A conceptual framework for Small WSN Configuration using Intelligent Decision Support System

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Abstract— A novel intelligent decision support system (IDSS) based on policy settings is proposed in this paper. This work supports the design and configuration of small wireless sensor networks (WSN) used to supply real time environmental and context related data to emergency response applications specifically in the domain of civil defense.

This integrated system is advocated to enhance the quality and the scope of automated individual and group decision making in emergency preparedness and response applications.

The conceptual framework is firstly presented after a brief definition of the problem and requirements. 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.

Index Terms— intelligent decision support system, Wireless sensor networks, Service composition and orchestration, Multi-agent systems.

I. 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].

This paper is organized as follows, next section briefly discuss the problems faced in the design of a WSN based IDSS. Section III presents the conceptual framework and section IV details a case study based on a multi-room building. Lastly, the conclusion of this work is presented in section V.

II. THE PROBLEM

Emergency response systems depend upon time critical and detailed information to make in time decisions. Design of an optimal intelligent decision system will help to make correct and quick decisions in case of disasters. WSN's provide efficient, low power and fast communication mechanism to collate critical data and transfer it to the central control system of the IDSS. The design of such a WSN based IDSS have the following design 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. This is a complex task to synchronize data generated from different sources in a multi-agent system to generate some meaningful results. One of the aims of this work is to design an efficient IDSS to support the network sensors to adapt their behaviour dynamically to effectively 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.

III. Conceptual Framework

Evolutionary development in monitoring and data acquisition 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, including entities such as building, home and shipboards. One such WSN based central IDSS system has been proposed in this work and the main requirements and conceptual framework is presented in next few sections.

A. Requirements

The main conceptual framework 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 network level and then finally turning this into knowledge and decision data by the support system.

2. The optimization of WSN and addressing the issues mentioned in the research conceptual model, mainly:

- The distinctive use and importance between heterogeneous and homogeneous devices,
- The importance of local data processing at the node level, and its implication on the WSN performance; the performance improvement is in terms of network congestion avoidance and integration in the client/server architecture. Wherever possible, the data is processed at the local sensor nodes using mobile agents rather than bringing them to the central processor [4].
- Wherever possible reducing the number of redundant of sensor devices and messages.
- The improvement of the message routing mechanism, addressing the key problems of: 1) energy consumption and residual energy in sensor nodes 2) routing path 3) link quality requiring a thorough instantaneous monitoring of WSN.
- A tool measures WSNs design, configuration, reconfiguration, and impact on its performance. This enables the network to auto adaptation to external events from the environment.

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.

B. 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 composition to integrate the different business processes and intelligent agents.

C. The conceptual framework

The definition of the conceptual framework is in the context of smart environments. 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 to acquire data and turn it into knowledge. . These sensors performs data acquisition, while distribution of this data over the networks is monitored and controlled by a management center, 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 to 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.

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.

2. *Organisational entities*

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

a) *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.

b) *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: 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 [5].

c) *A 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 [6] 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.

d) *A 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.

e) *Emergency and rescue services* are police, fire and rescue service, emergency medical services.

3. *The functional model*

The functional model proposed in this research 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.

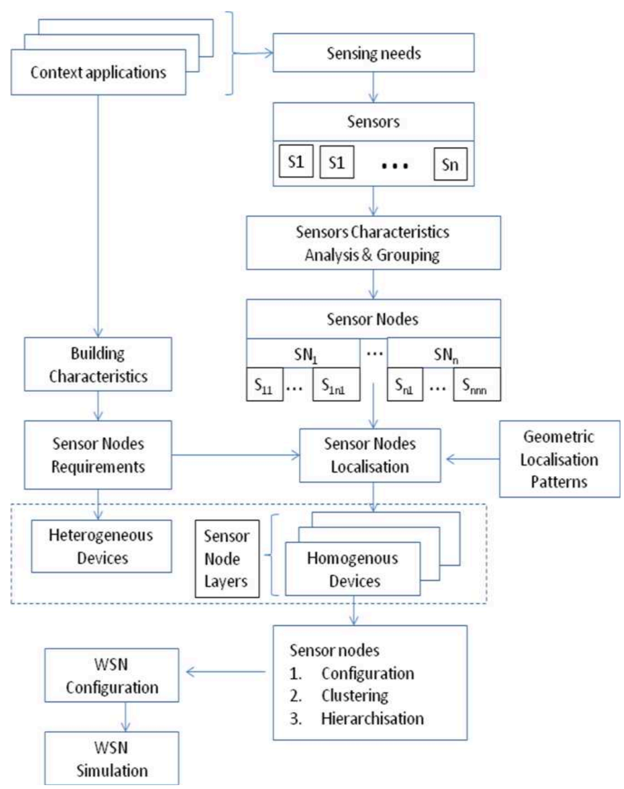

Figure 1: Emergency service functional model.

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.

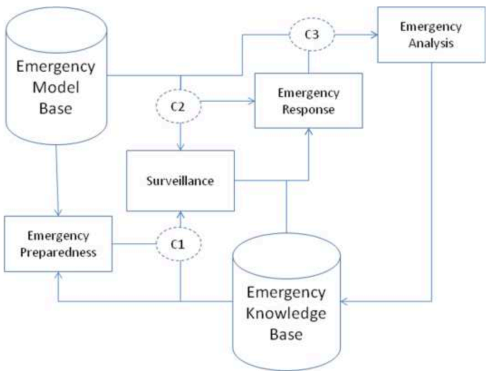

Figure 2: Intelligent decision support system architecture.

4. The service composition model

The conditions C1, C2 and C3 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.

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.

IV. THE CASE STUDY IMPLEMENTATION

A. 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.

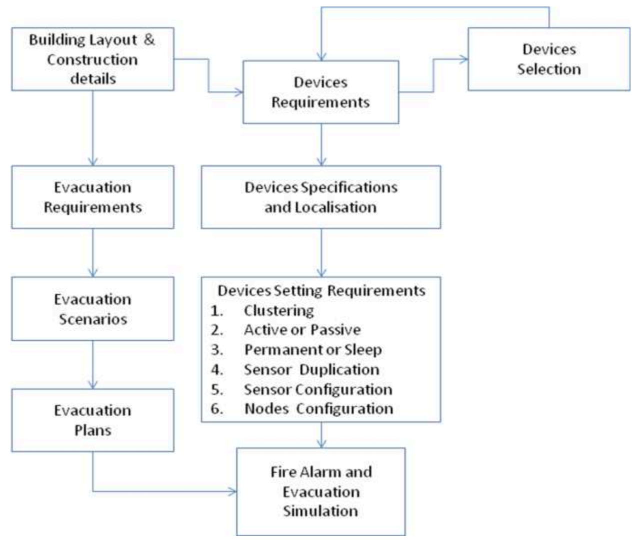

Figure3: Emergency preparedness process.

B. Implementation

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 [7].

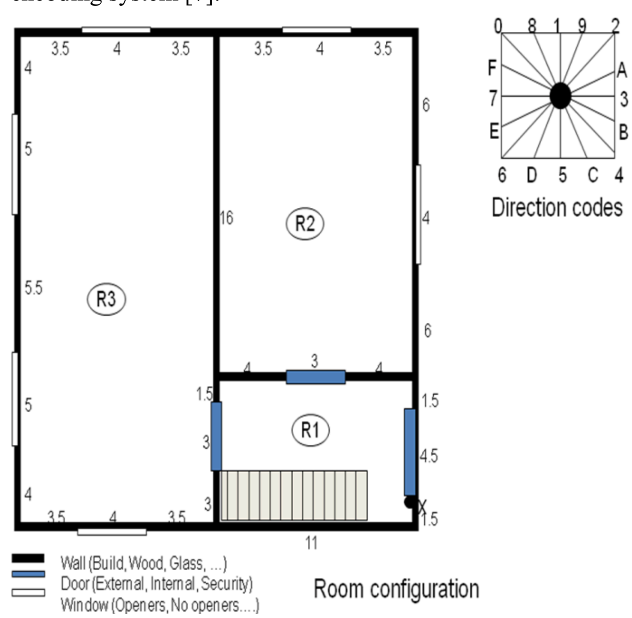

Figure 4: Building wall segments drawing & Encoding system

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.

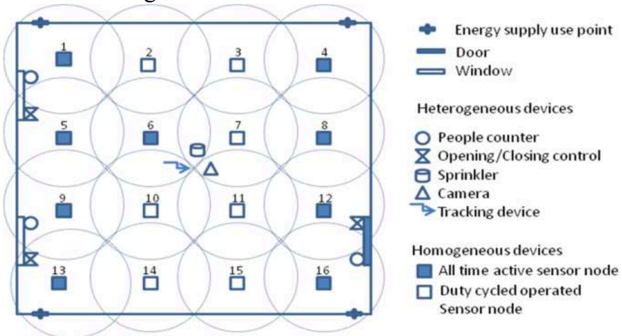

Figure 5: Nodes localisation model.

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).

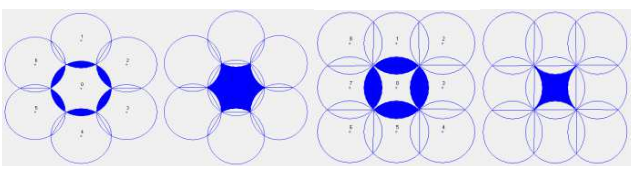

Figure 6A1 Figure 6A2 Figure 6B1 Figure 6B2

Figure 6: Geometric location distribution pattern.

b) *Sensor nodes and devices localization example*

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

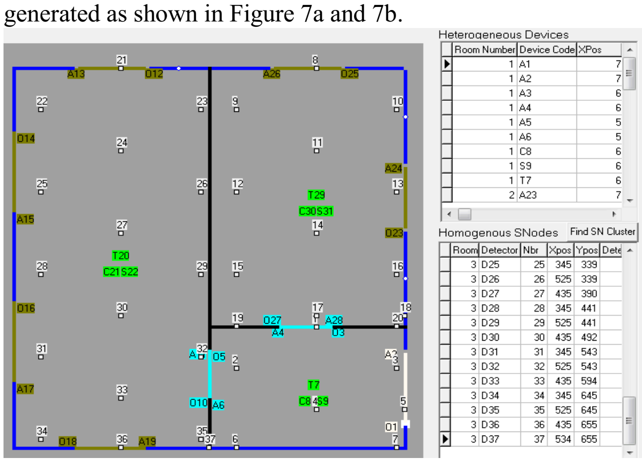

Figure 7a: Hexagonal geometric location distribution pattern.

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

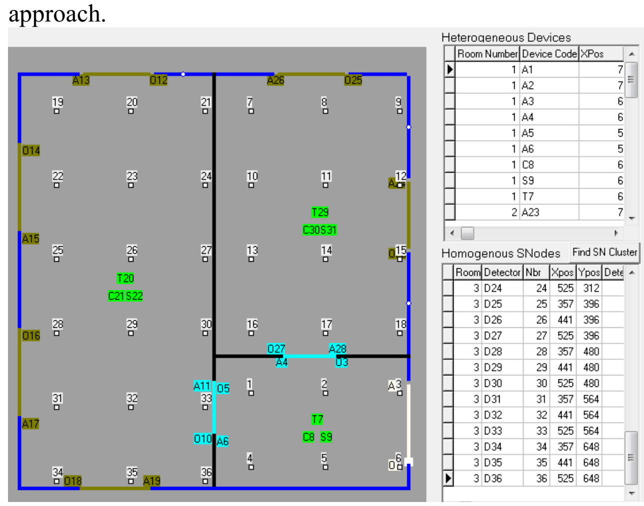

Figure 7b: Square geometric location distribution pattern.

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.

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.

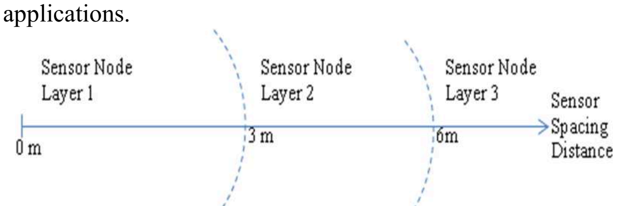

Figure 8: Senor node and sensor status setting.

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:

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

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

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

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

Square NLDP: $$Ssz = \pi r^2 - 2(\pi r^2 - 2r^2) \quad (4)$$

('r' indicates the spacing distance between two sensor nodes)

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.

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.

4. Sensor nodes status

a) 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.

b) 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.

c) Active versus Inactive sensor

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

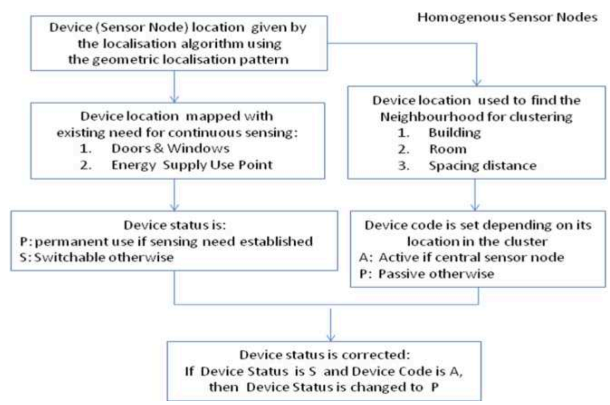

Figure 9: Senor node and sensor status setting.

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 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 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 [8].
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 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.

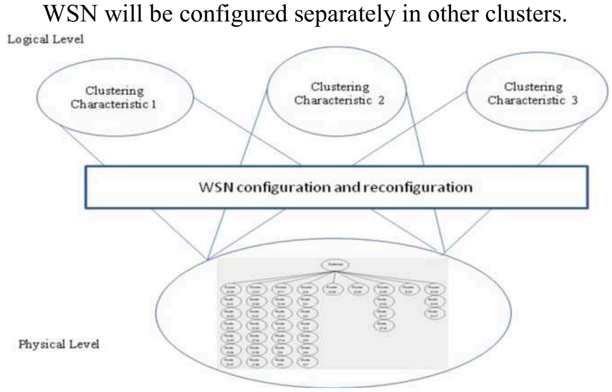

Figure 10: Automatically generated sensor node clusters

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 occupancy and standard evacuation times is shown in Figure 11.

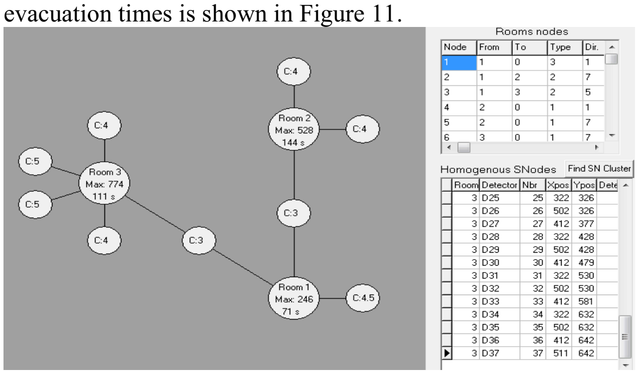

Figure 11: Example of evacuation decision model

V. 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 IDSS. This contribution is also in the domain of service provision and composition that requires the development of both intelligent agents and 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.

Acknowledgment

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