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Automated and Specific State Detection of RDX and TNT using Wireless Sensor Networks

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Abstract: Unlawful use of munitions and explosives against civilians in the pursuit of political aims is what known as terrorism. As counter terrorism activities different research groups are working in the real world. Explosive detection is an inevitable and indispensable mechanism needed by any country to protect the lives and property of public. Towards this end, many researchers contributed. However, the use of Wireless Senor Network (WSN) for explosive detection is relatively new research area. It assumes importance due to the ubiquitous nature of WSN and its utility. The traditional devices are bulky and they are physically visible to public when they are deployed. In this context, WSN makes it more useful solution as the presence of sensor nodes and the network are not disclosed to public. WSN with automatic detection of explosives like RDX and TNT is an important step forward in the combat against terrorism. Towards this end, we proposed an algorithm and implemented it in our prior works. In this study we extend our work in order to provide more flexible means for not only detection of explosives like TNT and RDX but also finding whether the explosive is in gaseous state or liquid state or solid state. We defined many algorithms that work in coordination. NS2 simulations are used to demonstrate proof of the concept. Our experimental results revealed that the proposed algorithms are capable of serving intended purpose.

Key words: RDX, TNT, detection of explosives, WSN, state detection mechanisms, proposed algorithms

INTRODUCTION

Humans are subject to more terrorist attacks in the last decade. This is increasing every year. There are anti-social elements that target civilians of a nation to achieve their political ends. Energetic compounds like RDX (hexogen; cyclo-1, 3, 5 trimethylene-2, 4, 6-trinitramine) and TNT (2, 4, 6-trinitrotoluene) exhibited enormous influence on human life either positively or negatively (Bolton and Matzger, 2011). Such materials also contaminate water, soil and sediments causing ecological hazards (Drzyzga *et al*., 1995). Molecule structure of RDX (hexahydro-1, 3, 5-trinitro-1, 3, 5-triazine) and TCT are as follows Fig. 1.

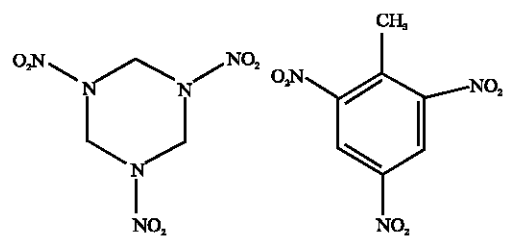

Fig. 1: Molecule structure of RDX (hexahydro-1, 3, 5-trinitro-1, 3, 5-triazine) (Sheremata *et al*., 2001; Usmanov *et al*., 2015)

These explosives are widely used in military and civilian applications as Insensitive High Explosives (IHEs) (Shen *et al*., 2011). They are used for both constructive and destructive purposes. Constructive purposes include explosion of rocks in soil and explosion of hills for making way for railroad and so on. Apart from these constructive purposes, they are playing havoc in the real world as they are being used by adversaries or anti-social elements for destructive purposes. RDX and TNT are most widely misused explosives in the world. Terrorists are constantly using them either directly or with combination of others. Before indulging into the work of this study, it is good to see more details of these two highly explosive materials here.

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RDX (Hexahydro-1, 3, 5-trinitro-1, 3, 5-triazine): RDX is also known as Royal Demolition Explosive. It belongs to a class of chemical compounds named as explosive nitramines. This is highly explosive material which appears in solid crystalline format and in white colour. It is not a component that is naturally available in nature. It is synthetic product especially manufactured for different purposes. However, it is extensively used in the manufacturing of munitions across the world. Under aerobic conditions, its biodegradation process is very slow. It cannot persist long time in surface waters due to its transformation features. It is a Group C carcinogen for human beings. When this product is inhaled, it is capable of damaging nervous system. Field screening methods that can be used to detect this explosive are EXPRAY and colorimetric. Major analytical methods for RDX are gas and liquid chromatography. When humans are affected by RDX health issues, possible treatment techniques include incineration, phytoremediation, composting, granular activated carbon treatment and situ bioremediation. This explosive is often used along with other explosives, waxes and oils in order make munitions used for military purposes (EPA., 2014).

RDX has many properties as described here. Chemical Abstracts Service (CAS) number given to RDX is 121-82-4. At room temperature, the RDX is in the form of a white crystalline solid. It has molecular weight 222.26 g/mol. At 25 degree centigrade RDX has water solubility 59.7. At boiling point, it decomposes. Melting point of RDX is 204-206 degree centigrade. At 20°C, its specific gravity is 1.82 g/mL. This product can be released into atmosphere due to detonation of ordnance, open incineration, disposal of ordnance, firing of munitions and spills. In atmosphere, RDX is expected to stay in specific format and then settles by dry or wet deposition. RDX is not retained by most of the soils. However, it can propagate through vadose zones causing underlying ground waters to be contaminated. It can dissolve slowly in water. It has low vapour pressure and its evaporation from water is very slow. RDX has potential to contaminate plants and water animals has exposure route to humans and herbivorous wildlife. The routes of exposure of RDX include inhalation, dermal contact, contaminated drinking water, agricultural and crops that used contaminated water. Potential health effects of RDX include nervous system damage, vomiting, nausea, headache, skin irritation, eye irritation, fatigue, irritability, convulsions, insomnia, tremor and dizziness (EPA., 2014)

TNT (2, 4, 6-trinitrotoluene): It is a yellow coloured, odourless solid substance which is highly explosive in nature. It is the combination of toluene and nitric and sulphuric acids. At room temperature it is a crystalline solid. It is not a component that is available in nature. Instead it is a synthesized product. Its high utility is found in manufacturing of munitions and explosives. This material is sorbed by most of the soils across the globe. Therefore, its migration to water is minimized. It is regarded as a Group C human carcinogen. In surface of waters, TNT material cannot persist long time due to processes of transformation. If it is ingested of inhaled, it spoils blood systems and liver. Specific field screening methods to detect TNT include EPA SW-846 method 4050 (immunoassay method) and EPA SW-846 method 8515 (colorimetric screening method). It has well established laboratory methods in the form of gas and liquid chromatography. Chromatography is a technique used to separate components of a mixture. TNT involves in manufacturing impurities and products related t environment transformations. It makes it highly influential material causes environmental and health concerns. When people are affected by TNT related health issues, there are treatment technologies known as incineration, compositing, granular activated carbon treatment and situ bioremediation (EPA., 2014).

TNT is used either as a pure explosive or a binary mixture such as cyclotols or octols. TNT combined with RDX is known as cyclotols mixture while TNT with octahydro-1, 3, 5, 7-tetranitro-1, 5,7-tetrazocine. TNT is widely used in military applications. It is also used by industries for digging deep wells and underwater blasting. Chemical Abstracts Service (CAS) number of TNT is 118-96-7. At room temperature TNT is an odourless solid and coloured yellow. Its molecular weight is 227.13 g/mol. Water solubility is at 20°C is 130 mg/L. Its boiling point is 240 explodes while melting point is 80.1°C. Its specific gravity is 1.654. There are different forms in which TNT is released into environment. They include destruction of munitions, improperly sealed impoundments, firing with munitions and disposal of ordnance. It has many environmental impacts. TNT is degraded into surface soil. In surface water it is subjected to number of degradation products. Its bio degradation has resulted in causing health problems. It has many routes of exposure such as inhalation of dust in manufacturing environments, army ammunition plants and contaminated soils. It causes anaemia, liver malfunctions, cataract, skin irritation and other issues (EPA., 2014).

Contributions: In this study, we defined a methodology with five underlying algorithms to work together to achieve two objectives. The first objective is to detect explosives like RDX and TNT. Our study is limited to these two explosives only. The rationale behind this is that these are widely used explosives by anti-social elements. The second objective is to find whether an identified explosive is in gaseous state or liquid state or solid state. WSN is chosen as the network with clustered topology. Sensors are associated with the proposed algorithms in order to achieve the intended objectives.

Literature review: Kuznetsov *et al*. (1944) used onion carbon and ultra disperse diamond for fining effects of explosions. Walsh (2001) employed two methods for explosive detection. They are electron capture detector and gas chromatography. They used TNT, RDX and other explosive materials for experiments. Kubota (2002) studied about propellants and explosives. They understood various aspects of the explosives including energy conversion, combustion, wave propagation, energetic features of explosives and so on. Monteil-Rivera *et al*. (2004) studied the process of extraction of nine kinds of explosives including TNT and RDX from aqueous media. The detection technique they employed is High-Performance Liquid Chromatography with Ultraviolet Detection (HPLC-UV). They found that explosives are polar analyses that exhibit affinity with low vapour pressures and aqueous solutions. Meurer *et al*. made experiments on TNT and RDX using observations on gas-phase reactions. It was done selectively on the given explosives. Zhang *et al*. (2005) explored different approaches for working with explosive materials. They are known as pressurized liquid extraction, electron capture detection and gas chromatography used for detecting RDX in sols.

Shen *et al*. (2005) employed terahertz pulsed spectroscopic imaging for identification and detection of explosives like RDX. Singh (2007) identified sensors as an effective approache for detecting explosives. They made a review on different approaches that are used based on sensors. Potyrailo and Morris (2007) used a sensor known as Radio Frequency Identification (RFID) sensor for chemical identification and quantification. Multi-variate statistical methods are used to analyze and detect explosives. Euler and Sweetman studied sensors known as thin film fluorescent sensors for detection of explosives. Fammini and Pragliola (2008) proposed a novel framework for detection of explosives. It is known as DETECT. It can detect different kinds of attacks on critical infrastructures. Its main focus was Critical Infrastructure Protection (CIP). It has phases like vulnerability assessment and risk analysis. Millar *et al*. (2009) studied crystal form of RDX and understood its explosive nature. Sekhar *et al*. (2010) employed chemical sensors in order to secure homeland and monitor environments for hazardous materials. The sensors are actually known as biosensors that have more capabilities.

Engel *et al*. (2010) proposed a method for detection of explosives like TNT and RDX. They used silicon nanowire arrays in order to achieve this. Becher *et al*. (2010) proposed a gas sensor network. This network detects hazardous material in the gaseous form. The sensor used for empirical study is metal oxide gas sensors. Freeman and Simi (2011) explored indoor environments for explosive detection. Towards the end, they proposed an approach based on robot assisted WSN. Robots are trained to sense environmental data and detect the presence or absence of explosives. Tourne (2014) made a review of different approaches used to characterize and detect explosives. Zagreb *et al*. used WSN for gas monitoring in an energy efficient fashion. Adaptive multi-model is used for building WSN. They used two sensors such as Pyroelectric InfraRed (PIR) and semiconductor gas sensors. They tested their approach in a four-storey building. Characteristics of liquid explosives are explored.

Raghuram and Venkatesh (2012) proposed an automatic robot which is based on ZigBee network. They built a WSN using ZigBee technology in order to enhance mine safety. The robot is able to detect explosions and locate the place as well. Muthukumarasen *et al*. (2012) proposed a qualitative approach for detecting explosives. They used low power devices with IoT in order to detect explosives. They also studied other approaches for detecting explosives. They include Ion Mobility Spectrometry (IMS), Laser-induced Breakdown Spectroscopy and Raman Spectroscopy. Jain and Kushwaha (2012) studied areas where oil and gas industries located. They did research on detection of explosive and harmful gases and built a gas sensor network for detection of explosives.

Lopez-Moreno *et al*. (2006) studied the means of detecting explosive residues in solid surfaces. They focused on detection and characterization of explosive materials by using LIBS (Laser Induced Breakdown Spectroscopy). Jaaz (2014) proposed a methodology for metropolitan explosive detection using WSN integrated with Internet of Things (IoT). Zhang *et al*. (2014) studied a technique knwon as Nuclear Quadruple Resonance (NQR) and proposed NQR-based explosive detection system for energy efficient means of detection. Azzarelli *et al*. (2014) proposed a methodology that is used to detect gas which has characteristics of an explosive. They used a smart phone with Radio Frequency (RF) communication to achieve this.

Somov *et al*. (2014) explored an approach for detection of explosives in the form of gases. They used WSN along with ZigBee network to achieve this. Jeon *et al*. (2014) employed Hidden Markov Model (HMM) for automatic surveillance of situations where hazardous materials are carried out. In such situations Jeon explored HMM for automatic surveillance. Romero *et al.* (2014) employed WSN in underground coal mines in order to detect explosives. Their system was named as SCADA and it was based on ZigBee systems. Kuhl *et al.* (2014) observed that electromagnetic waves are released from TNT explosions. They investigated the effects of such explosions using the released EM waves. Banerjee *et al.* (2014) proposed sensors for finding explosives by using luminescent metal-organic frameworks. Pablos *et al.* (2014) proposed a methodology for detection of TNT. It is done using smart fibres and solid polymer substrates. Pablos *et al.* (2014) explored identification of TNT in both gaseous and liquid forms.

Ball *et al.* (2016) studied military surveillance networks and explored the computational intelligence needed for explosive detection. Makeenkov *et al.* (2015) use infrared sensor nodes in order to have detection of vapours flammable liquids and flammable gases. They used a sensor that could monitor the above said situations. Usmanov *et al.* (2015) employed an approach known as alternating current corona discharge for detecting explosive traces in atmosphere. Lopez *et al.* (2015) employed a method known as TNT equivalent method for detection of explosives in gaseous form. Rehman and Zeng (2015) used ionic liquids as materials used for gas sensing. Based on this they built their approaches for explosive detection. Pablos and Sarabia (2015) proposed methodology for explosive detection using selective detection and discrimination. They used three luminescent sensors for this purpose.

Mohan and Shelly (2016) exploited wireless sensor network architecture for building a border security robot. The robot makes use of PNR sensor in order to detect movement of humans. Bluetooth technology is used as part of it. Simi and Ramesh (2010) proposed a method known as W-ReMADE for remote monitoring and detection of explosives. The method was intended for remote monitoring of critical infrastructures. Kumar and Murali (2016) threw light into different aspects of explosive, explosive detection and usage of WSN for automatic detection of explosives. Kumar and Sushanth (2016) on the other hand proposed a robotic arm which is controlled by gestures in order to detect explosives. Liu *et al.* (2016) used two techniques known as spectral fingerprints and terahertz imaging in order to in order to detect the high explosive RDX. Tiwari and Premi (2016) explored a factory to know its vulnerability against highly flammable gases. They used a model known as vapour cloud explosion model.

Millar *et al.* (2009) studied the concept of pressure-cooking of explosives. They characterised explosives like RDX in the situation of high temperature and high pressure. Millar *et al.* (2009) studied the structure of RDX and understood the crystal structure to be high explosive nature of it. The existing approaches are used differently for different purposes. With respect to WSN usage for detection of explosives, there is no single approach that can cater to the needs of detection of highly explosive materials like RDX and TNT. In this study, we proposed a methodology that not only detects the energetic materials but also fin their state such as gaseous, liquid and solid.

Problem formulation: Explosives like RDX and TNT can be used for both constructive and destructive purposes. However, they are being used by anti-social elements and consequences are alarming. In this era, man is able to visit other planets and made wonderful discoveries. This is one side of the coin. But the other side of the coin is people of most of the countries are victims to the misuse of explosives. There is widespread fear among people who are frequently affected by terrorist activities. Of late terrorists are exploiting social engineering to meet their ends. This has become very dangerous as it is difficult to identify threats from local people who were subjected to social engineering. This is the motivation behind the research which is aimed at finding mechanisms to have automatic detection of explosives in any form. This kind of detection can pave way for taking necessary measures to minimize cruel incidents caused by terrorists.

Most of the existing solutions to detect explosives are machinery that is expensive, bulky and they need manual attention and maintenance. Finding the presence of such equipment is also an important issue that helps adversaries. With ubiquitous growth of sensor networks, there is research going on with Wireless Sensor Network (WSN) to detect explosives automatically. Since, WSN is a network of sensor devices, this network can be maintained without disclosing its presence to public. It is an important thought to exploit WSN for explosive detection. Empowering WSN to have ability to detect explosives is very essential research activity. Let N be the WSN which has a collection of nodes denoted as $N = \{SN_1, SN_2, ..., SN_n\}$. Let us consider energetic and hazardous materials such as M = (m1, m2, ...). Here, RDX and TNT are considered for experiments. Let S denote states such as gaseous, liquid and solid. It is denoted as $S = \{s, l, g\}$. It is non-trivial to detect and find the state of an explosive. Towards this end, we proposed a methodology. This can effectively be used to minimize terror incidents with strategic deployment. The existing literature shows little progress over WSN being used as explosive detection phenomenon. This is the motivation

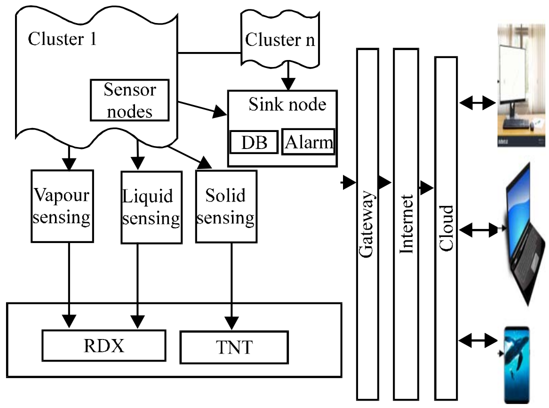

Fig. 2: Illustrates system model employed for explosive detection

behind this research work where we explored two explosives and their detection mechanism with WSN. TNT and RDX are considered for experiments. The proposed detection mechanism not only detects the explosives but also identifies whether they are in gas, liquid or solid states. This will help to have well-informed decision making and gaining real time intelligence with the proposed system model and network topology.

System and network models: This study provides the proposed system model and network model for detection of explosives such as TNT and RDX and with their states as well. The finding of state of an explosive such as gas, liquid or solid has its utility in the real world applications. The aim of this study is to have methodology for automatic detection of TNT and RDX and their state at the time of detection. Since, terrorism is the burning problem in civilized societies across the globe, this research assumes importance. Real time detection of explosive materials can help in alarming systems so as to take corrective measures immediately. Towards this end, the proposed system model is illustrated in Fig. 2. The system model includes a WSN which is has sensors having abilities to detect TNT and RDX in gas, liquid and solid states. The methodology for detection of explosives is explored in the ensuing section. Sensors are grouped into n-number of clusters. Clusters are linked to a sink or base station to which the results of sensing are sent by the sensor nodes.

Each sensor node has mechanism to detect explosives like RDX and TNT in different forms as mentioned earlier. The sink node maintains the database that can be shared across globe in order to provide information to all stakeholders in real time. For connecting to information super highway, the WSN takes the help of a gateway which supports inter-connectivity. Through

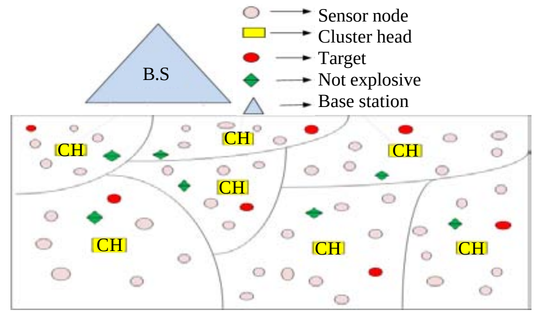

Fig. 3: Network topology

Internet the sensed data can make use of cloud resources. Cloud is a shared pool of computing resources that are provided on demand in pay per use fashion. Since, WSN is the network which results in continuous streaming of data to destination, it is important to have cloud resources as the data collected assumes the characteristics of big data such as volume, variety and velocity. Stakeholders across the globe can access the data stored in cloud data centres. Further analytics on sensed data is possible in distributed computing environments.

As presented in Fig. 3, the network topology used for proposed WSN meant for explosive detection is cluster based. Sensors are grouped into different clusters. Sensor nodes can communicate with other sensor nodes and also cluster head. Cluster head in turn communicates with other cluster heads and base station. The data sensed by the sensors reach sink or base station through cluster heads. The sensor nodes are provided with mechanism to detect an explosive and its state as well. The methodology for specific state explosive detection is provided in the following study.

MATERIALS AND METHODS

Methodology for specific state explosive detection: In our previous work, we explored detection of explosives with wireless sensor network. In this study we not only detect TNT and RDX materials but also identify whether they are in gaseous state or liquid state or solid state. This kind of detection has utility in the real world for making well-informed decisions. It is a simulation study with NS2 which is widely used network simulator. Before identification of explosives, the sensor nodes are given knowledge on the features and compositions of RDX and TNT. There are different compositions of RDX. RDX can be used in the form of plasticizing wax which is known as composition A. RDX explosives can be made up of 40% TNT, 1% wax and 60% RDX. It is known as composition B. Another variant of RDX known as composition C contains mix of 5.3% dioctyl sebacate, 2.1% binder, 1% of non-detergent motor oil and 91% RDX. Another composition of RDX is composition CH-6 which comprises of 97.5% RDX, 1.5% calcium stearate, 0.5% polyisobutylene and 0.5% graphite.

Similarly, TNT has its variants. It is highly explosive with three variants. The combination of RDX and Ammonium nitrate is one of the variants. It is known as Amatex. The second composition is Ammonium nitrate, aluminium powder and charcoal. It is known as Ammonal. The third variant of TNT is made up of wax and Barium nitrate. Both the explosives have specific characteristics. RDX is said to have high sensitivity to booster properties, brisance and friction. It can be ignited easily with a match box. Its combustion with an air-tight enclosure can cause severe explosion. When RDX is mixed with Alkali, RDX decomposes at 50°C. It is then followed by explosion. RDX is hardly soluble in alcohol, ether and benzene while it is insoluble in water. It can slightly solve in acetone and cyclohexanone. It is quite soluble in dense nitric acid and warm.

When it comes to TNT, it is relatively less sensitive to friction. When TNT is combined with Alkali, it decomposes at 100°C followed by explosion. TNT is soluble in alcohol and ether slightly while it is not soluble in water. It is not subjected to decomposition intuitively as it is a stable component. In order to achieve detection of these explosives including their state such as gaseous, liquid and solid, 4 algorithms are proposed.

Algorithm 1; Explosive and state Detection Algorithm (EDA):

Initialization
01. Initialize false to explosive target
02. Initialize false to non-explosive target net
03. X = { RDX features}
04. Y = { TNT features}
05. IDV = {ID_1, ID_2, ID_3, ID_4, ..., ID_n}
06. Initialize target t
07. Initialize found to null
Periodic target identification
08. Z = foreign object
09. For each ID€IDV
10. Compatible ID (t = foreign object)
11. End For
Explosive detection
12. For each feature €X
13. [(t = feature) (found = rdx)] & [(~(t = feature)) (found = normal)]
14. End For
15. For each feature€Y
16. [(t = feature) (found = tnt)] & [(~(t = feature)) (found = normal)]
17. End For
Decision making
18. [(found = rdx) target is detected as RDX based explosive, take necessary action] & [(found = (~rdx) & tnt) target is detected as RDX based explosive, take necessary action] & [(found = (~rdx) & (~tnt)) target is detected as RDX based explosive, no action needed]
State detection
19. If found = rdx then
20. Invoke state detection algorithm for rdx
21. Else if found = tnt then
22. Invoke state detection algorithm for tnt
23. Print explosive and state details

There are many stages in Algorithm 1. The initialization phase initializes variables needed. Target objects are initialized with features of TNT and RDX features for simulation study. The periodic target detection is meant for exchanging IDs of sensors and finding any foreign objects to be sensed. When foreign object is found, it moves on to the explosive detection phase. Explosive detection is an iterative process which makes use of all vectors containing characteristics of RDX and TNT in order to detect them. After completion of the detection phase, the decision making phase confirms whether the identified explosive is an RDX or TNT. Afterwards, the state detection algorithm is invoked in order to perform the liquid state, gaseous state and solid state detection algorithms.

Algorithm 2; State detection algorithm:

Liquid state detection
Gaseous state detection
Solid state detection

As shown in Algorithm 2, it is evident that three more algorithms are involved in order to find whether the detected material is in solid, liquid or gaseous state. The process of finding the state detection is as presented in the flow chart shown in Fig. 4.

The flow chart shown in Fig. 4, it is evident that the explosives such as TNT or RDX are further investigated with simulation study to find whether the identified material is in solid or liquid or gaseous state. Three algorithms for state detection are implemented in C++ whose details are as follows.

Algorithm 3; Solid state detection algorithm:

```
if(Could == High accuracy && High Sensitivity && High Resolution){
{
puts "It's Enter into the Solid State"
    if(State == Homogenous)
{
if(Propellent == Single)
{
if(Chemicals == Nitro-cellulose)
puts "It' s Single-Base Propellent "
else
puts "It's not a Single-Base Propellent"
else if(Propellent == Double)
{
if(Chemicals == Ballisite)
puts "It' s Double-Base Propellent"
else
puts "It' s not a Double-Base Propellent"
}}
if(material==Carbon Steel){
if(State==corrsion)
{
If(Material==Nickel alloy || Titanium || Zirconium)
{
Puts "it's a solid state Rdx Explosion"
 }
}}
Else{
Puts "It's not a solid state explosion"
}
```

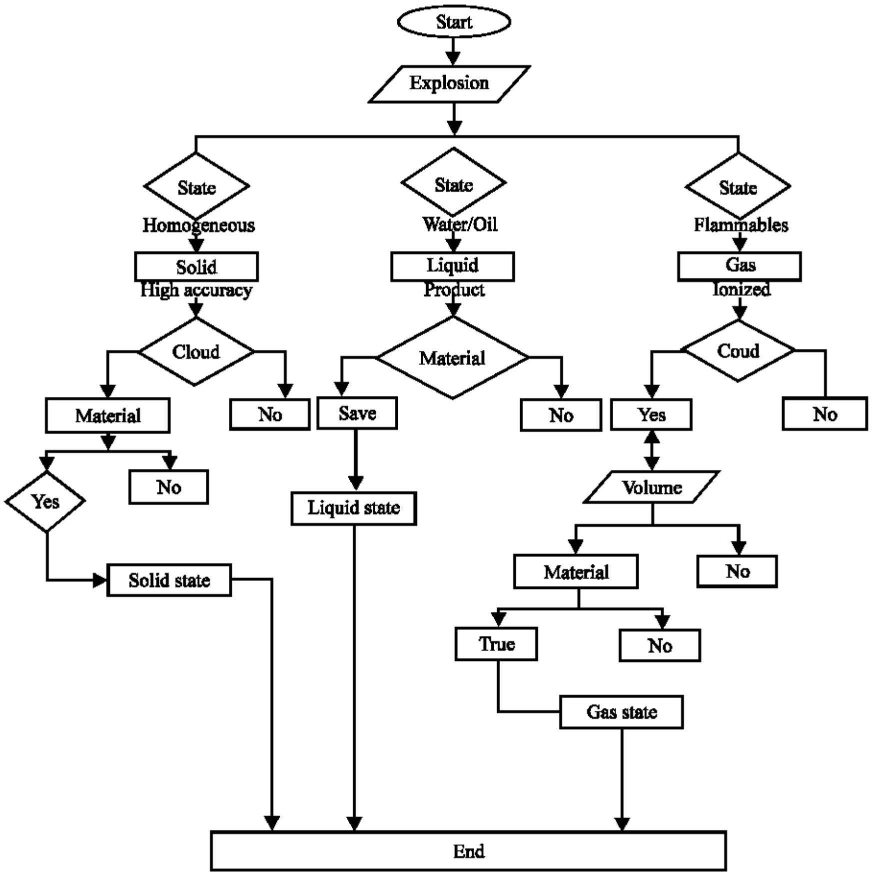

Fig. 4: Flow chart showing mechanisms for state detection

Algorithm 4; Liquid state detection algorithm:

```
if(Liquid== Oily || Clear Liquid)
{
If(Acid ==Nitroglycerin)
{
if(Product == Methyi Nitrate)
{
if(Mixtures == nitrous && sulfate acids)
{
puts "Product is ok"
}
If(Explosion==Yellowish)
{
Puts "It's a Liquid state Explosion"
}
}
else
{
Puts "It's not  liquid state"
}
```

Algorithm 5; Gaseous state detection algorithm

```
if(Cloud == Ionized Cloud){
if(Volume == Flamable Gas && Production Gas)
{
If(Gas==Natural gas)
{
if(Aircomponents == rare gases || oxides || nitrogens)
{
printf("These are the gases")
}
else if(Hydrocarbon ==  Hydrozens && Carbon){
printf("It' a Natural gas");}
else if(Hydrocorbon == methene && Carbon atom && hydrogen atom)
{
printf("These are the sample gases")
}
if(Condition==Meteorological Condition
{
if(Product==Flammable)
{
puts "It's a RDX Gas Explosion "
}}
}}
else
{
Puts "It's not a Flammable Gas
}
```

RESULTS AND DISCUSSION

Wireless Sensor Network (WSN) is created in simulation environment using NS 2. It is used to realize the network topology presented in Fig. 3. The environment contains sensor nodes, cluster heads, base station and target objects that are to be detected as explosives or not. Different classes are implemented using C++ language for implementation of different algorithms proposed in this study. Crucial to the simulations are the vectors initialized in the Algorithm 1 where the characteristics of explosives are provided. Accordingly the proposed algorithms are able to detect explosives like TNT and RDX besides finding whether the detected explosive is in gaseous or liquid or solid state.

As shown in Table 1, confusion matrix is presented with precision and recall. The predicted positives are actual positives then it is considered as True Positive (TP). Second case is that predicted positives but actually negatives. Such results are known as False Positives (FP). The third case is predicted negative but actually positive. It is known as False Negative (FN). The fourth case is that predicted negative but actually negative. It is known as true negative (Fig. 5).

Other performance metrics: Different performance metrics are used for evaluating the performance of the proposed methodology. The performance metrics are described here that can provide quantitative results.

End to end delay: It is the time taken for packets to be transmitted from source to destination. This is computed as follows:

End-to-end delay = Time taken to transmission from source to destination

Packet delivery ratio: This is the metric used to denote the data packets sent by the sender and received at destination:

PDR = (No. of packet received/ No. of packet sent) *100

Packet dropping: This is the metric used to denote the packets dropped when they are transmitted from source to destination:

Packet drop = No. of packets sent-No. of packets received

Throughput: It is the ratio of packets delivered to the destination to the number of packets sent by the sender:

Throughput = No. of packets received/Time for simulation

Joule (J): It is the metric used to measure energy consumption. As shown in Fig. 6, the simulation time is presented in X axis while the Y axis is showing packet delivery ratio. The proposed method showed higher performance. PDR is increased as simulation time is increased.

As shown in Fig. 7, the simulation time is presented in X axis while the Y axis is showing delay in milliseconds. The proposed method showed higher performance. Delay time is increased as simulation time is increased.

As shown in Fig. 8, the simulation time is presented in X axis while the Y axis is showing throughput. The proposed method showed higher performance. Throughput is increased as simulation time is increased.

Table 1: Confusion matrix for precision and recall

Variables	Actual positive	Actual negative
Predicted poistive	TP	FP
Predicted negative	FN	TN

Recall = TP/TP+FN; Precision = TP/TP+FP; True Positive Rate (TPR) = TP/TP+FN; Flase Positive Rate (FPR) = FP/FP+TN

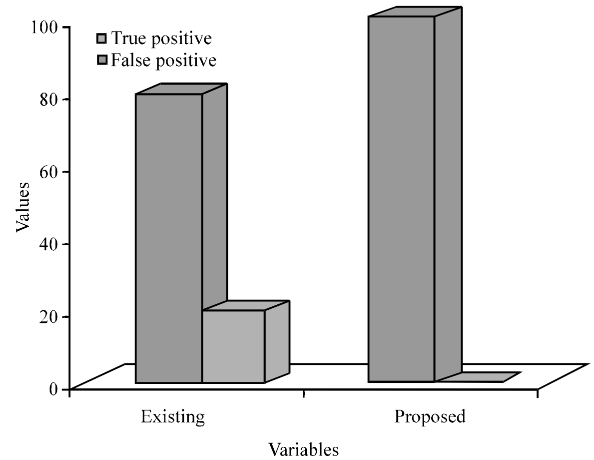

Fig. 5: Evaluation with true positives and false positives

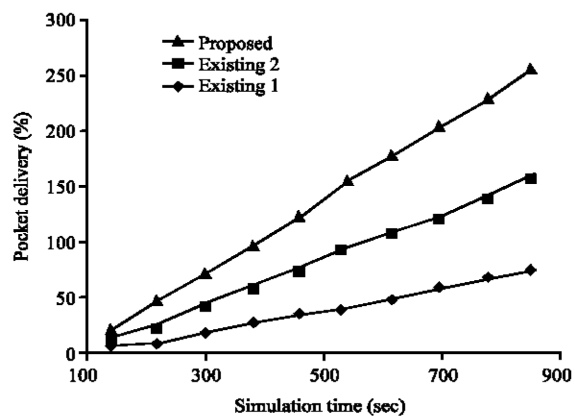

Fig. 6: Simulation time vs. PDR

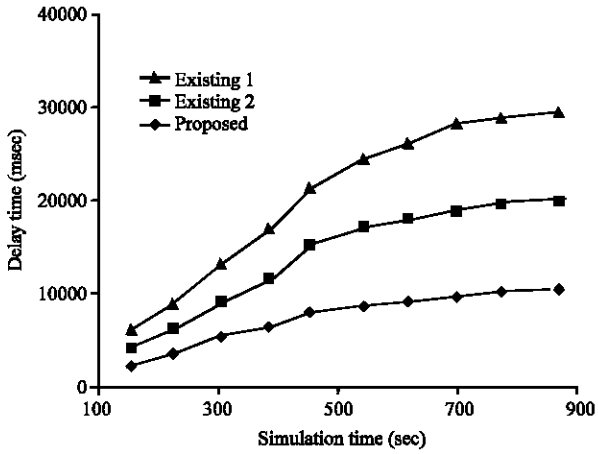

Fig. 7: Simulation time vs. end to end delay

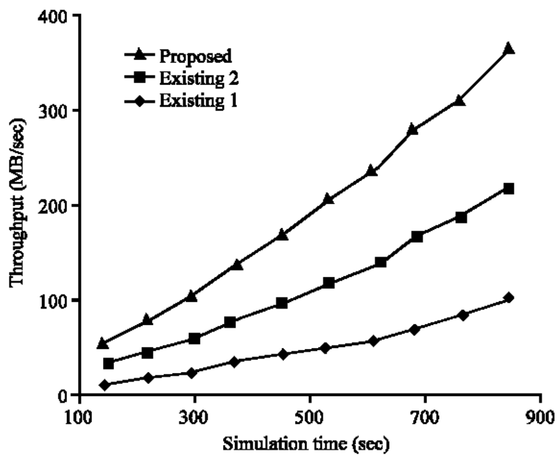

Fig. 8: Simulation time vs. throughput

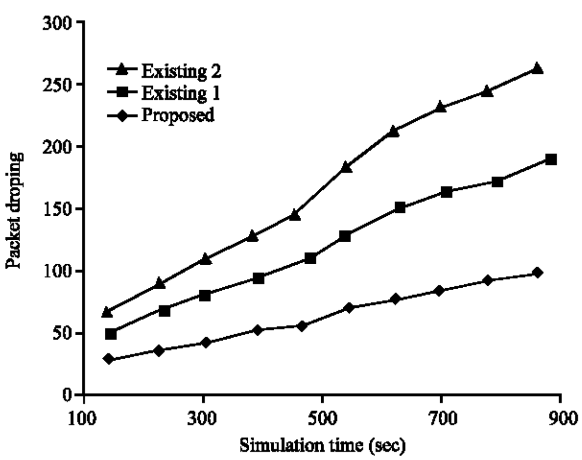

Fig. 9: Simulation time vs. packet dropping

As shown in Fig. 9, the simulation time is presented in X axis while the Y axis is showing packet dropping. The proposed method showed higher performance. Packet drop is increased as simulation time is increased.

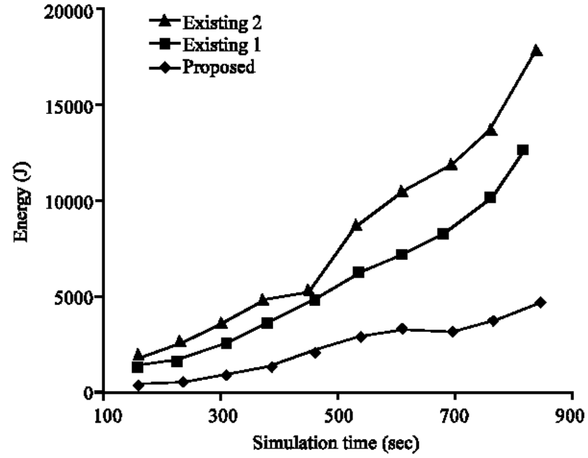

Fig. 10: Simulation time vs. energy consumption

As shown in Fig. 10, the simulation time is presented in X axis while the Y axis is showing energy consumption. The proposed method showed higher performance. Energy consumption is increased as simulation time is increased.

CONCLUSION

Detection of explosives is the main focus of this study. In our prior works our research resulted in an algorithm to detect RDX and TNT explosives using WSN. This study extends it further to have mechanisms not only for detection of explosives but also finding whether the explosive is in its gaseous state or liquid state or solid state. This research assumes importance in the wake or terrorist attacks in different countries. And the rationale behind taking up RDX and TNT is that they are widely used explosives that are misused by anti-social elements. Moreover, they are highly explosive in nature. When detection equipment is very huge and known to public, it may help adversaries to have different strategies to carry out their terror activities. For this reason in this study, we found that WSN is suitable candidate to protect lives of public and properties of government as it is not disclosed to public. Towards this end, we proposed and implemented different algorithms that focus on detection of explosives and fining the state of explosives as well. We made extensive simulations using NS2. Our simulation results revealed that the proposed algorithms are able to help detect explosives such as RDX and TNT. The limitations of the study include inability to have real time sensors and environment with real materials. In future we intend to have real sensors with our algorithms as underlying mechanisms to detect explosives. Another future direction is to expand detection process to other explosives as well.

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