Fire Detection in Coal Mines Using WSN

Master's Thesis in Computer Systems Engineering

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Preface

This Master’s Thesis in Computer Systems Engineering has been conducted at the School of Information Science, Computer and Electrical Engineering at Halmstad University, as part of the degree programme. We would like to thank Edison Pignaton de Freitas for providing us an opportunity to work on this project, under his supervision and guidance throughout the project. We would also like to thank Prof. Rafael H. Bordini and Jomi Hübner for their help and support through the Jason community on the web.

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Abstract

Fire Detection in Coal Mines Using WSN is an application for monitoring and detection of fire in coal mines using wireless sensor networks. The application uses BDI (Belief, Desire and Intention) based multi agent model and its implementation on sensor networks.

The Language which is interpreted by Jason is an extension of AgentSpeak; this is based on the BDI Architecture. The BDI agents are reactive planning systems, systems that are not meant to compute the value of a function and terminate, but rather designed to be permanently running, reacting to some form of event.

The distributed model of environment is adopted to overcome the communication overhead, power consumption, network delay and reliability on a centralized base station.
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1 Introduction

WSN Stands for Wireless Sensor Networks, WSN consists of distributed autonomous devices that use sensor nodes to monitor the physical and environmental conditions.

The autonomous devices connect to the routers and the gateways (sink) to create WSN system. Normally the distributed nodes communicate to the gateway wirelessly and the gateway provides data to a terminal where someone has access to the data that was collected, processed and may be analyzed by WSN. To expand the WSN network possibly the routers are used to gain an additional communication link between nodes and gateway.

Wireless Sensor Networks provides nodes that can operate for hours on different types of batteries e.g. AA batteries, their deployment is effective and long-term, remote operations where the access is too difficult or even impossible. The IEEE 802.15.4 WSN protocol provides a low-power communication standard and it offers mesh routing capability to extend network distance and reliability. The selection of wireless protocol for a network depends on the application requirements.

1.1 Application Area and Motivation

Wireless sensor nodes are embedded systems used for monitoring of large number of application area including those where power and wire are the limitations or sometimes impossible to deploy due to power and wire limitations. It is possible to deploy the wireless sensor networks and wired networks to make a measuring and control system.

![Figure1. WSN Application Areas](image)

*Figure1. WSN Application Areas*
A WSN system is an ultimate system for applications resembling environmental monitoring to acquire water, soil, or climate measurements. WSN is used for monitoring street lights, electricity grid stations, water resources, security and monitoring in prohibited areas and to collect system data to trim down energy usage and to better deal with the resources. Another important area of WSN is structural health monitoring; it is possible to use wireless sensors to efficiently monitor highways, bridges, tunnels, office buildings, hospitals, airports, factories, power plants, or production facilities.

### 1.1.1 Power and Network Standards

The WSN hardware contains a radio part, microcontroller to process data, analogue circuitry and the sensor interface. The battery powered systems faces problem of consumption of more power when high data rates are required or the transmission takes place.

Normally the today’s WSN systems are based on ZigBee or IEEE 802.15.4 protocols due to their low-power utilization. The IEEE 802.15.4 protocol defines the Physical and MAC layers in the networking model, providing communication in the 868 to 915 MHz and 2.4 GHz ISM bands, with data rates support up to 250 kb/s.

### 1.1.2 Networking Topologies

The basic topology the WSN follow is star topology, where each node maintains a single, direct communication link with the gateway node. This topology is simple but bounds the network in distance it can achieve.

To increase the coverage distance a network can cover, the clusters can be implemented, or tree, topology. Each node maintains a single path but through some other node. If any of the router nodes goes down, all the nodes that depend on this router node will also lose their communication paths to the gateway node.

The mesh network topology covers all these issues by using additional communication paths to increase system reliability. The mesh topology is very reliable but does suffer from an increase in network delay because data must make multiple hops before arriving at the gateway.
1.1.3 Choosing the Right Technology – Wired or Wireless

The wired protocols are selected due to high bandwidth and reliability. The 100Base-TX Ethernet is faster than both wireless standards IEEE 802.11g and IEEE 802.15.4 which provides bases for ZigBee. When the bandwidth above than 100Mbits/s is not required than the cost savings combined with installation flexibility makes wireless more effective choice.

The ZigBee operates at lowest power rate, provides coverage to almost 300meters with battery life of 3-5 years. This is the best choice for the sensor networks due to its nature of use.

1.1.4 Bandwidth, Range, and Power Requirements

Three main factors needs to be considered for wireless technology are bandwidth, range and power requirements. Comparison shows that wireless protocol based on IEEE 802.11 or Wi-Fi has advantage in high bandwidth with a maximum bit rate of 54Mbits/s, while IEEE 802.15.4 has advantage on distance and power requirements.

The IEEE 802.15.4 based technologies are ideal for low data rate, low speed, long distance remote monitoring applications. Wi-Fi is ideal for high speed, high data rate and short distance applications.
1.1.5 Coal Mines and Statistics

Coal mines are one of the most important sources of energy for every country. The issue of security in the mines is still unsolved almost all over the world, which is responsible for the heavy losses in the form of human lives, machinery and infrastructure. To monitor the mines is a way to offer safety from such disasters.

China is the largest producer of coal with 70% incidents related to fire and explosions. The diagram below shows the contribution to risk of fatality around the globe. It is obvious that explosion and fires are worth considerable for the safety of miners.

![Coal Mines Statistics](image)

*Figure3. Coal Mines Statistics*

1.1.6 Possible Disasters

This is worth important to study the factors and the reasons behind the explosions and the fire disasters. It is very important to know what a mine is, and how it looks like. The mines are underground and are almost closed having any entry point or somehow having an exit point, sometimes the entry/exits are, or may be, more than one, but due to improper ventilation and air flow different gases are accumulated inside the mines. These gases can create suffocation, explosion or fire in the mines.

There are a number of risk factors involved in the underground coal mines, which are

1. **Fires** (diesel fire, electrical fire)
2. **Explosions** (Underground gas explosions, dust explosions, premature explosions of charges, drilling etc).
3. **Falls of roof or face.**
4. **Transport Accidents.**

Build-ups of hazardous gases are known as damps:

**Black Damp**

When carbon dioxide is mixed with nitrogen it can cause suffocation, and is formed due to corrosion in enclosed spaces so removing oxygen from the atmosphere.

**After Damp**

Similar to black damp and after damp consists of carbon monoxide and nitrogen which is formed after a mine explosion.

**White Damp**

Air containing carbon monoxide is toxic even at low concentration.

**Fire Damp**

Fire damp mostly consists of methane CH₄ a flammable gas.

**Stink Damp**

The stink damp is named for the rotten egg smell of the hydrogen sulphide gas, and hydrogen sulphide can explode.

As the Fire Damp and Stink Damp are more dangerous from the point of view of fire risk, this project will explore the ways how to monitor and avoid both.
1.2 Problem Studied

The fire is caused in the coal mines due to different factors but the major factors for fire are the explosive gases like ‘Hydrogen Sulphide’ and ‘Methane’. So it is very important to monitor the gas concentration in the air before fire detection.

Three different sensor nodes are deployed to monitor and make decisions about the concentration levels in the air. When hydrogen sulphide reacts to air it forms such a reaction where the temperature of atmosphere increases very high so the temperature sensors are required to monitor the temperature changes in the environment.

The air flow sensor monitors the changes in the air caused by the change in temperature and gas concentrations.

1.3 Approach Chosen to Solve the Problem

Multi-Agent Systems provides adequate modelling to autonomous and distributed intelligence entities. Specifically the BDI agent theory developed to operate within dynamic environments. BDI model represents an abstraction of human deliberation based upon a theory of rational actions in the human thought process.

In BDI architecture an agent is situated within its environment and executes autonomous actions to reach certain goals in a non deterministic environment. The states of agent are represented by three components: Beliefs, Desires, and Intentions.

The agent architecture is the software framework within which an agent program runs. The program that will direct the agent behaviour, but much of what the agent effectively does is determined by the architecture itself. The language interpreted by Jason is an extension of AgentSpeak, which is based on the BDI architecture. Thus one of the components of agent architecture is a belief base, and an example of one of the things that the interpreter will be doing constantly is to perceive the environment and update the belief base accordingly.

Another component is the agent’s goals, which are achieved by the execution of plans.
The BDI agents are reactive planning systems, systems that are not meant to compute the value of a function and terminate, but rather designed to be permanently running, reacting to some form of events.

1.4 Thesis Goals and Expected Results

The applications of WSN require data acquisition, processing and possibly an action. This cycle continues throughout the life of the network. A simple solution to this is to perform the processing at the base station of WSN. In this type of solution, each node sends its sensed data to the base station. This approach is not very efficient, because of a number of reasons, firstly is the delay between the time the values are sensed and the time the base station receives them, and the other is the increased number of messages that are communicated in the network.

In multi-hop scenarios, data may have to make many hops before reaching its destination. This delay will mean that any action the Base station chooses to take may be based on information that may not be representative of the current state of the environment.

Secondly, considering the power consumption in WSN’s, there is a rule of thumb for most of the WSN’s, that the transmission of 1 bit is roughly equivalent to the execution of 1000 instructions, so the advantage in sending summary data, locally processed in the nodes, avoiding a great number of raw data transmissions. In this way lot of energy is conserved and the life of network could be increased.

The local nodes can decide by themselves that the sampling rate has to be increased depending on the event occurred. And the other parameters related to sensing have to be changed by the analysis of gathered data by the nodes. Besides sampling the energy and communication parameters are changed without consulting the base station because all nodes are capable of making decision saving energy, time and dependence on centralized or multi-level decentralised nodes. This increases the efficiency of the network and decreases the dependence of nodes and reduces the resource utilization.
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## 2 Background

The BDI agent theory is a good model of intelligence theory for such autonomous electronic devices as WSN nodes. The sophisticated agents operating in open environments must make complex real time decisions on scheduling and coordination of domain activities.

The decisions are made in the context of limited resources and uncertainty. Moreover, the time and energy are critical to MAS performance in resource bounded systems.

The sensor nodes have three states to operate, actions, deliberation and sleep. Deliberation is the reasoning or processing, deciding which argument to agree.

Meta level reasoning deals with the optimization of the agent’s performance by choosing and sequencing agent activities. It deals with the selection between reasoning and action. The sensor nodes with limited resources are only involved in some local deliberations and actions. In this way, Meta level reasoning of WSN needs to deal with optimization of more complex situation where global coordination is essential.

Decision making process of BDI agents can be considered as a process of weighting a group of available options and selecting an appropriate one as an intention.

If a goal has successfully passed through a weighing function and is chosen by an agent as an intention, it is said that the agent has made a commitment to this goal.

Desires denote states that the agent wishes to bring about, and the Beliefs represent the set of perceptions of the world within which the agent is situated. Due to uncertainties caused by the limitations of the agent’s perception abilities and environmental dynamics, beliefs can be considered as fuzzy. Reasoning based on fuzzy sets is effective in dealing with uncertain environment.
Decisions are made by the centralized Base Station in the centralized environment, through a hierarchy of network. The problem with this networked approach is that it takes long to return the decision to the node as the nodes are resource bounded and all the related information is kept at BS.

While the communication failure of WSN’s make centralized decision making hard to achieve. In this case the best solution would be a decentralized architecture.

2.1 Current Solution and Best Praxis

Normally the BS’s are the centre of gravity for the WSN environments, for the decision making. In some autonomous applications only BS with intelligence is not sufficient, the sensor nodes be smart and intelligent enough to make such intelligent decisions as routing, data fusion and also deals with some autonomous activities as healing, protection, configuration and optimization.

Different types of agent architectures are applied on WSN depending upon the complexity. They vary depending upon the intelligence level required by the application and intelligence modelling. Two levels BDI multi-agent system was proposed. (Song Shen and Gregory M.P. O’Hare 2007). The high level multi-agent system consists of the resource rich base stations and the low level multi-agent systems consists of base stations and groups of sensor nodes which are connected as groups of sensors to the low level base stations and are dedicated to local perception.

The belief of a base station agent is the information that it can gain from the base station network, which keeps the global information from whole network, or from the individual sensors. The desire is to monitor the whole environment but with the minimum cost which means the lowest power usage.

The monitoring systems are intelligent enough that it increases its sampling when it expects some threat, and must normalize when the conditions are normal in the environment. To satisfy these both the sensor node and Base Station are intelligent agents.
System works normal under normal conditions, but if the gas concentration is increasing in the environment than the high-level MAS instructs the sensor agent to increase the sampling speed and instructs to be normal in the normal conditions again, or to be in sleep mode, but not all sensors at the same time. The low-level MAS have dynamic architecture, as the resources and transmission relayed to BS indirectly.

The behaviours of an agent depends on reasoning and action, actions are executable activities to achieve particular tasks. While reasoning is made up of deliberation and planning, where the former decide what to do in order to satisfy the desire, while latter decides how to satisfy the intention by scheduling a set of actions to accomplish it know as Meta level reasoning. The agent is cost aware in terms of energy and time of its tasks and sub tasks.

2.2 Problem or Improvement Potential

The sensor nodes are autonomous devices, which are capable of operating independently and can make decisions regarding the environmental changes depending on the perceptions and the gathered data. In the work discussed above agents are not fully autonomous because the sensor nodes depends on the low level base stations for decision making, while sometimes the low level base station agents do not have the authority to decide, the resource rich high level base stations are involved in decision making which is challenging the autonomous nature of a sensor node agent.

The sensor nodes could be placed as an independent entity making decisions by their own, and communicating with their peer group members only to make decisions which reduces the resources. And the nodes can communicate outside the group and don’t need any mediator node for deciding about this communication.

The communication overhead is increased in the network for requesting services and accepting services from the low level and high level agents finally can cause increase in time delay and power consumption.
While adopting this approach of having autonomous nodes which are capable for deciding about the actions definitely reduces the communication overhead, time delay and complexity of computation and resource utilization by updating their beliefs in real time.

Another factor is the energy utilization is controlled by keeping the nodes sleeping until it reaches some specific concentration level; different sampling rates are defined as per the requirement and defined danger.
3 Solution Idea to be Investigated

WSN are embedded and autonomous systems exposed to the dynamic world. Mostly its applications need to adapt changes from the environment; these changes could be physical or chemical. Change in the concentration of different gases or the movement of robots are examples of environmental changes, and the application must adapt these changes, so new programming models and middleware’s are needed to support application self adaptability in WSN’s. There are different approaches to model coal mines WSN monitoring systems like Agilla, TinyOS, Object oriented approach or Milan etc.

3.1 Agilla Approach

To overcome this problem Agilla was developed for self adaptive applications on WSN. Agilla provides such application structure for one or more mobile agents in the form of special processes, which moves from node to node but maintains their states. Agilla ensures the autonomous nature of the agents, enabling inter agent coordination.

Agilla provides higher degree of application adaptability depending upon its unique programming model. Agilla supports agent migration; the application resides on relevant nodes. But as the environment changes the application can self adapt by migrating its agent to that position which are best to fulfil its goals. Any agent can be replaced without suffering other agents in the network. With mobile agents tuple spaces are also introduced for self adaptive applications in WSN.

3.2 MiLAN Approach

Another approach to model coal mine scenario is by MiLAN. MiLAN permits the sensor network application to specify their quality needs and adjust the network parameters to increase the application lifetime, while meeting quality needs and standards.

MiLAN receives information about the requirements of the application individually overtime and how to achieve these requirements using different combination of sensors. MiLAN adapts the network configuration continuously i-e which sensors should act as routers in multi-hop environment, which are responsible to send data and what other roles the sensor must play.
System shows the MiLAN in diagram, each sensor node runs copy of MiLAN and receives the information from the application about their QoS requirements.

![Diagram of MiLAN system](image)

*Figure 4 System employs MiLAN*

### 3.3 Object Oriented Approach

Object oriented is another approach to the coal mines monitoring system, like “Wireless information and safety system for underground miners” (L K Bandyopadhyay, S K Chaulya, P K Mishra, A choure). The system was development in visual basic (VB) under windows environment as front end and SQL server work as background.

Visual basic is an object oriented based software package, different objects available in VB are used with crystal report as reporting tool.

The system operates as; the monitoring unit is connected to a coordinator physically, which reads the data periodically from sensor nodes through routers in the network by multi-hoping technique.
Each RFID device transmit/receive data from its neighbours. The devices have the ZigBee compliant interfaces and can form network autonomously.

![General Schematic Layout of a Mine with WSN Implementation](image)

**Figure 5 Object Oriented Approach**

The agent oriented techniques provides wider approach for supporting the whole software development process. The analysis, design and implementation in the agent oriented techniques are done in a natural or simple way. Agent oriented techniques follows a uniform concept that is called agents. Agents are the acting entities of problem domain. The actions of agents are specified in the design phase. Then finally the agents are programmed with the help of an agent oriented programming language or environment.
Agent oriented techniques are natural extension of object oriented techniques. The agents are active objects. The difference between agents and objects as stated by Y. Shoham (i) the structuring of the internal state of an agent by mental notions like beliefs, goals, intentions and (ii) characterization of messages by message types and the structuring of messages into protocols. Due to this conceptual and logical differences agent oriented techniques must be designed and implemented differently.

The behaviour of an agent is more complex then object, they differ in internal architecture, agents follows more complex functional architecture such as BDI (Beliefs, Desires and Intentions) architecture.

The internal states of objects are defined in terms of arbitrary attributes; on the other hand agents are defined in terms of mental notions like beliefs, plans and goals.

Agents are active entities, while the objects became active through messages, while the agents act by their own following their goals. An agent can decide whether they have to respond or act to events and messages sent by other agents.

Behaviours of the agents are described as plans by some state transition diagrams as describes object life cycles in some object oriented techniques.

In the agent oriented techniques messages are characterized by types and the agent dialogues with respect to specific contest are pre-structured into cooperation protocols, while communication in the objects is by simple messages.

3.4 BDI Approach

BDI (belief, desires, intentions) model is multi-agent system, the belief of a system is the information the agent can obtain from its own perceptions or from the network which contains the global information over the whole network. The desire for the base stations is to monitor the environment at minimum cost that is power.
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BDI model provides intelligence modelling, the agents having repeated perceptions and the belief base is not changed than there is no reconsideration on the decision, because the decision is executed depending on the last same perceptions. The decision making follows a cognitive process; it does not follow the goal directed behaviour.

The BDI architecture has their roots in the philosophical tradition of understanding practical reasoning, the process of deciding every moment, which actions to perform to reach the goals. Practical reasoning is an important concept addressing two processes, deciding what goals to be achieved, and secondly how to achieve these goals. The first process is known as deliberation and the second one as means-ends-reasoning. To obtain goals there should be number of options available. Chosen options becomes intentions which determines the agent’s actions. And the intentions feed back to the agent’s future practical reasoning. For Example if someone decided to be an academic, then he/she must commit to this objective and devote time and effort to achieve it.

Intentions play a vital role in practical reasoning; most important property of intentions is that they lead towards actions.
4 Detailed Description of the Investigated Solution

4.1 Logical or Schematic Structure of BDI in WSN

Introduction:

The BDI architecture model consists of eight main functional blocks and a sensor input. Based on the perceived value by the sensor the function of each block is defined as follows.

Working of the functional Blocks: Example Gas concentrations

BUF (Belief Updating Function)

Belief updating function accepts a perceptual input by the sensor (current gas concentration) and compares with the predefined threshold values for gas concentrations. Depending on the threshold values it decides whether to create a new belief or not. The new belief removes the
old belief and new takes the place and the new information is considered as always the most correct.

**BELIEF:**

Belief Block contains the updated version of the current beliefs (latest information of the gas concentrations in the environment) and the copies of the current beliefs are to be passed on to the next block for the selection of the behaviour for an agent.

**BEHAVIORAL PARAMETERS:**

Behavioural parameters block contains mainly three types of behaviours of an agent which are

1. Energy consumption
2. Communication
3. Sampling

Behavioural block takes updated current beliefs as an input and the said behaviours are selected, after applying reasoning by considering minimum and the maximum thresholds on the basis of current beliefs. The selected parameters are then fed into the produce alternatives block for further selection of possibilities.

**Reasoning:**

\[
\text{If (Belief < MinTh) || (Belief > MinTh) && (Belief < MaxTh)}
\]

*Select Parameters:* Energy and Sampling

\[
\text{If (Belief > MaxTh)}
\]

*Select Parameters:* Energy and Sampling and Communication

**PRODUCE ALTERNATIVES:**

This block takes the ‘selected behavioural parameters’ and ‘current intentions’ as input and generate all possible courses of actions (All options) for the selected behavioural parameters. Any option generated here must be consistent with both the agent’s ‘selected behavioural parameters’ and the current intentions.

Defined, set of all possible courses of actions for the given respective behavioural parameters can be following.
Here,

**No signal** means conditions are normal no need to communicate.

**Alert signal +services** means, alert signal to adjacent nodes and inform them to check and send their readings as we

II.

**DESIRE**

The desire block accepts set of current options representing ‘all possible courses of actions for the selected behavioural parameters’ available to an agent, which are actually high level goals of the agent. These high level goals are then passed to the Filter function block for the identification of the intentions for the agent.

**FILTER:**

Filter block represents the agent’s deliberation process, which means it, decides what goal to achieve by an agent. It determines the agent’s specific intensions out of all possible courses of actions on the basis of current beliefs, current desires and current intentions. It must drop intensions that are not achievable and pass the achievable intentions to the intentions block.
INTENTIONS:

This block contains those goals that an agent has committed to achieve. Actually it takes immediate goals as an input which will trigger some actions.

ACTIONS:

Actions block determines an action to perform on the basis of current intentions.

SUGGESTION TO MINIMIZE THE DESIGN:

The idea to minimize the design is that it is possible to get rid of two blocks which are BUF and Produce Alternatives. The goal to simplify the traditional BDI model is to reduce the complexity of the architecture, the complexity in the computation involved in the whole architecture and to demand fewer resources. So the goal is to save resources.

WHY BUF:

The BUF block is actually not removed to compact the design and to overcome the complexity and computation. The Belief block is customized in a way that it receives the new quantitative inputs from the sensor device, it uses thresholds to determine if a new belief will be created or not, as the previous percept are maintained in the belief block, as to compare the perception with the predefined concentration thresholds in the same block.

WHY PRODUCE ALTERNATIVES:

As produce alternatives block is producing all set of options or all possible courses of actions for selected behavioural parameters. In fact it has a record of all options for all behavioural parameters, so after selection of parameters it will forward the options for selected behavioural parameters only to the desire block. As if the threshold value is in between the MinTh and MaxTh the sampling and the energy will be selected where all possible actions are generated as desires, which further filtered out by a filter as intentions.
4.2 AGENTSPEAK

The AgentSpeak (L) programming language was introduced in 1996 by A. S. Rao. It is for the BDI agents and based on the logic programming and provides a well-designed abstract framework for agent based programming. The BDI architecture is the dominant approach to the implementation of intelligent or rational agents.

AgentSpeak agent is defined by a set of beliefs giving the initial state of ground (first-order) atomic formulae, and a set of plans which form its plan library. An AgentSpeak plan has a head which consists of a triggering event, and a number of beliefs represent the context. The conjunction of literals in the context must be a logical outcome of that Agent’s current beliefs if the plan is to be considered applicable when the triggering event happens. Plan has a body, which is sequence of sub-goals or the actions that the agent must achieve when the plan is triggered.

Basic actions represent the atomic operations the agent can perform so as to change the environment. Such actions are also written as atomic formulae, but using a set of action symbols rather than predicate symbols.

The AgentSpeak differentiates for two types of goals: achievement goals and test goals. Achievement goals are formed by an atomic formulae prefixed with the ‘!’ operator, while test goals are prefixed with ‘?’ operator.

Plans are triggered by the addition ‘+’ or deletion ‘-‘of beliefs due to perception of the environment.

4.3 JASON

The Jason interpreter implements the operational semantics of AgentSpeak in figure 7 (detailed design). Jason is written in java, and its IDE supports the development and execution of distributed multi-agent systems, some of the features of Jason are:

- Speech-act based inter-Agent communication.
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- It is possible to run a distributed multi-Agent system over a network (using SACI or some other middleware).

- Fully customizable (in java) selection functions, trust functions and overall agent architecture (perception, belief-revision, inter-agent communication and acting).

- Clear notion of multi-agent environments, which can be implemented in java (for simulation of real environment, for testing purpose before the actual deployment).

To implement agent, two of these features are especially useful: architecture customisation and internal actions. As figure shows:

![Diagram](image)

**Figure 8. Agent extensibility and customisation**

A customisation of the agent architecture is used to interface between the agent and its environment. The environment simulates the mining field. Sending perception to the agents and receiving requests for action execution therefore, when an agent attempts to perceive the environment, the architecture sends to it the information provided by the simulator, and when
the agent chooses an action to be performed, the architecture sends the action execution request to the simulator.

The overall scenario for the mining environment looks like a number of neighbouring agents shown in figure 9, are communicating with each other.

*Figure 9 Overall Scenario of WSN system*
4.4 Behavioural or Functional Description

The figure.8 shows the overall working states of a node, there are four different states of a node as:

Sleep State

The node remains in sleep state for time period ‘T’ and keeps on sensing the environment after time period ‘T’, if the concentration level is lower than the minimum threshold.

Normal State

Normal state is when the node is sensing concentration after time period ‘T’ for the sleep mode and the concentration level is below than the minimum threshold.

Alert State

If in the normal state the agent detects a concentration level greater than the minimum threshold it will switch to the alert state, where the alert signal with service request is sent to all the group members, if any of them is in sleep mode, and start sensing the samples with the sampling rate of ‘T/2’. All nodes share their concentration levels with one which decides the level of danger. It will remain in this mode until the concentration level crosses the maximum threshold value or returns back to minimum threshold level.

Emergency State

When the concentration level crosses the maximum threshold value the agent will be in emergency state which is the critical state, the sampling rate is immediately increased to maximum ‘T/4’ and the alert messages are sent to the neighbouring agent groups to be aware of danger. In this way the nodes operates and communicate with each other and other groups.
Figure 10. State Diagram for WSN node
5 Test or Analysis of Solution

The fire detection model is implemented in AgentSpeak Jason, depending on the gas, temperature and airflow concentrations the agents decide whether fire is triggered or not. The parameters for testing the environment are:

1. Gas
2. Temperature
3. Airflow

5.1 Prometheus Methodology for WSN

Gas:

The implementation design shown in diagram give an overview of the agents’ perceptions (left blocks) and actions (right blocks), every agent perceives the environment and generates actions depending on the perceptions. Every time the agent’s initial belief base is updated the diagram following Prometheus Methodology shows.
**Temperature:**

Temperature has same perceptions; the agent has to perceive the environment grid size (width, height), its own position in the environment on ‘x’ and ‘y’ axis, and the environment perception for the temperature level in the environment, and keep updating its initial belief base.

**Air Flow:**

Airflow agent repeats the same perceptions and the actions; the initial belief base is updated on regular bases as the new perceptions are perceived.
Communication between Agents:

The system overview diagram shows the group of agents (gas, temp, Airflow) which is necessary to minimize the risk of the fire in the coal mines, because all three factors are interdependent and if any of them is neglected it can create danger e.g. if the temperature agent is missing and hydrogen sulphide gas mixes with air and increases the temperature of the environment and it can trigger the low concentration of the gas so all three factors must be catered. Agents communicate with each other through messaging (alert/service). The alert message is sent to the agents so that all the agents must be active and the service messages returns their status back to the requesting node through hand shaking.
Their levels of concentration are defined as MinTh (minimum threshold), in between (min and max threshold) and greater than MaxTh.

If the concentration level detected is less than ‘MinTh’ than the agents keep continuing their sleep for period ‘T’. When the level of concentration increases and is in between ‘MinTh and MaxTh’ than alert state will be executed which will increase the sampling rate as well as send service request to all the neighbouring agents. The state will be in emergency mode if the concentration level is more than ‘MaxTh’ the sampling rate reaches it’s maximum and alerts all the agents from this danger.
6 Results of Simulation

6.1 Environment Creation

Successful creation of the environment for twelve agents as shown:

![Simulation of WSN in Coal Mines Using AgentSpeak Jason](image)

*Figure 15. Simulation of WSN in Coal Mines Using AgentSpeak Jason*

Random values are generated for the agents using a random function. The agents shown in the simulation diagram as T1, A1, and G1 identifies that these three agents are the neighbouring agents. T2, A2, and G2 shows the second group of neighbouring agents and similarly the rest of the groups third and fourth total of twelve agents constitutes the overall WSN system for coal mines.
6.2 Random Percept Generation

The simulation results generated in AgentSpeak Jason are shown in the diagrams; the diagram shows the snapshot of a log window of Jason interpreter, which shows the number of different values generated and assigned randomly to the twelve agents. These random values are actually the percepts of our agents from the environment. The percepts are the concentrations of gas, temperature and air flow in the environment. Depending on these values the plans are triggered and the actions are executed.

Snap shot also shows the number of messages (alert/service) broadcasted by the agents.

6.3 Addition of Percepts

The environmental percepts are added against all the agents, the log shows the grid percept updation of the environment, the positions of the agents and all the positions of the agents so that all the agents must know the positions of other agents at the time of initialization. As figure shows:
Fire Detection in Coal Mines Using WSN

6.4 Message Passing (Broadcasting)

The agents are broadcasting messages (alert/service) as per the conditions in proper way. The agents are responding to the service requests too, as the log shows in diagram.
6.5 Internal Actions

The internal action execution is one of the most important goals. The log shows the sleep time for all agents, the agents sleep for 6 sec if the concentration is less than MinTh, but if it is greater than MinTh and less than MaxTh, the sampling will increase to T/2 (3 sec), similarly it will sleep if the agent perceives the concentration more than MaxTh. The energy is also shown in the log as the agent 3 shows the lowest energy consumption, agent 2 shows high energy consumption.

![Figure 19 Execution of Internal Actions](image)

6.6 Risk Identification in Coal Mine through Comparison of Sent Messages.

Agent's position based risk identification in coal mine through comparison of sent messages by the agents. For test purpose ten snap shots of the simulation log are shows than readings are being taken from the snapshot logs and compared in two different tables for identification of the uncertain zone of the coal mine and the utilization of energy.
Figure 20 Snapshot Log1

Figure 21 Snapshot Log2
### Figure 22 Snapshot Log3

<table>
<thead>
<tr>
<th>Common</th>
<th>Environment 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>ai12</td>
<td>Perceived Value for Agent 1 is 25</td>
</tr>
<tr>
<td>ai11</td>
<td>Perceived Value for Agent 2 is 23</td>
</tr>
<tr>
<td>ai10</td>
<td>Perceived Value for Agent 3 is 8</td>
</tr>
<tr>
<td>ai9</td>
<td>Perceived Value for Agent 4 is 23</td>
</tr>
<tr>
<td>ai8</td>
<td>Perceived Value for Agent 5 is 15</td>
</tr>
<tr>
<td>ai7</td>
<td>Perceived Value for Agent 6 is 21</td>
</tr>
<tr>
<td>ai6</td>
<td>Perceived Value for Agent 7 is 24</td>
</tr>
<tr>
<td>ai5</td>
<td>Perceived Value for Agent 8 is 20</td>
</tr>
<tr>
<td>ai4</td>
<td>Perceived Value for Agent 9 is 10</td>
</tr>
<tr>
<td>ai3</td>
<td>Perceived Value for Agent 10 is 17</td>
</tr>
<tr>
<td>ai2</td>
<td>Perceived Value for Agent 11 is 2</td>
</tr>
<tr>
<td>ai1</td>
<td>Perceived Value for Agent 12 is 8</td>
</tr>
<tr>
<td>gas3</td>
<td>Wao Agent 1 is Checking 3rd Threshold Condition = Max 12</td>
</tr>
<tr>
<td>gas2</td>
<td>Broadcasting 1 times 11 alert msgs by agent 1 at pos (15,1): so total msgs sent are 11. *****</td>
</tr>
<tr>
<td>gas1</td>
<td>Broadcasting 2 times 11 alert msgs by agent 2 at pos (11,4): so total msgs sent are 22. *****</td>
</tr>
<tr>
<td>MineModel</td>
<td>Environment 1</td>
</tr>
</tbody>
</table>

### Figure 23 Snapshot Log4

<table>
<thead>
<tr>
<th>Common</th>
<th>Environment 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>ai12</td>
<td>Perceived Value for Agent 1 is 25</td>
</tr>
<tr>
<td>ai11</td>
<td>Perceived Value for Agent 2 is 23</td>
</tr>
<tr>
<td>ai10</td>
<td>Perceived Value for Agent 3 is 8</td>
</tr>
<tr>
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<td>Perceived Value for Agent 4 is 23</td>
</tr>
<tr>
<td>ai8</td>
<td>Perceived Value for Agent 5 is 15</td>
</tr>
<tr>
<td>ai7</td>
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<tr>
<td>ai6</td>
<td>Perceived Value for Agent 7 is 24</td>
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<tr>
<td>ai5</td>
<td>Perceived Value for Agent 8 is 20</td>
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<td>ai4</td>
<td>Perceived Value for Agent 9 is 10</td>
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<td>ai3</td>
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</tr>
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<td>Perceived Value for Agent 11 is 2</td>
</tr>
<tr>
<td>ai1</td>
<td>Perceived Value for Agent 12 is 8</td>
</tr>
<tr>
<td>gas3</td>
<td>Wao Agent 1 is Checking 3rd Threshold Condition = Max 25</td>
</tr>
<tr>
<td>gas2</td>
<td>Broadcasting 1 times 11 alert msgs by agent 1 at pos (15,1): so total msgs sent are 11. *****</td>
</tr>
<tr>
<td>gas1</td>
<td>Broadcasting 2 times 11 alert msgs by agent 2 at pos (11,4): so total msgs sent are 22. *****</td>
</tr>
<tr>
<td>MineModel</td>
<td>Environment 1</td>
</tr>
</tbody>
</table>

---

**Defining Mine Environment for 30x30 simulation ID:**

[Description of environment setup and parameters]
Fire Detection in Coal Mines Using WSN

**Figure 24 Snapshot Log5**

**Figure 25 Snapshot Log6**
Figure 26 Snapshot Log7

Figure 27 Snapshot Log8
Fire Detection in Coal Mines Using WSN

**Figure 28** Snapshot Log9

**Figure 29** Snapshot Log10
The agents are shown in groups of three as neighbours the number of runs are shown in the table, every time the number of normal agents, service request agents and the alert agents are calculated. After every ten runs all the three states are calculated one of the tables is shown.

<table>
<thead>
<tr>
<th>RUNS</th>
<th>NEIGHBOURING AGENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N 11 N N 11 11 N S N N S 11</td>
</tr>
<tr>
<td>2</td>
<td>S 11 11 11 S S N N N N N S</td>
</tr>
<tr>
<td>3</td>
<td>11 11 N 11 S 11 11 11 S S N N S</td>
</tr>
<tr>
<td>4</td>
<td>S N N S 11 S N N S N N 11</td>
</tr>
<tr>
<td>5</td>
<td>11 S N N S N N 11 S N N 11 N</td>
</tr>
<tr>
<td>6</td>
<td>S N N 11 11 S S S N 11 11 S</td>
</tr>
<tr>
<td>7</td>
<td>11 11 N N S S S N N 11 N N S</td>
</tr>
<tr>
<td>8</td>
<td>N N N 11 S N N 11 N 11 N N</td>
</tr>
<tr>
<td>9</td>
<td>11 S 11 11 S N 11 N N 11 S 11</td>
</tr>
<tr>
<td>10</td>
<td>S N S 11 N 11 S N 11 S 11 N</td>
</tr>
<tr>
<td>SUM OF MSGS</td>
<td>110</td>
</tr>
</tbody>
</table>

*Table 1 Risk Identification in Coal Mine through Comparison of Sent Messages*

The table shows the neighbours which are generating maximum messages and this identifies the most uncertain area of the mine. This is one the achievement to identify the most dangerous zone of the mine.

6.7 Energy Consumption in Coal Mine by Agents through Comparison of sent message.

Energy is the most important issue in the sensor networks. This is why the low power consuming sensor nodes are used, which are autonomous devices. There are methods used to make them more energy efficient. The coal mines are such an application where it is not easy to power up the nodes again and again so the minimum energy consumption is main goal in
such environments. The table shows the energy consumption by the agents through sent messages by the agents. The service messages are the most costly messages, alert messages are medium energy consuming agents and the normal state is the low power state.

<table>
<thead>
<tr>
<th>Service State</th>
<th>Service msgs</th>
<th>High Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alert State</td>
<td>Alert msgs</td>
<td>Med Energy</td>
</tr>
<tr>
<td>Normal State</td>
<td>No msgs</td>
<td>Low Energy</td>
</tr>
</tbody>
</table>

The tests conducted for a number of runs showed that the agents in normal state are always more than the alert state agents, which confirms the minimum utilization of energy as the normal state agents are the low energy agents. Secondly the alert agents are more than the service requesting agents, where the alert message agents are medium energy consuming agents, and the minimum number of agents, the service requesting agents are less than all so this test shows minimum utilization of energy. This is another important achievement of the work.

**Table 2 Energy consumption in Coal Mine by Agents through Comparison of Sent Messages**

The tests conducted for a number of runs showed that the agents in normal state are always more than the alert state agents, which confirms the minimum utilization of energy as the normal state agents are the low energy agents. Secondly the alert agents are more than the service requesting agents, where the alert message agents are medium energy consuming agents, and the minimum number of agents, the service requesting agents are less than all so this test shows minimum utilization of energy. This is another important achievement of the work.
7 Conclusions and Suggestions to Future Work

WSN is autonomous in nature, and the approach ‘BDI’ model which is also a design parameter for decentralized and autonomous agents. There are a number of approaches following decentralized or distributed approaches, but somehow the decision making is always dependent on some centralized resource rich agent.

Such environments put a question mark again on the resources used, the time delay and the communication overhead, and most importantly the autonomous nature of WSN.

The system designed is fully decentralized; every agent has the same power of decision making independently as others. The resource utilization is less due to the belief customization and no centralized decision making in any case.

The uncertain areas of the mine are identified through the comparison of messages generated from the neighbour agents, to monitor the dangerous zones of the mine.

Energy utilization is calculated through the message calculations and the number of agents in different states, normal, alert and the service requesting state. This confirms the minimum utilization of the energy.

The approach used for implementation in coal mines is ‘BDI’, programmed in AgentSpeak Jason; this is also somehow a unique work and approach for coal mine scenario.

The work focused on the sensing part only, which is the monitoring and the data acquisition for analysing the real time environment. But there are things to be implemented for the future perspective.

Most important is the actuation, the system is acting but this actuation is logical actuation where the nodes only change their states of operations as per the environmental changes without any physical actuation.
Physical actuation could be ventilation in coal mines scenario, if the agents detected ample amount of gases, temperature or airflow change in the environment the control should operate ventilators to decrease the concentration of gases, high temperature or to maintain the required airflow so that the danger of explosion of gases could be overcome. This ventilation could be one of the best solutions to overcome such danger in coal mine environments.

If the air flow for ventilation is not as per required, to decrease the concentration of gases or high temperature than air blowers could be used to blow artificial air and provides ventilation to the gases. These air blowers could be part of the WSN system design too.

The ID based communication between the agents is the most important work to be worked out by catering with the dynamic nature of the decentralised environments.
8 References


Fred Kissell Mine Safety Consultancy, Glenshaw, PA, 15116.

University of Missouri, Mining Engineering Dept, Rolla, MO, 65401.

National Institute for Occupational Safety and Health, Pittsburgh, PA, 15236


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[16] “Jason” A Java-based interpreter for an extended version of AgentSpeak developed by Rafael H. Bordini and Jomi F. Hübner.


9 Appendix