.pdf, PDF document
[11] *R. N. Taylor*, *N.Medvidovic*, *E. M. Dashofy*, “Software Architecture: Foundations, Theory, and Practice”, John Wiley & Sons Inc., 2009, ISBN-13: 978-0470-16774-8
[12] *F. Eady*, “Hand-on ZigBee: implementing 802.15.4 with microcontrollers”, Newnes, ISBN-13: 978-0-12-370887-8, ISBN-10: 0-1237-0887-8