# A Multi-agent framework for WSN Configuration using Hybrid Intelligent Decision Support System

F. Alshahrany[1], H.Zedan[1], I. Moualek[2]
[1]School of Computer Science and Informatics (STRL) De Montfort University
The Gateway, United Kingdom
Leicester, LE1 9BH
[2] Hybrid Intelligent Decision Systems Jerjer House
Nottingham, United Kingdom

***ABSTRACT**: A conceptual multi-agent framework based on a knowledge-based collaborative decision support is proposed in this paper to design hybrid intelligent decision support systems (HIDSS) based on policy settings for the support of intelligent and pro-active decision making activities. An example of HIDSS has been developed to support the design and configuration of small wireless sensor networks (WSN). A WSN prototype is designed in this research to supply real time environmental and context related data and decision knowledge to emergency response applications specifically in the domain of civil defense. Its integration in the HIDSS is essential for the interactive support of all the decision making process phases, and will contribute to enhance the quality and the scope of automated individual and group decision making in emergency preparedness and response applications. This automation is based on the concept of Just In Time Knowledge Management (JITKM) enabled by the use of WSNs.*

*The conceptual framework is firstly presented after a brief definition of the problem and design requirements focusing on both organizational and technical perspectives, in the context of inter-organizational activities performed in a complex and dynamic management environment. Then the solution developed for the design and configuration of the WSN is succinctly described. It consists of eliciting the sensing requirements translated into the homogenous sensor node specifications, localizing these sensor nodes using a pre-planning process and configuring them prior to their deployment. The configuration characteristics of the homogenous and heterogeneous sensor nodes are presented in terms of policy settings for the definition of the WSN architecture. Results from the case study are finally presented to illustrate the implementation of the solution in emergency preparedness for fire detection.*

**Keywords:** Hybrid Intelligent Decision Support System, Knowledge-based Collaborative Decision Support, Wireless Sensor Networks, Service Composition and Orchestration, Multi-agent Systems

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## 1. Introduction

Emergency preparedness and response decision making is an essential aspect of emergency management. The decisions may involve difficult steps of ad hoc decision-making tasks performed in isolation or cooperation by individuals or groups of people. Every individual or group might have different perceptions of the problem to provide plausible and feasible solutions [1].

The difficulty in performing these tasks in ad-hoc situations can be accentuated by the varied nature of the emergency typology mainly when its complexity is characterized by the extent of the disaster. The disaster context has several aspects that include the hazard, the scope, the site, and the prevailing conditions. The emergency response can be one in a kind, making even harder its planning and execution.

The fast growing WSN technology has imposed new challenges on network design, such as to improve the connectivity and optimal message routing to integrate heterogonous devices. This integration must enhance the performance of the overall efficient decision support, and the overall system must be flexible enough to adapt to changes rapidly. This step takes the existing networks towards the generalization of fully automated true web-based networks [2, 3], supported by a variety of different types of support systems intelligence and knowledge oriented.

These Support systems integrating various intelligent computing techniques based on advanced intelligent computing theories, have been widely developed for many different application domains to solve intractable problems involving complex modeling, optimization and genetic programming. These techniques include AI technologies such as fuzzy logic, rule induction, neural networks, genetic algorithms, case-base reasoning, hybrid artificial intelligent systems, data-mining algorithms, intelligent agents, expert systems [4]. Contemporary intelligent computing techniques introduced the concept of agent and web-service composition to enhance the generation of intelligent agents advocated to bridge the computational intelligence, knowledge discovery in database, decision support and intelligent computing technologies in the support perspective of JITKM [5].

This paper is organized as follows: next section briefly discusses the problems faced in the design of a WSN based HIDSS with a particular emphasize on the key issues of the problem domain. Related works are presented in section II, and the conceptual framework is described in Section III after the examination of the framework requirements and the strategy. Section IV details a case study based on a multi- room building. Lastly, the conclusion of this work is presented in section V.

## 2. The Problem

Disaster management, which involves a huge number of heterogeneous agents in a hostile environment, is supported by emergency response systems depending upon time critical and detailed information to make real time decisions. Such systems are:

- Configured as optimal hybrid intelligent decision support systems to make correct and quick decisions at all the disaster stages

- Supported by WSN's to provide efficient, low power and fast communication mechanism to collate critical decision data and transfer it to update the core knowledge of the HIDSS.

The design of such systems requires taking into account the following constraints:

1. The fast communication of the critical data from the WSN to the central control system depends upon many but importantly on two factors: available bandwidth and network traffic. The network traffic load is minimized using data control and processing at the active sensor node level. The main research question is to how much local processing shall be performed as not to overburden the limited capabilities of the WSN nodes.

2. The synchronization of decision making data generated from different wireless network sources in a multi-agent system and the adaptation of its agents is a complex decision task aimed at generating some meaningful results in the context of knowledge discovery. This knowledge is essential to support multiple policy making processes to elaborate strategic decisions. The decision making process knowledge support is essential in the design of HIDSS to automatically support the network sensors intelligence elaboration needed to adapt their behaviour dynamically to appropriately react to the changes identified in the context environment.

3. A federation of autonomous intelligent agents assures the dynamics of the WSN. These agents use sensing and elaborated data made available from the network and the corporate database to identify new changes occurring in both the network and the environment controlled by the multi-agent distributed system.

4. Agents interaction in multi-agent systems reflecting the changes for dynamic agent environment requires negotiation

mechanisms to support the incorporation of causal relationships between structured negotiation terms (SNT) and unstructured negotiation terms (UNT) in the process of agent negotiation and conflict resolution. SNT and UNT are a concept used in this research framework to represent the influence of variables on other variables, all characterised by an influence direction and magnitude. The mutual impact of intelligent agents characterised by plausible causal relationships when established between SNT and UNT, induces knowledge and inference rules that can be represented in a cognitive map [6] using intelligent agents to support the automatic negotiation mechanism between agents.

5. The HIDSS supports complex integrated decision tasks aimed at adapting decisions to changes in the decision making environment. These changes are based on the decision making knowledge gained in real time from the domain data. They are the results of decision making composed processes called composed decision services which integrate intelligent agents and inducing fuzzy relationships to provide explanations of the reasoning processes. A natural language is therefore needed at the external level to interpret the decision making models represented by internal or logical decision making composed services to make the system accessible to decision makers, enabling them to change any existing knowledge and to add new knowledge.

The above mentioned design constrains are derived from the characteristics of the direct and indirect interactive support needs to group and individual decision making styles, partly or fully automated. These characteristics are broadly common to a wide variety of decision making problem domains constitute the theoretical basis from which the architectural forms support mechanisms are constructed. The adaptive and flexible design and development strategies used to smoothly integrate technical and organisational aspects are supported by the conduct of several evaluation approaches.

## 3. Related Work

The fast growing number of virtual enterprises has a substantial impact on emerging applications of the new paradigm of HIDSS. These applications resulted from studies based on using different technologies to develop capabilities that enable organisations to adapt to a new rapid changing heterogeneous environment characterised by multi-level inter-organizational interdependencies.

Related work includes several studies and projects based on different conceptual frameworks and system architectures integrating new analytical web-based applications. These studies have been carried out specifically in the domain of HIDSS applied to complex systems [7] and in various domain applications such as medical diagnostic [8], water resource management [9], business and marketing strategy [10,11], aviation weather forecasting [12], and natural disaster management [13].

Projects focusing more specifically on WSNs design and communication issues include:

- The Harvard MoteLab project, a web-enabled sensor network Testbed [14],
- The SLAM project, describing a network architecture integrating a huge number of sensor actuators and distributed software applications for rapid disaster response, scalable crime detection and prevention and asset monitoring and navigation [15],
- The TriSentinel project, aimed at designing the first emergency responder wireless communication system (FRCS) that supports inter-agency and intra-agency collaboration in emergency response between police, fire, emergency medical services and other civil defence emergencies [16].
- The RoboCup Rescue Agents Simulation project aimed at providing a research platform for developing and testing strategies and comprehensive simulation systems for emergency search and rescue in disaster management [17].

## 4. Conceptual Framework

The main focus in the proposed conceptual multi-agent framework is the design specifications of HIDSS characterized by the shift from providing the traditional support based on analytical tools and techniques to produce and evaluate the best decisions options, to an intelligent gateway for the comprehensive and adaptive support of specific knowledge needs [18]. This support is essential to build descriptive and predictive models needed to perform interactively the aggregation of previous information and elaborated knowledge to form the domain knowledge. The consistence of the domain knowledge, which is composed of factual knowledge and expert knowledge, is a key requirement for the improvement of policy making processes generating the strategic decision for the WSN configuration.

The domain knowledge supports the HIDSS capabilities, mainly the predicting capability which consists of a reasoning based on a classification [19] requiring environmental data. The prediction capabilities are built upon the use of a set of situations or observations to interpret the occurrence of an event within a class spectrum. An example of such capabilities is the decision refinement performed to reduce the decision uncertainty between the occurrence of fire conditions indicated by sensing data ranging beyond the threshold values or mal-functioning sensing network devices in the domain of fire prevention and detection.

Evolutionary development in monitoring and data acquisition in environmental domain applications, has imposed the definition of smart environments based on the use of wireless data collection and distribution networks. Distributed real time systems are using wireless technologies for the support of varied indoor monitoring and control applications in buildings, homes and shipboards. A hybrid WSN supported by an HIDSS system for its configuration and management has been proposed in this work to illustrate the main concepts examined in this research. The main design requirements for the design of the system as integrated in the conceptual multi-agent framework are below presented.

### 4.1 Requirements

The main design requirements are:

1. The tasks distribution in the multi-distributed system environment; this distribution needs to clearly separate the capture of environmental and context aware data and then its communication at the network level and then finally turning this into knowledge and decision data by the support system using the inference mechanisms of the HIDSS in the context of JITKM .

2. The optimal use of WSNs and the improvement of its performance over time is to be considered upon addressing the major issues mentioned in the research conceptual model, mainly:

- The distinctive use and importance between heterogeneous and homogeneous devices used in combination to enhance the decisions refinement in terms of analyzing and interpreting the sensing data outcomes by invoking intelligent agents to perform inherent decision making processes to identify the best strategy and derive the appropriate actions to be taken in the context of the multi-agent system service composition.
- The importance of local data processing at the node level and its impact on the WSN performance in terms of network congestion avoidance and processing delay reduction, and co-operation with the distributed client/server architecture for the sensor nodes deployment, configuration and management, and messages processing.
- The balance between sensors and sensor nodes duplication within the WSN and their switching off when appropriate in the case of multiple sensing, to ensure a high reliability and performance of the network by:
    - Duplicating sensible sensors in strategic sensor nodes,
    - Adding additional sensor nodes or reduce the sensing spacing distance while localizing the sensor nodes
    - Using active sensor nodes to locally process the sensing data using mobile agents rather than bringing them to the central processor [20], and
    - Reducing the number of redundant sensor devices and messages.
- The improvement of the message routing mechanism, addressing the key problems of:
    - Energy consumption and residual energy in sensor nodes
    - Routing path, and
    - Link quality requiring a thorough instantaneous monitoring of WSN.
- The auto adaptation of the WSN to external events from the environment requires monitoring and measurement of criteria inherent to its deployment, configuration, reconfiguration, communications improve its performance.

3. The composition requirements of services of both context applications and WSN to determine the specifications of composed services to support:

    - The network configuration and control,
    - The facilitation of the emergency response and
    - The planning of emergency actions using intelligent software agents and mobile devices.

4. The implementation issues of system prototypes aimed at integrating several technologies controlled by composed agents and services using a hybrid approach.

### 4.2 The Strategy

The focus in this study is not on the point-to-point and multi-drop networks, but on the web network topology. This architecture assumes that all the intelligent sensor nodes are always wirelessly connected, and cooperate with the aid of intelligent agents to reduce the computing load on the host. This cooperation results in additional network capabilities distributed between the host and the WSN, and for the WSN between the gateway and the sensor node to enable self-hosting networks including self-configuration.

The strategy adopted in this conceptual framework is to clearly dissociate the network from the client functions to enable a functional separation of the technical system services from the business services; with a view of implementing an adaptable and flexible service and agent composition to integrate the different business processes and intelligent agents.

### 4.3 The conceptual framework

The definition of the conceptual framework is in the context of smart environments supported by a distributed multi-agent system. This environment relates to the distributed smart devices, which takes up sensory data from the real world locations. The integrated sensors of different functionalities are remotely controlled at diverse locations to acquire data and turn it into knowledge. These sensors when switched on, performs data acquisition, while distribution of this data over the networks is monitored and controlled by a management center supported by an HIDSS, which then forward this data to a smart control room (explained in next section). These networks vary in their architecture depending on their complexity that is based upon factors such as the specificity of the sensing, processing and decision making tasks, and the technology used in design the networks.

These decision-making tasks are based on a smooth integration of non-intuitive analytical solutions to counter the different problem aspects of emergency preparedness and response. These analytical solutions are advocated in this conceptual framework to meet the objectives listed below.

#### 4.3.1 Objectives

- Support the centralized situation model of the emergency response in all its aspects and phases,
- Improve the computer supported cooperative work in the emergency response control room,
- Enhance the emergency response facilitation process,
- Enhance the quality of the group decision making in team based operations, and
- Enhance situational awareness for:
    - Improved emergency response tactical and operational efficiency,
    - Emergency services safety and emergency response reliability.

#### 4.3.2 Organisational entities

The main entities characterising the organisation level of the conceptual framework are:

##### 4.3.2.1 The site under surveillance

The Site described below is used in the Case Study mentioned in the next section. This site is a hierarchical structure of a number of rooms grouped to form a building.

- Each room is made up of partitions, separated by walls; these partitions have different construction patterns (wall partition, door and window) and characteristics (single, double, and glass).
- The Energy supply use points for gas and electricity are indicated where existing.Walls and wall partitions are identified, such as to associate characteristics information to them, to enable the calculation of the hazard level. This can be derived from the construction characteristics of the building, in addition to its conditions of use. For e.g. a fire risk assesment module is used to assess the fire hazard and measures to emergency preparedness.

#### 4.3.2.2 The WSN

A small scale WSN is considered in this work, and involves a structured sensor node placement by hand using a priori planning. Multi-modal sensor nodes with sensors on board are used in this WSN. Structurally, this WSN is organised as a grouping of homogenous sensors nodes and heterogeneous devices wirelessly connected to a gateway via router nodes.

- **Homogenous sensor nodes:** Contain all the sensors needed for sensing the detection elements for fire prediction and detection such as temperature, smoke, light, gas, etc...
- **Heterogeneous devices:** Include the entire auxiliary intelligent and smart devices needed to support and enhance the activity of the homogenous sensor nodes; these devices include cameras, motion tracking, sprinklers, people counters and control devices for automatic instantaneous closure and opening of doors and windows.
- **Router node:** It is an active sensor node involved in routing network messages between gateway and group of sensor nodes. These nodes maintain a routing table and manage local address allocation.

Due to the devices differences, their integration in the WSN requires a high-level of data modularity and adaptability as described in the Multi-Agent System Architecture [21].

#### 4.3.2.3 Smart Control Room

Based on the use of a video wall and other display devices, the control room is connected to several computers with multithreading and GPU programming to provide intelligent context dependant user interface needed to:

- Display the site surveillance situation at any time and show the results of the risk assessment procedures,
- Conduct emergency response scenarios using situation modelling [22] in person detection and tracking, also fire prediction and detection to design plausible emergency evacuation procedures, and
- Support the cooperative work of the emergency response team and running of the emergency operations in their different aspects in parallel and real time.

#### 4.3.2.4 Computer Room

Locating several computers with multithreading programming for the storage of data and deployment of intelligent agents composed services. This will enable the automatic selection and reconfiguration of WSN clusters of buildings and emergency services.

#### 4.3.2.5 Emergency and rescue services

These are police, fire and rescue service, emergency medical services.

### 4.3.3 The functional model

The functional model proposed in this research and shown in Figure 1, is a conceptual framework, which aims at studying the context application sensing requirements and defining the specifications of WSNs.

A federation of intelligent autonomous agents deployed in a multi-agent system to support the activity structured in the context applications controls the deployment of these WSNs. In this paper, this activity concerns emergency preparedness and response. This activity consists of supporting the need for detecting temperature rises and fires, identifying, localizing and tracking human presence in public attended closed places such as buildings and improve the fire detection and mitigation decision-making process.

The activity of emergency preparedness and response is structured in a sequence of processes linked by conditions to be met to establish the triggering events that define the services orchestration rules, as described in the IDSS architecture shown in Figure 2.

### 4.3.4 The service composition model

The conditions C1, C2, C3 and C4 as shown above in Figure 2, and the internal conditions present in the different components of the IDSS. These conditions are the identification base of the events, which dynamically link them to the available services created by the intelligent agents deployed in the IDSS and connected through the WSNs.

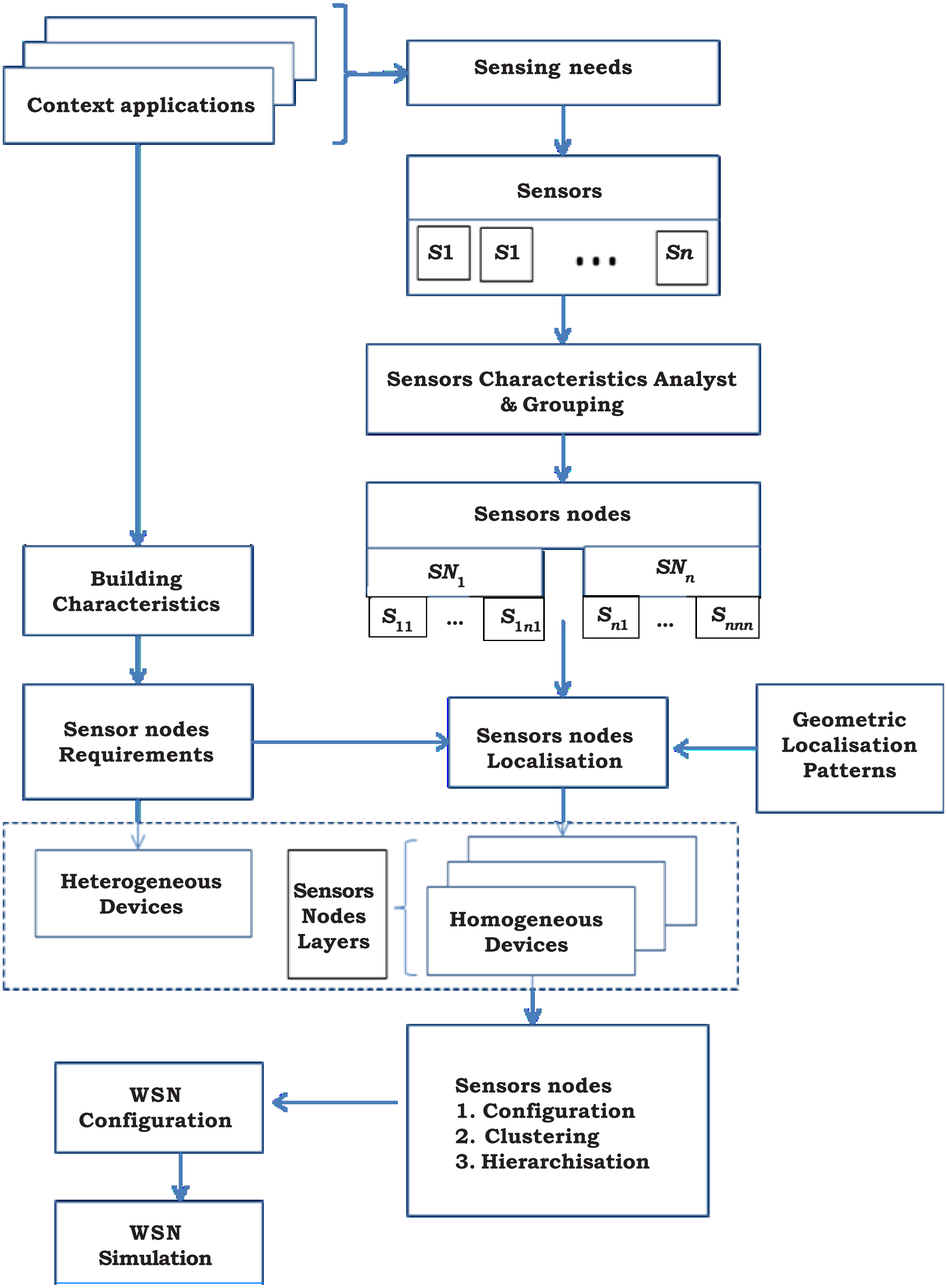


Figure 1. Emergency service functional model

For example, the condition C1 is based on the identification of factual links between the activities of emergency preparedness and surveillance establishing elaborated information of a nature to produce knowledge needed to formulate the knowledge rules contained in the various models composing the model base. This condition requires the use data mining intelligent agents during the service composition process.

The Available services for a given WSN or application domain are contained in a repository, while the composition rules are stored in the IDSS model base, whereas the whole composition scenario for this service is described in the IDSS knowledge base.

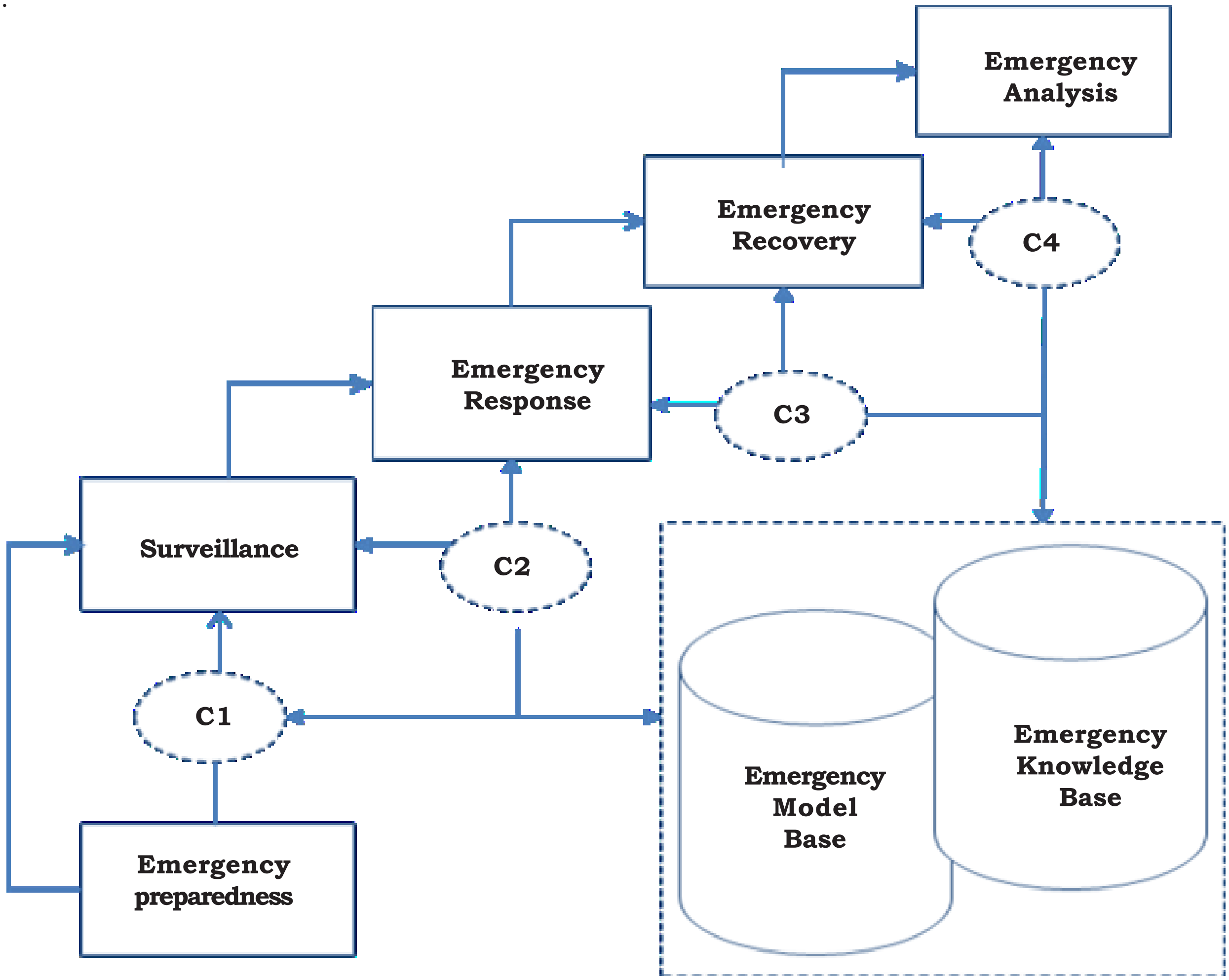


Figure 2. Intelligent decision support system architecture

## 5. The Case Study Implementation

### 5.1 The Case Study

The Case study presented in this section will illustrate the emergency preparedness and response system design as proposed in this work. A single building structure under a small WSN surveillance is modelled using the process shown in Figure 3.

In this process, the details of the building layout and construction are used to derive concurrently the evacuation and surveillance devices requirements. The evacuation requirements are the basis for the study of the evacuation scenarios, whereas the surveillance devices requirements are needed to design the appropriate sensor nodes by selecting available sensors and their specifications. These nodes, once automatically localised, will be configured, clustered and linked to compose the WSN homogeneous nodes. The WSN similarly connects the heterogeneous devices which are also automatically allocated. The WSN homogeneous and heterogeneous sensor nodes are shown in Figure 5.

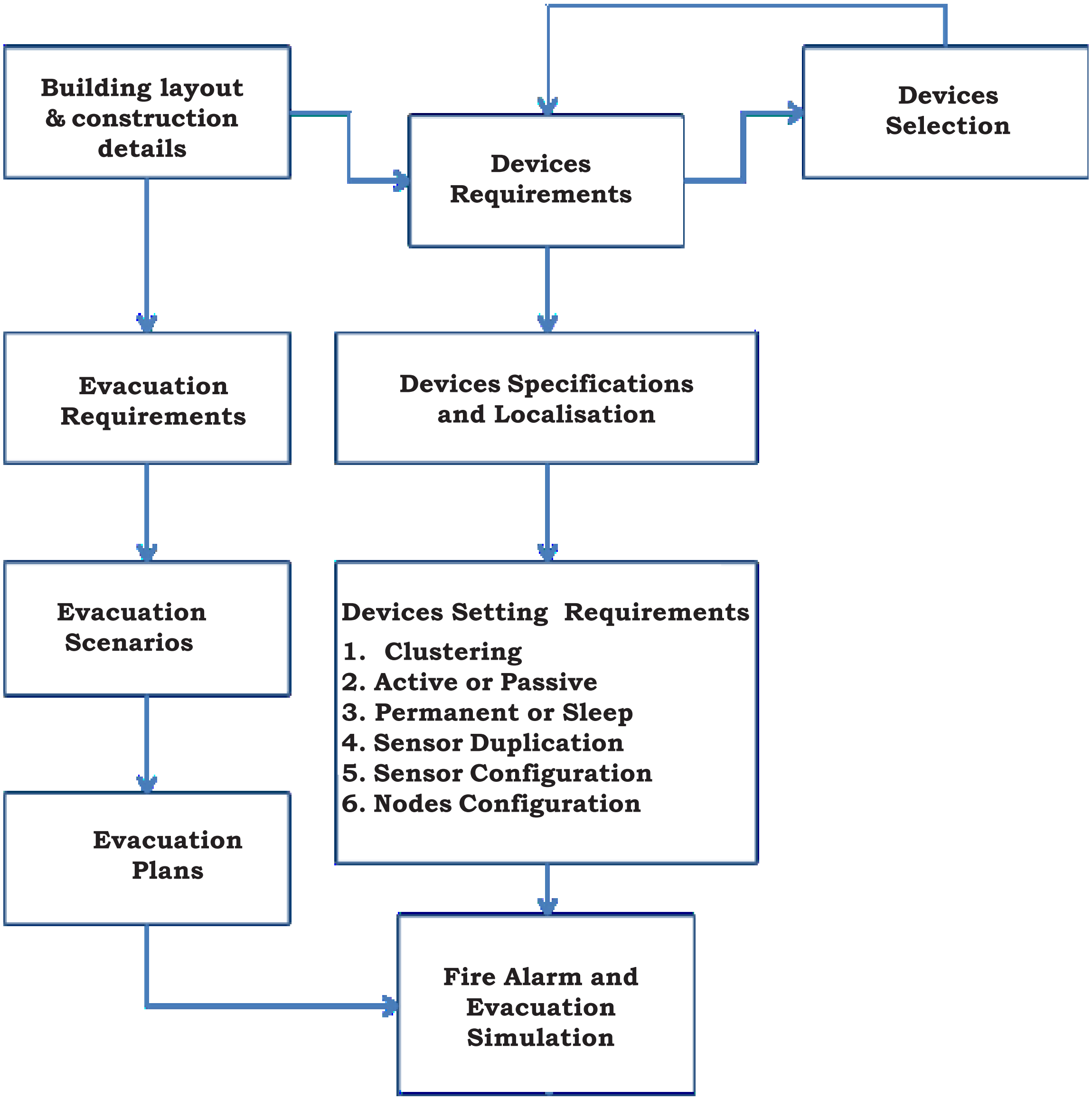


Figure 3. Emergency preparedness process

## 5.2 Implementation

### 5.2.1 Building modelling

The creation of the building layout is a requirement for the localization of heterogeneous devices and homogenous sensor nodes. The layout is generated from a building wall segments drawing as shown in Figure 4, drawn using the direction encoding system.

### 5.2.2 Nodes localization

**a) Nodes localisation model**

Rules of thumb are used to localize the heterogeneous devices (centre of the ceiling and proximity to doors and windows), whereas the central place theory algorithm is used to localize the homogeneous sensor nodes. The nodes localization model is shown in Figure 5.

In this case study, two modes of node localizations Hexagonal (Figures 6A) and square geometric (Figures 6B), have been implemented using different node location distribution patterns (NLDP).

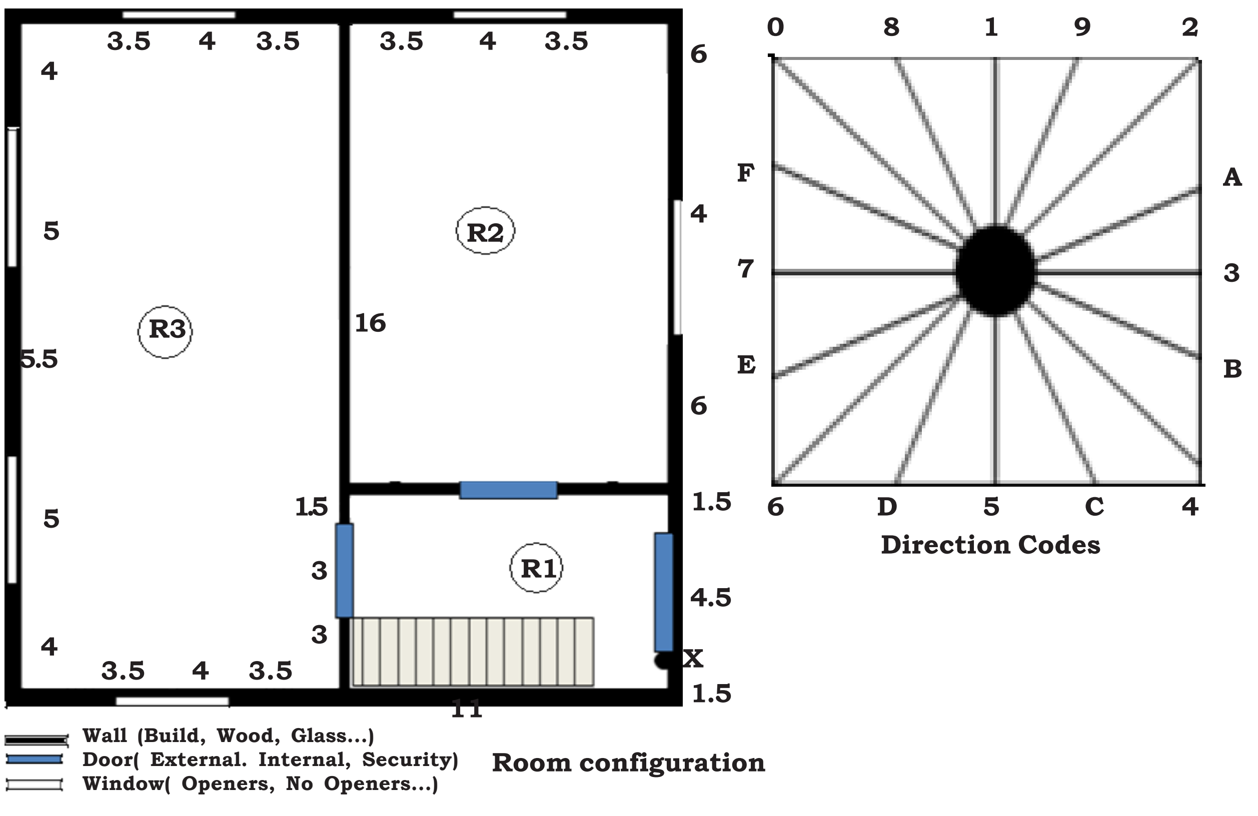


Figure 4. Building wall segments drawing & Encoding system

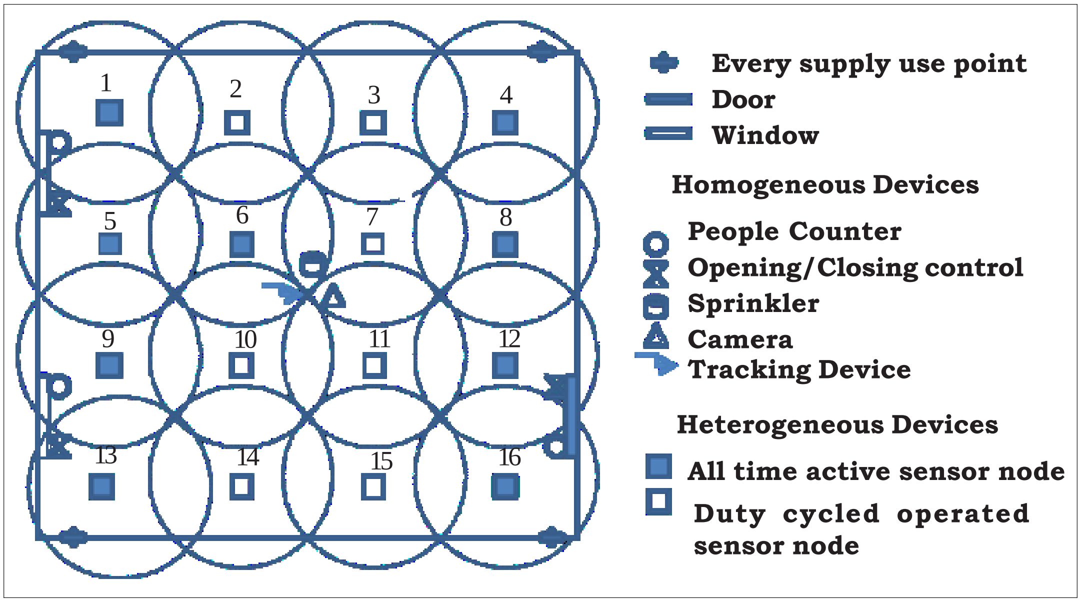


Figure 5. Nodes localisation model

### 5.2.2 Sensor nodes and devices localization example

Using a sensor sensing distance of 3m, the following sensor nodes and devices location is automatically generated as shown in Figure 7a and 7b.

The geometrical location distribution pattern is considered in this framework as the basis for the sensor nodes localization. The

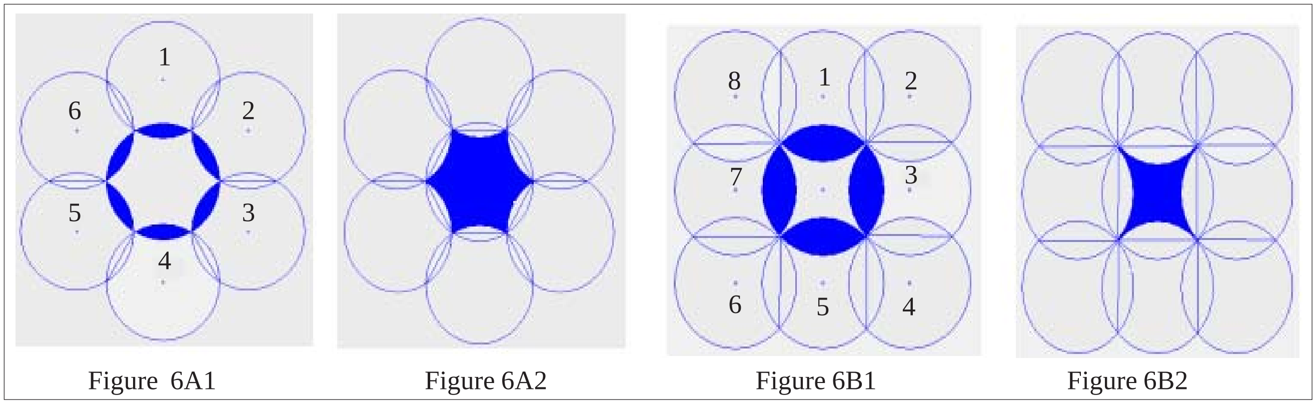
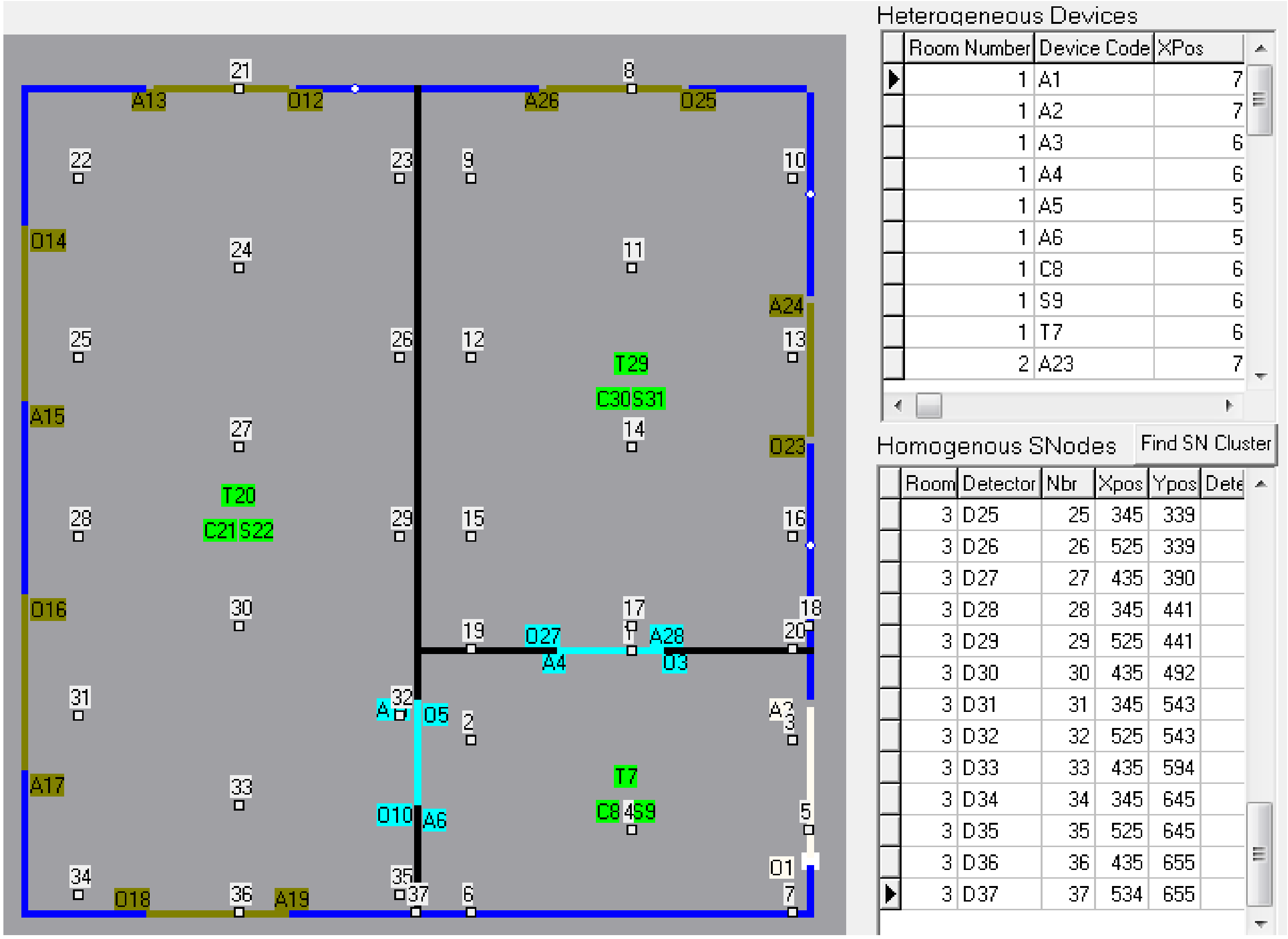


Figure 6A1 Figure 6A2 Figure 6B1 Figure 6B2

Figure 6. Geometric location distribution pattern



Heterogeneous Devices

| Room Number | Device Code | XPos |
|---|---|---|
| 1 | A1 | 7 |
| 1 | A2 | 7 |
| 1 | A3 | 6 |
| 1 | A4 | 6 |
| 1 | A5 | 5 |
| 1 | A6 | 5 |
| 1 | C8 | 6 |
| 1 | S9 | 6 |
| 1 | T7 | 6 |
| 2 | A23 | 7 |

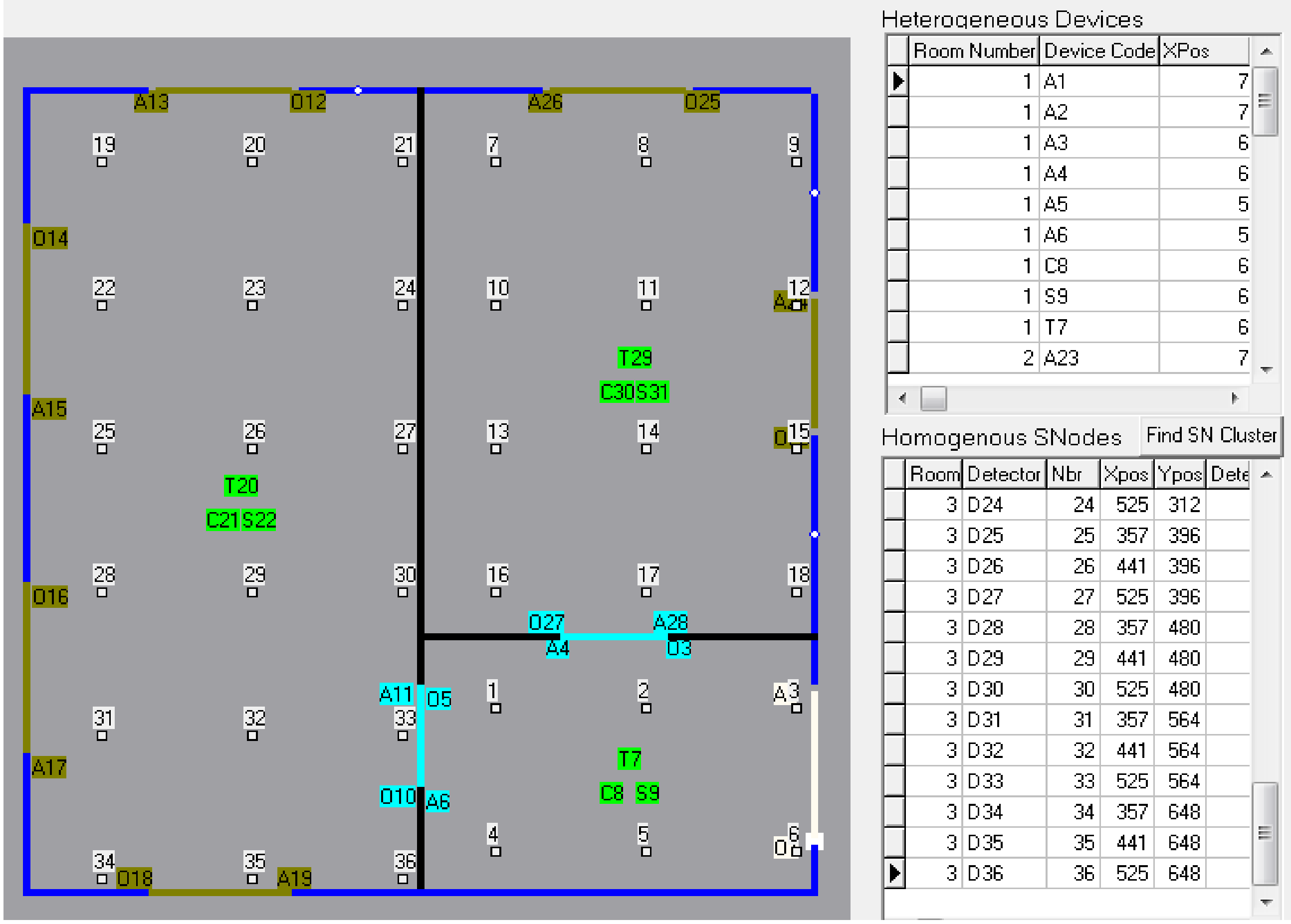
Homogenous SNodes

| Room | Detector | Nbr | Xpos | Ypos | Dete |
|---|---|---|---|---|---|
| 3 | D25 | 25 | 345 | 339 | |
| 3 | D26 | 26 | 525 | 339 | |
| 3 | D27 | 27 | 435 | 390 | |
| 3 | D28 | 28 | 345 | 441 | |
| 3 | D29 | 29 | 525 | 441 | |
| 3 | D30 | 30 | 435 | 492 | |
| 3 | D31 | 31 | 345 | 543 | |
| 3 | D32 | 32 | 525 | 543 | |
| 3 | D33 | 33 | 435 | 594 | |
| 3 | D34 | 34 | 345 | 645 | |
| 3 | D35 | 35 | 525 | 645 | |
| 3 | D36 | 36 | 435 | 655 | |
| 3 | D37 | 37 | 534 | 655 | |

Figure 7a. Hexagonal geometric location distribution pattern

consideration of both patterns hexagonal and square with different settings (localization per room or building, spacing distances, different clusters, …) procures an extensive support for a multi-criteria sensor nodes localization decision making approach.

The increase of the number of sensor nodes when the spacing distance is reduced poses the problem of how optimal can the grouping of sensors in the sensor node be organized. Table 1 shows for example, for the building layout shown in Figure 4, those 7 extra nodes (23.33%) will be required, when 3 m spacing is used instead of 4 m for the Hexagon pattern.



Heterogeneous Devices

| Room Number | Device Code | XPos |
|---|---|---|
| 1 | A1 | 7 |
| 1 | A2 | 7 |
| 1 | A3 | 6 |
| 1 | A4 | 6 |
| 1 | A5 | 5 |
| 1 | A6 | 5 |
| 1 | C8 | 6 |
| 1 | S9 | 6 |
| 1 | T7 | 6 |
| 2 | A23 | 7 |

Homogenous SNodes

| Room | Detector | Nbr | Xpos | Ypos | Dete |
|---|---|---|---|---|---|
| 3 | D24 | 24 | 525 | 312 | |
| 3 | D25 | 25 | 357 | 396 | |
| 3 | D26 | 26 | 441 | 396 | |
| 3 | D27 | 27 | 525 | 396 | |
| 3 | D28 | 28 | 357 | 480 | |
| 3 | D29 | 29 | 441 | 480 | |
| 3 | D30 | 30 | 525 | 480 | |
| 3 | D31 | 31 | 357 | 564 | |
| 3 | D32 | 32 | 441 | 564 | |
| 3 | D33 | 33 | 525 | 564 | |
| 3 | D34 | 34 | 357 | 648 | |
| 3 | D35 | 35 | 441 | 648 | |
| 3 | D36 | 36 | 525 | 648 | |

Figure 7b. Square geometric location distribution pattern

| **NLDP** | **Hexagon** | | | **Square** | | |
|---|---|---|---|---|---|---|
| **Sp dist (m)** | 3 | 4 | 5 | 3 | 4 | 5 |
| **Number of Sensor nodes** | 37 | 30 | 18 | 36 | 20 | 18 |
| **Difference** | 7 | 12 | -- | 16 | 2 | -- |
| **Ratio** | 23.33 | 66.67 | -- | 80.00 | 11.11 | -- |

Table 1. Relation between spacing distance and number of sensor nodes

It is thus of interest to consider the segmentation of the spacing distance range to enable the grouping of the sensors to characterise the sensor nodes. Each segment of this range will correspond to a layer of sensor nodes as illustrated in Figure 8 where 3 and 6 m are just examples of segments threshold, which can be elaborated when considering the variety of sensors required for use in the domain of the context applications.

### 5.3 Sensing overlapping

The concept of single and double sensing zone for homogenous sensor nodes is used to evaluate the sensing overlapping shown shaded in Figures 6 and in Table 2.

- The double sensing zone (Dsz) is calculated using the following formula:

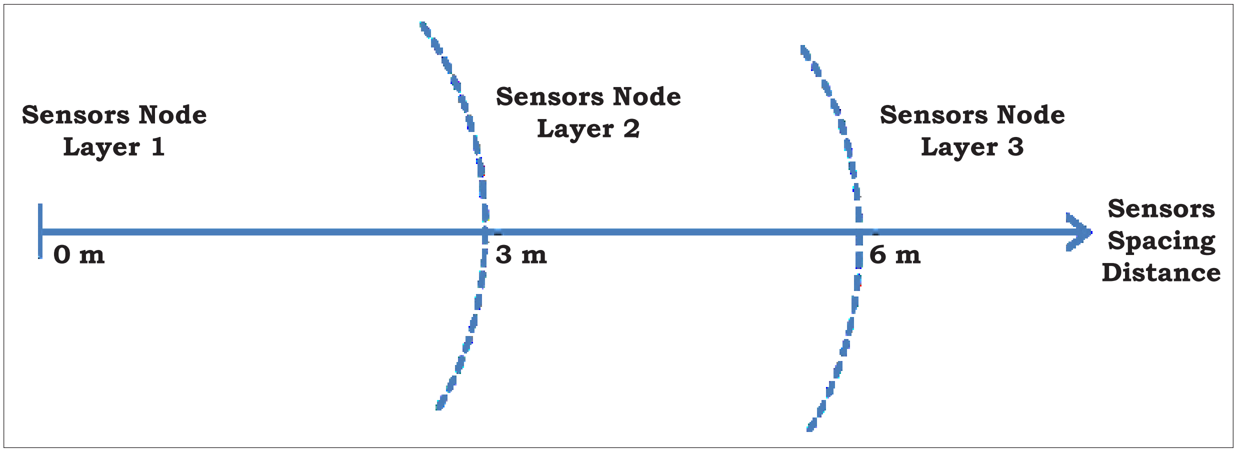


Figure 8. Senor node and sensor status setting

Hexagon NLDP: $Dsz = 2\,(\pi r^2 - \frac{3r^2\sqrt{3}}{2})$ (1)

Square NLDP: $Dsz = 2\,(\pi r^2 - 2r^2)$ (2)

- The single sensing zone (Ssz) is calculated using the following formula:

Hexagon NLDP: $Ssz = \pi r^2 - 2\,(\pi r^2 - \frac{3r^2\sqrt{3}}{2})$ (3)

Square NLDP: $\mathrm{Ssz} = \pi r^2 - 2\,(\pi r^2 - 2r^2)$ (4)

(‘$r$’ indicates the sensor sensing distance)

SN/B sensor nodes allocated ignoring the existence of wall between the building rooms; SN/R takes into account the walls.

Relevant information can be extracted from Table 2: the ratio (Double/Single) sensing zone is 2.65 times more important when using the Square geometric and only 0.52 time more important when using the Hexagon geometric sensor node allocation pattern. This suggests the preference for the square model, which results in sensing overlap simultaneously between two operating sensor nodes. This sensing overlapping could result in some activity redundancy (example of alarm stripping) which if detected can be processed at the node level should one at least of the sensor nodes involved is active.

### 5.4 Sensor nodes status

#### 5.4.1 All time active versus Duty cycled sensor nodes

All time active sensors nodes are those localised, either at the centre of a cluster of sensor nodes or nearest to the energy supply use points, doors and windows, whereas duty cycled manner sensors nodes concern the remaining ones.

#### 5.4.2 Active versus passive sensor nodes

Active sensors nodes are those localised at the centre of a cluster of sensor nodes with additional functionality to perform the network functions at the sensor node and also data processing and storage.

#### 5.4.3 Active versus Inactive sensor

Indicates the sensor configuration status of the sensor nodes as described by the process model in Figure 9.

### 5.5 Sensor nodes clustering

Sensor nodes clusters (SNC) are required to connect sensor nodes to router nodes and to distribute the network functions for sensor deployment, configuration, activation and data processing. A SNC is a group of sensor nodes surrounding a central sensor node. The process of definition of these SNCs is based on searching all plausible clusters, ranking them on the descending order of their population, and browsing the building layout from the left to the right, and from the top to the bottom

| **NLDP** | **Hexagon** | | | **Square** | | |
|---|---|---|---|---|---|---|
| **Sp Dist** | 3 | 4 | 5 | 3 | 4 | 5 |
| **S N/R** | 37 | 30 | 18 | 36 | 20 | 18 |
| **S N/B** | 33 | 17 | 14 | 36 | 20 | 16 |
| **Sensing Area** | 28.26 | 50.24 | 78.5 | 28.26 | 50.24 | 78.5 |
| **Double Sensing** | 9.76 | 17.34 | 27.09 | 20.52 | 36.48 | 57.00 |
| **Single sensing** | 18.5 | 32.89 | 51.40 | 7.74 | 13.76 | 21.50 |
| **Ratio Double/S** | 52.71 | 52.71 | 52.71 | 265.1 | 265.11 | 265.11 |
| **Ratio SSz** | 34.52 | 34.52 | 34.52 | 72.61 | 72.61 | 72.61 |
| **Ratio Ssz** | 65.48 | 65.48 | 65.48 | 27.39 | 27.39 | 27.39 |

SN/B sensor nodes allocated ignoring the existence of wall between the building rooms; SN/R takes into account the walls.

Table 2. Double and single coverage ratios

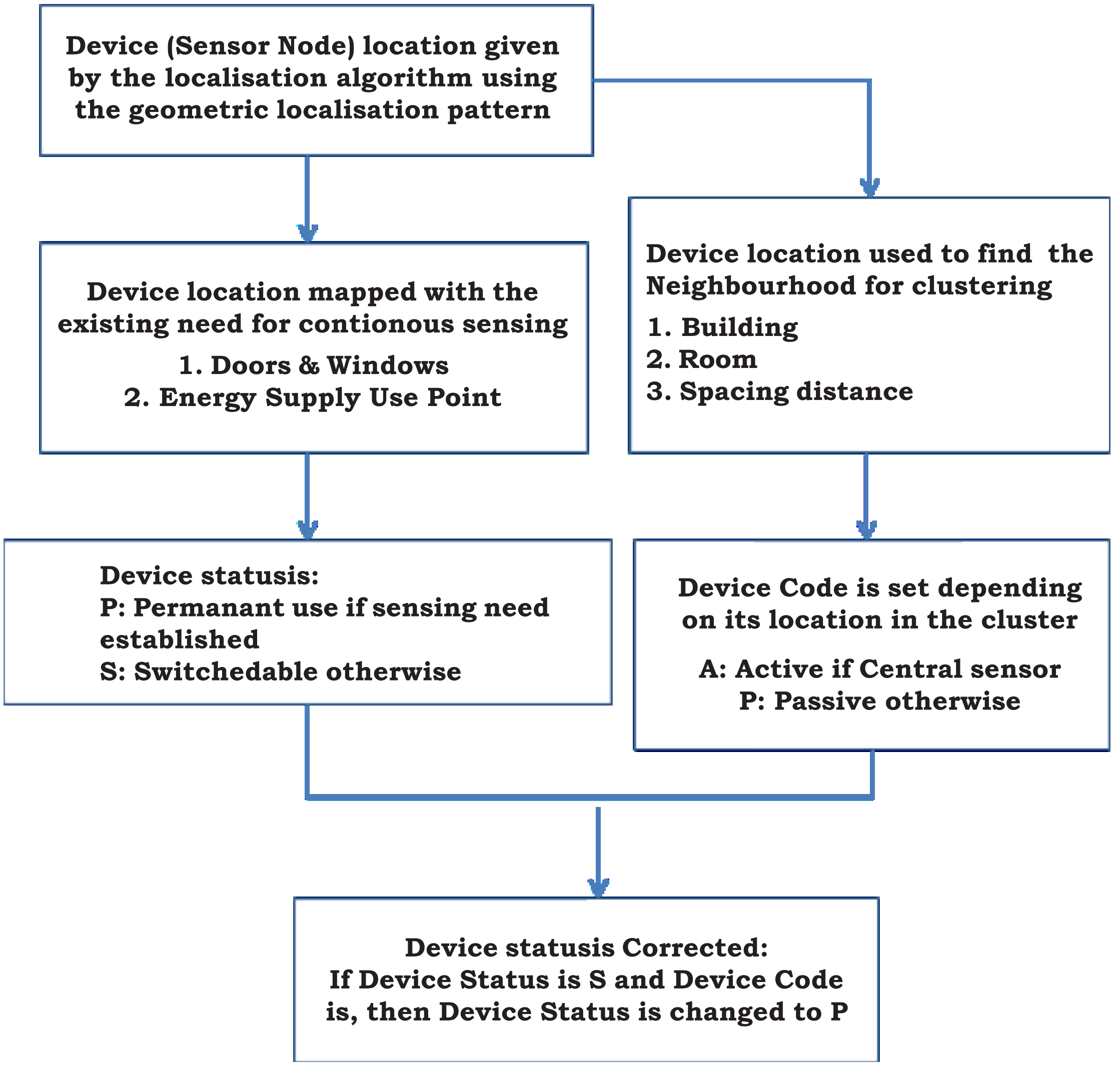


Figure 9. Senor node and sensor status setting

to select the SNCs ideal candidates using the Cartesian coordinates of the central sensor node location of the cluster. All the sensor nodes forming the selected SNC are removed from the remaining SNCs waiting to be selected. A process of cluster

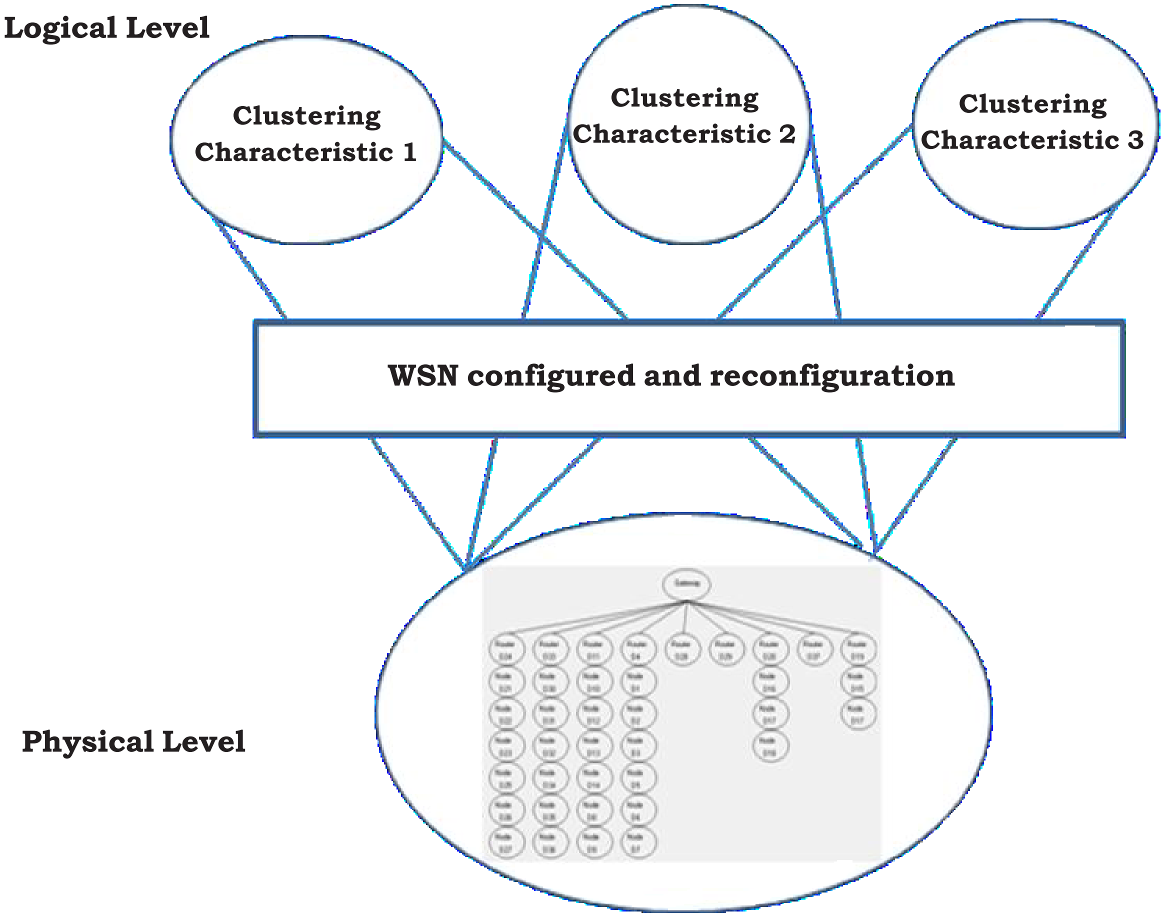


Figure 10. Automatically generated sensor node clusters

aggregation is proposed to add the selected less populated SNCs to the most populated SNCs of their proximity.

A SNC is required to have a sensor node cluster head (snCH) that must be supplemented by a sensor node cluster head substitute (snCHS) in case of the snCH malfunctioning.

The structural uniformity of the network can be extended to integrate:

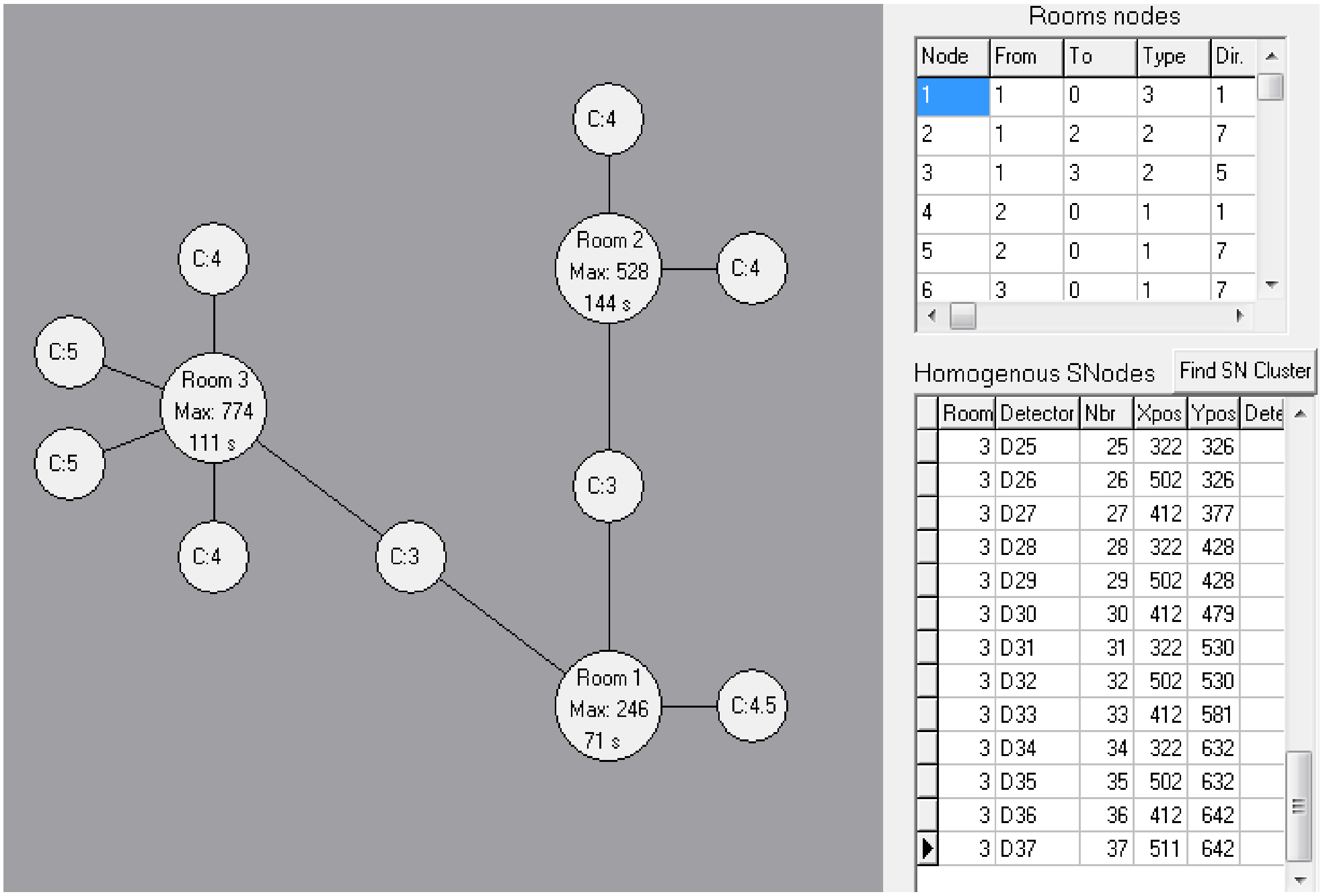
1. The network needs to preserve energy by assigning, taking into account the sensing requirements at each sensor node location, the sleeping mode to sensor nodes enabling them to switch between active and sleep modes depending on the network activity to conserve energy [23].

2. The gulf existing between sensing spacing distances (SSD) of sensors that are needed at the same sensing location, which might result in grouping sensors of the same SSD in different types of sensor nodes.

3. The prevailing conditions while using the network and the probable detected events require migration, which might suggest the network reconfiguration.

These three structural characteristics can be modeled around the concept of virtual cluster defined at a logical level whereas the initial clustering made of the aggregated SNCs corresponds to the physical level, which is associated to one, or several logical levels, as illustrated in Figure 10. Examples of cluster logical levels are:

1. All the sensor nodes involved in an emergency response configured as one sensor node cluster with more reliable connection specifications (active connection, high performance routers, high band signal) whereas the other sensor nodes of the WSN will



Rooms nodes

| Node | From | To | Type | Dir. |
|---|---|---|---|---|
| 1 | 1 | 0 | 3 | 1 |
| 2 | 1 | 2 | 2 | 7 |
| 3 | 1 | 3 | 2 | 5 |
| 4 | 2 | 0 | 1 | 1 |
| 5 | 2 | 0 | 1 | 7 |
| 6 | 3 | 0 | 1 | 7 |

Homogenous SNodes

| Room | Detector | Nbr | Xpos | Ypos | Dete |
|---|---|---|---|---|---|
| 3 | D25 | 25 | 322 | 326 | |
| 3 | D26 | 26 | 502 | 326 | |
| 3 | D27 | 27 | 412 | 377 | |
| 3 | D28 | 28 | 322 | 428 | |
| 3 | D29 | 29 | 502 | 428 | |
| 3 | D30 | 30 | 412 | 479 | |
| 3 | D31 | 31 | 322 | 530 | |
| 3 | D32 | 32 | 502 | 530 | |
| 3 | D33 | 33 | 412 | 581 | |
| 3 | D34 | 34 | 322 | 632 | |
| 3 | D35 | 35 | 502 | 632 | |
| 3 | D36 | 36 | 412 | 642 | |
| 3 | D37 | 37 | 511 | 642 | |

Figure 11. Example of evacuation decision model

be configured separately in other clusters.

2. All the non switchable sensor nodes are configured as one sensor node cluster whereas the other sensor nodes of the WSN will be configured separately in other clusters.

### 5.6 Evacuation flows

Evacuation planning is an essential function of emergency preparedness. The presence of people attending a building requires continuous monitoring and tracking, this will enable the IDSS to elaborate the key data needed to check the safe use of the building in terms of real occupancy, and the evacuation feasibility given the existence of emergency exits and their dimensions. An example of evacuation decision model displaying the real room ccupancy and standard evacuation times is shown in Figure 11.

### 5.7 Messages management system support

The message management system focuses on two key particular issues: message routing and message authentication. Their importance depends greatly on the complexity of the nature of the nature and the type of WSNs.

### 5.7.1 Message routing

Message routing is a very critical which begins with nodes localisation and neighbourhood discovery for the building up of the local neighbour tables, starting first by identifying the sensor nodes and their locations, their remaining energy, the quality of their link, and their routing delays. Then, messages are routed using a geographic forwarding algorithms that takes all into account the sensor nodes locations of the routing path. In this framework, the small adhoc WSN sensor nodes are localised using the planned method of the WSN deployment, and the main issues addressed in the design of the HIDSS are the message routing reliability, integration with wake/sleep schedule, mobility, real-time, security, voids and congestion [24].

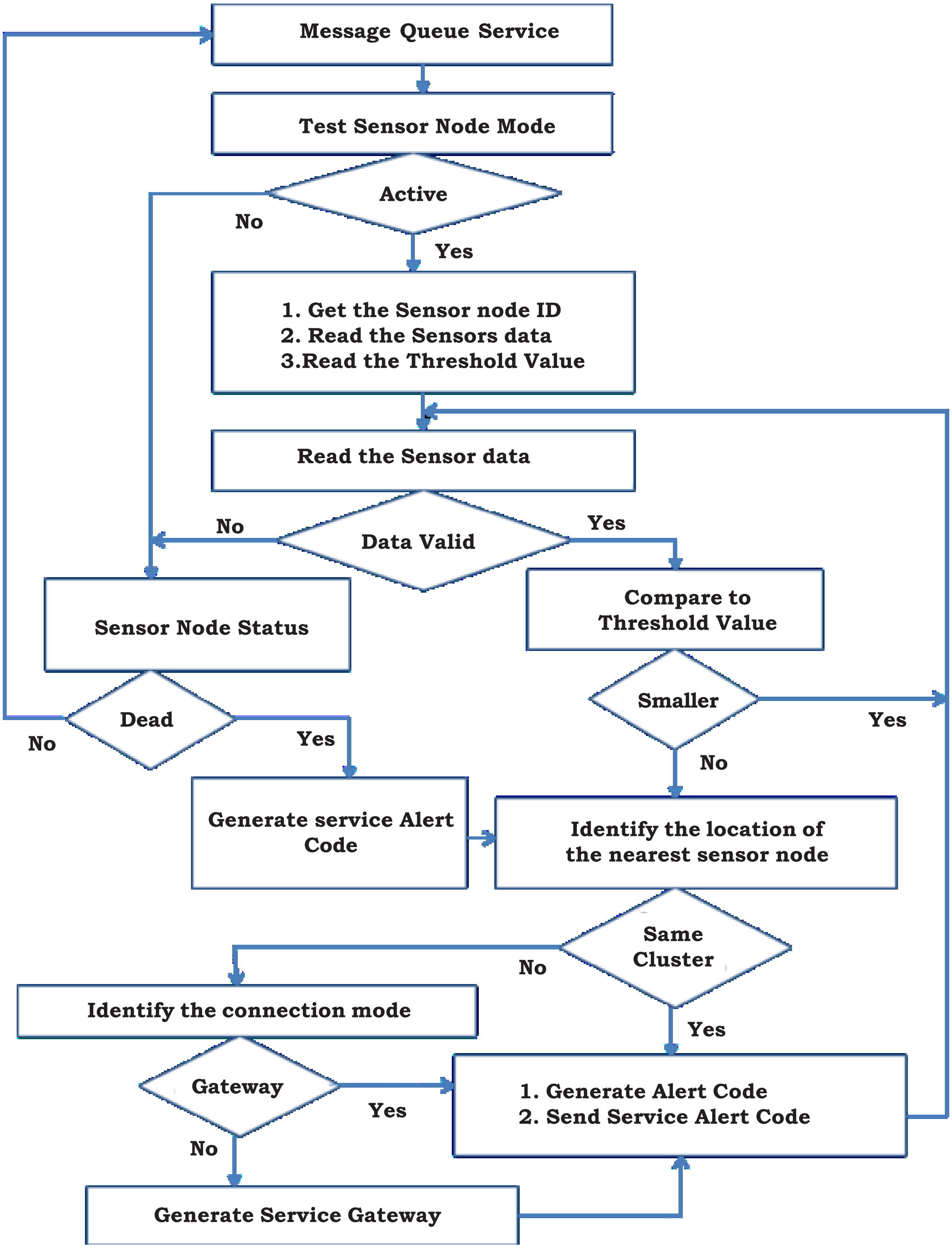


Figure 12. Message service structure

### 5.7.2 Message authentication

Message authentication is a key mandatory service in a message management system for a secure WSN to reduce message falsification and modification as well as node impersonation [25]. The WSN security is essential, and the prevention of malicious agents injecting messages to the network without being detected must be supported by the WSN management of the HIDSS using cryptographic techniques.

The WSN messages which are properly authenticated, are the result of the network activity consisting of:

o The sensor nodes deployment and node defeated replacement,

o The sensor node configuration and re-configuration,

o The collection of the Sensing data, and

o The network management, setting network and security parameters.

The message management system is supported by a message service composition of different intelligent agents, as illustrated in Figure 12.

The message management system can be specific to the WSN or integrated in the HIDSS.

## 6. Conclusions

The work presented in this paper is a contribution to the enhancement of the physical world or real-world interaction using distributed networks of integrated wireless and digital embedded sensor-based and control devices technology supported by an HIDSS. This contribution is also in the domain of integrating different computing techniques to support the service provision and composition that requires the development of intelligent agents including both intelligent devices and software agents. These intelligent agents are the vectors of the knowledge discovery and computational intelligence required by adaptive and flexible decision models for the processing of context-aware data using the mutual benefits of the varied service access devices. The major benefit of this framework is the control of distributed small networks of activity surveillance in a fully automated setting required for the optimal use of emergency response resources.

The use of both physical and logical clustering levels procures a flexible and adaptable policy making support to various organizational scenarios for different types of emergency responses.

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