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Implementation of CRSN in Mobile Phones for Detection of Explosives

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Abstract

By utilizing the applications of wireless sensor networks we aim at improving the security of human life by preventing terrorist attacks causing explosion in certain areas. In real time monitoring we require fast transmission of the information and also high scalability of the sensor network for explosive detection. The aim of this paper is to utilize nano sensors for explosive trace detection to secure populated area using cellular networks. It would further help the police in detection of explosives more quickly, isolation of suicide bombers, remediation of explosives manufacturing sites, and forensic and criminal investigation. The idea is to embed tiny cognitive radio sensor node into mobile phones that adapts to changing environment by analyzing RF surroundings and adjusting spectrum use properly. This implementation would be able to detect explosives which in turn would inform the law and enforcement agency.

Keywords: Sensor Network, Cognitive Radio Sensor Node, Explosive Vapour Sensor, Software-Defined Radio, Explosive Trace Detection, Mobile Phone.

Introduction

Selective and Sensitive detection of explosives is very important in countering terrorist threats. Detecting trace explosives has become a very complex and expensive endeavor because of a number of factors, such as the wide variety of materials that can be used as explosives, the lack of easily detectable signatures, the vast number of avenues by which these weapons can be deployed, and the lack of inexpensive sensors with high sensitivity and selectivity. High sensitivity and selectivity, combined with the ability to lower the deployment cost of sensors using mass production, is essential in winning the war on explosives based terrorism. These sensors need to be a part of a complete system solution that is adaptable to different user needs and skills. To obtain a secure world free from terrorist attacks we should employ a system which is suitable for explosive trace detection. Central to detection is chemical recognition using a selective agent and signal transductions. The most important performance characteristics of trace explosive sensors include high sensitivity, selectivity, reversibility and real time operation.

The main objective of the paper is to form a system which integrates mobile phones with cognitive sensor nodes for explosive trace detection. Sensor Networks are dense wireless networks of small, low-cost sensors which collect and disseminate environmental data. Wireless sensor networks facilitate monitoring and controlling of physical environments from remote locations with better accuracy. The sensory data is forwarded from the originator sensor node to the base station in multi hop ad-hoc fashion.

The three basic functional units present in the sensor node are : Sensing Unit, Processing Unit, Transceiver Unit.

- Sensing Unit –Used to convert analog signals to digital signals which are generated by sensor nodes.
- Processing Unit – Used to manage the functions that are responsible for communicating with the other sensor nodes.
- Transceiver Unit – Used to connect a node to the sensor network.

Understanding the accept ability issue, growth nature and physical security of mobile phones an integrated system whereby the explosive trace detection may be done by using the existing mobile network instead of a separate sensor network. A sensor network basically consists of specially distributed tiny sensor nodes that are used to measure physical and environmental parameters like temperature, humidity, pressure, mechanical stress level etc., and the network is formed by deploying these nodes in the region of interest with wireless connectivity in between them.

The sensory data is forwarded from the originator sensor node to the base station in multi hop ad-hoc fashion.

Figure 1 shows the basic functional unit of a sensor node. Sensing unit consists of a sensor and an analog-to-digital converter (ADC), which converts the analog sensory data to digital data. This in turn is stored and processed by the processing unit which consists of a digital signal processor and a small memory unit. Transceiver serves the purpose of both transmitting the digital signal to the next sensor node or the nearby base station as well as receiving the signal from other sensor nodes. The sensor unit may consist of one or more different types of sensors such as seismic sensor, low sampling rate magnetic sensor, thermal sensor, visual sensor, infrared sensor, acoustic sensor and radar sensor[1,2].

When multiple nodes desire to transmit, collisions occur and data may be lost. Different media access protocols are used to avoid collisions[3]. In Frequency Division Multiple Access(FDMA), different nodes transmit at different carrier frequencies. However this decreases the bandwidth available for each node as the frequency resources are divided and further requires additional hardware and intelligence at each node. In Code Division Multiple Access (CDMA), a unique code is assigned to each node to encode its messages. But this increases the complexity of the transmitter and the receiver. In Time Division Multiple Access (TDMA), the RF link is divided along a time axis, with each node being given a predetermined time slot for transmission of messages. The major advantage of TDMA is that it can be easily implemented in software. All nodes require accurate, synchronized clocks for TDMA.

Sensor network is a very promising technology in the field of battlefield surveillance and environment monitoring. In a structured sensor network application (e.g. video surveillance system) sensors are placed at the exact specific locations. While in an unstructured sensor network application (e.g. battlefield surveillance) sensors may be randomly dropped.

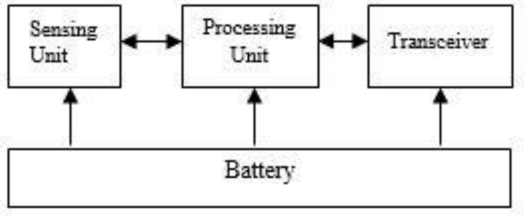

Figure 1. Basic functional units of a sensor node.

There are certain limitations of the sensor network that restrict the application area of it in the field of explosive detection[4-6]. They are as follows.

1) Power consumption is the most predominant issue in designing a sensor network supporting real time communication as the power supply of a sensor is limited. Also recharging of the battery may not be possible every time. To reduce power consumption different schemes have been proposed by turning off the redundant sensors. So the transmission of sensory data in the sensor network is highly affected by the node failure due to lack of power, physical damage.

2) Scalability of the sensor network depends on the transmission range of the sensor and number of sensor nodes used in the network. Depending on the application the density of the sensor nodes may reach from a few hundreds of sensor nodes to few thousand sensor nodes per km. So the cost of the network design will increase if size of the area of deployment increases.

The idea is to embed a tiny sensor node in the mobile phone capable of scanning the surrounding without the knowledge of the user and having the ability to dynamically adapt their communication parameters such as carrier frequency, transmission power and modulation to send the sensory information to the nearest base station. Each cell phone can then be treated as a mobile sensor node for explosive trace detection with the existing base station of the cellular network as the base station for the sensor network. In doing so, the coverage area will not be limited and multi-hop routing may be avoided as each cell phone can send the sensed information directly to the base station as shown in Figure 2. So the data transmission time must be less than the conventional sensor network. The problem of recharging of the battery of the sensor node can be overcome by using the battery of the cell phone. The sensor node will also get global mobility which will increase the scalability of the network. Hardware based transreceiver may not be fruitful but cognitive radio sensor node (CRSN) will be very effective.

Cognitive radio is a system that can sense the spectrum and determine the vacant bands and use these vacant bands in an opportunistic manner[7]. It can operate both in licensed as well as unlicensed band. To realize CRSN, the transreceiver of the sensor node should provide the capability of reconfiguring its operating frequency, modulation, channel coding and output power without hardware replacement. Software-Defined Radio (SDR) or reconfigurable radio system based trans-receivers are used for CRSN because of their reconfigurability[8]. Here the size of the sensor node is a constraint, as the sensor node has to be embedded in the cell phone. Most recently, chemical vapor nano sensor systems based on Nano Electrochemical Systems (NEMS) are developed that are used for explosive trace detection in non-conducting mode[10,11]. This type of sensor may be used to design CRSN. The advantages of chemical vapor nano sensor include small size (<100 nm) that miniaturizes the sensor node, less sensing time, low power consumption in the range of mW, reusability and less idle time between the sensor activities as compared to other sensor types.

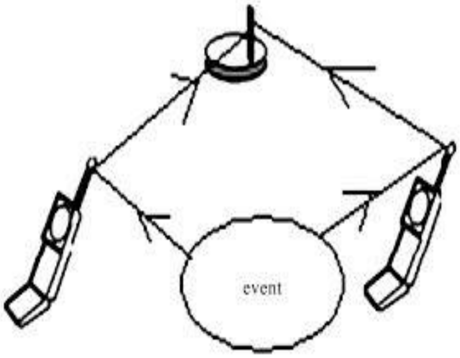

Figure 2. Routing of sensory information from cell phone to base station.

The paper is organized as follows. After the introduction an overview of chemical vapor sensor is provided in Section 2. Section 3 deals with the overview of SDR followed by implementation details in Section 4. The paper ends with conclusion in Section 5.

Overview of Chemical Vapor Sensor

Chemical vapor sensors are mostly used for explosive trace detection due to their mass scale deployment ability, automatic detection process, low cost, high detection accuracy, high portability, continuous monitoring capability, small size and high reliability as compared to techniques like metal detection and canine. Most commonly used explosives can be divided into six categories based on their chemistry and organic compound which emit certain amount of vapor in air. These are as follows. 1) Organic peroxides, such as triacetone triperoxide (TATP) and hexamethylene triperoxide diamine (HMTD). 2) Nitroaromatic compounds, such as TNT, dinitrobenzene (DNB), hexanitrostilbene, picric acid. 3)Aliphatic nitro compounds, such as nitromethane, hydrazine nitrate. 4) Nitramines or nitrosamines, such as octogen (HMX) or RDX. 5) Nitrate esters, such as pentrite (PETN), ethylene glycol dinitrate (EDGN), nitroglycerine, and nitroguanidine (NQ). 6) Acid salts, such as ammonium nitrate. A generalized explosive vapor sensor consists of a transducer and a receptor coating layer as shown in Figure 3. When the explosive molecules react with the receptor coating layer, an electrical, optical or mechanical signal is generated from the transducer due to the molecular interaction. Sensors that detect analytes by monitoring changes in the resistance are called chemiresistive sensors. The response of chemiresistors to gas concentration is found to follow the following equation.

$$R_s = 1/(AC^{\alpha}) \qquad (1)$$

In (1) Rs is the resistance of a conducting polymer (receptor coating layer), C is the concentration of a gas molecule and (A, α) are constants that change with the type of gas and temperature of the sensor respectively. To get a reversible sensor, explosive gas molecule must bind to the receptor with weak molecular interaction like Vander Waals force, electrostatic and hydrogen bonding that can be broken at room temperature.

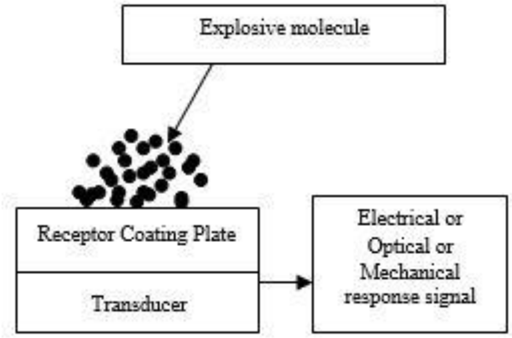

Figure 3. Generalized explosive vapor sensor.

Chemical selectivity based on weak interaction is poor but it can be enhanced by using sensor array with different receptor coating. Sensitivity may be increased by careful design of the receptor. In this era, chemiresistive sensors using Carbon Nano Tube (CNT) and piezo resistive cantilever beams are the promising technologies to design an explosive vapor sensor. A CNT consists of one or several graphite sheet(s) rolled up into hollow cylinder to form a nano tube. The major classifications of carbon nanotubes are singlewalled varieties (SWNTs), which have a single cylindrical wall, and multiwalled varieties (MWNTs), which have cylinders within cylinders as shown in Figure 4. Figure 5 shows the use of carbon nano tube as electronic wire between two metal electrode. The conducting properties of the nano tube change when chemicals in the surrounding environment bond to the tube and the conductance between the electrodes may be measured as a function of the gate bias voltage.

The capability of nanotubes to detect small concentrations of gas molecules with high sensitivity at room temperature was found by Kong et al. Sensors made from singlewall nanotubes have high sensitivity and a fast response time at room temperature, which are important advantages for sensing applications. Another approach is nanocantilever sensor arrays which offer a clear path to the development of miniature sensors with very low power consumption. Nanoscale cantilever beams are bent by forces in the range of intermolecular forces. When molecular absorption is confined to a single broad surface by applying a suitable coating, the cantilever undergoes bending due to changes in surface stress Due to the large surface to volume ratio for these micron size levers, the bending signal is extremely sensitive and the selectivity is attained by applying chemically selective coatings on cantilevers in an array.

$$Z = (4L^3F)/(Ewh^3) \qquad (2)$$

Here F is the force applied at the free end perpendicularly to the beam considering rectangular cross section of width w and thickness h with length L and Young's modulus E. Different types of transducing principles have been used over the years to convert mechanical displacements into electrical signals. Among them the piezo resistive principle in which the variation in resistivity of a conductor exposed to mechanical stress is converted to electrical signal, is widely used in NEMS/MEMS because this effect is especially strong in semiconductors such as silicon.

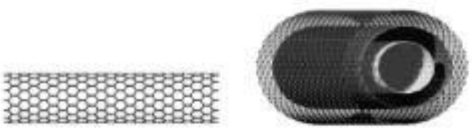

Figure 4. Structure of single-and multi-walled nanotubes

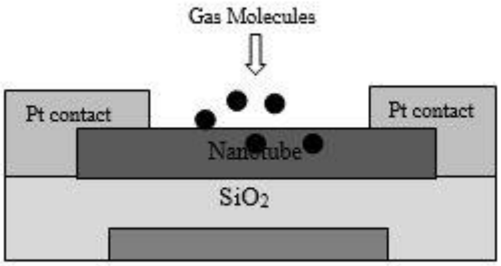

Figure 5. Carbon nanotube used as electronic wire.

For this reason piezo resistive cantilever beams are usually fabricated from silicon with length 200 micrometer to a few microns.

A resistor is placed on one of its surfaces to detect the deflection of a cantilever, where the mechanical stress is highest. The resistor may be integrated on the bulk material or located on a thin film over its surface. Molecular absorption causes the bending of the cantilever beams that change the resistance of the cantilever.

An electronic nose is usually composed of an array of chemical sensors and a pattern recognition system, such as an artificial neural network to recognize and automatically identify each chemical as shown in Figure 8. The array response corresponds to the change in the resistance, $R_{ji}(t)$ (j = 1, , n, where n = number of the sensors) due to the vapor absorption with concentration level C_i as every element of the array is filtered for noise and complexity reduction in order to meet the odor recognition task. This is digitized and the converted signal is then represented by an n dimensional vector. The interface electronics subsystem converts the small analog signals generated by the nano sensor due to deviation in resistances to digital quantities that act as input to the pattern classifier. The nanosensors are positioned above the VLSI circuitry on the epitaxial layer of the CMOS processor using Post-IC placement technique. Sensor placement is considered successful if after final alignment a nanowire provides a resistive bridge no short or open circuit across the matting electrodes.

Overview of Software-Defined Radio

In radio development one key method is reconfigurability. Reconfigurable receivers include interesting features like automatic recognition of the modulation mode of a received signal or bit stream analysis. A transceiver may be regarded as a software radio (SR) if its communication functions are realized as programs running on a suitable processor. SR can be defined as reprogrammable and reconfigurable radio in which same piece of hardware can be used to perform different functions at different times. Based on the same hardware, different transmitter/receiver algorithms, which usually describe transmission standards, are implemented in software. An SR transceiver comprises all the layers of a communication system. The baseband signal processing of a digital radio (DR) is invariably implemented on a digital processor. The SDR forum defined the SDR as the radio that can accept fully programmable traffic and control information and support a broad range of frequencies air interface and application software. So an SDR may be regarded is a practical version of an SR. Here the received signals are sampled after a suitable band selection filter.

A cognitive radio (CR) on the other hand is an SDR that additionally senses its environment, tracks changes, and reacts upon its findings. A CR is an autonomous unit in a communications environment that frequently exchanges information with the networks it is able to access as well as with other CRs.

For supporting a new standard or multiple standards in a single device a new hardware must be added. For this reason it is very expensive to upgrade and maintain a wireless system each time a new standard comes into existence. However integration of additional radio hardware is impractical after a certain point as it increases the handset size, complexity and price. The attraction of SDR is its ability to support multiple waveforms by reusing the same hardware while changing its parameters in software. This has enormous benefits for handset size, cost, development cycle, upgrade and interoperability.It allows users to change transmitter and receiver characteristics such as modulation type, wideband and narrowband operations, coding and link-layer protocols, radiated power etc., by making software changes without any hardware alternation. In more modern SDRs, digital signal processor (DSP) chips are used that can alter its functionality by executing different software algorithms. Figure 6 provides a schematic diagram of SDR. The RF front-end is used for amplification and filtering because the signal received by the antenna is usually a weak signal and also has the much greater bandwidth than the information bandwidth. A block diagram of a typical frontend is shown in Figure 8. Amplification is generally done by low noise amplifier (LNA) and sometimes multi stage amplification is also used. The first band pass filter (BPF) is used for initial filtering and the second BPF is used to decrease the harmonic distortion that may occur during amplification. In SDR the frequency of the mixer is also controlled by the software.

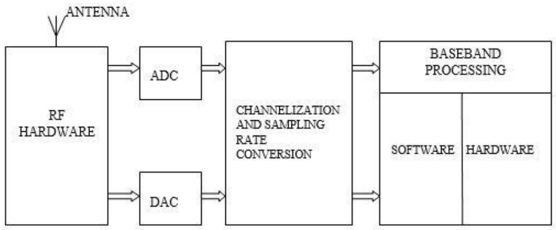

Figure 6. Schematic diagram of a typical SDR.

In almost all SDR the digitization of the signal is done in the intermediate frequency (IF) range to overcome the problems of carrier offset and imaging involved in digitizing the signal using super-heterodyne method. Channelization and sample rate conversion on the transmit path are used for interfacing the digital hardware to the ADC and ADC to the processing hardware on the received path. In the receiver, the channelizer extracts the channel of interest from the digitized RF bands, and then forwards the channel for baseband processing. In the transmitter it inserts the channel into the RF band after base band processing.

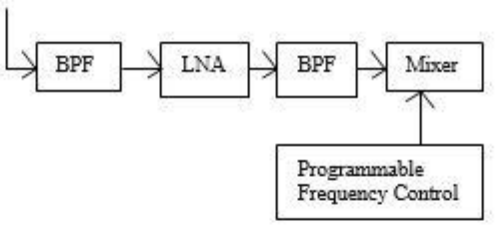

Figure 8. Block diagram of a typical frontend.

The channelization architectures that systems are Digital Down Conversion (DDC), Frequency Domain Filtering, and Polyphase FFT Filter Banks[11]. Baseband processing is performed in software using digital signal processors (DSPs), field programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), or general purpose processors (GPPs).

Implementation

This section provides a brief outline for the implementation of a mobile sensor network for explosive trace detection using cellular network. The idea is to design a tiny CRSN using a Nano Electronic Nose and integrate it with SDR. The sensor with SDR consisting of minimum hardware miniaturizes the sensor node. Sensor array will generate an analog signal due to absorption of explosive molecules and for processing the data it is converted to digital signal by ADC. The processing unit is required to store the data and recognize the explosive using an efficient algorithm. Before transmitting that information, it gathers spectrum usage information through spectrum sensing and then takes a decision about the channel transmission parameters e.g. transmission power, modulation etc. This is called spectrum decision. After that it reconfigures its SDR based transreceiver to send the sensory data to the nearest base station. In this approach the cell phone user is the primary user with a specific license to communicate over the allocated band and has the priority to access the channel whereas CRSN is the secondary user that can access the channel as long as it does not cause interference to the primary user. It should have the ability to create an ad-hoc network with the other sensor nodes of conventional sensor network to send the data to the place where cell phone tower is not available. The CRSN node should have the ability to switch channel if channel condition gets worse. This functionality is called spectrum handoff. But this can incur long delays. To implement this approach, the main challenge lies in the design of a power efficient and cost effective CRSN which must have the ability of opportunistic communication over licensed as well as unlicensed band maintaining minimum end-to-end delay and interference with the primary user. To achieve this thorough study is required to be done on mobility aware dynamic spectrum management solution over resource constraint CRSN and different methods of adaptive power control to analyze the trade-off between power and interference.

Conclusions

In this paper a discussion about SDR and nano nose using explosive vapor sensor has been made. Investigation of a method for designing a CRSN for explosive trace detection has been carried out. Ultimately an approach towards designing a mobile sensor network utilizing CRSN has been proposed. Out of the total power consumed by the sensor node the major portion is provided by the RF section. So a carefully designed CRSN may be helpful in minimizing the power consumed. This approach is expected to provide real time situation awareness and decision making with secure information exchange that may help the Department of the Defense and Security of any country to design a network for global security.

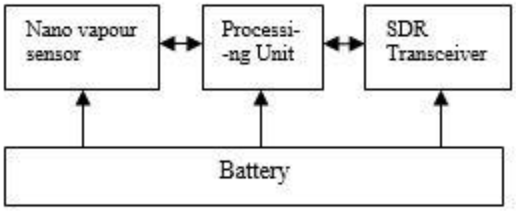

Figure 10. Block diagram representation of sensor based explosive trace detector using SDR.

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