Journal of Applied Mathematics & Bioinformatics, vol.3, no.4, 2013, 163-180
ISSN: 1792-6602 (print), 1792-6939 (online)
Scienpress Ltd, 2013

A Military Real Time Locating System Installation and Utilization Approach

Nikolaos V. Karadimas[1] and Nikolaos P. Papastamatiou[2]

Abstract

The proposed work describes an integrated advanced surveillance system for monitoring and recording environmental data (temperature, humidity, dust, smoke, etc) and all movement of people and specific categories of equipment (armor, vehicles, etc) within a specific under surveillance area. The system covers buildings with several floors and basement areas, open areas, gates, and generally areas with authorized access only, which they may be within a building or in independent areas. The purpose of the proposed work is to upgrade the safety in a military area by covering all the internal, external and the perimeter areas overcoming the shortcomings of GPS in indoor areas and the high cost of camera surveillance systems. The main objective of this project is both the security of the personnel who is present in this area and at the same time the safety of certain items (weapons, armor, ammunition, vehicles, etc.) that need special attention utilizing internet technology and specialized equipment to detect motion,

[1] Division of Mathematics and Science Engineering, Department of Military Science, Hellenic Military Academy, 16673, Vari, Greece.
E-mail: nkaradimas@sse.gr, nkaradimas@gmail.com
[2] Omega Technology, 4 El. Venizelou, 17676, Kallithea, Greece.
E-mail: nikos@omegatech.gr

Article Info: *Received* : August 1, 2013. *Revised* : October 20, 2013.
Published online : December 10, 2013.

positioning, heartbeats and environmental parameters (temperature, humidity, smoke, etc).

Keywords: Real Time Location Systems; Safety in Military; Locating Assets or People

1 Introduction

No matter how stringent the safety standards are in military units, unforeseen events will occur and military officers must be prepared to deal with their consequences. Since a large proportion of the military personnel are inexperienced young people like junior commissioned or non-commissioned officers and conscription soldiers, hazards are highly likely to become realized causing dramatic results firstly for the families of the sufferers and most importantly for the morale and credibility of the entire armed forces [1]. Commanding officers are responsible for the safety of their soldiers and are in several cases charged for injuries or deaths occurring to personnel under their commands in periods of peace.

The project respecting the value of the human life provides the ability of tracing and informing directly about the problems that the personnel of specific areas might face. The system receives signals from sensors (position, speed, heart rate, ambient temperature, humidity, smoke, flood, etc.), which are located in the area under study. It evaluates these data and through risk and behavior rules, which would be defined dynamically by authorized personnel (i.e. who from the personnel has the authority to insert in some prohibited areas, gates must not open after a certain time, etc.) will send warning signals and supports authorized users and will derive conclusions from the observation of the behavior of some, under observation, personnel for a specified period. The system is based on wireless communications from which, RSSI, as discussed below, is the simplest and least expensive solution, as it depends on RF propagating properties and requires no special hardware manipulation.

The paper is structured in the following sections. Firstly, the ZigBee Protocol and the ZigBee Pro network topology are presented as well as the Received Signal Strength Indicator (RSSI) which is used as a distance calculation method. Furthermore, Section 3 describes the signal attenuation during its transport between two points and in Section 4 the proposed system is presented. Section 5 is devoted to discussion and future works.

2 Wireless Sensor Networks

2.1 ZigBee Protocol

Wireless sensor networks (WSNs) generated an increasing interest from industrial and research perspectives [2]-[5]. Different types of wireless communications can be used in a system and their cost is continuously declining. Those networks have the ability to self-configure, so there is no need for configuration during installation. The sensors detect each other and build the wireless network.

ZigBee Pro wireless protocol is one such protocol that enables the buildup of a WSN. ZigBee has been explicitly designed for low consumption and minor radiation levels, making it the best choice for applications involving besides others and people tracking. In addition, its long battery life guarantees that infrequent maintenance is required - reducing the cost.

Providing Real Time Location System (RTLS) solutions based on ZigBee offers many advantages over other possible approaches, such as:

- reduces the time needed for locating assets or people - improving productivity particularly when time critical issues arise,

- enhances centralized management and control, as information acquired can be available both locally and remotely,
- decreases time required for any statistical calculations over samples of data gathered, as data logging is fully automated,
- fortifies or enhances security and allows for custom rules definitions over accessibility of certain areas of importance.

2.2 ZigBee Pro Network Topology

ZigBee Pro features mesh networking topology, which allows link connections between several points of the network structure. That means that each node can communicate with all other nodes in range, providing stable and versatile grid formation with increased resistance to transmission errors. These qualities, along with very low levels of energy consumption and radiation emission, forge a great candidate for indoor location system assembly.

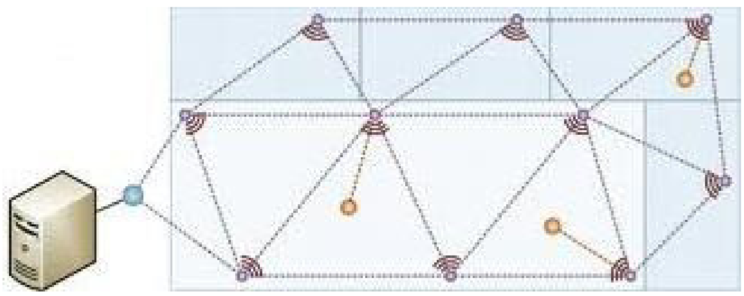

Figure 1: ZigBee Mesh Network

Mesh networking allows nodes to transmit and receive information using the best available path in real time. Such a topology results to an auto repairable wireless network with multiple routes for successful signal propagation. Furthermore, environmental influences on transmissions are greatly reduced.

2.3 RSSI as a distance calculation method

Several methods exist for measuring the distances between two antennas in a wireless network: Received Signal Strength Indicator (RSSI) values, signal the angle of arrival and time difference of signal arrival using multiple nodes are the most common. The RSSI is the simplest and most cost effective way, as it is merely a property of signal propagation. Thus, not requiring specific hardware, it has gained the majority of interest. RSSI is the quantized expression of Received Signal Strength (RSS) [6], which directly refers to the power level of a received packet. Hence, it is greatly affected by many parameters as Shashank [7] describes in his work.

What is more; RSSI, being directly affected by the distance the signal has travelled until reaching its destination, can be used to obtain information about the source's location if more measurements from other network nodes are available. The formula (1) and RSS (and thus RSSI) relation to distance has been proposed by Aamodt [8].

$$RSSI = -(10n\log_{10} d + A) \quad (1)$$

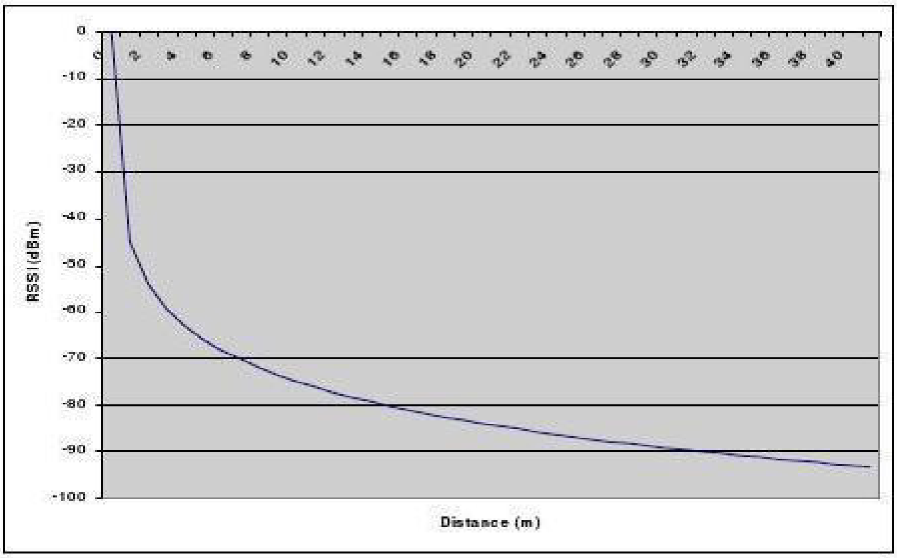

Figure 2: RSSI versus distance for A=40, and n=3

Evidently, path loss does have a great role in reducing the power level of the signals recorded. Parameter ‘n’ [9] is also defined as “the path loss exponent” (although Texas Instruments [9] uses an index analogy for parameter ‘n’), highlighting even more the need of a clear line of sight when possible [10].

3 Signal attenuation

3.1 Clear Line of Sight

Wireless transmissions, being waves, decrease over distance. The least power loss of signals is usually observed when propagating on a path of what is known as a clear line of sight [11]. Clear line of sight for radio waves is an imaginary straight line connecting two points of the wireless network, free - at a percentage of 80% minimum - of obstacles in the Fresnel Zone of the signal. Fresnel zone (Figure 3) is defined as a circle around the theoretical line that shows the direction of a wave [11].

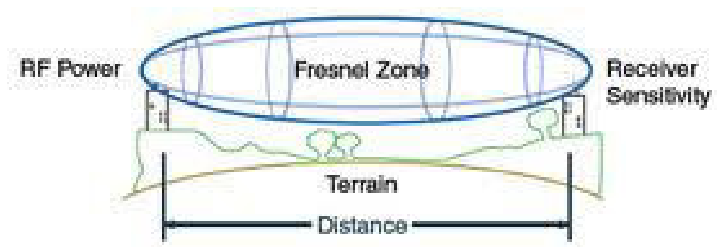

Figure 3: Fresnel Zone

Fresnel Zone $$R = \frac{1}{2}\sqrt{L * D} \quad (2)$$

where R is the radius of the first Fresnel zone, L is the wavelength and D is the distance between sites. For example at 2.4GHz the wavelength is around 12cm, thus the radius of the first Fresnel zone is around 1.22 meters at 50 meters distance. Ergo, indoor deployments should avoid placements of nodes closer to ceilings or floors than 1.22 meters to refrain from blocking the clear line of sight from the start.

Being indoors can greatly distort one's view of clear line of sight in many other ways as well; mainly due to reflections, scattering, diffraction which cause, among others, a multi-path fading and shadowing of the frequency band in use. Best practice to take all these into account and minimize data loss later on, is to define the effect these have on wireless transmission on site [12], [13].

3.2 Attenuation

Whenever a Radio Frequency (RF) signal loses a portion of its original power, it is due to the attenuation that the medium it travels through exhibits under current circumstances. Conditions such as heat and humidity also affect signal absorption, as well as the angle of incidence upon joints of different materials. Furthermore, it is evident that space travelled by a transmission may not be of uniform attenuation, hence calculating how much power the signal has at the end is not always trivial as Figure 4 presents. Attenuation unit is dB, and it is calculated via the formula (3).

Figure 4: Calculating Attenuation Sample

$$\text{Attenuation} \quad 10 * \log_{10}(P_{\text{after}} / P_{\text{before}})_{\text{dB}} \qquad (3)$$

An example of attenuation calculation is demonstrated in Erin-Ee-Lin et al work [12] as follows: “If, due to attenuation, half the power is lost (Pout/Pin = 2), attenuation in dB is 10 x Log (2) = 3dB”. In addition to the previous statements, path loss, material absorption as well as any other reason why network link quality suffers, can be attributed to attenuation and is measured in dB.

3.3 Path Loss estimation

Deploying wireless networks has always been a challenging task to plan, due to the complexity of the problem. Efficiency of signal propagation depends upon a large set of environmental variables; such as obstacle frequency along a signal’s path, the diffraction, reflection and scattering of the signal and many more. Path loss is a quantity that describes the overall reduction of signal level which derives from the former reasons. Thus, path loss estimation is necessary as it provides valuable data for predicting when wireless communication is viable between two nodes of the network.

Calculating path loss involves correctly combining mathematical formulas concerning clear line of sight and signal absorption due to attenuation, caused by physical objects. However, one should first define the path followed itself; a difficult problem on its own. Solution to the aforementioned tasks is a tiresome repetitive procedure, given that in addition to network stability, optimal RSSI measurements are needed as well. Hence, an algorithm was developed to transform all available data to something that can be used effectively.

3.4 Empirical Attenuation Calculation

One of the things that holds a primary role in path loss calculations is the materials that indoor physical obstacles consist of. This multidimensional variable is introduced by the building structure and indoor environment complexity, cited previously - being mainly responsible for signal attenuation.

Attenuation, as previously noted, relies greatly on the kind of material in question. Obviously, preliminary knowledge of each object's material, and therefore its attenuation is of high importance when planning a wireless network deployment. Attenuation also depends on the thickness of the object, as well as the angle of arrival on the object's surface. The latter is also determined by the type of the antennas being used. Concerning omnidirectional antennas, and their waveform spreading pattern, the importance of the angle of arrival is minimized and thus not taken into consideration. The following figure (Figure 5) shows the radiation pattern of an omni – directional antenna with its side lobes in polar form. This antenna radiates and receives in all directions in azimuth, in an isotropic way.

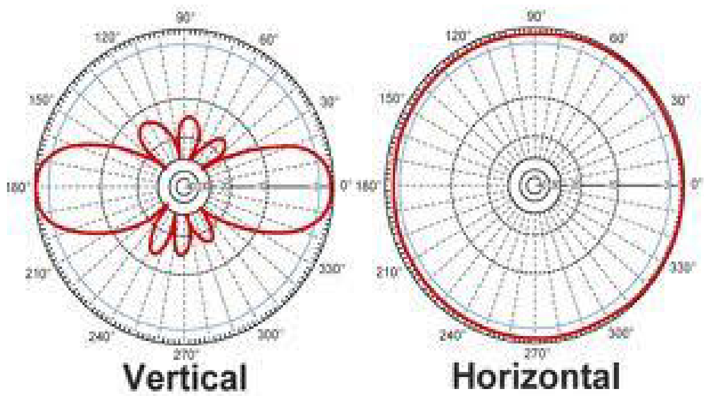

Figure 5: Omni – Directional Antenna

Finally and most importantly, given the material, a specific amount of attenuation is measured. This led to the establishment of databases that list attenuation of many standardized objects with detailed precision. Data can be extracted and used accordingly, forming tables containing data-set addressing certain needs is a common practice to tackle attenuation calculation.

However, mainly due to lacking the ability to correctly identify all materials of interest, experimental values are obtained on site as it has been presented by Shahin [6]. A procedure, known as site survey [6], for collecting attenuation data consists of the following simple steps:

- properly placing receiver and transmitter nodes at both edges of measured obstacle
- retrieve a satisfactory sample of measurements, reducing errors by using statistical tools
- define object's thickness
- divide attenuation result with object's thickness to find attenuation per length unit
- repeat steps for all kinds of objects of interest

Attenuation per length unit, for example dB per meters, can be applied for sets of obstacles consisting of the same material. Thus, it is most practical and is used by the algorithm mentioned above. It should be noted again, that attenuation does depend on signal frequency - yet it is common when deploying a wireless network to use only one specific RF band.

4 Proposed System

The above methodology was applied for the setup of a wireless sensors' network to cover a military area offering both indoors (chambers, tolls, buildings, underground areas) and outdoors area coverage (Figure 6).

Our work was consisted of the following basic components:

- **Wearable localization system.** The system exploits location engines and algorithms to offers location accuracy. Research work focused on the exploitation of low cost and low consumption wireless sensors, and wearable, waterproof and comfortable mobile tags in which further sensors can be embedded to offer additionally functionality like identifying falls, shocks and in general movement.

- **Control System:** This component involves formation of rule based behavioral patterns. Through pattern matching, location identification, it raises alerts and/or activates other devices that will react upon helping the military area personnel (sirens, SMS messages, emails, etc).

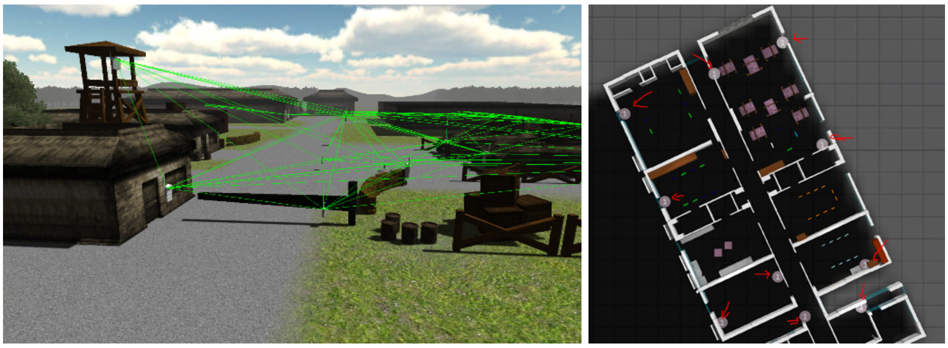

Figure 6: Example of positioning nodes in a military area (indoors and outdoors)

The procedure consists of selecting the type of wireless nodes to be added and the positioning of them on site. Then for each node, the strength of signal among its neighborhood nodes is calculated. The RSSI strength is produced through a modified site survey algorithm based on the obstacles between the node and the losses their materials causes to the signals send [14].

In Figure 7 a part of the database that records all data from our system's sensors is presented. For example, the lines 5-9 (Figure 8) represent an event; the opening of a door and some movement in an area under surveillance (area: WH12). Besides, the time, the identification number of the particular sensor and other data are shown. Those data could be modified and customized depending on what a user wants to record in the database. The elaboration of these data and the raise of possible alerts is part of the Control System's business intelligence.

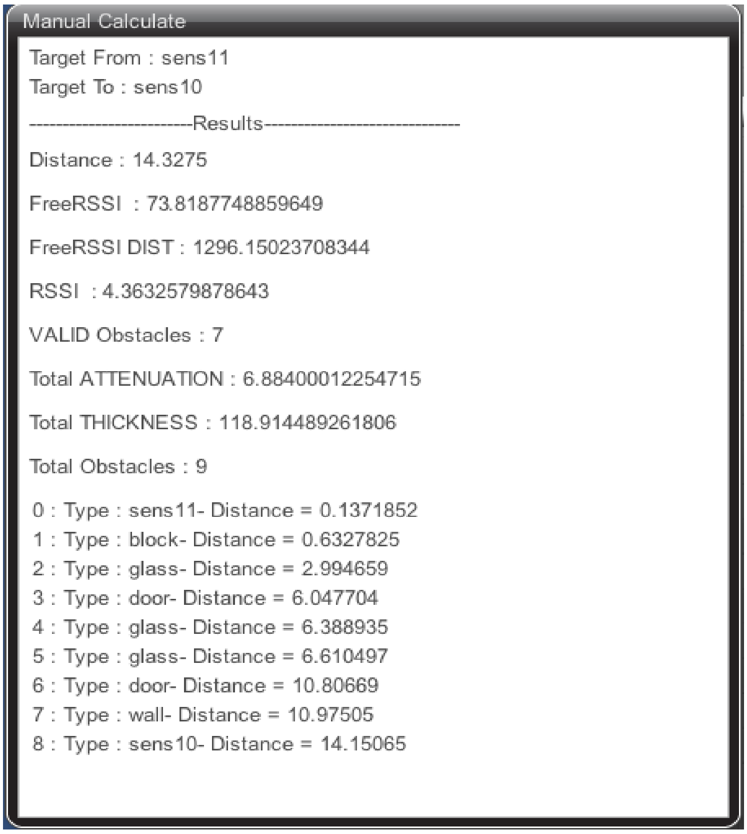

Figure 7: Attenuation calculation

2012-07-05 20:05:02.000	Gate 010	MOTION	ON	OFF
2012-07-05 20:06:23.000	Weapon WH01	MOTION	OFF	OFF
2012-07-05 20:06:50.000	Weapon WH01	MOTION	ON	OFF
2012-07-05 20:07:25.000	Gate 010	MOTION	ON	OFF
2012-07-05 20:07:51.000	Armor WH12	DOOR	ON	OFF
2012-07-05 20:07:54.000	Armor WH12	DOOR	OFF	OFF
2012-07-05 20:08:14.000	Armor WH12	MOTION	ON	OFF
2012-07-05 20:09:42.000	Armor WH12	DOOR	ON	OFF
2012-07-05 20:09:52.000	Armor WH12	DOOR	OFF	OFF

Figure 8: Describing an event in lines 5-9 of a database instance of 9 lines

In Figure 9, we see the information of a soldier location. Comparing the coordinates given by the system with the coordinates of the buildings (Figure 10), the specific is located inside the central Warehouse which is under surveillance.

Date	Person	X	Y
2012-07-07 12:50:38.000	SOLDIER 22312	1334	1222
2012-07-07 12:52:29.000	SOLDIER 22312	1380	1250
2012-07-07 12:54:15.000	SOLDIER 22312	1375	1250
2012-07-07 12:56:01.000	SOLDIER 22312	1388	1252
2012-07-07 12:57:56.000	SOLDIER 22312	1400	1240
2012-07-07 12:59:41.000	SOLDIER 22312	1385	1230
2012-07-07 13:03:56.000	SOLDIER 22312	1360	1190

Figure 9: A snapshot of a Real time position of a Soldier

Area	X1	X2	X3	X4	Y1	Y2	Y3	Y3	Area Id	Sector
Toll1	165	165	1150	1200	300	800	800	320	10	1
Central Warehouse	1200	1240	1600	1600	900	1400	1380	899	11	1
Toll2	2400	2400	3000	3000	109	371	371	110	12	1
Administration Buildings	3400	3400	3600	3600	400	436	436	400	1014	2
Restaurant	3200	3200	3340	3350	900	1400	1380	899	1015	2

Figure 10: Coordinates of a sample of the military structures

For the same soldier the real time information for his heart rate is shown in the figure (Figure 11) and his acceleration information (Figure 12).

Date	Person	Heartrate	Signal
2012-07-07 12:50:38.	SOLDIER 22312	90	-48
2012-07-07 12:50:39.	SOLDIER 22312	90	-45
2012-07-07 12:50:40.	SOLDIER 22312	90	-45
2012-07-07 12:50:41.	SOLDIER 22312	90	-42
2012-07-07 12:50:42.	SOLDIER 22312	90	-48
2012-07-07 12:50:43.	SOLDIER 22312	90	-49
2012-07-07 12:50:44.	SOLDIER 22312	90	-47
2012-07-07 12:50:45.	SOLDIER 22312	90	-43
2012-07-07 12:50:46.	SOLDIER 22312	90	-44
2012-07-07 12:50:47.	SOLDIER 22312	91	-41
2012-07-07 12:50:48.	SOLDIER 22312	92	-42
2012-07-07 12:50:49.	SOLDIER 22312	92	-39

Figure 11: Real time heart rate

Date	Person	accx	accy	accz
2012-07-07 12:50:38.	SOLDIER 22312	-0,04	0,09	0,93
2012-07-07 12:50:39.	SOLDIER 22312	-0,02	0,09	0,88
2012-07-07 12:50:40.	SOLDIER 22312	-0,02	0,1	0,91
2012-07-07 12:50:41.	SOLDIER 22312	0,01	0,09	0,89
2012-07-07 12:50:42.	SOLDIER 22312	-0,02	0,09	0,91
2012-07-07 12:50:43.	SOLDIER 22312	0	0,11	0,88

Figure 12: Real time acceleration information

Via the Control system the authorized users have the opportunity to be informed about any kind of situations that may occur in the area that the indicators have been installed. The added value compared to camera surveillance systems is that they not need to be in front of a screen all the time. Operators are informed real time for an event and have the ability to view real-time the location of each person or asset that is involved in that alert. Also the users can inform the system about the referred alarm. If the user presses the position locating button, then it appears on the screen a red spot with the current position of that particular user or asset. The location of the monitored user or asset is updated in real-time as the user or the asset is moving. The alerts that are supported in our work are already eight (8):

- Pressure of Panic Button
- Warning of any fainting accident
- Open gate / door
- Entering in prohibited areas
- Exceeded limit of temperature, humidity, smoke, etc
- Any other custom rules (i.e. entrance or exit of a specific user from an area under surveillance, Open a gate from a person, etc.)
- A threshold of heart beat pulses
- Shock detection

All the alerts are generated either by predefined rules (such as the panic button, the smoke indicator, etc) or from customized rules which are defined by the user himself (i.e. notification if someone enters into a room). A user can also define even the duration of each rule in order to be taken under consideration by the control system, as well as the risk level of each alert (High - Medium - Low) when a specific rule is matched. The sensors for motion, smoke and movement could return values “ON” and “OFF”, while the temperature and humidity sensors return the exact value of the temperature and humidity limits specified.

The administration system manages all the users of the system and defines three categories of roles. The three roles are: Administrators, Supervisors and Naïve Users. Naïve Users can monitor the location of the personnel or the assets as well as each warning of the system. In addition, the Supervisors are also able to define the sensors of the personnel and the assets as well as the areas under surveillance and any kind of the rules. Finally, the Administrators have all the authorities of the system and they are the ones responsible for giving the authorities to each category of the users of the surveillance system.

5 Discussion and future work

With a Wireless Sensor Network a military area can strengthen its security and allow also for custom rules definitions over accessibility of certain areas of importance. Most importantly, it increases safety of personnel (fall detection, speed monitoring, panic button, etc). Possible scenarios that the proposed system can be of great support are:

- Use of warning signals in order to avoid visits in prohibited areas by several groups of people.
- Reminder to avoid unnecessary stay in an area.
- Monitoring and controlling of the personnel or the assets which are leaving specific areas
- Surveillance of visitors in particular areas
- Income and outcome monitoring control of specific gates, doors and areas
- Panic button in case of emergency
- Warning of any fainting accident, monitoring of personnel's heartbeats.
- Online surveillance of the position of any person (whether s/he is inside or outside a building)

- Warning when particulars indicators of the under surveillance personnel (i.e. temperature, heart rates, etc) tend to be off-limits.

One of the basic advantages of our system, deriving from the ZigBee Pro Wireless Protocol is that it can be easily integrated with more wireless devices. Peoples' location tracking can be enhanced with vital signs monitoring (Heart rate monitoring, body temperature, blood pressure, Shock detection, etc). Additionally environmental indicators can be combined with the location information to upgrade the intelligence of the control system (Smoke detectors, Temperature, Humidity sensors, motion detectors, intrusion detectors, alarms, flood detectors, etc).

To begin with, nowadays mainly two categories - asset and people tracking - demand a stable and useful implementation of a Real Time Location System (RTLS). To deploy such a network is not a simple task. Information about building structure, indoor environment complexity need to be analyzed and attenuation and actual node quantity should be taken into account.

The Highlight of the solution, is its specific design for optimized deployment of ZigBee Real Time Location Systems (RTLS) with minimum planning effort required. Considering particularities of the RTLS which distinctly differentiate such networks, this approach introduces significant insight in the site survey software category.

This research has a limited repository of materials tested and used during the pilot study. In order to cover greater variety, further and more detailed experiments should follow to complete the basic construction materials.

References

[1] N.V. Karadimas, N. Doukas and N.P. Papastamatiou, Risk Preparedness and Management Scheme for Military Units, *MAMECTIS 2008 – 10th World*

Scientific and Engineering Academy and Society, International Conference on Mathematical Methods, Computational Techniques and Intelligent Systems, Corfu, Greece, (26-28 October, 2008), 481-485.

[2] D. Culler, D. Estrin and M. Srivastava, Overview of sensor networks, *IEEE Computer*, **37**(8), (2004), 41-49.

[3] C. Raghavendra, K. Sivalingam and T. Znati, *Wireless Sensor Networks*, Springer, New York, NY, USA, 2004.

[4] K. Sohrabi, J. Gao, V. Ailawadhi and G. Pottie, Protocols for self-organization of a wireless sensor network, *IEEE Personal Communication*, **7**, (2000), 16-27.

[5] M. Tubaishat and S. Madria, Sensor networks: an overview, *IEEE Potentials*, **22**, (2003), 20-30.

[6] F. Shahin, *Zigbee Wireless Networks and Transceivers*, Elsevier Ltd, 2008.

[7] Shashank T., 2006. "Indoor Local Positioning System for Zigbee, based on RSSI". MSc Thesis, Electronics Design in Electrical Engineering.

[8] K. Aamodt, CC2431 Location Engine, *Application Note AN 042, Chipcon Products from Texas Instruments*, (2008), 2-8, http://focus.ti.com/lit/an/swra095/swra095.pdf [Retrieved at: Feb 10, 2012].

[9] Texas Instruments, CC2431 – System-on-chip for 2.4 GHz Zigbee/IEEE 802.15.4 with Location Engine*, Data Sheet, Chipcon Products from Texas Instruments,* (2009, http://www.ti.com/lit/ds/swrs034b/swrs034b.pdf [Retrieved at: May 10, 2012].

[10] P. Chuan-Chin and L. Hoon-Jae, State and Path Analysis of RSSI in Indoor Environment, *International Conference on Machine Learning and Computing, IPCSIT, IACSIT Press, Singapore*, **3**, (2011), 289-293.

[11] Breeze Wireless Communications Ltd, Radio Signal Propagation, http://didier.quartier-rural.org/implic/ ran/sat_wifi/sigprop.pdf [Retrieved at: Feb 10, 2012].

[12] L. Erin-Ee-Lin, L. Boon-Giin, L. Seung-Chul and C. Wan-Young, Enhanced Rssi-Based High Accuracy Real-Time User Location Tracking System For Indoor And Outdoor Environments, *International Journal on Smart Sensing and Intelligent Systems*, **1**(2), (June, 2008), 534-548.

[13] T.A. Wysocki and H.J. Zepernick, Characterization of the indoor radio propagation channel at 2.4 GHz, *Journal of Telecommunications and Information Technology*, **3**(4), 2000. 84-90.

[14] G. Technitis, A. Sofios, N.V. Karadimas, K. Tsergoulas and N.P. Papastamatiou, 3D Algorithms to Improve Deployment of Wireless Location Systems Efficiency, *ECMS 2012 - Proceedings of the 26th European Conference on Modelling and Simulation*, Koblenz, Germany, (29 May – 1 June, 2012), 339-344.