Deployment of Wireless Sensor Networks in Mobile Robots for Emergency Surveillance

R.Selvakumar[1]

Research Scholar,
Karpagam University,
Coimbatore

Dr.K.Prasadh[2]

Principal,
Mookambika Technical Campus,
Kerala

ABSTRACT

For many long-standing problems, technology has become the solution and even if the current technology is effective, it is far from fully addressing the huge, complex, difficult and challenging tasks associated with disaster missions and risky intervention. The field of robotics draws on a multitude of engineering disciplines. Robotics can be used in finding creative and reliable scenarios in such uncertain conditions and in rescue systems. It should be cost effective, innovative and practically applicable without any constraints. The greatest advantage of using robotics is their flexibility and large movement range. This paper initially gives an overview of wireless sensor networks and robotics. Then muti-tier system architecture for monitoring the robots in disaster environments has been discussed. In this system, the wireless sensor nodes are carried by the mobile robots and deploy them on the ground or walls of the unstable environment. Using the sensor nodes, the mobile robots gather exact information regarding the environment and the victims. The proposed system also aims to save energy for increasing the lifetime of the sensor nodes.

Keywords— Search and rescue, mobile robotics, wireless sensor networks, navigation system, energy saving

I. Introduction

Disaster management is one of the most serious critical social issues which involve very large numbers of heterogeneous agents in the hostile environment. Robotics can be used as a perfect alternative for quick response system in which the environment is unstable and unsafe. Wall mounted cameras or search dogs cannot be used in those places. Also as the environment is unsafe, human personnel can be shielded from working in those dangerous environments and from handling hazardous materials. Without any human guidance robots can be used to monitor the environment and aggregate the sensed data. Recent events throughout the world have shown that robots are proving extremely valuable, even irreplaceable, in dealing with the consequences of industrial or natural disasters and other dangerous situations. Robots support reliability and robustness of the system during search and rescue operations. In those environments that deal with chemical explosives and radioactive substances that would kill people, robots can be used to perform rescue tasks. Thus people can be removed from direct exposure to such unfriendly conditions by the ideal use of robots. The safety and security of the personnel as well as work efficiency can be greatly improved. Solving and fulfilling the needs of such tasks presents challenges in robotic mechanical structure and mobility, sensors and sensor fusion, autonomous and semi autonomous control, planning and navigation, and machine intelligence. A wireless sensor network (WSN) is a computer network consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, at different locations.

The development of wireless sensor networks was originally motivated by military applications such as battlefield surveillance. However, wireless sensor networks are now used in many civilian application areas, including environment healthcare applications, home automation, and traffic control. In addition to one or more sensors, each node in a sensor network is typically equipped with a radio transceiver or other wireless communications device, a small microcontroller, and an energy source, usually a battery. The size a single sensor node can vary from shoebox-sized nodes down to devices the size of grain of dust. The cost of sensor nodes is similarly variable, ranging from hundreds of dollars to a few cents, depending on the size of the sensor network and the complexity required of individual sensor nodes. Size and cost constraints on sensor nodes result in corresponding constraints on resources such as energy, memory, computational speed and bandwidth. The proposed system also included mobile sensor nodes. It implements a smart mobile robot, which was not only mobile, but was also equipped with wireless communication.

In addition, a navigation protocol is designed to implement the application of sensor nodes replacement. The nodes replacement scheme can be used in sensor networks consisting of battery-powered sensor nodes, whose batteries may be difficult to recharge; these sensor nodes have heavy workloads and their energy is easily exhausted. Failure of a set of sensor nodes, within a network, because of energy depletion, can lead to sensor network partition and a potential loss of critical information. Low cost and energy efficient sensor nodes are proposed. The fundamental problem of mobile robots is their path planning and navigation which needs a map of the environment. But in case of the collapsed buildings due to an earthquake, it is highly difficult for planning the path for mobile robots. The deployment of wireless sensor nodes, on the other hand, allows the mobile robots to navigate without a map or location information. The mobile robots navigate themselves accurately and quickly using the signals received from sensors.

II.Related Work

Enabling integration of mobile robots and wireless sensor networks to operate within the disaster environment is possible. One of the important applications is to plan the path of the mobile robots by deploying WSNs. Based on the information received from the sensors path planning of the mobile robot is performed. Through the WSNs deployed this node sends the information to a PC. By validating the received information the PC monitors the robot's location and path. WSN track the location of the robots from the received beacons which are periodically sent by the robots. The robot position is calculated using a trilateration method. In this method it is required to calculate the distance between robots and sensors by using at least three nodes whose positions are known. This distance is inferred from RSSI (Radio Signal Strength Indicator). In another, wireless sensor networks are deployed which forms a distributed planning framework. Sensors consisting of laser rangefinders detect the obstacles in the sensing region. Using those sensors maps of the sensing region are generated which can be used to monitor the area. Relay points are equipped in the environment which is used to stitch the local maps generated by deferent sensors. Path planning for autonomous mobile robots in an indoor known environment uses wireless sensors. Here it requires sensor pre-deployment with at least three nodes per room with known locations is possible. These nodes transmit their locations for communicating with the mobile robots. Using RSSI the robots maintain their path. Sensors are used for solving localization problems.

In another, a system is proposed to calculate the moving target which is in the coverage area of the wireless sensors. In this scenario, a mobile robot is turned into a mobile sensor node by fixing a wireless sensor in the robot. All the static nodes are assumed to have known locations. Based on the received signal strength and position of the sensors the robot motion is determined. There is another possibility in integrating robots and WSN is that robots gather information from the wireless sensors. In that system mobile robot is used for harvesting information from the wireless sensors is presented. This solution is very much useful when the navigating area is large and the information must be gathered. In this scenario instead of using nodes for covering two regions, the use of mobile robots for surveillance is much needed. The mobile robot that carries the WSN localizes the nodes in the surveillance region. The mobile robots are attached with sensors that perform random walks within a WSN. The nearby nodes receive the periodic messages from the mobile robots along with its position.

Using these received messages the sensor nodes infer the distance to the robot and using that distances they construct and maintain the robots position estimates. In another, a different system for mapping a WSN is presented. In this system, there is no communication between the sensor nodes which are equipped with cameras. The mobile robots are also equipped with sensor nodes. They use the cameras mounted with the sensor nodes detects and navigates through the known environment and thus communicates with the sensors. Within the known environment, the mobile robots can detect their positions. In solving specific problems in specific scenarios, the integration of WSNs and robotics is much useful. The solutions involving navigation strategies that deploy WSNs usually rely on the fact all sensor nodes position and locations are known and can be inferred with ease. These solutions for the path planning problem often use RSSI readings which are not reliable in finding the robots positions.

III. Multi-System Architecture for Monitoring Robots

A. Sensor Network Scenario

In WSN deployment, each scenario has its own specific requirements. Each mobile robot is equipped with numerous sensors. The sensors are placed in the collapsed buildings or any other disaster environments by the mobile robots for supporting navigation. In the proposed system, the victims in a disaster environment are considered. Therefore, a centralized network solution with a base station is suitable for this application. For managing the whole communications this base station is interfaced with external communication systems. A hybrid and three-tier network architecture with distributed sensing, processing, and storage (base station and monitoring center) is considered. The network is constituted of four organized groups of wireless devices:

1. Sensor nodes (R) which are attached in the mobile robots handle physiological monitoring tasks (pulse, temperature, shock sensors, etc.). They are embedded on the person's body (WRN level) in a star topology which is chosen for its simplicity and power efficiency and are embedded by the mobile robots. Nodes of this level execute only sensing tasks and no complex routing is done.

2. Beacons (B) which are the environmental visual sensors route multimedia contents at the Beacon Network (BN) level. Each Beacon is fixed in the mobile robot to provide both environmental (ex: PIR sensor, CO sensor, smoke sensor, etc.) and video/pictures monitoring. The BN tier plays a fundamental role for recognition, sending alerts, and exchanging localization data (compute robot's current position and path).

3. Coordinators (C) which are the intelligent mobile nodes aggregate sensed data and manage communication and interconnection between WRN and BN tiers.

4. The sink (S) which is the manager base station which has a complete knowledge of the global network behavior. For easy installation purposes heterogeneous WSNs are used for surveillance in the disaster environments. One of this network model advantages is to provide two levels of communication management (coordinator and sink) with local and remote access to collect contents. Three different kinds of data are exchanged or disseminated (medical, environmental, and video/images contents). Hybrid communication technologies between sensor nodes could be judicious to enable transfer of the different contents. The BN level requires high bandwidth, low jitter, and low error rates for QoS purposes. The proposed design framework is based on protocols which describes sensor node behavior for organizing node wake up and activity periods. By using this system the lifetime of the global network can be increased.

B. Design Framework

To increase the lifetime of the network different aspects have to be taken into account. By this way if all the sensors are switched on indefinitely the energy consumption would be high. A vast coverage of the spaces which are monitored is not needed since the selected nodes cover, identify, and detect the presence of mobile robots with short transfer delays. High power is consumed by the radio component of the sensor than any others. In the proposed framework, all the nodes follow the transmission scheme. To minimize the power consumed by the sensors all the nodes enter into sleep position most of the time. The sleep position is disturbed only when a wake up message is received. Then they perform the sensing tasks without any delay. The implementation of multi-tier network consists in adapting the adequate node behavior and programming them to perform defined tasks corresponding to the environment. Sensor behaviors are described by three states: sensing, processing, and data dissemination. In the disaster environments walls and obstacles causes interferences which influences both sensing (exposure) and dissemination. The factors that influence the quality of processing the sensed data are processor type, memory, algorithm robustness, the ability to process in-network multimedia contents, source coding techniques, etc. The dissemination quality depends on MAC and routing protocol design which influence the QoS parameters (throughput, delay, and reliability of messages). Other aspects like the dissemination type (continue, periodic, and on demand) have an impact on energy consumption and should be adapted to the application requirements.

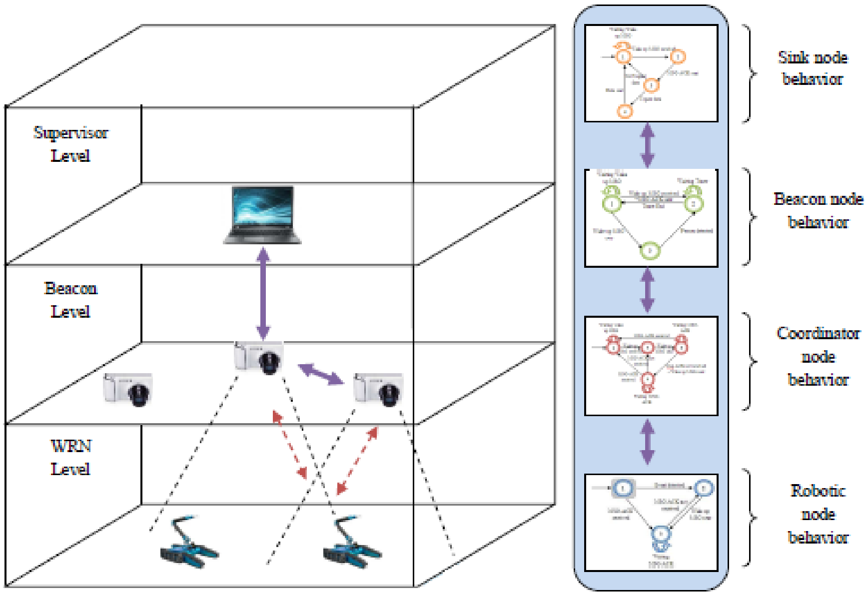

Figure 1: 3-Tier Sensor Network Architecture

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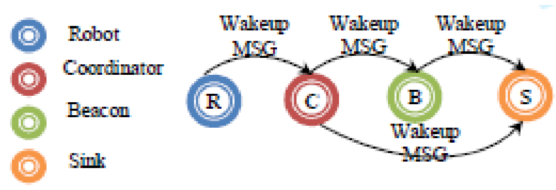

Figure 2: Interaction between the Tiers of the Network

C. Sensor Node Behaviours

The sensor node behaviours are distinguished in the proposed multi-tier network modelled with the state transition diagram. Each one corresponds to the sensor position as shown in Fig. 3 and depends on node functionalities and requirements. The difference is that the medical node (resp. the sink node) has no preceding node (resp. following node). Below, the operational states and possible transitions of each node are described.

1) Robot Node: Only sensing tasks are handled by this node and they do not participate in packet routing. It communicates directly with its coordinator in WRN level. Three states describe the behaviour of this node as shown in. During state 1 the medical sensor continuously monitors and controls the state of the monitored robot. If the sensed data shows a high variation, an event is triggered off and it goes to state 2 indicating to its successor an exceeded threshold. The medical node alert its coordinator by sending a wake up message (MSG) and waits in defined timer for an acknowledgment (MSGACK) (state 3). If the timer ends and if no MSG-ACK is received it re-transmits the message. As this happens again and again a special method of fixing retransmission number is done. If it receives MSG-ACK it returns sleep again to state 1.

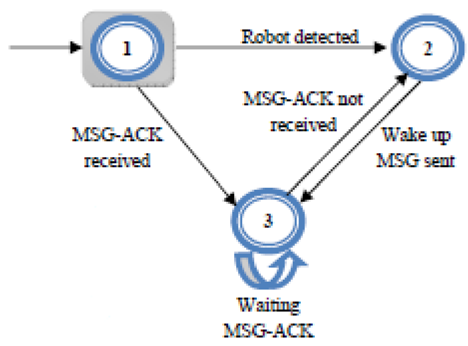

Figure 3: Robot Node Behaviour

2) Co-ordinator Node: This is a smart node which can take decision upon receives wake up messages from its associated robot nodes. It aggregates the sensed data and supervises the WRN and BN tier behavior. It permits a second level of data management with sink node. The received messages are analyzed to select its appropriate successor (Beacon or sink). There are four states describing the coordinator behavior as shown in. In state 1 it waits for a message from medical nodes. If it receives a message, a transition to state 2 takes place. In this state, it analyses received MSG, adds its own information and sends it to its successor. Many cases might be treated to select the appropriate successor. For example, it tries firstly to reach the sink (sends MSG) if delay and data priority for WRN are required and to MSG-ACK in state 3. If MSG-ACK is not received, it tries to send the message to the Beacon node and indicates the importance of data to adapt QoS parameters (selects the kind of contents to be transmitted: route medical messages and/or transmit images for example if a person is in a dangerous situation). In state 4, it waits for MSG-ACK from Beacon node. If MSG-ACK is not received it returns to state 2, otherwise, it returns to the initial state.

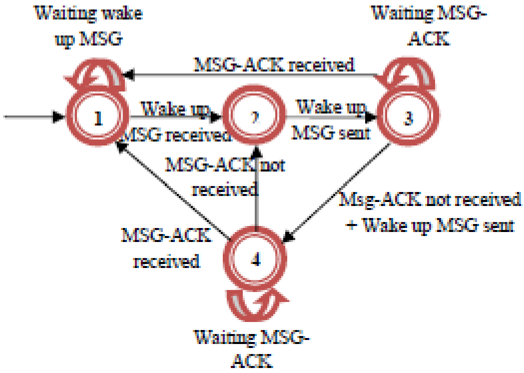

Figure 4: Co-ordinator Node Behaviour

3) Beacon Node: This is a smart multimedia node. Its main role is the recognition and identification of persons in its field of view. It enables the transfer of environmental data and permits to route packets toward the sink. For energy purposes, the radio component remains waiting for wake up messages and will be activated at the right time. During the monitoring phase, it can determine the type of data to forward. It analyses wake up MSGs received from the coordinator summarizes the Beacon node behaviour. The behaviour of this Beacon node provides multi-flow data transfer in the BN tier (on demand transfer of simple data and/or multimedia contents). When a message is received from the coordinator node it starts operating in state 2 and checks detected movements in its field of view (recognition by PIR sensor integrated in the Beacon). If somebody is detected (state 3 takes place), it adds its own information (to its predecessor data) and routes selected data (takes pictures for example) toward the sink. One of the advantages of the BN tier nodes is to provide auxiliary route (safety) to reach the sink.

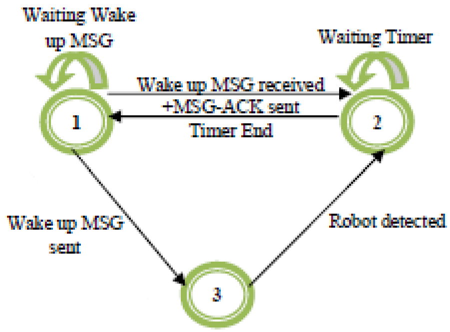

Figure 5: Beacon Node Behaviour

4) Sink Node: It provides a second level of data aggregation. As described in, in State 1, sink node remains waiting for a wake up message from low tier predecessors (coordinator or Beacon nodes). When it receives a MSG the state 2 is enabled. In this state it sends the appropriate acknowledgments (MSG-ACKs) and the alarm management state 3 takes place. At this state, sink node takes decisions to send or not received data to external communication systems. According to the selection state 4 or state 1 takes place.

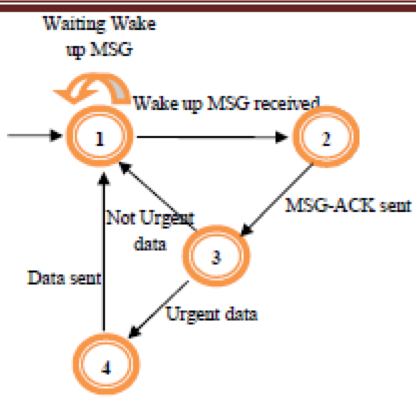

Figure 6: Sink Node Behaviour

IV. Evaluation

We have implemented and evaluated by using discrete event NS-2 simulator (Network Simulator 2). “Mannasim” framework was used with NS-2 to evaluate the performance of the three-tier heterogeneous sensor network. We have initially implemented the four organized node behaviours, and then we have setup each node to simulate real motes. “Imote2” motes were used as the reference node considered in this work. The “Imote2” transceiver operates at ISM 2.4 GHz frequencies. Its [-25, 0] dBm output power allows data rates of up to 250 Kb/s. The microcontroller runs from 13 to 416 MHz. This devices require 3,2 - 4,5 Volts and are powered by three 1.5V (3AAA) batteries. Table I presents a description of “Imote2” in each tier of the network, and Table II presents power dissipation expressed in Watts for different modes.

Table 1: Nodes Description

		Description	Initial Energy
WRN Tier	Robot Node	Imote 2 platform (with IPR2400CA processor/radio board and ITS400CA basic sensor board) with temperature and humidity sensors and three axis accelerometer.	16200 Joule
	Co-ordinator Node	Coordinator Imote 2 platform with only IPR2400CA processor/radio board	16200 Joule
BN Tier	Beacon Node	Imote 2 platform (with IPR2400CA, ITS400CA and equipped with IMB400CA Multimedia sensor board) with image/video camera chip, PIR sensor, microphone and miniature speaker.	16200 Joule
Supervisor Tier	Sink Node	Imote 2 platform with only IPR2400CA processor/radio board connected to a PC	16200 Joule

Table 2: Power Dissipation

	Transmission (P_{Tx})	Reception (P_{Rx})	Idle (P_{idle})	Processing (P_p)	Sensing (P_s)
Robot Node	0.198	0.198	0.001	0.139	0.004
Co-ordinator Node	0.198	0.198	0.001	0.139	X
Beacon Node	0.198	0.198	0.001	0.139	0.06
Sink Node	0.198	0.198	0.001	0.139	x

As shown in Table II, sensing power of "Imote2" visual Beacon node was fixed at 0.06 watts. Sensing power of medical node was fixed at 0.004 watts. Power dissipation for reception and transmission are equal. These values are taken from "Imote2" datasheet. A node is subject to four main modes: sensing, processing, idle, and communication (reception and transmission). To estimate the mean energy consumed by each node we need to add the various consumptions to each mode as described in equation:

$$E = \sum E\ Tx + \sum E\ Rx + \sum E\ idle + \sum E\ pr + \sum E\ s$$

Where: EX = PX . tX, X=Tx, Rx, Idle, Pr or S.

These sums of energy depend on the power dissipations and the time (tX) (cf Table II) according to the following modes: reception (PRX), transmission (PTX), idle (Pidle), processing (Ppr), and sensing (Ps). To simulate the WSN-HM network, medical nodes executes continuous data sensing unlike, coordinator, Beacon, and sink nodes execute reactive sensing. The interval between the reception and activation of reactive node was set to 5 seconds. We simulate the mobility of monitored person (WRN speed) with uniform mobility and constant speed equals to 0.5 m/s. Communications are based on IEEE 802.15.4 MAC protocol used by "Imote2" platform. Defined range is 30 m and radio data rate is 250 Kb/s.

V. Simulation Results

We consider a typical day of the system operation (24 hours). We consider a WSN with 13 nodes: 10 Beacon nodes, 2 nodes for WRN (one robotic node and one coordinator), and one sink node. House dimension was fixed to 9 m x 9 m. The disseminating interval and the number of nodes have an impact on energy consumption. Our simulation aims at dimensioning these parameters.

As illustrated in Fig. 7 the disseminating periods of robot node has an impact on energy consumption of the global network. The energy consumption inversely decreases with the increase of disseminating interval values between [5 – 20] s.

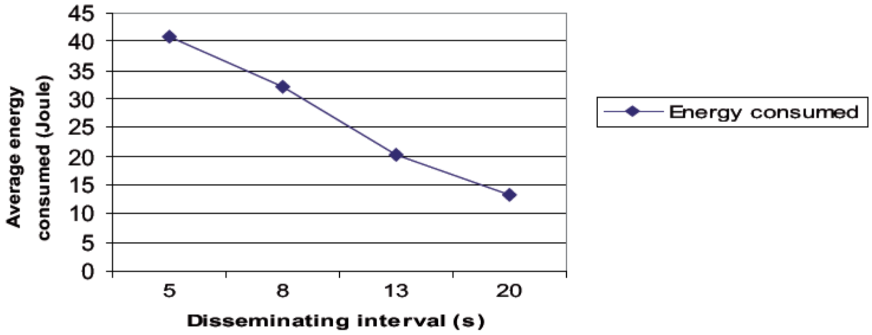

Figure 7: Average energy consumption of all nodes in the network according todisseminating interval

Fig. 8 shows the impact of scalability on energy consumption while varying the number of Beacon nodes from [10 - 50]. Clearly, the energy increases when the number of beacon nodes increase.

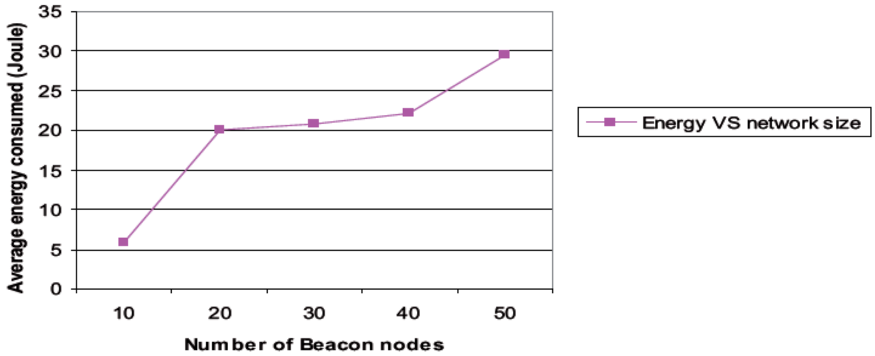

Figure 8: Energy consumption of all nodes in the network according to Beacon network size scalability

From our simulation results, let us comparing our solution to single tier and multi-tier video sensor network (MVSN) approaches. We use the same parameters in comparative analyses. Fig. 9 shows the average energy consumption of WSN according to the house size. The even driven behaviour used in our solution with coordinator and beacon nodes decisions permit to optimize around 1.96 times energy expenses than single tier approach.

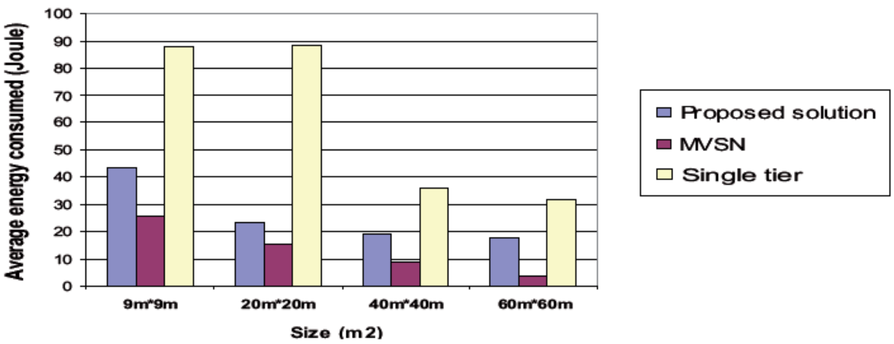

Figure 9: Average Energy Consumption

VI. Conclusions

In a disaster environment the rescue mission is very much dangerous and complicated for a human rescue team. Search and rescue robots can not only improve the efficiency of rescue operations but also reduce the casualty of rescuers. Robots can perform dangerous missions and even help rescue teams to replace rescuers. Search and rescue robots will play a more and more important role in the rescue operations. In this work, the design and implementation of three-tier sensor network solution with energy efficiency for monitoring mobile robots in rescue systems is proposed. The network is considered to be constituted of communicating heterogeneous sensors: medical, environmental, and video/audio sensors. To save nodes energy, the solution is based on organizing them into groups according to their role and functionalities and also on affecting them intelligent behavior. Communication at the same time and activity duration were reduced to allow better use of nodes component resources. The solution is based on event-driven behavior which gives good results than single tier architectures.

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